NEBOSH INTERNATIONAL DIPLOMA

UNIT IC: WORKPLACE AND WORK EQUIPMENT SAFETY - PART 1

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Suggested Answers

Course Structure

This textbook has been designed to provide the reader with the core knowledge needed to successfully complete the NEBOSH International Diploma in Occupational Health and Safety, as well as providing a useful overview of health and safety management. It follows the structure and content of the NEBOSH syllabus.

The NEBOSH International Diploma consists of four units of study. When you successfully complete any of the units you will receive a Unit Certificate, but to achieve a complete NEBOSH Diploma qualification you need to pass the three units within a five-year period. For more detailed information about how the syllabus is structured, visit the NEBOSH website (www.nebosh.org.uk).

Assessment

Unit IC is assessed by a two-part three-hour exam. Section A consists of six 10-mark compulsory questions, and Section B consists of five 20-mark questions, of which you must choose three.

NEBOSH set and mark this exam paper.

More Information

As you work your way through this book, always remember to relate your own experiences in the workplace to the topics you study. An appreciation of the practical application and significance of health and safety will help you understand the topics.

Keeping Yourself Up to Date

The field of health and safety is constantly evolving and, as such, it will be necessary for you to keep up to date with changing legislation and best practice.

RRC International publishes updates to all its course materials via a quarterly e-newsletter (issued in February, May, August and November), which alerts students to key changes in legislation, best practice and other information pertinent to current courses.

Unit IC: Workplace and Work Equipment Safety	
Element IC1	Workplace Welfare Requirements and Specific Workplace Issues
Element IC2	Fire and Explosion
Element IC3	Workplace Fire Risk Assessment
Element IC4	The Storage, Handling and Processing of Dangerous Substances
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Element IC1

Workplace Welfare Requirements and Specific Workplace Issues

Learning Outcomes

Once you've read this element, you'll understand how to:

1. Explain the need for, and factors involved in, the provision and maintenance of a safe working environment.
2. Explain the hazards, risks and control measures associated with work in confined spaces.
3. Outline the main issues associated with maintaining structural safety of workplaces.
4. Explain the hazards, risks, and controls when working at height.
5. Explain the hazards, risks and controls for lone working.

Contents

Safe Working Environment

IN THIS SECTION...

- It is a basic requirement of the **ILO Occupational Safety and Health Convention (C155)** to provide and maintain workplaces, equipment, devices and systems so that they remain safe. Consistent implementation of good housekeeping is an essential element of providing a safe place of work.
- A safe place of work includes cleanliness, workstations and seating, windows and transparent doors, and the provision and maintenance of safe means of access and egress.
- Safety signs are standardised so that they have the same meaning wherever they are used.
- The four categories of sign - prohibition, mandatory, safe condition and warning - are distinguished by their shape and colour and use symbols (pictograms) to convey their message.
- Floors and traffic routes need to be well constructed and free from hazards that might cause slips, trips and falls.
- The slipperiness of flooring materials can be assessed by using the Coefficient of Friction (CoF) test, which will provide information on different CoF values between one surface and another and the effects of contamination on surfaces in terms of CoF.
- The process of cleaning floors can create slip and trip hazards. Risks should be minimised by controlling the sequence in which cleaning is undertaken, the cleaning techniques used, good housekeeping, and providing appropriate slip-resistant footwear.

Safe Places of Work - Provision and Maintenance

The provision of a safe place of work is fundamental to workplace safety.

It is a basic requirement of the **ILO Occupational Safety and Health Convention (C155)** to provide and maintain workplaces, equipment, devices and systems so that they remain safe. We will now look at what this means in practice.

It is a basic requirement to provide a safe place of work

Equipment and devices which require a system of maintenance include:

- Emergency lighting.
- Fencing.
- Fixed equipment used for window cleaning.
- Anchorage points for safety harnesses.
- Devices to limit the opening of windows.
- Powered doors.
- Escalators and moving walkways.

A suitable system of maintenance involves ensuring that:

- Regular maintenance is carried out at suitable intervals (including, as necessary, inspection, testing, adjustment, lubrication and cleaning).
- Any potentially dangerous defects are remedied and access to defective equipment is prevented in the meantime.
- Regular maintenance and remedial work is carried out properly.
- A suitable record is kept to ensure the system is properly implemented and to assist in validating maintenance programmes.

Cleanliness

To achieve an acceptable standard of cleanliness, the following need to be kept sufficiently clean:

- Workplaces.
- Furniture, furnishings and fittings.
- Surfaces of floors, walls and ceilings.

Waste materials should not be allowed to accumulate in a workplace except in suitable receptacles.

Workstations and Seating

Workstations should:

- Be arranged so that each task can be carried out safely and comfortably.
- Be suitable for any special needs of the individual worker, including workers with disabilities.
- Allow people adequate freedom of movement and the ability to stand upright.
- Provide sufficient clear and unobstructed space to enable the work to be done safely.

Seating should:

- Provide adequate support for the lower back.
- Include a footrest for any worker who cannot comfortably place his or her feet flat on the floor.

Unsuitable workstation and seating for DSE use

Windows and Transparent Doors

Windows or other transparent surfaces in walls, partitions, doors or gates should be:

- Made of safety material (e.g. polycarbonates, glass blocks) or protected against breakage of the transparent or translucent material.
- Appropriately marked to make them apparent.

Provision of Safe Means of Access and Egress

There should be sufficient traffic routes, of sufficient width and headroom, to allow people on foot or in vehicles to circulate safely and without difficulty.

Floors and traffic routes should:

- Be of sound construction.
- Have adequate strength and stability, taking into account the loads placed on them and the traffic passing over them.
- Not be overloaded.
- Have no holes, slopes, or uneven or slippery surfaces likely to:
  - Cause a person to slip, trip or fall, or to drop or lose control of anything being lifted or carried.
  - Cause instability or loss of control of vehicles and/or their loads.
- Be kept free of obstructions which may present a hazard or impede access.

Open sides of staircases should be securely fenced and provided with a secure and substantial handrail.

Types of Safety Signs

Prohibition Signs

- Are round with a white background and red border and cross bar.
- Have symbols in black placed centrally on the background without obliterating the cross bar.
- Mean that something must **not** be done.


No smoking


Smoking and naked flames forbidden


Not drinkable


No access for unauthorised persons


No access for pedestrians


Do not extinguish with water


No access for industrial vehicles


Do not touch

Prohibition signs

Mandatory Signs

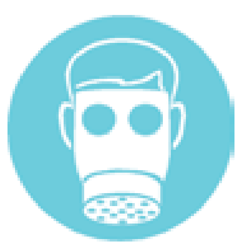
- Are round with a blue background and white symbol.
- State what must be done (or what protective equipment must be worn, as in the examples below).


Eyes


Head


Feet


Ears


Respiratory

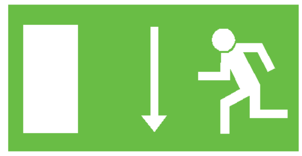

Hands

Mandatory signs

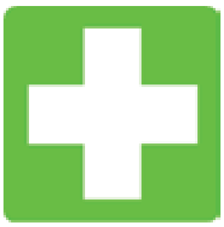
Safe Condition (Formerly Emergency) Signs

- Are square or oblong with white symbols on a green background.
- Indicate such safe conditions as a first-aid post or emergency evacuation route.

Exit

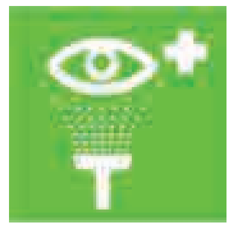


Exit



First-aid

Stretcher



Eyewash

Safe condition signs

Warning Signs

- Are triangular with a black border and a black pictogram on a yellow background.
- Warn of the presence of a particular hazard.

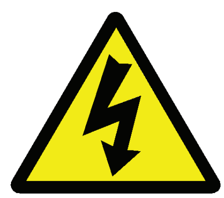
Flammable material

Explosive

Industrial vehicles

Toxic

Corrosive



Electricity

Radioactive

Overhead loads

Unspecified general danger

Warning signs

Fire Safety Signs

Fall into two categories:

- Those providing information on means of escape and which take the form of a 'Safe Condition'.
- Those identifying the location of fire equipment, e.g. 'Alarm Point', 'Fire Extinguisher'.

Acceptable fire safety sign

A fire safety sign which bears only text such as 'Fire Exit', is not acceptable, although text may be used in combination with pictograms.

Fire equipment signs are square or rectangular in shape with a white pictogram on a red background.

Fire extinguisher

Fire hose

Fire equipment signs

Typical Areas where Safety Signs would be Used

Signboards should be:

- Installed in a position appropriate to the line of sight, either at the access point to the area of a general hazard or in the immediate vicinity of a specific hazard.
- Clearly visible in a well lit position.

Avoid placing too many signs close together and remove signs if the situation to which they refer no longer exists.

Illuminated signs should be provided with emergency lighting power if power might be lost in an emergency.

Pipework containing dangerous substances should be marked. In particular, it should be identified and marked at sampling and discharge points using the same symbols or pictograms as those commonly seen on containers of dangerous substances.

Corrosive material

Flammable material

Explosive material

Toxic material

Labelling pipework

Stores and areas containing significant quantities of dangerous substances should be identified by an appropriate warning sign (the same signs as are used for marking pipework) unless:

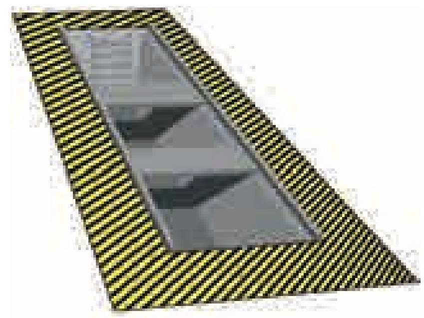
- They hold very small quantities.

- The labels on the containers can be seen clearly from outside the store.

Signs marking **obstacles, dangerous locations** and **traffic routes** can be used where:

- The risk is low.
- It is impractical to safeguard by other means.

Obstacles or dangerous locations such as the edge of a loading platform, or a danger zone adjacent to a process can be marked by the use of yellow and black (or red and white) angled stripes.



Inspection pit with clearly marked edges

Where clearly defined **traffic routes** are necessary, they should be marked using continuous yellow or white lines.

Standard road traffic signs and markings should be used in outdoor areas to control vehicles and pedestrians.

Designing Surfaces to Reduce Slipping

Holes, bumps or uneven areas resulting from damage or wear and tear which may cause a person to trip or fall, should be made good.

Slopes should not be steeper than necessary. Moderate and steep slopes, and ramps used by people with disabilities, should be provided with a secure handrail where necessary.

Slippery floor

Surfaces of floors and traffic routes which are likely to get wet or be subject to spillages should be of a type which does not become unduly slippery. A slip-resistant coating should be applied where necessary.

Floors near to machinery which could cause injury if anyone were to fall against it (for example, a woodworking or grinding machine) should be slip-resistant and kept free from slippery substances or loose materials.

Arrangements should be made to minimise risks from snow and ice. This may involve gritting, snow clearing and closure of some routes, particularly outside stairs, ladders and walkways on roofs.

Effective drainage should be provided where a floor is liable to get wet.

Slip-Resistance Testing

Coefficient of Friction (CoF)

Floors that are slippery could put people's safety at risk.

How slippery a floor is can be determined by measuring the Coefficient of Friction (CoF); the higher the CoF, the more slip-resistant the surface. We have already noted that surfaces of floors and traffic routes which are likely to get wet or be subject to spillages should be of a type which does not become unduly slippery. We can measure the CoF of such surfaces when they are wet; this represents the Wet Coefficient of Friction (WCoF). In order to prevent slips, the WCoF should be as close to the dry ideal as possible for surfaces that may become wet.

The slipperiness of flooring materials can be accurately assessed by using commercially available, portable scientific test instruments. The method of slipperiness assessment preferred by the UK's Health and Safety Executive uses a pendulum **Coefficient of Friction (CoF) test**. The pendulum CoF test is based on a swinging imitation heel (using a standardised rubber soling sample), which sweeps over a set area of flooring in a controlled manner. The slipperiness of the flooring has a direct and measurable effect on the pendulum test value.

Interpretation of Pendulum Results

The CoF results can be used to provide information on:

- Different CoF values between one surface and another.
- Effects of contamination on surfaces in terms of CoF.

Pendulum results should be interpreted using the information reproduced in the table below (from UK Slip Resistance Group):

Slip potential classification, based on Pendulum Test Values

	PTV
High slip potential	0-24
Moderate slip potential	25-35
Low slip potential	36 +

Using this technique on a dry or wet surface, values of 36 or more (equivalent to a CoF of 0.36) are currently accepted to indicate satisfactory slip resistance. Further tests are usually carried out after contamination of the test surface with any expected contaminant, which allows an insight into the actual CoF experienced in everyday working situations.

Methods for Cleaning Floors and the Appropriate Footwear to Wear While Cleaning

The process of cleaning can create slip and trip hazards, especially for those entering the area being cleaned, such as the cleaners. For example:

- Smooth floors left damp by a mop are likely to be extremely slippery.
- Trailing wires from a vacuum or buffing machine can present a trip hazard.

Contamination is implicated in almost all slip accidents. Regular and effective cleaning to remove contamination helps reduce accidents.

For **effective floor cleaning**:

- Use the right amount of the right cleaning product.
- Give time for detergent to work on greasy floors.
- Cleaning equipment will only be effective if it is well maintained.
- A dry mop or squeegee will reduce floor-drying time but while the floor is damp there will be a slip risk.
- A well-wrung mop will leave a thin film of water sufficient to create a slip risk on a smooth floor.
- Spot clean where possible.

People often slip on floors that have been left wet after cleaning so pedestrian access to smooth wet floors should be prevented by using barriers, locking doors, or cleaning in sections. Signs and cones only warn of a hazard, they do not prevent people from entering the area and if the spill is not visible they are usually ignored.

DEFINITION

COEFFICIENT OF FRICTION

Friction is "the resistance an object encounters in moving over another". It is easier to drag an object over ice than gravel. The reason for this is that the gravel exerts more frictional resistance.

The coefficient of friction is a number which represents the friction between two surfaces.

Smooth surfaces have lower friction coefficients, rough surfaces have higher coefficients.

The frictional force is the force needed to push an object over a given surface. So a smooth surface will require less "push" or force than a rough surface.

The formula that links the frictional force (F), coefficient of friction (μ) and weight (N – normal reaction) is:

$$F=\mu N$$

So for a heavy object (N) a greater force (F) is required to push it and the relationship between the two depends on the coefficient of friction (μ).

MORE...

www.

More information on testing surfaces for slip resistance can be found in HSE guidance:

Assessing the Slip Resistance of Flooring available at:

www.hse.gov.uk/pubns/geis2.htm

During the course of their work cleaners may be exposed to slip risks. Controls should ensure risks are minimised by careful planning of the:

- Sequence in which cleaning is undertaken.
- Cleaning techniques used.

It is also important to make sure that appropriate footwear is worn during cleaning operations. This means making sure that cleaners do not wear obviously unsuitable footwear such as high heels and encouraging them to choose slip-resistant footwear equipped with the correct type of sole for their work activity.

Safety cones warn of a hazard

Importance of Good Housekeeping

Obstructions and objects left lying around can easily go unnoticed and cause a trip accident. These causes are frequently overlooked, but generally easy to remedy. Potential trip hazards associated with cleaning and possible control measures to reduce the risk to cleaners and others are given below:

- **Cables and leads** from cleaning equipment such as scrubber-driers and vacuum cleaners:
  - Where possible cleaning should be undertaken during quiet times or outside normal work hours to reduce the likelihood of people tripping over equipment and cables.
  - If cleaning has to be carried out when there are people in the vicinity, ensure staff and others are made aware that cleaning is in progress by using effective signs or barriers.
  - Where the use of a cable is unavoidable:
    - Minimise the operating length.
    - Increase its visibility.
    - Cover it.
    - Move it out of the way of pedestrians.
    - Disconnect and tidy away equipment after use.
- **Rubbish** – discarded boxes, waste materials, bin bags:
  - Safely remove and dispose of any waste items that may cause a trip hazard.
  - Avoid temporary trip hazards by not leaving unattended rubbish in walkways.
- **Uneven floors** – curling mats, peeling or missing carpet tiles, holes, and changes in level:
  - Cleaners and supervisors should report any flooring defects or unmarked changes in level to the occupier.
  - Occupiers should put systems in place, which make it easy for cleaners to report defects.
- **Lighting** – poor lighting can increase the risk of trips, as obstacles may not be clearly visible:
  - Cleaners and supervisors should tell occupiers about areas where the light is poor or bulbs are missing or blown.
- **Housekeeping** – inform occupiers about housekeeping issues, such as:
  - Workers leaving clutter around workstations, which create trip hazards for cleaning staff.
  - Spillages, from leaking machinery, vending machines and leaking roof lights.
  - Cleaning equipment left unattended and not safely stored.

STUDY QUESTIONS

1. Explain how surfaces may be designed and maintained to reduce slipping.
2. Describe how the slipperiness of flooring materials can be assessed.
3. Explain the circumstances under which an employer should provide safety signs.
4. Describe the shape and colour of: prohibition, mandatory, safe condition, and warning signs.

(Suggested Answers are at the end.)

Confined Spaces

IN THIS SECTION...

- Confined spaces are defined by the possibility of a foreseeable specified risk, so the types of specified risk give us some indication of what might constitute a confined space in a work situation.
- In assessing the risk from working in a confined space we need to consider the:
  - Need to enter the confined space at all.
  - Provision and maintenance of a safe atmosphere.
  - Task, materials and equipment.
  - Persons at risk.
  - Reliability of safeguards in place.
- Employers must provide a safe system of work; this is vital when carrying out confined space entry and work, so safe working practices must include:
  - Permit-to-work systems.
  - Emergency arrangements.
  - Training for work in confined spaces.

The Meaning of Confined Spaces

A confined space is any place, including any chamber, tank, vat, silo, pit, trench, pipe, sewer, flue, well or other similar space in which, by virtue of its enclosed nature, there arises a reasonably foreseeable specified risk.

Working in a confined space is a high-risk activity

Confined spaces are recognised as workplaces that can be particularly hazardous. Consequently they are closely regulated by safety standards, such as those set out in the UK **Confined Spaces Regulations 1997** and the OSHA Occupational Safety and Health Standards relating to permit-required confined spaces (1910.146).

Working in confined spaces is a high risk activity and therefore there are legal requirements in force to ensure that the risk is minimised.

For example, the UK **Confined Spaces Regulations 1997** specify legal requirements for work in confined spaces and require that no person at work shall enter a **confined space** to carry out work for any purpose unless:

- It is not reasonably practicable to achieve that purpose without such entry.
- In accordance with a **system of work** which, in relation to any relevant **specified risks**, renders that work safe and without risks to health.
- There have been prepared, in respect of that **confined space**, suitable and sufficient arrangements for the rescue of persons in the event of an emergency, whether or not arising out of a **specified risk**.

DEFINITION

SPECIFIED RISK

- A serious risk of injury to any person at work arising from a **fire or explosion**.
- The loss of consciousness of any person at work arising from an **increase in body temperature**.
- The loss of consciousness or asphyxiation of any person at work arising from **gas, fume, vapour or the lack of oxygen**.
- The **drowning** of any person at work arising from an increase in the level of a liquid.
- The **asphyxiation** of any person at work **arising from a free flowing solid** or the inability to reach a respirable environment due to entrapment by a free-flowing solid.

FREE FLOWING SOLID

Any substance consisting of solid particles and which is of, or is capable of being in, a flowing or running consistency, and includes flour, grain, sugar, sand or other similar materials.

SYSTEM OF WORK

Includes the provision of suitable equipment which is in good working order.

Examples of Confined Spaces

Confined spaces are defined by the possibility of a foreseeable **specified risk**. The types of specified risk can give us some indication of what might constitute a confined space in a work situation. So, for example:

- **Fire or explosion** occurring during work in a tank previously storing flammable liquid.
- Loss of consciousness due to **heat stress** while welding in a storage vessel.
- Loss of consciousness or asphyxiation from **inhalation of fumes** generated by the disturbance of sludge in a sewer.
- **Drowning** as a water tank is inadvertently filled while repair work is being carried out inside.
- **Asphyxiation** due to being buried in grain as a silo is loaded while persons are working inside.

Examples such as these involving work in enclosed vessels and tanks are fairly obvious confined spaces but other examples such as pits in garages, trunking ducts, watercourses, trenches, tanks, silos and sewers can all constitute confined spaces if a **specified risk** is reasonably foreseeable.

Factors to be Considered When Assessing Risk

Having studied some examples of where confined spaces might occur in the workplace, we shall now look at precautions, including emergency arrangements, to be taken when working in a confined space.

Access Arrangements

Need for Safe Access

- Justification of the need to enter the confined space at all.
- Consideration of whether the work could be carried out outside the confined space.

Access and Egress

Should be under a safe system of work (usually a permit-to-work system), which may involve:

- Use of approved breathing apparatus if dangerous fumes are present or in an oxygen-deficient atmosphere.
- Authorisation to enter by a responsible person.

- Use of a belt or harness with a rope securely attached to a retrieval line. The other end of the retrieval line must be attached to a mechanical device or a fixed point outside the permit space. A mechanical device must be available to retrieve someone from vertical-type permit spaces more than five feet (1.524 metres) deep.
- Employment of a person to keep watch outside.

Confined space entry

Work may be carried out in a confined space without breathing apparatus if steps have been taken to ensure a breathable atmosphere. This means:

- Effective steps have been taken to avoid ingress of dangerous fumes.
- Sludge or other deposits liable to give off dangerous fumes have been removed.
- The space contains no other material liable to give off such fumes.
- The space has been adequately ventilated and tested for fumes.
- There is a supply of air adequate for respiration.
- The space has been certified by a responsible person as being safe for entry for a specified period without breathing apparatus.

Removal of Contaminants

- 'Purge' pipelines and tanks using inert gas (normally nitrogen).
- In the case of sewers, it may be enough to lift manhole lids along the line of work to allow lighter-than-air gases to escape.

Likely Atmospheres to be Encountered

Continuous monitoring may have to be carried out to ensure that the atmosphere does not change while work is being carried out.

Monitoring may be needed to check for some or all of the following:

- Oxygen content.
- Presence of flammable/explosive atmosphere.
- Presence of toxic contamination.

An adequate air supply must be maintained to dilute any gases released. The responsible person will have to determine the method of ventilation and the quantity of air required:

- **Natural ventilation** is suitable in limited cases where sufficient openings are available.
- **Forced ventilation** involves use of:
  - Compressed air.
  - Blower fan and trunking.
  - Exhaust fan or ejector and trunking.

Oxygen must not be used to 'sweeten' the air.

Entry where Breathing Apparatus is Necessary

- Breathing Apparatus (BA) sets must generally be of a type approved by the enforcement authority.
- BA sets must be well-fitting and properly worn.

- A positive pressure inside the mask is recommended.
- Respirators must **not** be used in an oxygen-deficient atmosphere (as they simply filter the surrounding air).
- A safety harness and life-line should be worn, with the free end held by a person outside.

Breathing apparatus

Certification and Monitoring

In many industries the concentration of flammable or explosive gases should not be allowed to rise above 25% of the Lower Explosive Limit (LEL) but quite often (particularly in the Oil and Gas industry) the level is set at 0% of the LEL. Forced ventilation may be necessary. Frequent checks should be made with an explosimeter.

Effective Training

Effective training is necessary for:

- Supervisors.
- People likely to work in confined spaces.
- People likely to act as attendants.
- Members of rescue teams.

In practice, these functions may overlap, but **all** persons must be trained.

Training should include:

- Use of the equipment provided, including knowledge of its construction and working.
- Check procedures when donning apparatus.
- Dealing with malfunctions and failures of equipment during use.
- Emergency procedures.
- Artificial resuscitation.
- Equipment, including methods of use, limitations, interpretation of results, maintenance and calibration.

Testing

- Testing of the atmosphere should be carried out before entry is allowed.
- Test samples should be taken from the whole volume of the space, since concentrations of gases may vary.
- Any person entering the confined space to carry out tests should wear breathing apparatus, safety harness and line.
- Resuscitation equipment should be ready for immediate use.

Assessing Risks

Persons at Risk

When assessing the risk associated with entry into, and work being carried out in, a confined space, it is necessary to consider who may be put at risk by the operation:

- Are those entering and working in the confined space lone workers or will a number of people be involved?
- What type of work is being carried out?
- How experienced are the people who are working in the confined space?

- Have they received training in working in confined spaces?
- Do any of the workers suffer from any medical conditions that may be affected by working in a confined space?

Task

The assessment should consider whether the tasks to be carried out will increase the risks to the persons working in the confined space.

Welding, for example, could reduce the amount of oxygen in the air.

Materials

It is also necessary to consider the materials that will be used:

- Cleaning with solvents or carrying out painting operations could produce an explosive atmosphere.
- The use of powders could produce large amounts of dust.

Equipment

Any work equipment being used should also be part of the assessment. For example:

- Trailing leads from electrical equipment can increase the chance of trips.
- Mechanical equipment could increase noise and cause problems from exhaust emissions.

Reliability of Safeguards (Including Personal Protective Equipment)

An important part of the risk evaluation is to look at the controls and safeguards already in place to check that they are doing the job effectively, or whether more needs to be done.


Controls and safeguards should be in place

Safeguards associated with entry into, and work being carried out in, a confined space may include:

- Access/Egress

  This includes suitable means of getting into the confined space and getting out, particularly in the case of an emergency. Access or egress may be by means of ladders, scaffold or tripods and harnesses. Are the means of entry properly maintained?

- Ventilation

  If ventilation is provided to ensure a safe working environment, is it working effectively?

- Avoidance of Ignition Sources
  - Is all equipment in good condition, well maintained and properly used?
  - Is intrinsically safe equipment and lighting used where there is a possibility of a flammable atmosphere?

- PPE/BA

  Is the PPE and any BA that is used suitable for the task, kept in good condition and being used properly by trained workers?

In addition, any other safeguards associated with work to be carried out in the confined space must also be assessed for suitability and condition.

Design of Safe Working Practices

Operating Procedures

Application of Permits-to-Work

The only possible way to ensure a safe system of working in confined spaces is by using a permit-to-work, so this is a **mandatory** requirement. The permit system must be under the control of a **competent manager** and will detail the operating procedures to be adopted.

The key precautions to be included in a permit-to-work are:

- Isolation of the confined space.
- Adequate ventilation.
- The absence of substances likely to give off fumes.
- Atmospheric testing for the presence of dangerous fumes.
- A supply of respirable air.
- A specified working period.
- Rescue and resuscitation arrangements.

Operation of a Permit-to-Work System in Relation to Entry into Confined Spaces

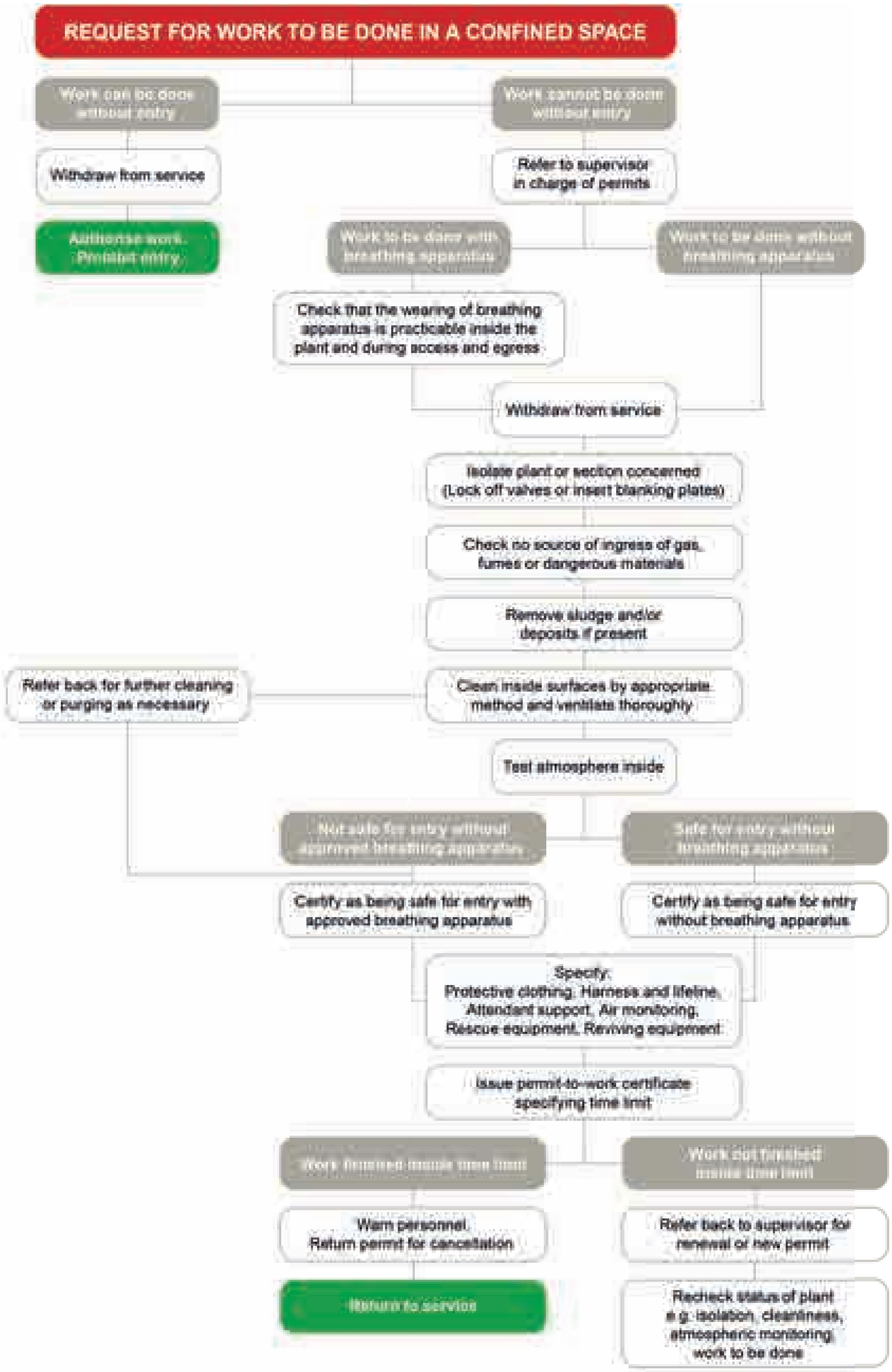
The first and most important step is the assessment of the situation by a responsible person familiar with the technical aspects of the job. They must be given time to consider the job in detail, so their workload must not be too heavy.

Assessment

Factors to consider during assessment include:

- Most important: is entry really necessary?
- Work needing to be done.
- Methods of working.
- Hazards inherent in the plant.
- Hazards from neighbouring plant.
- Steps necessary to make the job safe.

The sequence is shown in the following figure.



Typical arrangements associated with work in a confined space

Withdrawal from Service

- The person in charge of the process should sign the permit.
- Warning notices should be displayed.
- All plant operators should be notified.

Isolation

Plant should be physically disconnected from other items of plant. Reliance on shut-off valves, water seals or even a single brick wall has led to fatal accidents.

TOPIC FOCUS

Safe Isolation Steps

(a) Plant that is to be entered with power isolated is to be stopped by normal means.

(b) All residual energy reserves, be they pneumatic, hydraulic, electric, etc. must be exhausted or discharged.

(c) Liquid or free-flowing-solid lines should be positively isolated using flange blanks or blinds.

(d) Steam lines, because of the danger they represent, are normally isolated using "Double Block and Bleed", which involves use of a three-valve system where a pipe has two closed valves and an open drain valve positioned between them so that material is prevented from flowing.

(e) All moving parts must be stopped in a safe position that is suitable for the work to be carried out.

(f) The electrical main isolator is turned "OFF". This is the primary means of isolation on most plant and equipment.

(g) A padlock is fitted to the isolator to secure it in the off position. Locks should ideally be labelled or coded to identify the owner of the lock, the date and time of isolation and Permit reference.

Emergency stop buttons with integral locks normally only lockout the control circuitry and therefore are not suitable for access into confined spaces. Access should only be carried out with the main isolator locked off.

Cleaning and Purging

- Cleaning

  Cleaning methods include:

  – Steam.
  – Partial filling with water and boiling.
  – Washing with hot or cold water.
  – Use of solvents or neutralising agents.

- Purging

  On completion of cleaning, flammable vapours may be purged with an inert gas.

Cancellation of Permits

- On completion of work, the permit should be returned to the responsible person.
- Check that persons and equipment are removed from the space and that all personnel are warned that entry is no longer permitted.
- Return plant to service.

Checking of Permits

Managers or Safety Officers should regularly audit the permit-to-work system for observance of rules and procedures.

Maintenance of Equipment

- Inspections of breathing apparatus, life-lines, signal equipment and other equipment monthly and after use.
- A competent person should carry out the checks and enter at least the following details in a register:
  - The name of the occupier of the place of work.
  - The address of the place of work.
  - Particulars of the apparatus (distinguishing number/description).
  - The date of the examination and by whom it was carried out.
  - The condition of the apparatus, belt or rope, and particulars of any defects found during the examination.

Emergency Policy/Procedures

Arrangements for rescue in an emergency should be prepared:

- Personnel and equipment should be readily available for emergencies.
- Equipment should consist of:
  - BA sets.
  - Resuscitators.
  - Means of summoning help, e.g. two-way radio.
  - Life-lines.
  - Oxygen for resuscitation.
- Rescue teams should not enter a confined space without BA.
- Rescue teams should be thoroughly trained in:
  - Rescue techniques.
  - First aid.
  - Use of resuscitators.

Training for Work in Confined Spaces

Those likely to be involved in an emergency rescue operation should have appropriate training to cover:

- Likely causes of an emergency.
- Use of rescue equipment, including:
  - Maintaining
  - Testing.
- Resuscitation procedures.
- Initiation of emergency response.

This should be supplemented with regular rehearsals or exercises.

MORE... www.

The current applicable standards for Breathing Apparatus are: BS EN 14593 (airline) and BS EN 137 (self-contained).

Further information can be obtained from the HSE publication, HSG53 *Respiratory protective equipment at work - A practical guide*, available at:

www.hse.gov.uk/pubns/books/hsg53.htm

MORE... www.

Information on confined spaces can be found in the following publications:

Safe Work in Confined Spaces – Confined Spaces Regulations 1997 – Approved Code of Practice and Guidance available from the UK HSE at:

www.hse.gov.uk/pubns/priced/l101.pdf

Chapter 58 of the ILO's *Encyclopaedia of Occupational Health and Safety*, available at:

www.iloencyclopaedia.org/part-viii-12633/safety-applications/94-58-safety-applications/confined-spaces

STUDY QUESTIONS

5. Identify the specific risks relating to confined spaces.
6. Identify three ways in which the atmosphere within a confined space can be hazardous to workers.
7. When is it possible for a worker to enter or work in a confined space without breathing apparatus?
8. What equipment should be available in case of an emergency?

(Suggested Answers are at the end.)

Structural Safety of Workplaces

IN THIS SECTION...

- Damage to buildings might affect their structural safety. Causes include:
  - Adverse weather conditions.
  - Overloading of the structure.
  - Hot and corrosive atmospheres.
  - Vibration.
  - Alteration to structural members.
  - Subsidence.
  - Deterioration of building materials.
  - Excavations.
  - Unauthorised modifications.
- Failure modes - possible causes of structural failures such as:
  - Poor design that does not take into account the possible loading of the structure or specify the necessary materials of construction.
  - Substandard construction, which is not able to withstand the expected loading of the structure.
  - Cutting roof beams, which weakens the supporting structure for the roof.
  - Puncturing holes through floors, which will affect the integrity of the floor and both its load bearing capacity and its contribution to the overall building structure.
  - Removal of internal walls, which may be load-bearing walls supporting the floors and roof structure above, leading to collapse.

Causes of Damage to the Structure of Buildings

Once completed, a building must withstand the effects of weather, overloading and attack by rodents as well as potential damage from vehicles. All of these are potential causes of damage to the structure of buildings and therefore deserve important consideration.

Structural damage

Adverse Weather Conditions

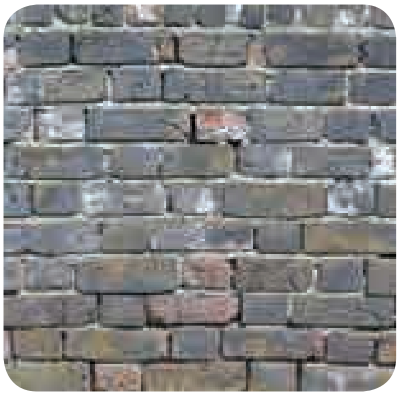
Solar Radiation

Solar radiation can affect buildings in two ways: firstly, by photochemical reaction and secondly, by thermal movements. In terms of the potential for building collapse, we can ignore photochemical reaction.

Solar radiation is absorbed when it strikes a material. As the material warms up it expands and, as it cools off, contracts. The extent of dimensional change in each material depends upon its co-efficient of thermal expansion.

Solar radiation causes surfaces to heat up fairly quickly. Rain falling on the heated surface can cause severe shock to the material and may result in tension cracking, especially on roofing membranes.

Rain



Moisture is the greatest cause of deterioration in buildings

Moisture is the greatest cause of deterioration in building materials and, of course, this includes snow and hailstones. The effects of moisture include:

- Humidity fluctuation, which causes dimensional changes leading to deformation, crazing and cracking.
- Rain, when driven by strong winds, can erode and dissolve some soft materials.
- Water, rising from damp ground into walls, can cause flaking and cracking.
- When water freezes in the pores of materials such as bricks, stones and concrete, stresses are produced.
- The presence of moisture can promote the corrosion of metals.
- Moisture creates an environment for fungal growth, as well as attack by insects.
- The build-up of snow on roof structures can significantly increase the loading, depending on depth.

Raindrops tend to fall vertically but if there is a steady wind it will carry the drops along with it, and when a droplet of rain, driven by wind, strikes a building surface, it disintegrates and part of the droplet is forced into the pores of the building material. The accumulation of moisture within the building material may cause expansion, while slower surface drying causes contraction on the surface, thus setting up stresses which may cause disintegration of the surface layer.

Wind

Wind can cause:

- direct physical damage to the building;
- dampness by driving moisture into the fabric of the building; and
- excessive heat losses from the interior of the building by uncontrolled air changes.

Wind pressure on a building can vary according to the direction and strength of the wind. The consequential compression and suction forces may result in the overloading or even the lifting of the building. This effect becomes more apparent with increasing height and where a building is exposed; there are many examples of suction forces, where roofs or coverings have been lifted.

Overloading of Structures

During the design stage, the engineer's job is to determine the loads which act on the building. There are three different types of load that need to be considered:

- Dead Loads

  Dead loads include the materials of which the building is constructed, e.g. columns, beams and floors, which must support the other components of the building, such as dividing walls and partitions, as well as their own weight.

- Live Loads

  In addition to the dead load, the building must support other weights, such as people, furniture, equipment and goods. These loads can be constantly moving and change day by day.

- Dynamic Loads

  Dead loads and live loads normally change slowly and for this reason are called static loads. Other loads, however, can change rapidly, like a gust of wind, and such loads are called dynamic. We must consider these in conjunction with the effects of weather on a building.

Damage from Moving Plant

Construction, plant and equipment can also cause damage, for example pile-driving, and it is not unknown for excavations adjacent to buildings to cause severe subsidence. Effects caused by buildings being struck by heavy lorries, particularly when they are repetitive, can cause weaknesses. In such cases, heavy steel guards should be erected to prevent permanent damage.

Hot and Corrosive Atmospheres

Atmospheric contaminants include sulphur dioxide, carbon dioxide, oxygen and ozone. In the presence of moisture they contribute to the formation of acids that attack certain materials, e.g. metals, concrete, cement and stone.

Atmospheric corrosion occurs when a metal combines with oxygen in the air to form rust. The process is usually accompanied by expansion of the metal, which can affect adjacent materials. Electrolytic corrosion is the result of contact between two dissimilar metals or between a metal and a non-metal; in the presence of moisture, galvanic action occurs.

Vibration

Vibrations caused by traffic, machinery and certain processes can be prolonged and intense, and can affect the foundations of buildings and the structural members of the building.

Vibration can be caused by:

- Out-of-balance rotation.
- Friction between moving parts.
- Impacts and percussion.

All of the above can cause weaknesses to occur, not only in the structural members, but also in the jointing systems, i.e. welds, bolts and even adhesives.

Alteration to Structural Members

Structures are now designed so that the maximum is gained from the minimum. It is very rare to find a new structure that has been 'over-designed'. Sixteenth-century timber-framed buildings, however, were very over-designed, which explains why there are so many still standing.

If another storey is required to be added to the top of an existing building, the first things which have to be checked are the foundations; primarily to determine whether they are capable of supporting the extra pressure that is going to be exerted upon them. When structural members are under load, they are normally either under compression or tension and the removal of one of these or part of these, for example to allow another piece of equipment or extension, could have major repercussions. Designers must therefore be involved at the initial feasibility stage to ensure that these points have been considered.

Subsidence

A structure is only as good as its foundations. If the foundations fail, then the structure will also fail. Therefore, we have to ask ourselves: what could possibly reduce the load-bearing capacity of the soil beneath the foundations to such an extent as to result in movement? Unfortunately, the answer is 'many things', including:

- Overloading

  The introduction of additional structural parts, different materials or additional process plant.

- **Water Content**

  If the water content changes dramatically, the nature of the soil will change. For example, if water is removed by drying out, the soil will shrink. Conversely, if water is added, the soil will 'heave'. This could be caused by weather, the designed removal of water to enable a basement or pit to be constructed, or by the planting or removal of trees.

- **Mines and Tunnels**

  Structures which are built over mines are prone to subsidence when the mine is no longer worked and its roof collapses, resulting in the whole ground level at the surface moving; this can sometimes be seen as a gradual wave across the surface of the ground.

Excavation close to foundations

- **Excavations**

  Excavations in close proximity to structures can remove part of the load-bearing bulb of pressure which supports the foundations. (This will be mentioned later.) The same effect can be observed when tunnelling is carried out underneath the structure; an example of this (from the UK) is Heathrow Airport and its underground link (see Case Study).

CASE STUDY

Heathrow Tunnel Collapse

In the early hours of 21 October 1994, during the construction of the Heathrow Express Rail Link, newly constructed tunnels close to the Piccadilly Tube Line started to collapse due to subsidence in the clay substrata in that area. The tunnels continued to fail over the next three days and the incident brought chaos to the heart of Heathrow Airport, causing a huge crater to appear between the airport's two main runways and damaging car parks and buildings in the surrounding complex.

Construction workers escaped uninjured with minutes to spare, but the collapse of three tunnels led to widespread disruption at the airport. The incident severely delayed the project, and also the Jubilee extension project, on which the same tunnelling methods were being used. Although no one was killed or injured in the accident, hundreds of flights in and out of Heathrow Airport were either cancelled or delayed as a result.

According to HSE Inspectors who were involved in the investigation, there was "a catalogue of design and management errors, poor workmanship and quality control" at the root of the incident and they went on to describe it as "the worst civil engineering disaster in the UK in the last quarter century".

The final report, published in July 2000, concluded that:

- "The collapses could have been prevented, but a cultural mind-set focused attention on the apparent economies and the need for production rather than the particular risks."
- "Warnings of the approaching collapse were present from an early stage in construction but these were not recognised."
- Errors were made, "leading to poor design and planning, a lack of quality during construction, a lack of engineering control and most importantly a lack of safety management."

According to the HSE, a chain of events led directly to the collapse. This included a failure to check substandard construction over a period of some three months, grout jacking that damaged the tunnel plus inadequately executed repairs some two months before the collapse.

Heathrow Express tunnelling contractor Balfour Beatty and its designer Geoconsult were subsequently fined a total of £1.7m - a record at the time for offences under health and safety legislation.

Buildings constructed over mine tunnels or large holes can cause severe deformation as the ground subsides. The apparent signs of defect include semi-random cracks in the walls, sagging of arches and beams and the fracture of pipe joints.

Deterioration of Building Materials

The main building materials used in structures are timber, concrete and steel, in all their many forms. All of these will deteriorate in time and in adverse conditions.

Each material has its own characteristics which make it good for certain conditions, but not for others. Some of these are shown in the following table:

Building materials characteristics

Material	Characteristics
Timber	**Positive characteristics:** • Relatively light weight. • Can be laminated for large spans. • Very good fire-resistant properties. • Good in both compression and tension. • Easily treated and easy to cut/work. **Negative characteristics:** • It is a natural material weakened by natural sources, such as: grain; knots; insects and rot.
Concrete	• Concrete is a mixture of cement, aggregate and water. • The aggregate is sometimes made up of sand and gravel but not always both depending on the type of finish and properties required. • It is imperative that the 'mix' is correct for the load it is designed to support. • Concrete is very good in compression but very weak in tension. • For this reason, reinforcement is introduced to take up the tensile stresses. • Deterioration/weakening can be the result of: – An incorrect mix (i.e. too much water can affect the cement strength). – The type and nature of the steel reinforcement. – 'Spalling' (where the face of the concrete breaks away exposing the reinforcement which gets rusty and expands forcing the face off). – The wrong type of aggregate/cement. – A reaction with a hostile environment.
Steel	• Steel has a high strength: weight ratio and can be produced in many forms. • It is therefore used extensively as structural material. • Structures can be rapidly erected and covered using steel. • It can deteriorate in many ways, e.g. by corrosion; brittle failure; fatigue; creep; or stress depending on the design and location of the material.

All the above materials can further deteriorate due to:

- The environment.
- Vibration.
- The standard of workmanship.
- Lack of maintenance.

Excavations

It is vitally important to ensure, before excavations are carried out, that the stability of buildings adjacent to the work area will not be adversely affected by the excavation. Consideration may have to be given to constructing temporary supports for buildings while work is being carried out.

Signs of Structural Damage

TOPIC FOCUS

Structural damage may be visible in certain circumstances.

Typical signs of damage might include:

- Sagging roof.
- Bulging or cracked walls.
- Signs of flaking masonry.
- Collapsed walls.
- Signs of corrosion on brickwork.
- Dampness.
- Dry or wet rot.
- Gaps around window or door frames.
- Uneven floors.

If any of the above are identified, it is necessary to get the opinion of an expert to determine the extent of damage and what, if any, remedial action is necessary.

Unauthorised Modifications to Buildings

The structural safety of a building relies on the integrity of load bearing roof beams, walls and floors. If there are proposals to carry out significant alterations to the structure of a building then it is essential that the effects of these alterations are considered at the planning stage.

Failure Modes

Structural failures can lead to collapse. Such failures can arise from:

- **Poor design** that does not take into account the loading of the structure, the likely forces or circumstances which may increase the loading or specifies inappropriate materials of construction.
- **Substandard construction** employing poor quality materials or building methods that will not withstand the expected loading of the structure.
- **Cutting roof beams**, which weakens the supporting structure for the roof.

- **Puncturing holes through floors**, which will affect the integrity of the floor and both its load bearing capacity and its contribution to the overall building structure.
- **Removal of internal walls**, which may be load-bearing walls supporting the floors and roof structure above.

STUDY QUESTIONS

9. Describe the adverse effects of weather on a structure.
10. Identify four reasons for ground subsidence.
11. What signs would indicate possible structural damage to a building?

(Suggested Answers are at the end.)

Working at Height

IN THIS SECTION...

- The main risks from working at height are those of injury or death resulting from:
  - **People falling** from height.
  - **Objects falling** from height onto people below.
- Employers should follow a simple hierarchy of control for working at height:
  - **Avoid** working at height.
  - **Prevent** falls.
  - **Minimise** distances/consequences.
- Safe working procedures for working at height in general workplaces should also include rescue measures.
- When choosing equipment for work at height, give **collective protection** priority over **personal protection**.

Introduction

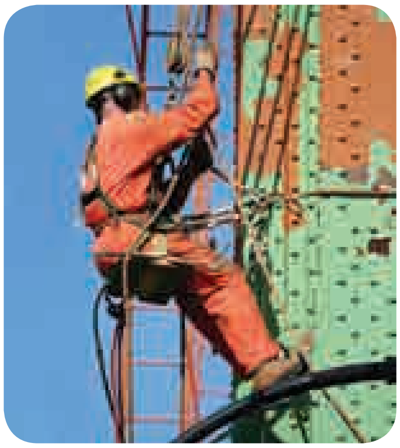
The **ILO Code of Practice – Safety and Health in Construction (C167)** refers, in Articles 14 and 18, to standards for safe working at height. Construction, and particularly work at height, is often highly regulated throughout the world. We will look at some common principles here.

Hazards and Risks for Working at Height in General Workplaces

Main Risks

The main risks from working at height are those of injury or death resulting from:

- **People falling** from height:
  - Falling from ground level into pits.
  - Falling off a ladder.
  - Collapse of the structure itself (such as a fragile roof).
- **Objects falling** from height onto people below.



Working at height is regulated throughout the World

Alternatives, Precautions and Safe Working Procedures

Work at height should be:

- Properly planned.
- Appropriately supervised.
- Conducted safely.
- Only carried out by competent people.
- Avoided if it is possible to carry out the work safely in a way other than at height.

Employers should follow a simple hierarchy of control for working at height: **Avoid – Prevent – Minimise**

- Avoid work at height:
  - Use long-handled tools to clean windows instead of using a ladder.
  - Install lighting that can be lowered to ground level for maintenance/ bulb replacement.
- Prevent falls:
  - Use an existing place of work at height to provide protection, e.g. a strong flat roof with existing edge protection such as guardrails.
  - Use additional equipment such as tower scaffolds, 'cherry pickers', etc. which have guardrails permanently attached.
- Minimise distances/consequences of a fall:
  - Netting.
  - Airbags.
  - Personal protective equipment such as fall-arrest and rope systems.

Avoid work at height

Other significant protection measures could include instruction, training and supervision, and the inspection and maintenance of equipment in use.

When choosing equipment for work at height, the following points should be taken into account:

- Where possible, give collective protection priority over personal protection, but first take into account whether it **prevents** or **minimises**:
  - **Prevents**: collective protection – guardrails, scaffolds, etc.; personal protection – work restraint.
  - **Minimises**: collective protection – nets, airbags, etc.; personal protection – fall arrest.
- Working conditions/risks at the site.
- Access to and egress from the work.
- Distance and consequences of a potential fall.
- Duration/frequency of use of the relevant equipment.
- Ease and speed of rescue/evacuation if required.
- Additional risk from the equipment itself (installation, use, removal, evacuation from it).

Rescue Measures

The hierarchy referred to above requires that no work should be done at height unless there is no alternative, and any work done at height should be properly planned, appropriately supervised and carried out in a safe way, with planning for emergencies and rescue.

Consequently, safe working procedures for working at height in general workplaces should also include rescue measures. In particular, if fall-arrest systems are in use or work is carried out from temporary access equipment such as cradles, boatswains' chairs, rope access or positioning systems, then there is a real possibility of situations arising where a casualty may need to be recovered. Suitable provision should therefore be made to rescue such casualties.

(These specific methods of working at height will be covered in Element IC9.)

Hierarchy of Control

Practical examples of the application of the hierarchy of control measures for working at height:

- Avoid working at height:
  - Design out the need to work at height.
  - Erect handrails/edge protection at ground level and crane in.
  - Working from the floor below, e.g. by using extending poles, where possible.

- Prevent working at height by using an existing place of work:
  - A flat roof with permanent edge protection.
  - A tanker roof with fixed edge protection.
- Prevent working at height by using collective work equipment:

  Access equipment fitted with guardrails:
  - MEWPs.
  - Scissor lifts.
  - Mast climbers.
  - Cradles.
  - Tower scaffolds.
  - Independent scaffolds.
- Prevent working at height by using personal work equipment:

  PPE used in a way that makes it impossible to get to a fall position:
  - Work restraint.
- Mitigate by using collective work equipment to minimise the distance and consequences of a fall:

  Nets and soft landing systems, such as air bags positioned close under work equipment to minimise distance from work surface.
- Mitigate by using personal work equipment to minimise the distance and consequences of a fall:
  - A personal fall-arrest system with the anchorage point sited above the head.
  - Rope access.
  - A work-positioning system.
  - A personal fall-arrest system with anchorage level at sternum/dorsal attachment point.
  - A personal fall-arrest system with an anchorage point sited at the feet.
- Mitigate by using collective work equipment to minimise the consequences of a fall:
  - Nets positioned at a lower level.
  - Soft landing systems.
- Mitigate by using personal work equipment to minimise the consequences of a fall:
  - A personal injury system (life jacket while working next to unguarded water).
- Mitigate through training and instruction or other means:
  - Ladders.
  - Hop ups.

Mobile Elevating Work Platform (MEWP)

MORE... www.

More information on working at height can be found in the UK HSE guidance document INDG401(rev2) *Working at height – A brief guide*, available at:

www.hse.gov.uk/pubns/indg401.htm

and also in INDG455 *Safe use of ladders and stepladders – A brief guide*, available at:

www.hse.gov.uk/pubns/indg455.htm

STUDY QUESTIONS

12. What are the main risks from working at height?
13. Give one example for each of the following elements of the hierarchy of control measures for working at height:
    - Avoid.
    - Prevent.
    - Minimise.

(Suggested Answers are at the end.)

Lone Working

IN THIS SECTION...

- Lone workers are those who work by themselves without close or direct supervision. They may be found in a wide range of situations, both in fixed establishments and working away from their fixed base.
- Employers need to investigate the potential hazards faced by lone workers and assess the risks involved both to the lone worker and to any person who may be affected by their work. Obvious risks include violence to lone workers and the need for a second person to assist with the task or in a rescue role.
- Particular problems facing lone workers include:
  - Medical conditions.
  - Training.
  - Supervision.
  - Emergency procedures.
  - Lifting objects that are too heavy for one person.
  - The need for more than one person to operate essential controls or transport.
- Employers should ensure that measures are in place either to avoid the risks or to control them.
- The precautions and safe working procedures for lone working will depend on the work activity.

The Hazards of Lone Working

Lone workers are those who work by themselves without close or direct supervision. Working alone is not necessarily hazardous in its own right and the hazards of lone working depend very much on the nature of the activity.

Lone workers may be found in a wide range of situations, both in a fixed establishment and work away from their fixed base.

- **Fixed establishments**, for example:
  - Small workshops, petrol stations, kiosks or shops.
  - Working from home.
  - Separately from others in factories, warehouses, research and training establishments, leisure centres.
  - Outside normal hours such as cleaners and security, production, maintenance or repair staff.
- **Work away from their fixed base**, for example:
  - Construction, plant installation, maintenance, electrical repairs, vehicle recovery.
  - Agricultural and forestry work.
  - Service work such as rent collectors, postal staff, social workers, doctors, drivers, sales representatives and other professionals visiting domestic and commercial premises.

Lone worker taking soil samples

The Risks and Alternatives for Lone Working

Employers need to investigate the potential hazards faced by lone workers and assess the risks involved both to the lone worker and to any person who may be affected by their work. Obvious risks from the examples given above include violence to lone workers and the need for a second person to assist with the task or in a rescue role. However, each work activity will need to be assessed individually. Employers should ensure that measures are in place either to:

- Avoid the Risks

  The alternative to lone working is to ensure that at least one other person is present. High-risk activities where this may be required include:

  - Working in a high-risk confined space, where a supervisor may need to be present, along with someone dedicated to the rescue role.
  - People working at or near exposed live electricity conductors.
  - Other electrical work where at least two people are sometimes required.

- Control the Risks

  When a risk assessment shows it is not possible for the work to be conducted safely by a lone worker, the risk may be addressed by making arrangements to provide help or back-up, or through control measures such as instruction, training, supervision and issuing protective equipment.

Precautions and Safe Working Procedures for Lone Working

The precautions and safe working procedures will depend on the work activity, since lone working may occur in a wide range of different work environments.

Lone workers should not be put at more risk than other employees and to achieve this, extra risk control measures may be necessary.

Precautions should take account of normal work and foreseeable emergencies such as fire, equipment failure, illness and accidents.

Employers should identify situations where people work alone and ensure that controls are in place if there is a need for a single worker to:

- Handle temporary access equipment, such as portable ladders or trestles.
- Handle machinery and goods.
- Lift objects too large for one person.
- Operate essential controls for the safe running of equipment or workplace transport.
- Work in a situation where there is a risk of violence.

Particular Problems Facing Lone Workers

The problems that might arise from lone working will depend very much on the nature of the work activity but the following issues will need to be considered:

- Medical Conditions

  Employers need to:

  - Check that lone workers have no medical conditions that may make them unsuitable for working alone.
  - Consider both routine work and foreseeable emergencies that may impose additional physical and mental burdens on an individual.

- **Training**
  - Training may be critical to avoid people panicking in unusual situations where there is limited supervision.
  - Lone workers need to be sufficiently experienced and fully understand the risks and precautions.
  - Employers should set the limits to what can and cannot be done while working alone and ensure employees are competent to deal with circumstances that are new, unusual or beyond the scope of training, for example:
    - When to stop work and seek advice from a supervisor.
    - How to handle aggression.
- **Supervision**
  - The extent of supervision required depends on the risks involved and the ability of the lone worker to identify and handle health and safety issues.
  - The higher the risk, the greater the level of supervision required. This may involve:
    - Supervisors periodically visiting and observing people working alone.
    - Regular contact between the lone worker and supervisor, using mobile phones, telephones, radios or e-mail.
    - Automatic warning devices which operate if specific signals are not received periodically from the lone worker.
    - Other devices designed to raise the alarm in an emergency, operated manually or automatically by the absence of activity.
    - Checks to ensure a lone worker has returned to their base or home once their task is completed.
- **Emergency Procedures**

  The risk assessment should identify foreseeable emergencies that might affect lone workers. Procedures should be established to deal with them and relevant information and training provided. Lone workers should also have access to adequate first-aid facilities; they may even need first-aid training themselves and mobile workers may need a first-aid kit.
- **Lifting Objects that are Too Heavy for One Person**

  Manual handling risk assessments may identify situations where two persons are needed for a lifting operation and therefore such activities will not be able to be carried out by lone workers without mechanical assistance.
- **More than One Person Needed to Operate Essential Controls or Transport**

  Similarly, general risk assessments may identify plant and equipment where two or more persons are required for its safe operation and, again, lone workers will not be able to operate such equipment without assistance. A simple example is the use of a banksman for crane operations or vehicle movements.

MORE...

www.

More information on working alone can be found in the HSE guidance document INDG73 (rev3), *Working Alone, Health and Safety Guidance on the Risks of Lone Working* which can be found at:

www.hse.gov.uk/pubns/indg73.pdf

STUDY QUESTIONS

14. Explain:

    (a) the hazards and

    (b) the risks

    of lone working.

15. Outline controls employers can put in place to deal with the risks involved in lone working.

(Suggested Answers are at the end.)

Summary

Safe Working Environment

We have:

- Outlined what constitutes a safe working environment, including design and maintenance issues.
- Identified the common types of safety sign - prohibition, mandatory, safe condition and warning signs - displayed in the workplace.
- Outlined where signs should be used and considered how other standard warning markings and signs should be used.
- Identified slips as a major cause of workplace injury and outlined the ways to avoid slips, trips and falls at work.
- Explained that the slipperiness of flooring materials can be assessed by using the Coefficient of Friction (CoF) test, which will provide information on different CoF values between one surface and another and the effects of contamination on surfaces in terms of CoF.

Confined Spaces

We have:

- Outlined the conditions which constitute a confined space, defined by the possibility of a foreseeable specified risk, and the factors to be considered when assessing risks, including safe access and egress and the removal of contaminants.
- Explained the importance of providing and maintaining a safe atmosphere, including provision of breathing apparatus.
- Outlined the risk assessment method to be followed, considering the persons at risk, task, material, equipment and the reliability of existing safeguards.
- Outlined the design of safe working practices, particularly the need for a permit-to-work in a confined space.
- Outlined the requirement for emergency procedures and the provision of training before any work in a confined space.

Structural Safety of Workplaces

We have:

- Identified the most likely causes of damage to the structure of buildings, including adverse weather conditions, overloading of the structure, hot and corrosive atmospheres, vibration, alteration to structural members, subsidence, deterioration of building materials, excavations and unauthorised modifications.
- Outlined the common signs of structural damage and noted that structural alterations can lead to collapse.
- Identified how failure modes involved in the causes of structural failure, such as poor design, substandard construction, cutting of roof beams, puncturing holes through floors and removal of internal walls, can lead to collapse of a building.

Working at Height

We have:

- Identified the hazards and risks associated with working at height and the alternatives, precautions which can be taken.
- Outlined the hierarchy of control for working at height:
  - Avoid working at height.

– Prevent working at height by using an existing place of work.
– Prevent working at height by using collective or personal work equipment.
– Mitigate by using collective or personal work equipment to minimise the distance and consequences of a fall.
– Mitigate by using collective or personal work equipment to minimise the consequences of a fall.
– Mitigate through training and instruction or other means.

Lone Working

We have:

- Identified the hazards and risks of lone working and the precautions which should be taken for safe working.
- Described the common problems faced by lone workers and the procedures which should be followed to avoid these.

Exam Skills

Introduction

It should go without saying that to achieve the NEBOSH International Diploma you will need to work carefully through your course. But you also need to perform when it really matters - in the exam.

As you work through the course you will build up your confidence in preparation for the exam day.

Before we get any further, let's just outline some basic information about the exam itself:

- You have three hours to complete the exam, plus 10 minutes' reading time.
- There are two sections:
  - Section A: **six** compulsory questions (10 marks each).
  - Section B: you can choose to answer **three** questions from five on the paper (20 marks per question).

  So there are 120 marks available in total.

The exam questions require you to demonstrate your knowledge and understanding of the elements you have studied as part of your course – and to show that you can apply your knowledge and understanding to both familiar and unfamiliar situations.

That might sound daunting, but basic exam technique is really quite simple (as long as you know the information, of course!). Essentially, what you need to do is:

- **Step 1:** Read each question carefully.
- **Step 2:** Review the marks available (consider how long you should spend on the question and how many points of information you need to include).
- **Step 3:** Highlight the key action words.
- **Step 4:** Read the question again.
- **Step 5:** Plan your answer (using mind maps, bullet points, etc.) so that you have a structure to work to.
- **Step 6:** Answer the question in full, keeping a close eye on the time (allow 15 minutes for a Section A, 10 mark question, and 30 minutes for a Section B, 20-mark question).

You will find more guidance as you work through the course along with plenty of sample/practice questions. It's really important that you complete these and get in touch with a tutor if you have any queries or there is anything you are struggling with.

Taking notice of the action verbs when answering questions is essential! NEBOSH have published the following guide to understanding the action verbs:

Command Word	Meaning
Analyse	To divide or break down the subject matter or topic into parts, reasons, aspects, etc. and then examine their nature and relationship.
Assess	To present judgments of the factors raised, their significance, importance and why they are important and/or significant.
Calculate	To ascertain or determine by mathematical processes.
Comment	To give opinions (with justification) on an issue or statement by considering the issues relevant to it.
Compare and contrast	To provide a point-by-point account of the similarities and differences between two sets of information or two areas.
Consider	To offer some detail about an issue or event and to deliberate about the value of that issue/event.
Define	To give the meaning of a word, phrase or concept, determine or fix the boundaries or extent of. A relatively short answer, usually one or two sentences, where there is a generally recognised or accepted expression.
Demonstrate	To prove or make clear by reasoning or evidence how some relationship or event has occurred.
Describe	To give a detailed written account of the distinctive features of a subject. The account should be factual, without any attempt to explain.
Determine	To come to a decision as the result of investigation or reasoning.
Discuss	To give a critical account of the points involved in the topic.
Distinguish	To present the differences between; to separate into kinds, classes, or categories.
Evaluate	To determine the value or character of something by careful appraisal.
Explain	To provide an understanding. To make an idea or relationship clear.
Give	To provide short, factual answers. NB: Normally a single word, phrase or sentence will be sufficient.
Identify	To give a reference to an item, which could be its name or title.
Justify	To prove or show to be valid, sound, or conforming to fact or reason.
Outline	To indicate the principal features or different parts of.
Recommend	To bring forward as being fit or worthy; to indicate as being one's choice for something.
Review	To make a survey of; examine, look over carefully and give a critical account.

We have provided some sample answers that a student may give, together with some possible answer points that the examiners would expect to see covered. They are based on examiners' reports, **but neither the student response nor the possible answer points are model answers**. The possible answers are also NOT provided as a full answer – in an exam you would need to expand upon the bullet points, taking into account the action verbs, in order to answer the question correctly. Providing the examiner with such a brief answer would not attract good marks.

HINTS AND TIPS

As a rough guide, you will be expected to provide one answer point for each mark available in a sub-question, i.e. two points should be included to gain full marks for a two-mark sub-question, eight points for an eight-mark sub-question, etc.

However, if you have time, try to include an extra answer point or two where you can – this will increase your chances of gaining full marks.

Be aware of your timing. It's important not to spend too long on a particular question and run out of time at the end as a result. The real key to success is answering all the questions you need to and answering them well!

QUESTION

Taking into account what we have just covered on exam technique, consider the following question:

(a) **Give** the meaning of the term 'confined space'. **(2)**

(b) **Outline** the factors that should be considered to ensure that emergency rescue arrangements for confined space work are suitable and sufficient. **(8)**

Approaching the Question

Step 1: Read the question carefully.

Step 2: Consider the marks available. In this question there are 10 marks available, with 2 allocated to part (a) and 8 to part (b). In part (b) you should provide 8 factors (however, if you suggest 10 you will increase the likelihood of gaining full marks). The question should take around 15 minutes.

Step 3: Highlight the key words. In this case this might look like this:

(a) **Give** the meaning of the term 'confined space'.

(b) **Outline** the factors that should be considered to ensure that emergency rescue arrangements for confined space work are suitable and sufficient.

Step 4: Read the question again to make sure you understand it. (Re-read your notes if you need to.)

Step 5: Plan your answer. It is important to pay attention to the action verbs, as these indicate the depth of the answer that NEBOSH would be looking for. When you are asked to "give" you are expected to provide the information without explanation. For an "outline" you should provide a brief explanation (maybe a sentence or two). Many candidates fail to provide the right depth after ignoring the action verbs and as a result fail to gain good marks.

Step 6: Now have a go at the question, basing your answer on the key words that you have highlighted.

When you have finished have a look at the following comments and guidance.

Suggested Answer Outline

For part (a) the examiner would expect you to show that you understand the meaning of "confined space" and marks would be available for an explanation something like the following:

"A confined space is any enclosed or partially enclosed place such as a chamber, tank, vat, silo, pit, trench, pipe, sewer or flue or other similar space in which, by virtue of its enclosed nature, there arises a reasonably foreseeable specified risk such as a lack of oxygen, fire, drowning in liquids or the possibility of drowning in free flowing solids."

For part (b) the examiner would expect you to outline eight (remember, there are eight marks available for this part) of the following factors for emergency rescue (along with examples):

- Characteristics of the confined space (size, location, etc.).
- Specific risks associated with the confined space, e.g. oxygen depletion, noxious vapours, fire, drowning in liquids, being engulfed in solids.
- The risks of entering in an emergency.
- How a rescue would take place.
- The provisions in place for communication and raising the alarm in an emergency.
- Whether a rescue needs to be carried out from inside or outside of the confined space.
- The rescue equipment which is required for the task.
- Whether staff know how to use rescue equipment.
- Other plant in the area that may impact the rescue.
- Whether an emergency rescue would be carried out by on site personnel or the external emergency services and how the emergency services would be contacted.
- First-aid provision.
- Training/refresher training.
- Types of emergencies that may be encountered including fire.
- The types of injuries that may be encountered and therefore the rescue techniques that may be needed.

Example of How the Question Could be Answered

(a) A confined space is any enclosed space such as a chamber, pit, tank or trench, where, due to the enclosed nature, there is a reasonably foreseeable specified risk, such as lack of oxygen or drowning.

(b) Factors to be considered to ensure that emergency rescue arrangements are suitable and sufficient include:

- *The nature of the confined space – the nature of the hazards contained within the space, e.g. chemical vapours or free-flowing solids.*
- *The ease of access into the space – whether access is needed from above, e.g. through a tank hatch, at height, or via an access door, etc.*
- *The means of raising alarm in the event of an emergency – whether radios or telephones are in use.*
- *The personnel who would carry out a rescue, whether they are on-site personnel or external emergency services.*
- *Whether first-aid provision is available and whether the personnel are trained to enter confined spaces.*
- *Whether the rescue personnel are trained to use breathing apparatus to effect a rescue.*
- *The rescue equipment required to lower personnel into a vessel or extract a casualty, e.g. harness, life-line and tripod with winch.*
- *The fire-fighting equipment required, e.g. careful selection so as not to introduce a hazard into the confined space, such as an asphyxiant.*
- *The training provided for workers in the confined space, and rescue teams who may be called to enter a space.*
- *The need to practise emergency procedures in order to ensure that their skills are up to date.*

HINTS AND TIPS

Don't worry too much about the grammar and spelling in your answer, but the examiner MUST be able to understand what you are trying to say. There must be a logical flow to the information you provide and this is where your Answer Plan is so important.

When a question is asked in two parts, as this one is, it's important that you present each sub-question separately and label them clearly.

Also remember that the examiner MUST be able to read your handwriting – if they can't read what you have written, they can't award you any marks!

Reasons for Poor Marks Achieved by Exam Candidates

An exam candidate would achieve **poor marks** for not being aware that the question asked about emergency rescue and answering it as a general confined space entry question.

Element IC2

Fire and Explosion

Learning Outcomes

Once you've read this element, you'll understand how to:

1. Outline the properties of flammable and explosive materials and the mechanisms by which they ignite.
2. Outline the behaviour of structural materials, buildings and building contents in a fire.
3. Outline the main principles and practices of prevention and protection against fire and explosion.

Contents

Properties of Flammable and Explosive Materials and the Mechanisms by which they Ignite

IN THIS SECTION...

- The following terminology is essential in understanding the properties of combustible and potentially explosive solids, liquids and gases: flash point, fire point, auto-ignition temperature, vapour density, limits of flammability, maximum explosion pressure and rate of pressure rise.
- The three components of the fire triangle - fuel, oxygen and an ignition source - are all required for a fire to start.
- Fire is a combustion reaction - fuel is converted to combustion products (smoke, fumes, gases) in the presence of oxygen. Combustion can be divided into the following five stages: induction, ignition, growth, steady state and decay.
- An explosion is a sudden and violent release of energy, causing a pressure blast wave. Uncontrolled vapour cloud explosions and confined vapour cloud explosions have different mechanisms.
- Increasing atomisation/particle size and/or oxygen content aids the combustion process.
- There are five principles of control for safe working with flammable substances: ventilation, ignition, containment, exchange, separation. Failure of these control measures, coupled with the physico-chemical properties of flammable materials, can bring about an explosion.
- Vapour explosions may be categorised as confined, unconfined and boiling liquid expanding vapour explosions.
- Prevention and mitigation of vapour phase explosions may be achieved through structural protection; plant design and process control; segregation and storage of materials; hazardous area zoning; inerting; explosion relief; controlling the amount of material; prevention of release; control of ignition sources; and sensing of vapour between Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL) in order to detect the formation of an explosive atmosphere.
- Most organic solids, most metals and some combustible inorganic salts can form explosive dust clouds. The mechanisms of dust explosions involve combustible solid particle size, dispersal, explosive concentrations, ignition, energy, temperature and humidity.
- Dust suspended in air in process equipment can allow dust explosion conditions to occur (a primary explosion). Secondary explosions are caused when lying dust in the workplace is disturbed and forms a second dust cloud, which is then ignited by the heat released from the primary explosion.

Properties of Solids, Liquids and Gases

In order to be able to assess the risk of fire and explosion we need to understand how fires and explosions occur. This requires some knowledge of the properties of combustible and potentially explosive solids, liquids and gases and in particular, the following important terms.

Flash Point

Substances which have a flash point below ambient temperature will pose a hazard as they will be producing a flammable vapour.

> **DEFINITION**
>
> **FLASH POINT**
>
> The lowest temperature of the liquid at which sufficient vapour is given off to flash, i.e. ignite momentarily, when a source of ignition is applied.

Some common solvents and their flash points

Solvent	Flash Point (°C) (Abel closed cup)
Butanone (methyl ethyl ketone, MEK)	–7
Carbon disulphide (CS_2)	–30 (Auto-ignition temp. 102°C)
Diesel oil	+40 (approx.)
Ethyl ethanoate (ethyl acetate)	–4
Ethoxyethane (diethyl ether)	–40
Methylated spirit	10
Methylbenzene (toluene)	4
Petrol	–40 (approx.)
Phenylethene (styrene)	32
Propanone (acetone)	–17

Note: Petrol is far more dangerous than diesel oil if it is spilled because the vapours from petrol will ignite from any fortuitous ignition source, whereas those from diesel will not. Contemplate such a spillage into the bilges of a boat and you can see why the insurance premiums are higher if the boat has a petrol engine.

Substances with very low flash points are very volatile. Ether, acetone and carbon disulphide are all notoriously dangerous.

Flash point tests may be applied to **any** liquid and not just hydrocarbons. There are several types of apparatus which can be used for the determination of flash point.

Fire Point

The temperature is usually just above the flash point and, when the vapours are ignited, the heat of the flash raises the temperature of the liquid surface to a point where sufficient vapour is given off to sustain combustion.

DEFINITION

FIRE POINT

The lowest temperature at which the application of an ignition source will lead to continuing burning.

Auto-Ignition Temperature (AIT)

The material can be a solid, liquid or gas and once ignition has taken place the material will sustain the self-ignition in the absence of spark or flame.

The value is influenced by the material's size and the shape of the heated surface and, in the case of a solid, the rate of heating and other factors.

A chemical reaction can supply the heat to raise a substance above its AIT. Haystacks have been known to ignite due to bacteriological action causing internal heat rises.

On a more practical note, the relatively low AIT of diesel, which is, surprisingly, lower than petrol, means that diesel engines do not have to have a spark plug. The action of compressing the fuel/air mixture in the cylinders of the engine is enough to raise it above the AIT and cause ignition.

DEFINITION

AUTO-IGNITION TEMPERATURE

The lowest temperature at which the substance will ignite without the application of an external ignition source. (Different substances have different AITs.)

Vapour Density

Vapour is the dispersion of molecules of a substance in air that is liquid or solid in its normal state, e.g. water vapour, benzene vapour.

'Normal state' means at normal temperature and pressure, where the pressure is often expressed in millimetres of mercury (mm Hg).

Limits of Flammability

Below the LFL, the mixture has too much air to allow combustion to take place (lean or weak mixture). Above the UFL, the mixture has too much fuel for combustion to take place (rich mixture).

These figures are important in helping to decide suitable fire prevention strategies; it is usual to try to keep the atmosphere below the LFL.

DEFINITIONS

VAPOUR DENSITY

The mass of vapour per unit volume (its weight).

LIMITS OF FLAMMABILITY

The extremes of fuel (vapour or gas) to air ratios between which the mixture is combustible.

Examine the figure entitled "An illustration of flammable limits" and the table which follows, both of which show the limits for some flammable liquids and gases in air.

An illustration of flammable limits

In pure oxygen or oxygen-enriched atmospheres, the limits become wider than they are for air - so it is more likely for a mixture of gas or vapour to be within the flammable range, and fires are correspondingly more difficult to extinguish.

Conversely, if the air or oxygen is diluted with an inert gas such as nitrogen or carbon dioxide, the limits become narrower until they converge together and there is no flammable range. Such dilution would typically reduce the oxygen content to 8%-10% (the same limit below which an atmosphere would be irrespirable and unable to support life).

In the practical situation of a leak involving petrol, dispersion and natural dilution in still air would reduce the vapour content below the LFL at a distance of about 12m from the leak; this is known as the **safe dilution point** and gives an indication of the size of zone which would be needed to control sources of ignition in order to prevent a fire.

Examples of flammable limits in air

Fuel	Physical State	Lower % Limit	Upper % Limit
Hydrogen	GAS	4	74
Carbon monoxide		12.5	74
Methane		5	15
Propane		2.5	9.5
Butane		2	8.5
Ethylene (ethene)		3	32
Acetylene (ethyne)		2.5	80
Ethyl alcohol (ethanol)	VAPOUR FROM LIQUID	4	19
Carbon disulphide		1.3	50
Petrol		1.4	7.5
Paraffin		0.7	5.0
Diethyl ether (ethoxyethane)		2	36

Maximum Explosion Pressure

If an explosion takes place in an unvented vessel, the rise in pressure to the maximum explosion pressure may cause damage to the vessel and surrounding area. To produce a vessel that would withstand the maximum pressure of an explosion would probably result in an uneconomic, heavy, thick-walled structure.

The alternative is to provide venting in the form of bursting discs or panels, at a pressure below the maximum explosion pressure. On reaching this pressure, the vents will open and dissipate the pressure before excessive damage is caused. (This issue will be discussed later in this element.)

Rate of Pressure Rise

The damage caused as a result of the blast pressure front of an explosion is a result of two factors: the maximum explosive pressure and the rate of pressure rise. If the pressure rise is rapid, then the containing vessel will not have sufficient time to resist the forces. The need for venting is therefore important. The data from specified tests to determine maximum explosion pressure and rate of pressure rise are used to design explosion mitigation methods considered later in this element.

DEFINITIONS

MAXIMUM EXPLOSION PRESSURE

The maximum pressure occurring in a closed vessel during the explosion of an explosive atmosphere. It is determined under specified test conditions with different atmospheres (dust, gas, etc.) having different maximum explosion pressure values.

RATE OF PRESSURE RISE

The rate of the pressure rise in a given time during the explosion of an explosive atmosphere in a closed vessel. This is determined under test conditions.

The Fire Triangle

What do we need to start a fire?

1. A **combustible substance or fuel** (wood, paper, plastics, etc.).
2. **Oxygen** in a gas state (usually from air).
3. An **ignition source** (or heat).

The triangle of combustion

If the conditions are right and these three factors are present, the substance will catch fire, i.e. heat and light will be evolved, accompanied by volumes of smoke and gases which will rise away from the fire.

The three factors above form the basis of the 'Fire Triangle' - all must be present to produce and sustain a fire.

Fuel

Fuel consists of flammable and combustible materials which cover all states of matter. They include:

- Combustible solids such as: wood, plastics, paper and wrapping and packaging materials, soft furnishings and fabrics and even metals, e.g. magnesium.
- Flammable solids, e.g. magnesium (in finely divided form, such as powder).
- Flammable liquids such as: petroleum and its derivatives, paints, solvents, oils, etc.
- Flammable gases such as: hydrogen, LPG, methane, etc.

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www.rrc.co.uk

Air/Oxygen

Although under certain unusual circumstances it is possible to produce combustion-like chemical reactions with materials such as chlorine or sulphur, it is safe to say that nearly all combustion requires the presence of oxygen. The higher the concentration of oxygen in an atmosphere, the more rapidly burning will proceed.

While the most common source of oxygen is obviously from the air, in some workplaces there may also be additional sources, e.g. oxygen cylinders, or substances that are oxidising agents.

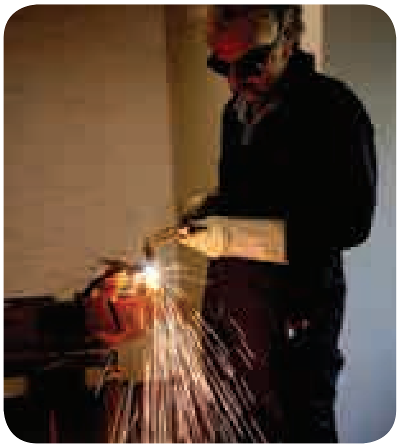
Heat

It is often overlooked that heating a very small quantity of fuel and oxygen mixture (to a sufficient degree) is enough to start a fire. Then, since fires are by definition exothermic (i.e. they release heat), the very small fire started by a tiny heat source supplies to its surroundings more heat than it absorbs, enabling it to ignite more fuel and oxygen mixture, and so on, until very quickly there is more heat available than is needed to propagate a large fire. The heat may be provided by various sources of ignition.

Ignition Sources

Ignition sources include:

- Open flames - matches, welding torches, etc.
- Electrical sparking sources.
- Spontaneous ignition.
- Sparks from grinding or tools.
- Static electricity.
- Friction.
- Hot surfaces (e.g. heaters or overheating equipment).
- Sparks (arising from impact of metal tools, electrical arcing and static discharges).
- Lasers and other intense radiant heat sources.
- Chemical reactions giving rise to heat/flame.
- Smoking.



Potential ignition source

Mechanisms of Explosions and Fire-Spread

How an Explosion/Fire Occurs

DEFINITIONS

EXPLOSION

A sudden and violent release of energy, causing a pressure blast wave. Usually it is the result, not the cause, of a sudden release of gas under high pressure, but the presence of a gas is not necessary for an explosion.

FIRE

A combustion reaction in which fuel is converted to combustion products (smoke, fumes, gases) in the presence of oxygen. It is a rapid, self-sustaining gas-phase oxidation process which produces heat and light. When combustion takes place in solids or liquids, it is the vapours given off which ignite rather than the solid or liquid itself.

An explosion may occur from a physical or mechanical change or from a chemical reaction. An explosion can occur without fire, such as the failure through over-pressure of a steam boiler or an air receiver.

In discussing the explosion of a flammable mixture, we must distinguish between detonation and deflagration:

- If a mixture **detonates**, the reaction zone propagates at **supersonic velocity** and the principal heating mechanism of the mixture is **shock compression**.
- In a **deflagration**, the combustion process is the same as in the normal burning of a gas mixture; the combustion zone propagates at **subsonic** velocity and the **pressure build-up is slow**.

Whether detonation or deflagration occurs in a gas-air mixture depends on various factors, including the concentration of the mixture and the source of ignition. Unless confined or ignited by a high-intensity source (a detonator), most materials will not detonate. However, the pressure wave (blast wave) caused by a deflagration can still cause considerable damage.

Certain materials, such as acetylene, can decompose explosively in the absence of oxygen and because of this are particularly hazardous.

In basic terms, volatile molecules of the fuel are combined with oxygen to produce new compounds (combustion products). This is an oxidation reaction which we will consider shortly.

Fuel does not generally spontaneously combust in air (think of coal). It requires some energy to vaporise sufficient fuel molecules and to initiate the reaction, e.g. by supplying heat. Once initiated, the heat produced by the reaction itself can supply the heat needed to sustain further vaporisation and combustion of fuel, so that the external heat source is no longer required.

The Stages of Combustion

Combustion can be divided into the following five stages:

- Induction

  Heat is initially supplied by an external source which results in production of flammable vapour. These vapours mix with air above the fuel and, if sufficient energy is provided, the combustion reaction begins between the vapour and the oxygen.

- Ignition

  The point of ignition is reached when the reaction becomes self-sustaining (and no longer requires an external heat source). At this stage combustion develops very quickly and there is a dramatic increase in temperature as the fire grows.

- Growth

  Once ignited, the fire may spread through direct burning or through the typical mechanisms of heat transmission (convection, conduction or radiation). The rate, scale and pattern of growth depend on a number of factors such as the:

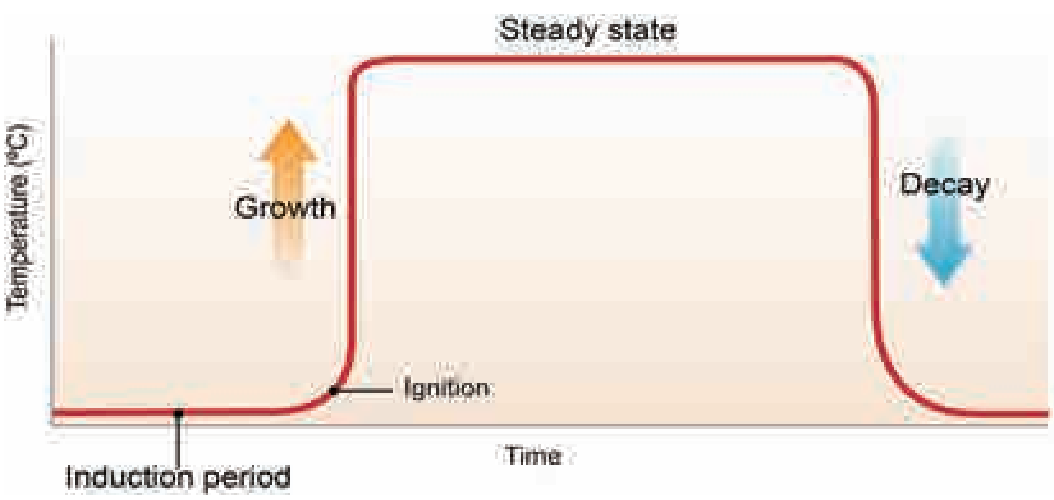
  - Nature, form and amount of the fuel.
  - Availability of oxygen (open, ventilated versus sealed containment).
  - Amount of heat produced by the reaction.

- Steady State

  After the growth period the temperature stabilises and the combustion process reaches a steady state where the reaction between fuel and oxygen is balanced until all the fuel is consumed.

- Decay

  Decay will begin when either the fuel or oxygen has been consumed. The fire will extinguish and gradually cool down. In the early stages of decay, there is still a considerable amount of heat; there is certainly enough to cause re-ignition if more fuel or oxygen is supplied. In the latter case, admission of oxygen (e.g. opening a window) into an oxygen-depleted room can result in the sudden explosive re-ignition of vapours.



Stages of combustion

Mechanisms of Explosions

Uncontrolled Vapour Cloud Explosion

An uncontrolled or Unconfined Vapour Cloud Explosion (UVCE) results from the release of a considerable quantity of flammable gas or vapour into the atmosphere, and its subsequent ignition. Such an explosion can cause extensive damage, such as occurred at Flixborough in the UK in 1974 (see http://www.hse.gov.uk/comah/sragtech/caseflixboroug74.htm for a summary of the accident).

When a large amount of volatile material is released rapidly into the atmosphere, a vapour cloud forms and disperses. If the cloud is ignited before it is diluted below its LFL, an unconfined (or uncontrolled) vapour cloud explosion will occur. This is one of the most serious hazards in the process industries. Both shock waves and thermal radiation will result from the explosion; the shock waves will usually produce the greater damage.

The energy of the blast wave is generally only a small fraction of the energy available from the combustion of all the material that constitutes the cloud. The ratio of the actual energy released to that available is often called the **explosion efficiency**.

Unconfined vapour clouds can deflagrate or detonate, but a deflagration is much more likely. A detonation is more destructive, but a deflagration can produce a damaging pressure wave. Deflagration occurs when the advancing flame front travels subsonically, in most cases <10 m/s. Detonation occurs from supersonic advancement of flame fronts, which is less common.

If a flammable mixture may be present in process equipment, precautions should be taken to eliminate ignition sources. However, it is prudent to assume that, despite these efforts, a source of ignition will at some time occur.

A UVCE requires a rapid release of a flammable liquid, moderate dispersion to produce a very large flammable air and hydrocarbon cloud, and usually some degree of containment.

Confined Vapour Cloud Explosion

If a flammable vapour cloud is ignited in a container, e.g. a process vessel, or in a building - so that it is confined - pressure can build up until the containing walls rupture. This is a Confined Vapour Cloud Explosion (CVCE). As with natural gas explosions in buildings, a relatively small amount of flammable material (a few kilograms) can lead to an explosion when released into the confined space of a building.

CVCEs can cause considerable damage, e.g. peak over-pressures of up to eight bars can be experienced in a fully confined explosion, and much higher in the unlikely event of a detonation, but in general they have insufficient energy to produce more than localised effects as far as off-site damage is concerned (e.g. broken windows). Much of the major damage found within the confines of the cloud following a UVCE probably results from local CVCEs. If the results of a CVCE affect nearby plant or equipment, serious secondary explosions can follow.

For personnel close to the blast, missiles and flash-burns can result in serious or fatal injuries. For instance, fatalities have occurred from explosions during hot work on inadequately cleaned/purged 45-gallon drums which had contained flammable residues, or in natural gas or LPG explosions following leaks into rooms.

TOPIC FOCUS

The **principles and effects of vapour cloud explosions** are as follows:

- Confined in a tank, vessel or building:
  - Vapour concentration in the confined space increases until it is above the LEL.
- Unconfined as a release of large quantities into the open air:
  - Vapour cloud at a concentration within the explosive limits may travel some distance.
  - Dispersal may reduce the concentration below the LEL.
- May arise from vaporisation of a release of liquefied gas from a ruptured vessel.
- Ignited by an ignition source of greater energy than the minimum ignition energy for the vapour cloud.
- Effects of overpressure, fire, explosion and resulting debris.

Boiling Liquid Expanding Vapour Explosion (BLEVE)

A Boiling Liquid Expanding Vapour Explosion (BLEVE) involves a sudden release of vapour, containing liquid droplets, owing to the failure of a storage vessel. This occurs when a pressure vessel containing liquid is heated so that the metal loses strength and ruptures, typically as a result of exposure to fire. The failure is usually in the metal in contact with the vapour phase; the metal in this area heats to a higher temperature because there is no liquid heat-sink to keep its temperature from rising rapidly, as there is where metal contacts a liquid phase.

A BLEVE can occur with both flammable and non-flammable materials (e.g. water). The initial explosion may generate a blast wave and missiles. If the material is flammable, it may cause a fire or may form a vapour cloud which then gives rise to a secondary explosion and fireball. The best-known type of BLEVE involves LPG. Once a fire impinges on the shell above the liquid level, the vessel usually fails within 10 to 20 minutes. In the case of a BLEVE involving a flammable material, the major consequences are, in decreasing order of importance:

- Thermal radiation from the resultant fireball.
- Fragments produced when the vessel fails.
- Blast wave produced by the expanding vapour liquid.

For example, a BLEVE of a propane sphere of 15m in diameter could cause damage as far away as 4,500m, and radiation damage and fragmentation damage would each extend to about 1,000m.

Effects of Atomisation/Particle Size and Oxygen Content

Atomisation (when referred to liquid) is a process where the liquid is turned into tiny liquid particles or droplets (typically by use of an aerosol spray or injector). This has the effect of allowing far better mixing with air as each droplet is surrounded by air (as opposed to a container of liquid where only the surface comes into contact with the air). In addition, the tiny droplets have a much greater surface area that enables reaction with the oxygen in the air. Consequently, should a source of ignition be applied to an atomised fuel/air mixture, the resulting combustion is far more rapid as each droplet will ignite almost instantaneously.

Less oxygen in the air causes the explosion to be much less severe as it limits the rate of combustion, so limiting the oxygen in process vessels can minimise the possibility of an explosion (fire can only be sustained if oxygen concentration is greater than 10% in air).

The principle of fuel atomisation is used in car engines to ensure rapid burning of the fuel/air mixture.

When it comes to solids, the equivalent of atomisation (for liquids) is breaking them down into small particles (like dusts). Breaking things down into smaller particles gives a greater surface area and makes it easier to burn when mixed with air.

Failure of Control Measures Leading to Explosion

An explosion can occur when:

- Flammable materials produce a concentration of gas or vapour in air which is above the LFL (and below the UFL), i.e. in the explosive or flammable range.
- A source of ignition of sufficient energy is present to ignite the vapour.

The UK HSE publication INDG227 *Safe Working with Flammable Substances*, establishes five principles of control for safe working with flammable substances which aim to prevent fires and explosions. Failure of these control measures coupled with the physico-chemical properties of flammable materials can bring about an explosion:

- **Ventilation** ensures that any vapours given off from a spill, leak, or release from any process will be rapidly dispersed, preventing the formation of a vapour/air mixture above the LFL.
- **Ignition** sources must be removed from storage and handling areas for flammable materials. If the ignition source generates energy above the Minimum Ignition Energy (MIE) for the combustible vapour or gas then an explosion will occur.
- **Containment** prevents the escape of flammable materials into the workplace which can release vapours and generate explosive mixtures.
- **Exchange** of a flammable substance for a less flammable one will reduce the risk of formation of an explosive mixture. Flammable liquids with flash points well above room temperature will be unlikely to form explosive atmospheres under normal working conditions. Controlling the flammability of substances used in the workplace or eliminating them altogether will prevent the formation of explosive mixtures.

- **Separation** of flammable substances from other processes and general storage areas by physical barriers, walls or partitions will contribute to a safer workplace by controlling the zone in which flammable atmospheres may be present.

Oxidisation

Oxidisation is the process of oxidising; the addition of oxygen to a compound. Combustion is a rapid, self-sustaining gas-phase oxidation process which produces heat and light. Volatile molecules of the fuel are combined with oxygen to produce new compounds (combustion products). The potential combustion products depend on the fuel (and its complexity) as well as the completeness of the combustion reaction. If we take a simple case such as the combustion of carbon (e.g. coal), combustion products would be carbon dioxide (complete combustion) and carbon monoxide (incomplete combustion). Incomplete combustion occurs where the oxygen is limited.

TOPIC FOCUS

Chemical Equations

Chemical reactions are depicted as **chemical equations** to explain what is happening.

In a **chemical equation** the tiny entities (**molecules**) that react with each other are shown as **chemical formulae**, e.g. $\mathbf{H_2O}$ represents water, $\mathbf{CO_2}$ represents carbon dioxide.

Sometimes more than one **molecule** of a substance reacts with another one in a reaction so this is shown by a number in front of the **formulae,** e.g. **2**H_2O represents two molecules of water, CO_2 represents one molecule of carbon dioxide (we don't need to show the **1**).

When methane gas (CH_4) burns in air (i.e. reacts with oxygen, O_2) we find that **one molecule** of methane (CH_4) reacts with **two molecules** of oxygen ($2O_2$).

This reaction produces **one molecule** of carbon dioxide (CO_2) and **two molecules** of water ($2H_2O$).

This can be represented by the **chemical equation:**

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

which is a simple form of shorthand to show what **molecules** are reacting together and **how many** of them are involved.

Complete Combustion

In a complete combustion reaction, fuel reacts with oxygen and the products are compounds of each element in the fuel with oxygen. For example, methane burns in air to form carbon dioxide and water:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Another example is the combustion of hydrogen and oxygen to form water vapour:

$$2H_2 + O_2 \rightarrow 2H_2O\ (g) + \text{heat}$$

Incomplete Combustion

Incomplete combustion occurs when there isn't enough oxygen to allow the fuel to react completely with the oxygen. When methane burns in limited air, the reaction will yield carbon dioxide and water, but also carbon monoxide and pure carbon (soot or ash). This results from the reduced oxygen supply and the inability for full oxidation to carbon dioxide and water:

$$4CH_4 + 6O_2 \rightarrow CO_2 + 2CO + C + 8H_2O$$

Flammable Atmospheres

Flammable atmospheres can arise or be caused by the release of flammable gases, mists, vapours or combustible dusts into an area where, if there is enough of the substance, mixed with air, then all that is required is a source of ignition to cause a fire or an explosion.

Many workplaces may contain potentially explosive atmospheres or have activities that produce such atmospheres. Examples include:

- Activities that create or release flammable gases or vapours, such as vehicle solvent paint spraying.
- Workplaces handling fine organic dusts such as grain flour or wood.

Control measures for entering areas where a flammable atmosphere may exist include:

- carrying out a thorough risk assessment;
- employing safe systems of work;
- use of a permit-to-work;
- a competent and well trained workforce; and
- cleaning and purging of the area to keep any flammable atmosphere to below the Lower Flammable Limit (LFL).

Ignition sources should be controlled and the workforce should use anti-static clothing, spark-proof (bronze) tools and intrinsically safe, explosion-proof (ATEX) electrical equipment.

Classification and zoning of the area should be established in accordance with the guidelines set out in the **UK Dangerous Substances and Explosive Atmospheres Regulations** (see **Hazardous Area Zoning** later in this element).

DEFINITION

ATEX

The name commonly given to the two European Directives for controlling explosive atmospheres:

- **Directive 99/92/EC** (also known as 'ATEX 137' or the 'ATEX Workplace Directive') legislates on minimum requirements for improving the health and safety protection of workers potentially at risk from explosive atmospheres. It has been transposed into UK law as the **Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR)**.
- **Directive 94/9/EC** (also known as 'ATEX 95' or the 'ATEX Equipment Directive') concerns equipment and protective systems intended for use in potentially explosive atmospheres. It has been transposed into UK law as the **Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 1996**.

Causes and Effects of Vapour Explosions

For combustion to take place, a material must first generate sufficient vapour/gas so that, when mixed with air, its concentration lies within the **explosive range** (also called flammable range), i.e. its concentration must be between the **LEL** and **UEL**. Some form of ignition source of sufficient energy is also, of course, required.

Confined Vapour Cloud Explosion (CVCE)

We've seen that CVCEs are simply the ignition of a flammable vapour under conditions of confinement, such as a process vessel or building. The pressure rise (which may be 8 bar for a deflagration and much higher for a detonation) may rupture the containment. Only small amounts of flammable gas/vapour are needed, e.g. a small gas leak in a building or the flammable residue left in a drum. Damage caused by explosions of this type may initiate secondary explosions.

Unconfined Vapour Cloud Explosion (UVCE)

This is where the vapour cloud is not confined to any great extent. Such explosions require the rapid release of large quantities (typically at least 5 tonnes) of flammable vapour/gas together with some moderate mixing with air (to produce a very large flammable gas/air mixture). Ignition then must occur before the cloud has sufficient time to dilute below the LEL. One of the best-known explosions of this type occurred at Flixborough in the UK in 1974 (mentioned earlier). It involved the ignition of an estimated 30-tonne cyclohexane vapour cloud.

Deflagration or detonation is possible and the resultant pressure waves and heat result in extensive damage.

Boiling Liquid Expanding Vapour Explosion (BLEVE)

Significant damage to equipment and buildings from radiation is possible from a BLEVE. Wooden structures may be ignited if the radiant heat density at the structure's location exceeds the threshold value for ignition of wood. Severe damage from fragmentation can be expected in the area where 50% or more of the fragments may fall (typically about 100m from the vessel).

As mentioned above, in a fire, a tank containing liquid is most vulnerable in the area controlling the vapour (because very little heat can be absorbed by the vapour) so the metal here will heat up rapidly and weaken. The metal contacting the liquid will heat up much more slowly. Therefore there is a dilemma: a BLEVE may occur sooner in a partly full vessel than a full one, but a full vessel will contain more fuel for the resulting fireball and fire than will a partly empty vessel.

Prevention and Mitigation of Vapour Phase Explosions

Investigation and analysis of the cause and consequences of vapour phase explosions identifies the following important control principles:

- **Structural protection** incorporated into building design can reduce the effects of a vapour phase explosion on occupants.
- **Plant and process design and control** can reduce the risk of fire and explosion by preventing flammable concentrations of vapour developing and coming into contact with sources of ignition. In addition, isolation can stop the explosion from reaching other areas of the plant through pipes or ducts. Pressure-resistant equipment will contain an explosion. Process controls can ensure that concentrations do not exceed the LFL.
- **Segregation and storage of materials** will aim to ensure that flammable substances are stored outside, in designated storage areas, but if kept inside they should be segregated from any work that is likely to produce a source of ignition.
- **Hazardous area zoning** classifies areas on the basis of the frequency and duration of the occurrence of an explosive atmosphere. For example, under UK legislation such areas are classified as follows:
  - **Zone 0**

    A place in which an explosive atmosphere consisting of a mixture of air with dangerous substances in the form of gas, vapour or mist is present continuously or for long periods of time or frequently.
  - **Zone 1**

    A place in which an explosive atmosphere consisting of a mixture of air with dangerous substances in the form of gas, vapour or mist is likely to occur in normal operation occasionally.
  - **Zone 2**

    A place in which an explosive atmosphere consisting of a mixture of air with dangerous substances in the form of gas, vapour or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

  Hazardous area zoning will be discussed in more detail later in this element.

- **Inerting** involves the partial or complete substitution of the air in an enclosed space by an inert gas and can be employed very effectively to prevent explosions.
- **Explosion relief** reduces the damage from a vapour phase explosion by either relieving the pressure generated by the explosion by means of vents, panels and bursting discs or by suppressing the explosion through inerting.
- **Control of amount of material** limits the quantity to be stored in a workroom or working area and requires justification of the need to store any particular quantity of flammable liquid within a workroom/working area. The guiding principle is that only the minimum quantity needed for frequently occurring activities or that required for use during half a day or one shift should be present in the workroom/working area.

  It is recommended that the maximum quantities that may be stored in cabinets and bins are no more than:

  – 50 litres for extremely/highly flammable liquids and those flammable liquids with a flash point below the maximum ambient temperature of the workroom/working area.
  – 250 litres for other flammable liquids with a higher flashpoint of up to 55°C.
- **Prevention of release** by storing flammable liquids in a separate storage area, or in a purpose-made bin or cupboard, keeping containers closed when not in use, using safety containers which have self-closing lids, dispensing liquids over a tray and using non-flammable absorbent material to mop up spills.
- **Control of ignition sources** by removing all the obvious ignition sources from the storage and handling areas for flammable liquids. Typical ignition sources include sparks from electrical equipment or welding and cutting tools, hot surfaces, open flames from heating equipment and smoking materials.

Flammable liquids must be kept in closed containers when not in use

- **Sensing of vapour between LEL and UEL** in order to detect the formation of an explosive atmosphere, which can trigger an alarm system or preventative actions such as ventilation or inerting.

Dust Explosions

Industries and Plant with Potential Dust Explosion Hazards

Explosions and fires from combustible materials used and generated in many industries are a known hazard and can have devastating and irreversible effects.

Examples of explosible dusts include materials such as: flour, custard powder, sugar, metal powder, paint powder, coal and grain.

Common processes generating explosible dusts include flour milling, sugar grinding, spray drying of milk and conveyance/storage of whole grains and finely divided materials.

Examples of typical plant where explosive concentrations of dust may exist include:

- Local exhaust ventilation systems.
- Dust-collecting filter units.
- Powder-handling systems.
- Bucket elevators.
- Silos and bins.

Mechanisms of Dust Explosions

Some dusts are capable of producing explosions which are every bit as destructive as those from gases or vapours. Most organic solids, most metals, and some combustible inorganic salts can form explosive dust clouds. The dust must be **explosible.** (The **ignition energy** can be determined experimentally in test apparatus.) Other factors that affect the possibility of dust explosions include:

- Combustible Solid Particulate Size

  The **dust particles must be of a suitable size**. Solids do not have the divisions of flammability that liquids do. Dusts, however, are finely divided solids and, as with sprays, they have an increased surface area. Generally, finer dusts are more hazardous. The fineness and composition of the dust may also be a factor in determining whether it is explosible, and it is this particle size that we must consider. The smaller the particle, the greater will be the total exposed surface area of a given mass. The result of putting a source of ignition to a concentration of airborne dust can be the same as discussed with atomised fuel, with very rapid burning.

- Dispersal

  The dust particles must be dispersed in air to form a combustible mixture. Dispersal is an important factor leading to secondary explosions, which are caused when dust accumulating on surfaces in the workplace is disturbed by the primary explosion and disperses to form a second dust cloud, which is then ignited by the heat released from the primary explosion.

- Explosive Concentrations

  The dust must be mixed with air and have a concentration which lies between the explosive limits:

  – The LEL is generally taken to be about 25g to 50g per cubic metre of air and a cloud will obscure visibility to about one metre - such a concentration would not normally be encountered in the workplace. A dust cloud will have variable density and tends to become finer over time as the heavier particles settle out.

  – The UEL is ill-defined but generally taken to be about ten times the LEL.

- Ignition Energy

  There must be a sufficient source of energy to ignite the dust cloud. It is a fact that explosible dust clouds can be ignited by sparks from electrical equipment such as switches and motors, and in short-circuiting caused by damaged cables. Additionally, electrostatic discharges may initiate dust explosions in industry. For an assessment of the hazard situation in dust-processing installations, knowledge of the **Minimum Ignition Energy** (MIE) is indispensable.

> **DEFINITION**
>
> **MINIMUM IGNITION ENERGY - DUST CLOUD**
>
> The MIE of a dust cloud is the lowest energy value of a high-voltage capacitor discharge required to ignite the most readily ignitable dust/air mixture at atmospheric pressure and room temperature. The dust concentration and the ignition delay are systematically varied until a minimum value of the ignition energy is found. The tested energy levels are 1,000, 300, 100, 30, 10, 3 and 1mJ.

- Temperature and Humidity

  In general, if a process is operating at a higher temperature then the initiation of a dust explosion will require less energy and the combustion reaction will proceed at a greater rate.

  Hot surfaces can initiate ignition of a dust cloud. The minimum ignition temperature is the lowest temperature of a heated vertical surface just capable of igniting a mixture of dust and air which comes into contact with it at the optimal concentration.

  The humidity of a dust has an effect on its ignition and explosive behaviour. A higher level of humidity will increase the required MIE and may impede the formation of dust clouds. In simple terms, "damping down the dust" will reduce the likelihood of a dust explosion.

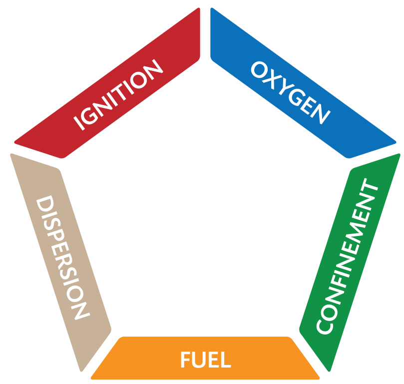
The Dust Pentagon

For a fire to start, there must be a fuel, a source of oxygen (usually taken from the surrounding air) and an ignition source. As we saw earlier, this is commonly known as the Fire Triangle.

In the case of a combustible dust explosion, two more elements are required to be added to the fire triangle, creating the Dust Explosion Pentagon.

These two new elements are: confinement of the reaction; and dispersion of the fuel. These elements are created when the fuel (a combustible dust) is dispersed as a cloud within an enclosed area, such as a factory or warehouse.

In just the same way as with the fire triangle, taking away one of these elements removes the risk of an explosion.



The dust pentagon

Primary and Secondary Explosions

The concentrations needed for a dust explosion do not usually occur outside of process vessels, so most severe dust explosions start within a piece of equipment (such as mills, mixers, dryers, cyclones, hoppers, silos, etc.). These are known as **primary explosions**. During processes, dust is generally suspended in air in process equipment, which can allow dust explosion conditions to occur. This explosion can cause the vessel to rupture.

Secondary explosions are caused when lying dust in the workplace is disturbed by the primary explosion and forms a second dust cloud, which is then ignited by the heat released from the primary explosion. The problem is that small amounts of lying dust occupy very little space, but once disturbed can easily form dangerous clouds. A 1mm layer of dust can give rise to a 5m deep cloud of dust.

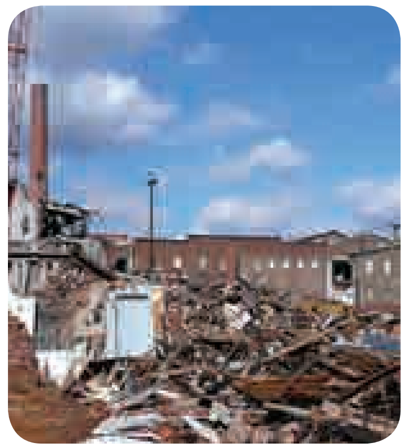
There can be a large series of explosions triggered in this manner, with devastating consequences if there is a lot of lying dust that is disturbed. It is important, therefore, to reduce the amount of lying dust to a minimum.

Prevention and Mitigation of Dust Explosions

In its guidance document, HSG103 *Safe handling of combustible dusts: Precautions against explosions*, the HSE maintains that:

"The most important mitigation measure is maintaining the process buildings in a clean condition. If you allow dust deposits to accumulate, they can provide the fuel for a secondary explosion. Dust deposits shaken into suspension from all the ledges within a room by a small primary explosion may then ignite".

Prevention involves ensuring all dust-producing plant is part of a Planned Preventive Maintenance strategy that ensures leak-tight conditions are maintained. Sources of ignition should be eliminated and dust deposits regularly removed using dust-tight vacuums. Maintaining high levels of humidity and ensuring that plant and machinery is designed to eliminate (as far as possible) flat surfaces where dust might accumulate are also recommended, as well as incorporating explosion relief vents, panels and bursting discs. Wet back collectors are often used in the metal-grinding industry – particularly where magnesium and aluminium are being worked. They are a safer alternative to ordinary Local Exhaust Ventilation, incorporating a water-flow system to collect the particles as they are generated.

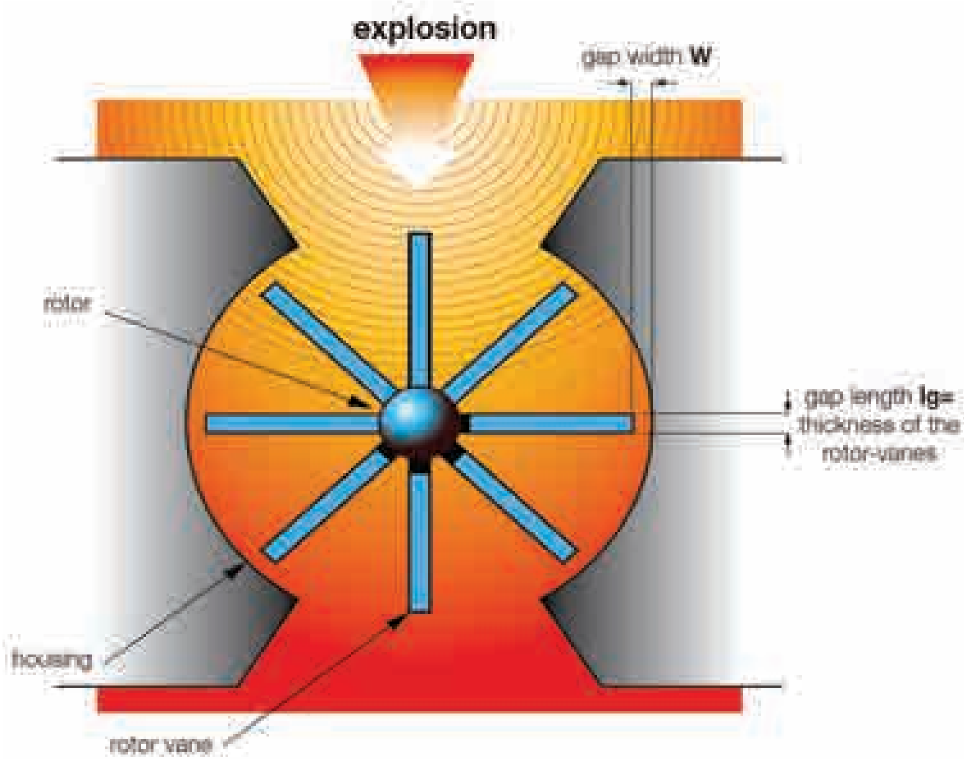

Damage from a dust explosion

Energy Suppression or Dissipation

In some industries the energy developed by a dust explosion within plant is sometimes dissipated with the use of:

- rotary valves;
- a choke of material in an intermediate hopper;
- screw conveyors with a missing flight and baffle plate;
- explosion suppression barriers; and
- explosion isolation valves.

The aim is to prevent both the spread of burning particles, and the pressure wave associated with the initial explosion.



Rotary valve used as an explosion choke

Source: HSG103 Safe handling of combustible dusts: Precautions against explosions, 2nd ed., HSE, 2003 (www.hse.gov.uk/pubns/priced/hsg103.pdf)

TOPIC FOCUS

The key principles underlying **control measures to prevent or minimise the effects of a dust explosion** are:

- **Eliminate sources of ignition:**
  - Electrically conducting footwear.
  - Non-sparking tools.
  - Electrical bonding and earthing.
  - Prevention of equipment hot-spots.
  - Magnetic extraction of ferrous metals that might generate sparks.

(Continued)

TOPIC FOCUS

- **Limit dust cloud generation:**
  - Dust tight ducting.
  - Prevention of dust build-up.
  - Damping down to suppress dust.
  - Interlocks to prevent overfilling.
  - LEV at transfer points.
- **Mitigate the explosion:**
  - Design equipment to withstand the explosion.
  - Explosion relief by vents, panels and bursting discs (will burn as the temperature increases).

STUDY QUESTIONS

1. Define what is meant by the terms 'flash point' and 'auto-ignition temperature'.
2. Explain why petrol, with a flash point of approximately –40°C, poses a constant fire risk.
3. Name three types of vapour cloud explosions.
4. Explain the main difference between a Confined Vapour Cloud Explosion (CVCE) and an Unconfined Vapour Cloud Explosion (UVCE).
5. Describe the sequence which triggers a secondary dust explosion.

(Suggested Answers are at the end.)

The Behaviour of Structural Materials, Buildings and Building Contents in a Fire

IN THIS SECTION...

- Building materials affect the safety of occupants and building contents by influencing the manner and rate of fire-spread. The selection of building materials depends on specific use and should consider combustibility, structural strength and products of combustion.
- Common building materials whose fire properties and level of fire resistance we need to understand include steel, concrete and wood.
- The effects of fire on a building depend on the behaviour of common building contents including paper-based materials, fabrics and plastics.

Behaviour of Building Structures and Materials in Fire

Many types of building material are in current use. Different materials respond in different ways to fire and therefore the choice of material will impact upon the manner and rate of fire spread. The selection of appropriate building materials depends on specific use and should consider the following:

- **Combustibility** (how readily it will burn).
- **Structural strength** when subject to heat.
- **Products of combustion** (harmful or otherwise).

Fire Properties of Common Building Materials and Structural Elements

Steel Frames

Steel has a high strength/weight ratio and is commonly used as load-bearing members. Structural members include: columns, beams, portal frames and roofs. Steel can also be used as 'profiled' sheets or lightweight roof members (purlins).

When exposed to fire, unprotected steel will rapidly lose its designed shape and, therefore, its strength. A steel beam reacts to fire by expanding and pushing the columns out, causing the floor slabs to collapse onto the floor below. This floor, not being strong enough to carry the extra load placed upon it, collapses and down everything goes. The steelwork can also spread the heat by conduction, causing the fire to spread.

Reinforced Concrete Frames

Almost all concrete used for structural purposes is reinforced. The fire resistance depends on:

- The **type** of aggregate used. All concrete is likely to 'spall' (break away) when hot, especially when hit with a jet, but the use of lightweight aggregate, or aerated concrete, can minimise this.
- The **thickness** of concrete over the reinforcing rods.

Generally the fire resistance is good, collapse is not usually sudden and many structures have been reinstated after severe fires.

The choice of material will impact on fire spread

Whether reinforced or pre-stressed, the fire resistance of concrete is mainly determined by the protection against an excessive rise in the temperature of the steel by the concrete cover. Mild steel loses half its cold strength at about 550°C and high-tensile steel at about 400°C. Structural concrete may then deflect under fire conditions but does not normally collapse suddenly.

Timber

Timber burns, but in a predictable manner. If designed with an adequate factor of safety, there can be a reasonable time lag before failure occurs, particularly if the timber is protected with plasterboard or other coverings.

Applied heat will not cause expansion to stress the structure, nor does wood collapse suddenly.

The fire resistance of timber depends on the following:

- **Thickness** or cross-sectional area of the piece.
- **Tightness** of any joints involved - in general, the fewer joints, the better.
- To some extent, the **type** of wood - generally, denser timber has better resistance. The surface chars but, because conduction is poor, the internal timber still performs structurally.
- Excess material (sacrificial timber) is added to exposed beams and columns as necessary. It is consumed by a fire before the structural core is attacked.
- Any **treatment** received - plywood or chipboard sheets may require flame-retardant treatment.

For several years now the use of laminated timber members has been on the increase, simply due to the fact that it can be designed to almost any profile and has excellent fire-resistant properties.

TOPIC FOCUS

The **effects of fire in a workplace on structural materials**:

- Steel
  - Heats up in a fire and conducts it throughout its structure.
  - Loses strength at high temperature (500°C).
  - Expands and buckles losing strength and structure.
  - Regains strength on cooling but properties may have changed.
- Concrete
  - Fire resistant and does not conduct heat.
  - Acts as an insulator at lower temperatures.
  - Will spall and disintegrate as the temperature rises.
  - Reinforcing rods will act as conductors and expand increasing any spalling.
  - Loses structural strength on cooling.
- Wood
  - Will smoulder and char initially.
  - Will burn as the temperature increases.
  - Rate of charring/burning depends on density of the wood and tightness of any joints.
  - Chars and burns from the outside so thicker wood will retain strength longer.
  - Generates smoke and fumes and allows surface propagation.

Brickwork

Clay bricks in use on a construction site

There are three types of brick in common usage: fired clay, calcium silicate and concrete.

No distinction is made between them in classifying their behaviour in fire when incorporated as a wall. The important features which affect the fire resistances of a wall are:

- Its thickness.
- The applied rendering or plastering, especially if lightweight plaster is used.
- Whether the wall is load-bearing or not.
- The presence of perforations or cavities within the bricks.

Normally, fired clay bricks respond better in a fire situation due to the manufacturing process involved, i.e. natural material (clay) and heat. They have already been exposed to greater temperatures, therefore there will be very little movement. The above features must still be taken into consideration, however.

Building Blocks

Blocks may be of clay or concrete. Their fire resistance is improved by the application of plaster.

Clay blocks generally are hollow. The greater the thickness and the smaller the voids, the better is the fire resistance. Spalling (blistering and exploding) is likely to occur on the face exposed to fire.

Concrete blocks may be made of dense or lightweight aggregates and can be either solid or hollow. All types give high fire resistance with little risk of collapse, so can be used for the walls of a fire compartment.

Building Boards

Boards are combustible if not easily ignitable. Types are:

- Softboard (non-compressed in manufacture), often called insulating board.
- Hardboard of both low and high density - if tempered by impregnation with oils and resin it has high strength and water resistance and is not easily ignitable.
- Plaster boards which retard fire spread until the paper face burns away.
- Asbestos boards (normally in older buildings), which have a high asbestos content and, consequently, have good fire-resistance properties.
- Asbestos cement sheets (again, normally in older buildings) which have a low asbestos content and usually fail by shattering under fire.
- Plywood, block boards - in both types there is variable fire resistance depending on the type of wood, thickness, etc.
- Plastic board of variable resistance depending on surface treatment.

Building Slabs

Slabs are similar to building boards but are much thicker. 'Wood-wool' slabs and compressed straw slabs are combustible and are often treated to give improved resistance. These are usually found as substrates for roofing materials.

Stone

Stone used in building will be of three general types:

- **Granite**: likely to expand rapidly and shatter at 575°C. There is always a risk of spalling, but less so with large blocks.
- **Limestone**: spalling is likely if hit with a jet at high temperature.
- **Sandstone**: generally comes between limestone and granite in behaviour. It is likely to shrink and crack.

Stone has a tendency to crack when subjected to continuous heat or to sudden cooling by a jet.

> **DEFINITION**
>
> **SPALLING**
>
> A physical process of the breakdown of surface layers of masonry, which crumble into small pebble-like pieces in response to high temperatures or mechanical pressure.
>
> Spalling is caused by heating, mechanical pressure, or both. This heat and/or pressure causes uneven expansion of the materials that make up the masonry.
>
> Pressure created by rapid changes in temperature, such as application of cold water to the heated surface during fire-fighting operations, can also cause spalling. These processes break the bond that holds the solids together and thus cause the masonry to crumble.

Glass

Glass is susceptible to breakage so cannot be used as a barrier to fire. Two exceptions are wired glass and copperlight glazing, which give some fire resistance. Other types of glazing:

- **Armourplate**: this is toughened glass which is incapable of providing fire resistance and will not stand temperatures above 300°C.
- **Double-glazing**: two or even three sheets of glass are mounted within a frame - again they are not fire-resisting and will probably shatter in a fire.
- **Fire-resistant glass blocks** are available, which need to meet the following criteria:
  - Mechanical resistance - the glass block wall must stay upright without too much damage following testing.
  - Thermal isolation.
  - Imperviousness against blaze.
  - No flammable emission during testing.
- **Fire-resistant glazing** is a recent development. Clear glasses which incorporate clear intumescent interlayers or laminates will provide fire resistance of up to 90 minutes.

Insulating Material

Most modern materials are non-combustible; unfortunately, in many older buildings, combustible materials (sawdust) have been used. Their location in concealed spaces can aid fire-spread considerably.

Lime (Plaster)

Lime is made by heating limestone (calcium carbonate), which is converted to quicklime (calcium oxide). It is then slaked with water to make calcium hydroxide. Lime is a component of plaster and mortar. It is used for plastering internal walls and, if supported by lathing or expanded metal, it has good fire resistance.

Paint

Most paints are flammable - a layer of many coats built up over years may be a fire risk. There are also flame-retardant paints and intumescent paints, which bubble up to protect the timber beneath.

Plastics

There are two types of plastic:

- **Thermosetting plastics** are formed by the action of heat and compression; they will not soften and melt when involved in a fire but will decompose.
- **Thermoplastic plastics** are moulded into the required shape by heating. On cooling they remain in that shape. If involved in a fire, they will melt and flow.

Plastics are used primarily in building services and surface fascias. The principal hazards caused are the dripping of molten plastic and from the products of incomplete combustion in the form of smoke.

Level of Fire Resistance

Even when an acceptable standard of fire resistance has been achieved within a building structure, it can be easily compromised through poor selection of decorative materials and furnishings.

Curtains, carpets, furniture and even wallpaper can provide a ready route for fire transfer, as well as smoke generation.

The effect of surface spread of flame should be taken into account when considering the linings of the walls, floors, ceilings, etc. Decisions will depend on the nature of the undertaking and who may be present on the premises (e.g. the public). The spread of fire can be minimised by the use of suitable fire-resistant walls, floors and fire doors.

Typically, fire doors will have a fire-resistance rating of 30 minutes, while the structural elements of an industrial building, not more than 5m in height and without a sprinkler system, must have 60 minutes' fire resistance.

Fire resistance of structural elements of buildings is often improved by:

- Insulation of steel members, e.g. covering with concrete.
- Separation into compartments (discussed later).
- Over-engineering – thicker concrete over inner steel reinforcement, thicker wood.
- Selection of material type – best mix for concrete, type of wood.
- Treatments – impregnation of timbers with fire retardants and intumescent coatings.
- Surface cladding with non-flammable materials, e.g. plasterboard.

Behaviour of Common Building Contents in Fire

Paper

Paper is used in various forms – wallpaper, books, magazines, etc. Paper will generally scorch, char and then ignite in a fire, producing smoke, water and carbon oxides. Ignition typically takes place around 250°C. It depends on the type of paper and on its form, e.g. shredded paper in a waste bin is easier to ignite than it would be in the form of a book. The two scenarios have very different surface area to volume ratios. Paper is also often coated in waxes or clays which can affect its ignitability.

Paper will ignite at around 250°C

Plastics

Plastics are widely used inside buildings. Expanded cellular plastics (typically urethane foam) are used as wall and ceiling linings as they offer very good insulation properties. If these linings are unprotected, they can present a serious fire hazard. UPVC window frames are also popular in buildings. Different plastics can behave very differently under fire conditions.

Some ignite, some self-extinguish and some smoulder. Unplasticised halogenated plastics (such as UPVC) are naturally flame-retardant. If plasticisers are added, however, this can render them combustible. The products of combustion of plastics are similar to those of paper or wood. In oxygen-deficient atmospheres, large volumes of smoke and carbon dioxide are produced.

Fabrics and Furnishings

Fabrics and furnishings are also commonly found in buildings in the form of seating, curtains, etc. Fabrics can be natural or synthetic (man-made). Natural fabrics tend to smoulder. Synthetic fabrics (which are predominantly thermoplastics) tend to melt and shrink when exposed to a smouldering ignition source, and then ignite and burn rapidly when exposed to open flame.

STUDY QUESTIONS

6. Describe the behaviour of steel construction materials in a fire.
7. Describe how flame-retardant paint protects covered timber.
8. How can the spread of fire within a building be minimised?

(Suggested Answers are at the end.)

Fire and Explosion Prevention and Protection

IN THIS SECTION...

- The rate of fire-spread in a building is influenced by the distance from the source of fire, the materials with which it is constructed, the layout and the materials used in decoration and furnishings.
- Structural protection can be achieved through the use of compartmentation, openings and voids and fire-stopping.
- Fire/explosion can be a consequence of poor plant and process design and control. Key features of plant design to prevent or minimise these effects include: isolation, pressure-resistant equipment and plant layout.
- There are three process controls to avoid creating an explosive dust cloud; adding inert gas, ensuring that the dust is outside of the combustible concentration limits or adding inert dust.
- Flammable, combustible and incompatible materials should be segregated.
- Hazardous places are classified in terms of zones on the basis of the frequency and duration of the occurrence of an explosive atmosphere.
- In zoned hazardous areas the effects of ignition sources are controlled by exclusion.
- Inerting involves substitution of the air in an enclosed space by an inert gas and can prevent explosions when the explosive or flammable hazard cannot be eliminated by other means.
- Methods of explosion relief include explosion venting, bursting discs, explosion panels and suppression.

Structural Protection

The main features which influence the rate of fire-spread are the:

- Distance from the source of fire.
- Materials with which the building is constructed.
- Layout and construction of the building.
- Materials used in decoration and furnishings.

Each factor can be integrated within building design, so providing **passive** protection. We looked at some aspects of this under "Level of Fire Resistance" earlier.

Fire spread

Compartmentation

By siting high fire-risk processes or storage of materials at some distance from occupied buildings, the risk of fire-spread is greatly reduced. Unfortunately, due to restricted space this is not always achievable, so other means must be sought.

The spread of fire and smoke within a building can be prevented by dividing the building into compartments or fire-tight cells using fire-resistant materials.

Fire compartment walls, floors and doors must generally provide a 60-minute resistance to fire, but this may vary depending on the level of risk within the compartment. Walls, floors and doors subdividing such compartments must generally provide a 30-minute resistance. If any services or ducting pass through any compartment wall, floor, ceiling or roof then the joints around the services, etc. must be **fire-stopped** (see later) to prevent the passage of fumes, smoke or gases.

In areas of high risk, the fire compartment would be designed to keep the fire in. High-risk areas are areas where:

- Highly flammable materials are used, transported and stored.
- Toxic fumes are produced.
- Gas cylinders are used or stored.

In areas of high-loss effect, the fire compartment would be designed to keep fire out. High-loss-effect areas are those where:

- Essential records or documents are kept.
- Essential equipment, plant or stock are located.

Fire doors, where fitted, should have effective self-closing devices and be labelled "Fire Door - Keep Shut". Self-closing fire doors may be held open by automatic door-release mechanisms which conform to one of the following:

- Connected into a manually operated electrical fire alarm system incorporating automatic smoke detectors in the vicinity of the door.
- Actuated by independent smoke detectors (not domestic smoke alarms) on each side of the door.

Where such mechanisms are provided, it should be possible to release them manually. The doors should be automatically closed by any of the following:

- The actuation of a smoke-sensitive device on either side of the door.
- A power failure to the door-release mechanism or smoke-sensitive devices.
- The actuation of a fire warning system linked to the door-release mechanisms or a fault in that system.

Such fire doors should be labelled with the words "Automatic Fire Door - Keep Clear".

Openings and Voids

Ceiling and floor voids, as well as openings around pipework and other services, can allow air to feed a fire and also assist in the spread of fire and smoke. Debris should not be allowed to accumulate in voids. When necessary, such openings should be bonded or firestopped with non-combustible material.

Fire-stopping

Very often, mechanical and electrical services breach compartment walls and floors and, where gaps around services have not been adequately fire-stopped, the insulation may fail, leading to a rise in temperature along the conductive materials and the danger that conducted heat may propagate fires elsewhere in the building. Smoke and heat may also pass through these inadequately insulated openings, endangering occupants and fire-fighters attempting to extinguish the fire.

Fire-stopping in fire-resisting separating compartments plays a critical role in containing a fire at its source and can be described as preventing the spread of smoke and flame by placing obstructions across air passageways. Ventilation ducts and gaps around doors must have the facility to be stopped in the event of a fire. This can be achieved by the use of baffles, self-closing doors and intumescent material which expands when heated, sealing the opening.

In the UK, **Approved Document B of the Building Regulations** and BS EN1366-4 *Fire resistance tests for service installations - Linear joint seals* give advice on the types of materials to be used and testing arrangements for CE-marked products.

Key Features of Plant Design and Process Control

Fire or explosion can be a consequence of poor plant and process design and control, where flammable concentrations of vapour or dust are allowed to develop and come into contact with sources of ignition. So we need to be aware of the key features of plant design and process control that should be taken into account in order to prevent or minimise the effects of such occurrences.

Plant Design

Isolation

By isolating an explosion, the amount of damage caused can be reduced in a number of ways. Isolation stops the explosion from reaching other areas of the plant through pipes or ducts. It also stops the possibility of jets of flame that can occur at the end of long pipes and can prevent the pressure from the primary explosion causing secondary explosions.

There are two different ways in which isolation can be achieved:

- Passive (activated by the explosion itself).
- Active (which requires tripping by a sensor for activation).

Passive systems are simpler and more reliable. These systems will spray the dust with an extinguishing agent, stopping further propagation. Alternatively, they may simply close a valve in front of the flame.

Items of plant that will avoid the spread of flame throughout the system include rotary airlocks and special bursting disc systems.

Pressure-Resistant Equipment

Perhaps the best way to contain the primary dust explosion is to have process equipment that is strong enough to withstand the explosion. Most vessels that may be at risk of dust explosions are designed so that, in an explosion, they will distort but not rupture.

Plant Layout

Buildings that could be in danger of dust explosions must be designed along the same lines as any plant which has the danger of explosion. The following features should be considered:

- Wherever possible, they should be isolated from other buildings.
- Buildings should preferably be one storey high.
- If inside, the vulnerable area of the building must be reinforced.
- The rest of the areas of the plant must be protected (a blast wall is needed).
- Sufficient venting to avoid structural damage from over-pressure must be provided.

Other features are safe escape routes in case of an explosion and fire, fire-resistant construction materials, fire-resistant doors and good electrical insulation.

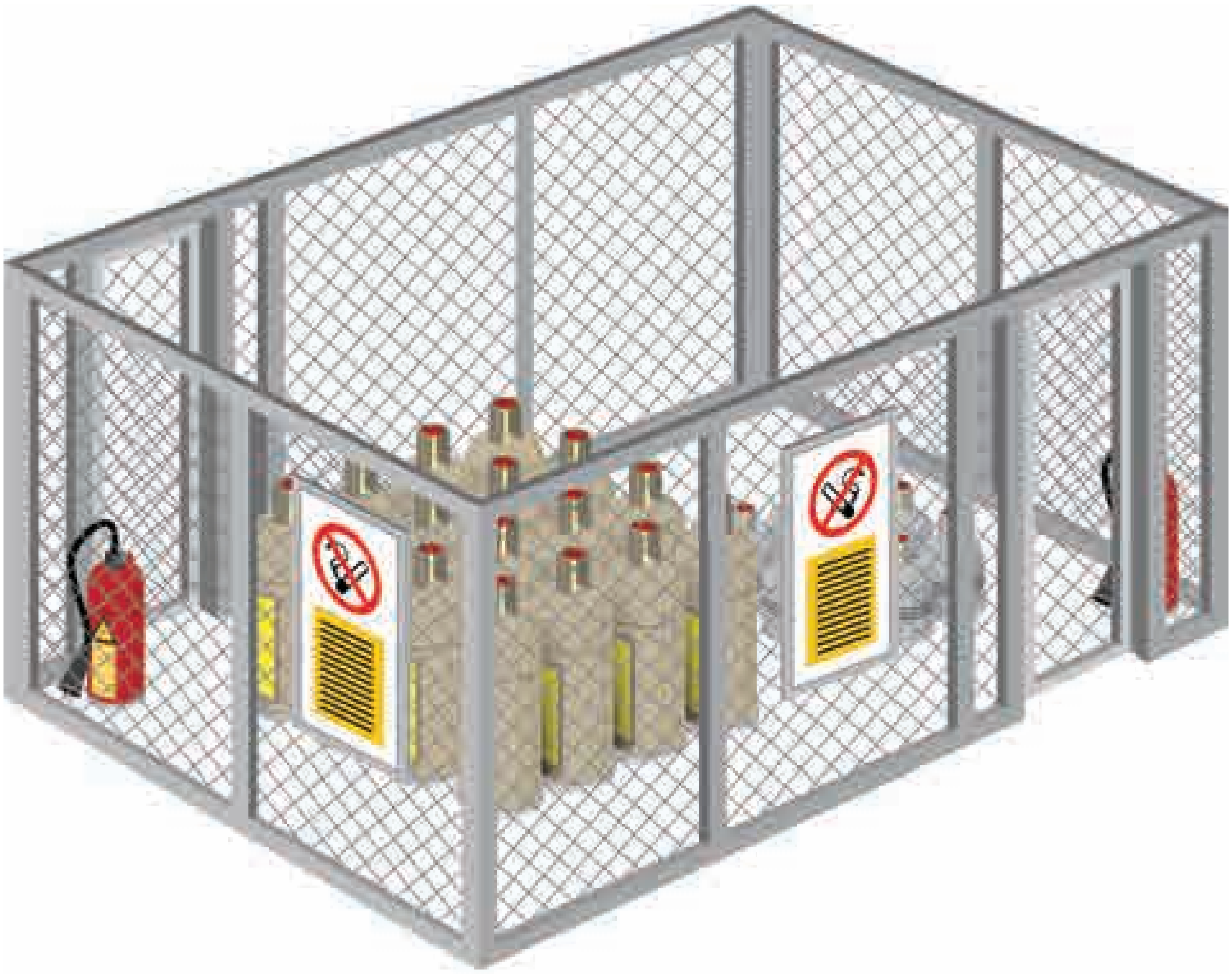
Process Controls

There are three main ways to avoid creating an explosive dust cloud without modifying the dust itself:

- Adding inert gas to the atmosphere - this will reduce the amount of oxygen in the process area and reduce the chances of an explosion.
- Ensuring that the dust is outside of the combustible concentration limits.
- Adding inert dust – a method that is used successfully in coal mines. It is not suitable in many processes due to the contamination of product.

Segregation and Storage of Flammable, Combustible and Incompatible Materials

Ideally, flammable substances will be stored outside in designated storage areas (dealt with later) but if kept inside they should be segregated from any work that is likely to produce a source of ignition.



Secure outdoor storage for flammable materials

Where flammable substances are kept inside buildings, it is important to ensure the following:

- The amount held is kept to an absolute minimum.
- They are kept away from any potential sources of ignition.
- All containers are properly closed or stoppered.
- When not in use, the containers are kept in a suitably marked, fireproof locker or cabinet.
- Incompatible materials (materials that may react with each other) should be stored separately.
- Other flammable material, such as packaging and waste material, should be collected in metal bins or skips and disposed of regularly before the accumulation becomes too great.

Hazardous Area Zoning

Section 7.4.2 of the **ILO Code of Practice - Safety in the Use of Chemicals at Work** requires that areas where flammable atmospheres may occur should be classified according to the degree of probability of a flammable concentration occurring in the area. We will now look at an example of such zoning from the UK **Dangerous Substances and Explosive Atmospheres Regulations**.

Determining which zone is suitable for different circumstances and where the boundaries between zones should be drawn is a complex process, which should involve expertise from a number of fields such as safety, production and chemical engineering.

TOPIC FOCUS

The UK **Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR)** set minimum requirements for the protection of workers from fire and explosion risks related to dangerous substances and potentially explosive atmospheres and from gases under pressure and substances corrosive to metals and require employers to control the risks to the safety of employees and others from these hazards.

Hazardous places are classified in terms of zones on the basis of the frequency and duration of the occurrence of an explosive atmosphere. Schedule 2 of **DSEAR** describes the different zones:

Flammable vapours:

- Zone 0

  A place in which an explosive atmosphere consisting of a mixture with air of dangerous substances in the form of gas, vapour or mist is present continuously or for long periods of time or frequently.

- Zone 1

  A place in which an explosive atmosphere consisting of a mixture with air of dangerous substances in the form of gas, vapour or mist is likely to occur in normal operation occasionally.

- Zone 2

  A place in which an explosive atmosphere consisting of a mixture with air of dangerous substances in the form of gas, vapour or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

Combustible dusts:

- Zone 20

  A place in which an explosive atmosphere in the form of a cloud of combustible dust in air is present continuously or for long periods or frequently.

- Zone 21

  A place in which an explosive atmosphere in the form of a cloud of combustible dust in air is likely to occur in normal operation occasionally.

- Zone 22

  A place in which an explosive atmosphere in the form of a cloud of combustible dust in air is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

Once the zone boundaries are established, equipment can be designed so that it is suitable for the intended area. This is an important stage in avoiding an explosion in the first place.

Exclusion of Ignition Sources

Controls for the exclusion of ignition sources in zoned hazardous areas will include:

- Selection of equipment that is designed to be safe for use in the area.
- Inspection and maintenance regimes to minimise the likelihood of faulty equipment giving rise to an ignition source.
- Ensuring that any portable/mobile equipment brought into the area is either suitable, or that the area is made safe before it is brought in. (Entry is controlled by permit-to-work systems.)
- Prohibition of open flames, e.g. smoking.
- Control of static discharge, e.g. by earthing.
- Ensuring heating equipment in such areas cannot act as an ignition source.
- Good housekeeping – not allowing combustibles to build up.
- Segregation of incompatible chemicals that could react to produce heat/flame/sparks.

Inerting

Inerting involves the partial or complete substitution of the air in an enclosed space by an inert gas such as nitrogen or carbon dioxide. It can be employed very effectively to prevent explosions, but is usually only used when the explosive or flammable hazard cannot be eliminated by other means, such as the use of non-flammable materials or the methods considered previously.

Inerting as a method of explosion control and prevention of fire-spread is used in enclosed spaces and plant. Plant that is substantially open will have varying oxygen concentrations and so cannot be successfully inerted. Inerting is used within reactor systems where the possibility of a flammable atmosphere exists, and within tanks where a material may be stored at temperatures above its flash point.

Methods of Explosion Relief

Explosion Venting

Vents must be designed to allow sufficient outflow of burnt dust and air to relieve the pressure generated by the explosion. Care must be taken not to vent toxic dusts into the atmosphere, but venting to a sealed area may be possible. There are a number of designs for venting, including hinged doors, simple panels that are ejected, and vent covers that are usually attached to the process vessel with clips or rubber seals which are designed to fail under the load of the explosion.

Bursting Discs

Bursting discs are commonly used for over-pressure protection, or sometimes to protect against excessive vacuum. They are the weakest point in the system – designed to fail and so avoid mechanical damage to the rest of the system. They usually consist of a thin metal disc, chosen so that it will fail at a set pressure. They are quite cheap but, of course, are a single use item; once they fail, they must be replaced. In designing the position of the bursting disc, due consideration should be given to ensuring that any fluids (gas or liquid) which may escape when the bursting disc fails, are safely vented away from the operator.

Explosion Panels

These are similar to bursting discs, but are designed for higher rates of pressure rise (such as happens during an explosion) and for larger capacities of gas to vent.

Suppression

If an explosion does occur, the consequences can be reduced by designing protective measures into the plant or equipment. An example of this is where the pressure rise from the developing explosion (0.02 bar increase) is detected by an appropriate sensor and triggers the discharge of an extinguishing agent (dry powder) to suppress the combustion process.

MORE... www.

Information on the design and installation of plant and equipment and the operational control of flammable, reactive and explosive chemicals and substances is available in the **ILO Code of Practice - Safety in the Use of Chemicals at Work**, ILO, 1993 (Section 6: Operational Control Measures and Section 7: Design and Installation) at:

www.ilo.org/safework/info/standards-and-instruments/codes/WCMS_107823/lang--en/index.htm

STUDY QUESTIONS

9. Describe what is meant by 'fire-stopping' and how this may be achieved.
10. Identify four features that should be considered for buildings that could be at risk from dust explosions.
11. Describe what is meant by Zone 0 and Zone 20 in regard to hazardous area zoning.
12. When considering explosion venting, what factor, other than the explosion itself, must be taken into account?
13. What is the basic principle of operation of a bursting disc?

(Suggested Answers are at the end.)

Summary

Properties of Flammable and Explosive Materials and the Mechanisms by which they Ignite

In particular, we have:

- Defined flash point, fire point, auto-ignition temperature, vapour density, limits of flammability, maximum explosion pressure and rate of pressure rise.
- Established that:
  - To start a fire, the following three elements of the fire triangle are needed: fuel, oxygen and an ignition source (heat).
  - Suitable ignition sources must be present such as naked flames, hot surfaces or sparks.
- Examined the mechanisms of explosions and fire-spread including:
  - How a fire or explosion occurs.
  - Combustion can be divided into the following five stages; induction, ignition, growth, steady state and decay.
  - The effects of atomisation/particle size and oxygen content on the likelihood and severity of a fire or explosion.
  - How failure of control measures coupled with the physico-chemical properties of flammable materials can bring about an explosion.
  - Oxidisation.
  - How flammable atmospheres arise and where they are found.
  - A vapour phase explosion is a sudden and violent release of energy causing a pressure blast wave:
    - **Confined Vapour Cloud Explosions (CVCEs)** occur when a flammable vapour cloud is ignited in a container or confined space.
    - **Unconfined Vapour Cloud Explosions (UVCEs)** result from the release of a considerable quantity of flammable gas or vapour into the atmosphere, and its subsequent ignition.
    - **Boiling Liquid Expanding Vapour Explosions (BLEVEs)** involve a sudden release of vapour, containing liquid droplets, owing to the failure of a storage vessel.
- Examined the prevention and mitigation of vapour phase explosions through structural protection, plant design and process control, segregation and storage of materials, hazardous area zoning, inerting, explosion relief, control of amount of material, prevention of release, control of ignition sources and sensing of vapour between the LEL and UEL.
- Considered:
  - Examples of industries/plant with potential dust explosion hazards.
  - Mechanisms of dust explosions, including the importance of:
    - Combustible solid particle size.
    - Dispersal.
    - Explosive concentrations.
    - Ignition, energy, temperature and humidity.
  - The dust pentagon.
  - Primary and secondary explosions.
  - Prevention and mitigation of dust explosions.

The Behaviour of Structural Materials, Buildings and Building Contents in a Fire

We have:

- Studied the behaviour of:
  - Building structures and materials in fire:
    - Fire properties of steel, concrete, wood, other materials, and level of fire resistance.
  - Common building contents in fire:
    - Paper-based, fabrics, plastics.

Fire and Explosion Prevention and Protection

We have:

- Examined structural protection issues such as openings and voids, compartmentation and fire-stopping.
- Studied key features of plant design:
  - Isolating an explosion (passive or active), to reduce the amount of damage.
  - Pressure-resistant equipment designed to be strong enough to withstand the explosion.
  - Plant layout, so buildings that could be in danger of dust explosions must be designed along the same lines as any plant which has the danger of explosion.
  - Process controls can be used to avoid creating an explosive dust cloud by:
    - Adding inert gas to the atmosphere.
    - Ensuring that the dust is outside of the combustible concentration limits.
    - Adding inert dust.
- Studied the segregation of flammable and incompatible materials.
- Studied hazardous area zoning and the classification of hazardous places in terms of zones on the basis of the frequency and duration of the occurrence of an explosive atmosphere. In zoned hazardous areas, the effects of ignition sources should be controlled by various means of exclusion.
- Noted that inerting can be used to prevent explosions and fire-spread.
- Studied methods of explosion relief and, in particular:
  - Vents must be designed to allow sufficient outflow of burnt dust and air to relieve pressure generated by the explosion.
  - Bursting discs are commonly used for over-pressure protection, or sometimes to protect against excessive vacuum.
  - Explosion panels are designed for higher rates of pressure rise.
  - Ensuring the pressure rise from the developing explosion is detected by an appropriate sensor and triggers the discharge of an extinguishing agent.

Exam Skills

It's important to complete as many practice questions as possible so that you develop a really good exam technique.

This is the first example of a 20-mark question, which is the format of all the Section B questions in the NEBOSH Diploma exam. This question is however split up into two sub-questions of varying marks, which can sometimes be the format of a 20-mark exam question.

Your question for Element 2 is as follows:

QUESTION

(a) **Describe** the effects of a fire in a workplace on the following structural materials:

(i) steel; **(4)**

(ii) concrete; **(4)**

(iii)wood. **(4)**

(b) **Outline** the precautions that could be taken to prevent failure of these materials in the event of fire. **(8)**

Approaching the Question

As before, to approach this question using good exam technique you should:

- Read the question.
- Consider the marks available. In this case there are 20 marks available, so you should spend around 30 minutes answering the question and provide around four or five different pieces of information for **each** part of question (a) and eight to ten for part (b).
- Highlight the key words - in this case they would include: describe, effects, fire, structural, steel, concrete, wood, outline, precautions, prevent, failure, fire.

Now it's time to attempt the question. This time, rather than providing the full answer, write a bullet-pointed answer, then compare it against the Suggested Answer Outline on the following page. Note: this is NOT a full enough answer to satisfy the examiner – in the exam you would be required to answer the question in full, taking into account the action verbs and providing the required depth.

HINTS AND TIPS

It's useful to practise answering questions in this way, just to check you understand the topics and the points that should be covered but it's really important that you don't fall into the trap of doing this in the exam. It's really important that you pay attention to the action verb in the question ("describe" and "outline" in this case) as they indicate the level of detail required in your answer. If you don't include enough detail you will not achieve full marks, but including too much detail is a waste of your time and you cannot gain additional marks.

Suggested Answer Outline

For part (a) the examiner would be looking for you to include the following:

Material	Fire – what happens?	Effect – strength?
Steel	Expands on heating, tends to deform and buckle.	Loses strength as the temperature rises, but regains on cooling - properties may be changed.
Concrete	Limited expansion on heating, spalls/cracks, steel reinforcement causes damage within the concrete expanding.	Lost on cooling, structural failure.
Wood	Thin sections will burn and promote fire, thicker structural members char and may act as an insulator to protect the inner timber. Generates smoke and fumes and allows the surface propagation of fire. Some varieties of timber are more resistant to fire than others.	Large timbers generally tend to retain their structural integrity.

For part (b) the examiner would require you to outline the precautions that could be taken to prevent failure of the materials in the event of fire, including:

- Steel – using sprayed concrete or intumescent coatings.
- Concrete – using a mix with fire resistance and increasing the thickness of concrete around reinforcement bars would provide some protection.
- Wood – selection of fire-resistant timber, increasing the thickness used to allow for a charring outer layer or impregnating the timber with fire-retardant material.

Other general precautions include the provision of means such as:

- The design of fire compartments and fire breaks to prevent heat transfer through long steel members in the event of fire.
- Automatic sprinkler and deluge systems to cool and protect structural members should fire occur.
- Use of fire-resistant surface cladding or flammable sacrificial cladding.

This is a great question, because you can really expand on the bullet points. Remember the number of marks available for each part of the question and remember that you have 30 minutes.

Example of How the Question Could be Answered

(a) *(i)* *Steel is affected by fire in such a way that when it is heated the steel expands and twists, and will break welds/bolted joints, destroying the integrity of the steelwork and building fabric, however when it cools down some of its strength will remain, but it may have changed in what it can take with regards to loading and strength.*

(ii) *Concrete doesn't expand in a fire but it can suffer some damage, e.g. cracks, but the worst effect is when steelwork is used as reinforcing, as the metal expands on heating and will badly damage the concrete.*

(iii) *Wood – generally burns in small quantities, but when used as large timbers it generally smoulders and then the charring builds up an insulating layer, which can protect the wood.*

(b) Precautions used to protect structural steel:

- *Sprinkler systems to dose down in the event of fire.*
- *Heat-resistant / insulating coatings can be applied to protect the steelwork, which includes concrete and specialist paints.*

Precautions used to protect concrete:

- *Increase thickness of material around metal reinforcement so that the heat doesn't reach the reinforcement and expansion is prevented.*
- *Surround the concrete in a fire-retardant material to protect it from the heat.*
- *Use a concrete mix which contains materials which provide fire resistance.*

Precautions used to protect wood:

- *Selection of wood with good fire-resistant properties.*
- *Use of larger timbers which allow an outer layer of charred material to form without affecting integrity.*
- *Impregnating the timbers with a coat of fire-retardant material.*

Reasons for Poor Marks Achieved by Exam Candidates

- Part (a) - not understanding the effects of heat on materials and what happens when they cool.
- Part (b) - not detailing correct precautions that might be taken to prevent failure.

Element IC3

Workplace Fire Risk Assessment

Learning Outcomes

Once you've read this element, you'll understand how to:

1. Explain the processes involved in the identification of hazards and the assessment of risk from fire.
2. Describe common fire detection and alarm systems and procedures.
3. Describe the factors to be considered when selecting fixed and portable fire-fighting equipment for the various types of fire.
4. Outline the factors to be considered in providing and maintaining the means of escape.
5. Explain the purpose of, and essential requirements for, emergency evacuation procedures.

Contents

The Identification of Hazards and the Assessment of Risk from Fire

IN THIS SECTION...

- Fire risk assessment assesses where and why a fire could start and what harm it would cause to those in and around the premises. Once this is established, measures can be put in place to prevent such fires.
- The five steps to fire risk assessment involve:
  - Identifying fire hazards to establish how a fire might start.
  - Identifying people at risk and those especially at risk.
  - Evaluating the risk of fire breaking out and people being harmed as a result and removing or reducing the risk by the use of protective measures.
  - Recording the significant findings, implementing appropriate emergency plans, and providing information, instruction and training.
  - Regularly reviewing the assessment.

Fire Hazards and Assessment of Risk

Fire risk assessment can be defined as 'an organised and methodical look at premises, the activities carried on there, and the likelihood that a fire could start and cause harm to those in and around the premises'.

While there are no fixed rules about how a fire risk assessment should be conducted, it is important to adopt a structured approach that ensures all fire hazards and associated risks are taken into account.

Fire safety

TOPIC FOCUS

"Risk" in relation to the occurrence of fire in a workplace depends on:

- The likelihood of a fire occurring.
- Its potential consequences for the safety of persons such as death, injury or ill health.

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(Continued)

TOPIC FOCUS

The types of physical harm that could be caused to persons by a workplace fire include:

- Smoke inhalation, causing burning to the lungs and triggering conditions such as asthma.
- Suffocation or respiratory difficulties caused by depletion of oxygen.
- Poisoning by inhalation of toxic gases and other combustion products.
- Burning by heat, flames or explosion.
- Injury from falling or collapsing structures.
- Falls from a height or on the same level caused by panicking and crushing.
- Injury from broken and flying glass.
- Mental or physical trauma.
- Death.

Five Steps to Fire Risk Assessment

The following five-step approach is commonly used in risk assessment:

Five steps to fire risk assessment

Step 1: Identify Fire Hazards

For fire to occur, it is necessary to have three elements - fuel, heat (or ignition) and oxygen - come together at the same time, in the correct amount. This is known as the fire triangle, which we considered earlier.

Identifying the fire hazards means looking for all the sources of ignition, fuel and oxygen that together might cause fire.

Step 2: Identify People at Risk

It is important to consider anyone who may be affected in the event of a fire, not just workers in the immediate area. Maintenance staff, contractors, other workers and people present outside normal working hours (such as cleaners and security guards) must also be taken into account.

Where visitors and members of the public, etc. have access to the premises they must also be included in the assessment.

Additionally, any individuals or groups who may be particularly at risk must be considered. For example, young or inexperienced workers, people with mobility or sensory impairment, lone workers and pregnant workers, etc. may all be at greater risk in the event of a fire.

Step 3: Evaluate, Remove, Reduce and Protect from Risk

This is the process of evaluating the risk of:

- fire breaking out; and, if a fire does occur,
- people being harmed as a result.

The risk of fire breaking out can be removed or reduced by the use of appropriate **preventive measures**, such as:

- Effective control of ignition sources.
- Appropriate storage of flammable materials.
- Good housekeeping.
- Maintenance and inspection of equipment.
- Providing adequate information and training, etc.

The risk of people being harmed in the event that a fire does occur can be removed or reduced by the use of appropriate **protective measures**, such as the provision of:

- Automatic detection and alarm systems.
- Adequate means of escape (including signage and emergency lighting).
- Fixed and portable fire-fighting equipment.
- Appropriate emergency procedures.
- Information and training, etc.

As it is rarely possible to entirely eliminate risk, it is important to ensure that remaining risks are controlled to an acceptable level.

Step 4: Record, Plan, Inform, Instruct and Train

The significant findings of the assessment, e.g. the fire hazards identified, individuals or groups at risk, the level of risk, and the actions taken to remove and/or reduce the risks must be **recorded**.

Appropriate **emergency plans** should be developed and implemented.

(Note that evacuation procedures should be practised regularly to ensure that all employees are familiar with the arrangements.)

Provide appropriate **information and instruction** to relevant persons on:

- Actions required to prevent fires.
- Actions required in the event of a fire.

Provide appropriate **training** for employees, in particular for those who may have specific duties in relation to fire prevention activities (e.g. conducting workplace inspections or checks on equipment, etc.) or in the event of a fire occurring (e.g. fire marshals).

Step 5: Review

The way we work is constantly changing – often as a result of new, or modifications to existing, equipment, buildings, procedures, products and processes, etc.

As such, it is important to continue to be vigilant about new, or changed, fire hazards and risks and to review the fire risk assessment regularly.

How often "regularly" means in practice will depend on the extent of the risks and the degree of change but, as a guide, the assessment should be reviewed:

- Whenever there is reason to suspect it is no longer valid.
- After a significant or major incident.
- If there has been a significant change in circumstances in the workplace.
- Periodically, with the frequency depending on the nature of the business and the fire risks.

3.1 Identification of Hazards and the Assessment of Risk from Fire

In all cases, the assessment should identify the hazards, assess the level of risk and consider how the risk may be minimised.

The risk assessment should be extensive and detailed enough to enable a responsible person to identify and prioritise the preventive and protective measures required to protect relevant persons from harm.

STUDY QUESTIONS

1. Describe the types of physical harm that could be caused to persons by a workplace fire.
2. Explain the method for carrying out a fire risk assessment.

(Suggested Answers are at the end.)

Fire Detection and Alarm Systems and Procedures

IN THIS SECTION...

- All buildings should have provision for detecting fire and sounding an alarm in the event of fire.
- The type of detection/alarm system used will be determined by the type of occupancy and escape strategy.
- A fire detector identifies physical changes in the protected environment indicative of the development of a fire condition such as combustion products, visible smoke, flame/illumination or temperature rise.
- The types of detector designed to identify these conditions are:
  - Ionisation smoke detectors.
  - Optical detectors.
  - Radiation detectors.
  - Heat detectors.
- Manual alarm systems are suitable for small workplaces and include rotary gongs, hand strikers, handbells, whistles and air-horns.
- An automatic fire-alarm system may be designed to respond to heat, smoke and the products of combustion and flames and may incorporate a facility for additional functions, such as closing down ventilation or air-conditioning plant, or activating automatic door releases.

Common Fire Detection and Alarm Systems and Procedures

In order to determine the most suitable type of detection/alarm system for a particular building, it is necessary to determine the type of occupancy and escape strategy.

Where the escape strategy is based on simultaneous evacuation, activation of a manual call point or detector should cause all fire alarm sounders to operate. Where the escape strategy is based on phased evacuation, a staged alarm system might be more appropriate (i.e. one tone for alert, another for evacuation). This system is used extensively in large organisations (hospitals, colleges and university campuses, for example) where full evacuation is often not necessary.


Fire warning signals

Design and Application of Fire Detection and Alarm Systems

All buildings should have provision for detecting fire. When a fire is detected, the following arrangements should be in place:

- Sounding an alarm in the event of fire.
- Evacuating staff to safe fire assembly points using means of escape routes.
- Fighting the fire.

Regular tests of an alarm system serve to check the circuits and to familiarise staff with the call note. The fire-warning signal must be distinct from other signals in use.

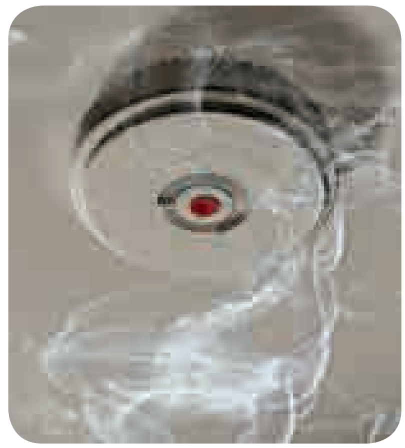
When selecting the method of alarm, it is important to ensure it will be heard in all parts of the building (the toilets, for example). Fitting fire doors to a building cuts down the distances over which call bells are heard, and may mean further bells must be fitted or noise levels raised.

A fire alarm can be raised automatically by a detection system or manually by a person in the affected building. We shall examine later the means available to somebody in the affected area for raising an alarm. These will generally be either manual or manual/electric, not forgetting that an alarm can always be raised by shouting.

Principal Components of Alarm Systems – Detection and Signalling

A fire detector identifies one or more physical changes in the protected environment indicative of the development of a fire condition. Usually mounted on ceilings or in air ducts, detectors are activated mainly by smoke or heat/light radiation. Such conditions can be readily identified:

- After ignition has occurred and the invisible products of combustion are released.
- When visible smoke is produced.
- When the fire produces flame and a degree of illumination.
- When the temperature in the vicinity of the fire rises rapidly or reaches a predetermined value.



Smoke detector

The types of detector designed to operate at one of these particular stages are:

- Ionisation smoke detectors.
- Optical detectors.
- Radiation detectors.
- Heat detectors.

The most common types of detector system in use at present are those actuated by smoke and those actuated by heat.

The final choice is based on the risk to be protected against and the individual circumstances of each case (see the following table).

Automatic fire detectors

Type	Suitability
Smoke	
Ionisation Sensitive in the early stages of a fire when smoke particles are small. Sensitivity tends to drop as particles grow in size.	Areas having a controlled environment, i.e. free from airborne dust, etc., and generally housing complex equipment of a high intrinsic value, e.g. computer installations.
Optical Most effective in situations where the protected risk is likely to give rise to dense smoke (i.e. large particles).	Normally used as point detectors but have been developed to form zone sampling systems by monitoring air samples drawn through tubes.
Thermal Radiation	
Infrared Rapid detection because of almost instantaneous transmission of thermal radiation to the detector head. This is dependent, however, on the detector having a clear 'view' of all parts of the protected area.	Warehouses or storage areas, etc. Detectors are available which can scan large open areas and will respond only to the distinctive flame flicker. Can be used to detect certain chemical fires.
Ultraviolet As for infrared.	The ultraviolet detector tends to be used mainly for specialised purposes.
Heat	
Fusible alloys Alloys will need replacing each time detector operates.	Areas of general risk where vapour and particles are normally present. Cost is relatively low compared to other types of detectors.
Expansion of metal, air and liquid Generally self-resetting.	Both 'fixed-temperature' and 'rate-of-rise' are equally efficient but 'fixed-temperature' types are preferred in areas where a rapid rise in temperature is a likely result of the normal work processes.
Electrical effect Not widely installed. Some specialist use.	
Note for all types of heat detectors May be used as point or line detectors and are designed to operate at a pre-selected temperature ('fixed-temperature' type) or on a rapid rise in temperature ('rate-of-rise' type) or both. With all heat detectors (particularly 'fixed-temperature' types), 'thermal lag' needs to be considered when choosing the operating temperature.	'Rate-of-rise' types will compensate for gradual rises in ambient temperature and are more efficient than the 'fixed-temperature' type in low-temperature situations. ('Rate-of-rise' detectors generally incorporate a fixed-temperature device.)

Not all detectors will be equally sensitive in every possible situation. In some cases a combination of different detectors may be required. For example:

- Smoke and heat detectors are suitable for most buildings.
- Radiation detectors are particularly useful for high-roofed buildings, e.g. warehouses, and situations in which clean-burning flammable liquids are kept.
- Laser infrared beam detectors appear to have advantages where there are tall compartments or long cable tunnels.

Such generalisations should be considered together with the nature of the risk to be protected against in order to establish:

- The reliability required. A more robust detector is necessary in an industrial setting than in a hotel, for example. Dusty or damp atmospheres will affect some detectors more than others.
- The sensitivity required. It would obviously be undesirable to install a smoke detector set at high sensitivity in a busy kitchen (or similar conditions).
- The location of detectors. The detectors should be located so they are in the best possible position to perform their function.

All alarm systems must be maintained and tested regularly, and the results recorded. Any faults discovered must be rectified and the system re-checked.

All staff must know how to raise the alarm and what to do when the fire alarm sounds.

Staff with hearing or other physical disabilities must be accommodated within an evacuation plan (e.g. people in wheelchairs cannot use stairs, as other people would, when a lift is inactivated). Emergency lights or vibrating devices may be used in addition to bells or sirens.

Manual and Automatic Systems

Manual Systems

Manual systems are suitable for small workplaces.

The purely manual means for raising an alarm involve the use of the following basic devices:

- Rotary gongs, which are sounded by turning a handle around the rim of the gong.
- Hand strikers, e.g. iron triangles suspended from a wall accompanied by a metal bar which is used to strike the triangle.
- Handbells.
- Whistles.
- Air-horns.

These devices are normally found on the walls of corridors, entrance halls and staircase landings, in a situation where they are readily available to anyone who may need to raise an alarm. While they give an alarm over a limited area, operation of one of them is rarely adequate to give a general alarm throughout the premises. As a person is required to operate them, a continuous alarm cannot be guaranteed for as long as may be necessary.

Manual/Electric Systems

These are systems which, although set in motion manually, operate as part of an electrical alarm circuit. The call points in a manual/electric system are invariably small wall-mounted boxes, which are designed to operate either:

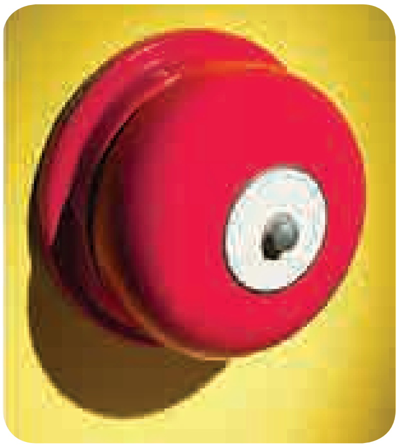
- automatically, when the glass front is broken; or
- when the glass front is broken and the button is pressed.

Most available models are designed to operate immediately when the glass front is broken.

In order to raise an alarm, it is possible to use facilities which may already be installed in a building for other purposes, e.g. a telephone or public address system. With automatic telephone systems, arrangements can be made for a particular dialling code to be reserved for reporting a fire to a person responsible for calling the fire service and sounding the general alarm. Alternatively, it can be arranged so that use of the code automatically sounds the general alarm.

Automatic Systems

An automatic fire-alarm system may be designed to respond to heat, smoke and the products of combustion and flames. Although the system will give warning of a fire, it cannot take action to contain it. However, some more elaborate designs do incorporate a facility for additional functions, such as closing down ventilation or air-conditioning plant, or activating automatic door releases.


Fire alarm

Reliability and False Alarms

We have already noted that all buildings should have provision for detecting a fire and sounding an alarm to initiate the evacuation of people to a place of safety. For this arrangement to be effective, the alarm system must be reliable and only activate in a fire situation. Frequent false alarms will only serve to undermine the system and lead to occupants disregarding any alarm and failing to evacuate the premises.

If the detector initiates some control action (such as plant shut- down or sprinklers), to reduce the potential for false alarms a **voting system** can be incorporated (i.e. several detectors are required to set off the alarm and subsequent control action), but this will require a higher density of detectors. Typically, voting systems may be set to trigger if two out of three detectors are activated, but it depends on the perceived level of risk. In some cases, it can be two out of 16 or three out of 75.

False alarms can arise from unwanted activation of the detector caused by:

- Wrong choice of head:
  - Smoke detector set at high sensitivity in a busy kitchen.
- Wrong positioning of detector:
  - Thermal radiation detectors out of sight of the protected area.
  - A single ultraviolet flame detector in the vicinity of an arc welding area.
- Lack of control of working environment:
  - Smoking.
  - Hot work.
  - Dust from spillages or maintenance.
- Malicious actuation:
  - Malicious operation of 'break glass' call points.
  - The intentional directing of smoke into smoke detectors.
- Wiring defects:
  - Poor installation.
  - Lack of maintenance.
- Deterioration of the system:
  - Corrosion.
  - Damp environments.

STUDY QUESTIONS

3. Name the four types of detector commonly used in buildings.
4. Explain the benefits of regular testing of fire alarms.
5. For what types of workplaces are manual alarm systems suitable?

(Suggested Answers are at the end.)

Fixed and Portable Fire-Fighting Equipment

IN THIS SECTION...

- Fixed fire-fighting systems fall into four main categories:
  - Sprinklers.
  - Drenchers.
  - Total flood systems.
  - Deluge systems.
- The main types of extinguishing agent used in fixed installations are:
  - Water.
  - Foam.
  - Carbon dioxide.
  - Halon.
  - Dry powder.
- Fires are classified into different categories - Class A, B, C, D and F - to help in the selection of extinguishing agent.
- Extinguishing a fire is based on removing one or more sides of the fire triangle:
  - Removing the fuel by starvation.
  - Removing the oxygen by smothering.
  - Removing the heat by cooling.
- Fire-fighting equipment should be sited in an easily seen and reached position, regularly inspected and maintained, and persons required to use it suitably trained.
- Environmental damage can result from contaminated fire-fighting water run-off - sites should consider the polluting effects of fire in their emergency plans.

Fixed Fire-Fighting Systems and Equipment - Design and Application

In certain establishments, fixed fire-fighting systems are installed. They fall into four main categories. Those systems dedicated to the protection of life have a higher specification than those dedicated to property.

Sprinkler

The four categories are as follows:

- **Sprinklers** are characterised by independent, sealed sprinkler heads. Only the discharge heads in the immediate vicinity of the fire rupture, so that water damage is limited. They are widely used and have a rating ranging from Light Hazard (LH) through Ordinary Hazard (OH) to High Hazard (HH).
- **Drenchers** are designed to protect adjacent buildings or facilities from the effects of radiated heat and flying brands from a fire. They provide a curtain of water over parts of a building (or openings). They are commonly used to protect large gas storage tanks.

- **Total flood systems** render the atmosphere inert by dilution or flame interference (CO_2 or halon). They are dangerous to occupants and therefore a safe system (manual lock-off) must be employed. There is also a danger of re-ignition when opened up.
- **Deluge systems** have all the discharge heads open, but the flow of extinguishing agent is controlled by a single deluge valve (which may be activated by a pilot sprinkler system). They are often used for high-risk cases such as flammable liquid storage tanks.

Fixed fire-fighting systems consist primarily of pipework which delivers and releases an extinguishing medium when activated directly by heat or indirectly by the warning/alarm system. Such systems are likely to be installed in large buildings where there is a high risk, where access is difficult, or where equipment or stock is valuable.

The main types of extinguishing agent used in fixed installations are:

- **Water** – generally used in sprinkler systems.
- **Foam** – includes either:
  - low expansion foam, which is suitable for flammable liquid fires, or
  - high expansion foam, which is especially useful in inaccessible areas, e.g. cable tunnels and basements.
- **Carbon dioxide** – suitable for hazardous plant, e.g. electrical equipment, computer areas, control rooms and sensitive materials.
- **Halon** – used in similar situations to carbon dioxide. There has been movement away from the use of halon over recent years due to its potential effect on the ozone layer and other undesirable environmental effects and it is now little used, because its use is strictly controlled (limited to specialist military and aerospace uses). (Alternatives to halon include water mist.)
- **Dry powder** – suitable for flammable liquids, electrical equipment, or situations where water damage must be kept to a minimum (dry powder is not suitable where re-ignition may occur).

For water-based systems, a supply of water is clearly required. There are two basic systems:

- **Wet riser** systems remain filled with water at fire mains pressure. Such systems are subject to frost damage in unprotected areas, corrosion and water leaks.
- With **dry risers**, water is only available at the outlets when the system is connected either to the fire mains or from a pumped reservoir or supply. These systems are not subject to frost damage, so they may be used in cold stores.

Wet and dry riser sprinkler systems have independent, sealed sprinkler heads. The sprinkler heads are designed to open under fire conditions (e.g. through fusible solder links). Water is only directed to those heads which have been activated – since they are all independent.

Deluge systems are designed for high-risk areas and consist of pipework with open heads, with the water being held back by a deluge valve. A fire-detection device trips the deluge valve and water is discharged from every head.

Classification of Fires

Class A	Fires involving mainly organic solids (wood, paper, plastics, etc.)
Class B	Fires involving flammable liquids (such as petrol, paint, oils) and liquefiable solids (such as fats, waxes, greases but excluding cooking oils/fats).
Class C	Fires involving gases (such as butane, propane).
Class D	Fires involving certain metals (such as sodium, magnesium, aluminium).
Class F	Fires involving commercial deep fat/oil fryers.

Portable Fire-Fighting Equipment

The range of fire extinguishers (their size, colour, method of operation and claims for performance) is so great that it can be confusing. The equipment which the average person will use in the event of fire should therefore be **suitably located** and **suitable for the risk**. The problems arise when more than one type of risk may be encountered and the person, who is operating under pressure, is faced with a choice of extinguishers. The wrong choice could render their efforts wasted or even expose the person to danger!

Firstly, we will identify the **nature of the risk** and the choices of agent which are available.

The nature of risk

Fire Class	Description		Examples	Extinguishing Agents
A	**Solid materials** Usually of organic origin (containing carbon-based compounds)		Wood, paper, fibres, rubber	Water Foam Dry powder (ABC)
B	**Flammable liquids and liquefied solids**	Those miscible with water (capable of being mixed)	Alcohol, acetone, methyl acetate	Dry powder Specialist foam CO_2
		Those immiscible with water	Petrol, diesel, oil, fats and waxes	Dry powder Foam
C	**Gases and liquefied gases**		Natural gas, liquefied petroleum gases (butane, propane)	Turn off the supply Liquid spills may be controlled by dry powder
D	**Flammable metals**		Potassium, sodium, magnesium, titanium	Special powders (m28 or l2) Dry sand or earth Graphite powder Sodium carbonate and salt and/or talc
F	**High temperature cooking oils**		-	Specialist 'wet chemical' Fire blanket (minor fire only)

Gas fires can be difficult to deal with. While dry powder and carbon dioxide may be used to knock the flame down, there is a risk of a build-up of gas if it cannot be turned off. In some situations, it may be preferable to allow the fire to continue and to call the fire service.

You will notice that electrical fires are not listed; this is because electricity is not a fuel – it will not burn. However, it can cause fires and it can be present in fires, so we have to consider it when fighting fires.

Extinguishing Media and Mode of Action

Extinguishing a fire is based on removing one or more sides of the fire triangle:

- Removing the Fuel

  Extinction by this process is known as **starvation**. This can be achieved by taking the fuel away from the fire, taking the fire away from the fuel and/or reducing the quantity or bulk of fuel available. Materials may therefore be moved away from the fire (to a distance sufficient to ensure that they will not be ignited by any continuing radiant heat) or a gas supply may be turned off.

- Removing the Oxygen

  Extinction by this process is known as **smothering**. This can be achieved by either allowing the fire to consume all the available oxygen, while preventing the inward flow of any more oxygen, or adding an inert gas to the mixture. The most usual method of smothering is by use of a blanket of foam or a fire blanket.

- Removing the Heat

  Extinction by this process is known as **cooling**. Cooling with water is the most common means of fighting a fire and this has a dual effect:

  – Absorbing the heat and thereby reducing the heat input into the fire.

  – Reducing the oxygen input, through the blanketing effect of the steam produced.

Although water is the most common medium used to fight fires, it is by no means either the only substance or the most suitable one. Indeed, using water on certain types of fire can make the situation worse.

The main different types of extinguishing media are described below and you should note their application to the classification of different types of fire.

Water

Water, applied as a pressurised jet or a spray, is the most effective means of extinguishing class A fires. It may also be used, as a spray, on class B fires involving liquids and liquefied solids which are miscible (capable of mixing) with water, such as methanol, acetone and acetic acid. While ineffective on class C fires themselves (those involving gases), water may be used to cool leaking containers.

It must **never** be used on:

- Fires involving electricity, as the current can flow up the stream of water.
- Non-miscible liquid fires, as only a cupful of water can cause the whole fire to erupt into a conflagration.

Standard, red-bodied extinguisher

Foam

Foam is a special mixture that forms a smothering blanket over the fire, cutting off the supply of oxygen. It can be used on class A and B fires (although there are some restrictions in its use on class B fires since certain types of foam break down on contact with alcohols) and also on small liquefied gas fires (which make up certain class C fires).

Using foam as an extinguishing agent demands considerable skill when dealing with anything but very small-scale liquid fires, since the procedure is to start at the rear and to lay a blanket of foam across the surface of the liquid.

Dry Chemical Powder

Usually ABC Dry Powder - so called because it's suitable for use on class A, B and C fires (although it's rarely the best extinguishant for class A).

The powder is sprayed as a cloud over the fire, again acting to smother the supply of oxygen. It can be used on class B fires and on small liquefied gas fires (within class C).

Specialised dry powders using inert substances are also used on class D fires, where they form a crust over the burning metal and exclude the oxygen.

Dry powders are also effective on fires involving electricity.

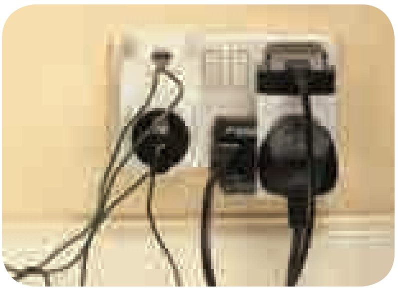
Carbon Dioxide Gas

This again works by means of smothering the supply of oxygen. It is effective on class B fires and also for electrical fires as the gas can enter into the inside of the equipment.

Vaporising Liquids

When applied to a fire, these agents produce a heavy vapour which extinguishes the fire by excluding oxygen. They are safe to use on class A and B fires, and are particularly effective on fires involving live electrical equipment since they interfere with electrical combustion reactions.

Halon 1211 is a vaporising liquid which used to be widely used in portable fire-fighting equipment. Halons have been banned in many countries since 1994 and are being phased out in others.



Vapourising liquids are effective on fires involving electrical equipment

Identification of Fire Extinguishers

In order to identify the different types of fire extinguisher in common use, they are colour-coded depending on the type of extinguishant inside. There are currently two systems in use:

- Older fire extinguishers will have the whole body colour-coded.
- Newer fire extinguishers will have a red body with a coloured band or label.

The following table shows the colour-coding for the different types of extinguishant:

Colour coding for fire extinguishants

Fire Extinguisher Content	Colour of Body or Label/Band
Water	Red
Foam	Cream
Dry Powder	Blue
Carbon Dioxide	Black
Wet Chemical	Yellow

Siting of Extinguishers

The correct type of extinguisher should be available for the risk it is going to protect against. The fire-fighting equipment should be sited in a position where it is easily seen and reached, usually by an escape route. The location should be marked and should not be further than 30m from an alternative equipment location (see the following figure).

Siting of extinguishers

The extinguishers should be located so they are:

- Conspicuous.
- Readily visible on escape routes.
- Properly mounted.
- Accessible (less than 30m from any fire).
- Sited to avoid temperatures beyond the operating range and corrosive environments.

Special extinguishers should be sited close (but not too close) to the risk.

Inspection and Maintenance

Regular inspections and examinations should be carried out on fire extinguishers by a suitably qualified technician. These will vary for different types of extinguisher, but best practice is as follows.

Water Extinguishers

- Stored-Pressure
  - Check that:
    - Pressure is correct.
    - Hoses and nozzles are not blocked.
    - There is no corrosion.

- Discharge annually and check:
  - Internally for corrosion.
  - Free working of operating mechanism.

- Gas-Cartridge
  - Open annually:
    - Check the working parts and contents.
    - Weigh the gas cartridge to check for losses.
  - Discharge every five years.

Foam Extinguishers

- Open annually and check:
  - That no clogging has occurred.
  - That all the working parts are in good order.
  - Weight of the gas cartridge - loss in excess of 10% requires replacement.
- Discharge every two years.

Dry Powder Extinguishers

- Annual examination.
- Discharge every five years.

Carbon Dioxide Extinguishers

- Annual examination:
  - Check contents by weighing.
  - Examine working parts and check the horn for freedom of movement.

Vaporising Liquid Extinguishers

- Annual working-order check by weighing the contents.
- Check by discharge every five years.

Wet Chemical Extinguishers

Same maintenance requirements and procedures as for foam extinguishers.

Training Requirements

It is very important that all personnel are familiar with the fire-fighting equipment and are able to use it correctly.

The following points form a general scheme for training in the use of fire-fighting equipment:

- General understanding of how extinguishers operate.
- The importance of using the correct extinguisher for different classes of fire.
- Recognition of whether the extinguisher has to be used in the upright position or in the upside-down position.
- Practice in the use of different extinguishers (with or without a practice fire).
- Understanding that evacuating the building must take precedence over fighting a fire if the condition demands immediate evacuation.
- When, and when not, to tackle a fire (if the fire is small and has not involved the building structure, then portable extinguishers can generally be used, but always ensure that a means of escape is maintained).

- When to leave a fire that has not been extinguished (as a general rule, once two extinguishers have been discharged, the fire requires specialist assistance).
- When leaving an unextinguished fire, try to close all doors and windows to help contain the fire.

Environmental Considerations

Environmental damage can result from contaminated fire-fighting water run-off:

- Fire-fighting water run-off can carry large amounts of chemicals.
- Run-off can make its way into drains, rivers and sewage treatment works.
- Groundwater contamination may take several months to become apparent, and may persist for many years.

Run-off containing large amounts of chemicals

Pre-Planning the Minimisation of Environmental Impact of Fire and Containment Procedures

Sites should consider the polluting effects of fire in their emergency plans. In case of a fire, there is the possibility of escape of contaminated fire water:

- Directly to surface run-off, into rivers and the ground.
- Via the site's surface water drainage system.
- Via the foul sewage system and out unaltered through the treatment works.

To mitigate the effects of the incident, pre-planning of containment is required, which depends on the following:

- The **hazardous nature** of substances on site.
- The **risk of fire**.
- Sensitivity of the **receiving environment**.
- The **reasonable practicability of the solution**, such as the dimensions of the site and the cost involved.
- **"Built-in" permanent remote containment systems** for a site include:
  - **Lagoons** – earth-banked containment basins:
    - Effective at containing firewater run-off, provided they are impermeable and incorporate some sort of isolation from the drainage system.
  - **Purpose-built tanks** – to intercept run-off:
    - Can be placed below or above ground.
    - Include as a last resort the possibility of using storm tanks at the sewage treatment works.
  - **Shut-off valves** – used to isolate part of a site's drainage system.
- **Emergency remote containment systems** (when permanent solutions are not practicable) include:
  - **Sacrificial areas** – run-off is conveyed to a designated "sacrificial" area:
    - Involves use of permeable soil or porous media with an impermeable lining.
  - **Temporary bunding** of impermeable car parks, e.g. using sandbags.
  - **Portable tanks and tankers**:
    - Requires temporary blocking of the site drainage system to set up a temporary sump from which the run-off can be pumped into the tank.
    - Also allows the possibility of re-using the run-off as fire-fighting water.
- **Site and damaged area clean-up considerations.** Having contained the fire-fighting water run-off, the last stage in minimising the environmental impact of fire and fire-fighting operations is to ensure that the area is cleaned up satisfactorily. This will principally rely on ensuring that collected contaminated run-off is disposed of properly, in accordance with prevailing waste regulations.

STUDY QUESTIONS

6. Describe the five basic classes of fire.
7. Identify the colour-coding of the five common types of fire extinguishers and the types of fire that they are suitable for.
8. With reference to fire extinction, describe what is meant by starvation.
9. Explain why gas fires may be difficult to deal with.

(Suggested Answers are at the end.)

Means of Escape

IN THIS SECTION...

- The main factors to consider in provision and maintenance of means of escape are the:
  - Nature of the occupants.
  - Number of people attempting to escape.
  - Distance they may have to travel to reach a place of safety.
  - Size and extent of the place of safety.
- Travel distance is related to the mobility of the occupants and the danger of fire-spread. If the travel distance exceeds 12m, two alternative escape routes should be provided.
- All stairways that comprise part of the means of escape should be constructed and arranged to permit persons using the route in an emergency to pass freely.
- Escape routes should take into account predicted fire, heat and smoke spread that will follow as a fire develops.
- Fire doors are incorporated for smoke control and/or to protect means of escape or to segregate areas of special risk.
- Emergency (or safety) lighting should be provided where failure of the normal system would cause problems in using the means of escape. The purposes of emergency lighting are to:
  - Identify the escape route.
  - Provide illumination along the route and at exits.
  - Ensure that alarm call points and fire-fighting equipment can be easily located.
- Landlords and owners of multi-occupancy buildings have a responsibility to maintain fire safety in communal areas.

Provision and Maintenance of Means of Escape

The main factors to consider in providing and maintaining a means of escape in the event of fire are the:

- Nature of the occupants, e.g. mobility.
- Number of people attempting to escape.
- Distance they may have to travel to reach a place of safety.
- Size and extent of the place of safety.

Means of escape

General Requirements

Travel Distances

This is the distance from an occupied area of the building to an exit leading to a place where a person would no longer be in immediate danger. This place can be a protected stairway or corridor, but is usually a place of safety outside the building.

Travel distance relates to the mobility of the occupants and the danger of fire-spread:

- Occupants should not be exposed to fire danger for longer than two to three minutes in normal conditions.
- Under favourable conditions, the assumed speed of travel (for mobile persons) is 12m/min., which approximates to 30 – 40m in that time.

The factors which have to be considered when assessing travel distances for means of escape will vary widely between different premises and consideration of them will form part of the risk assessment process.

Remember that the distance (travel distance) will not necessarily take people out of the building, but to a place of relative safety, placing a fire door between them and the fire. Once within this place, the structure will protect them from smoke and heat while they make their way to a place clear of risk.

The figures shown in the following table are general guidelines:

Distances from the workplace to a 'place of relative safety' (m)

	One escape route	More than one escape route
High risk	12	25
Sleeping	16	32
Normal risk	25	45
Low risk	45	60

Stairs

Stairways that comprise part of the means of escape should meet the following standards generally accepted for a well-designed staircase:

- Sited on an outer wall with good lighting and ventilation.
- Constructed to discharge to open air or into a protected lobby which discharges direct to open air.
- Fully enclosed with the minimum fire-resistant material required.
- Sufficient width for escaping occupants.
- Equipped with handrails.
- Clear headroom; no projection below two metres.
- Spaces below flights should be open, or closed without access.
- Covered with non-combustible linings.
- Provided with non-slip/trip surfaces.
- Ideally at least 1.05m wide.

Passageways and Doors

Corridors

Corridors form an essential part of the means of escape and should meet the following standards:

- Kept free of fire and smoke.
- Wide enough to allow all persons to escape safely.
- Non-slip floor surfaces and no tripping/slipping hazards.
- Linings of any escape corridor should be non-combustible.

Fire Doors

Fire-resisting doors (smoke-stop) are used to:

- Break corridors into sections and thereby reduce the area of smoke-logging.
- Separate stairs from the remainder of the floor area.
- Confine an outbreak of fire to its place of origin.
- Keep escape routes free of smoke for long enough to permit evacuation of occupants.

They should normally open in the direction of exit.

Construction of Doors

Any fire door (and the partition in which it is hung) should be rated to the fire-resistive standards required by the Fire Authority/Building Control. The workmanship must be to a high standard. Any glass panels within a fire door should also be fire-resisting and limited in size.

All fire doors must be fitted with the appropriate intumescent seals designed to expand under heat, and fill the gaps between the door leaf and frame, thereby preventing the passage of smoke and fire to other parts or compartments of the building.

Opening of Doors

- Means of escape doors should normally open **in the direction of exit**.
- A door which opens directly over steps or into a corridor should be **recessed to at least the width of the door**. This will prevent it obstructing the corridor or stairs and injuring passers- by.
- **Revolving doors** are not permitted on escape routes unless a clearly indicated pass door is provided beside them.
- **Rolling shutters**, when closed, can form an obstruction to means of escape when people are in the building. They should either be locked in the open position, or be provided with a clearly indicated pass door beside them.
- **Sliding doors** may be permitted with certain restrictions. They should not be positioned at the foot of stairs and never be used in assembly occupancies. The door should be clearly marked 'Slide to open', with an arrow showing the direction to open.
- **Pass doors** between different parts of the same building can be useful, providing satisfactory means of escape is available from both sides.
- **Intercommunicating doors and wall hatches** provide a good means of escape at low cost. They should be clearly marked 'Fire Exit - Do Not Obstruct', on both sides, and lack of obstruction should be ensured.

Door Fastening

All fire doors, except those to cupboards and service ducts, should be fitted with effective self-closing devices to ensure positive closure of the door. Rising butt hinges are not normally acceptable. Fire doors to cupboards, service ducts and any vertical shafts linking floors should either be self- closing or be kept locked shut when not in use and labelled accordingly.

In some buildings, self-closing fire doors may cause difficulties for staff and members of the public. **Automatic door releases** can be used to hold open such doors provided that:

- The door release mechanism fails safe (i.e. in the event of a fault or loss of power, the release mechanism is triggered automatically).
- All doors fitted with automatic door releases are linked to an automatic fire-warning system appropriate to the fire risk in the premises.
- All releases are automatically triggered by any one of the following:
  - The actuation of any automatic fire detector.
  - The actuation of any manual fire-alarm call point.
  - Any fault which renders the fire-warning system inoperable.
  - The isolation of the alarm system for any reason, e.g. maintenance.
- Doors so fitted are capable of being closed manually.
- The release mechanisms are tested at least once each week in conjunction with the fire alarm test to ensure that the mechanisms are working effectively and the doors close effectively onto their frames.
- The automatic release is fitted as close as possible to the self-closing device in order to reduce the possibility of the door becoming distorted.

Doors used for **means of escape** should be kept unlocked at all times when people are in the building; no door should ever be so fastened that it cannot be easily and immediately opened by people escaping, without the use of a key.

Wherever possible there should be **only one fastening**. However, where more than one fastening cannot be avoided, all but the single emergency fastening should be kept released at all times when people are on the premises.

Where the door:

- may be used at the time of a fire by more than 50 people; or
- is an exit from an area in which fire may develop very rapidly, and
- has to be kept fastened while people are in the building,

it should be fastened only by pressure release devices such as panic latches, panic bolts or pressure pads which ensure that the door can be easily and immediately opened.

Emergency Lighting

Emergency lighting should be provided where failure of normal lighting would hinder escape. It serves to:

- Identify the escape route.
- Provide illumination along the route and at exits.
- Ensure that alarm call points and fire-fighting equipment can be easily located.

Emergency lighting

It should be provided in those parts of buildings where there is:

- Underground or windowless accommodation.
- Core stairways.
- Extensive internal corridors.

Generally, the need for such lighting will arise more frequently in shops than in factories and offices because of the greater likelihood of people in the building being unfamiliar with the means of escape.

Emergency lighting is designed to ensure that people can find their way out of a building and so the light requirement is much lower than for normal use.

Exit and Directional Signs

Signage is most important to direct persons to the final exit and a place of safety. In Europe:

- Emergency signs should be square or rectangular and should have a **green background with white symbols**.
- The 'running man' sign (see the following figure) should appear over all fire escape exits, and the 'door and arrow' sign is used to mark escape routes.
- Text alone (e.g. the word 'exit') is not to be used, though text can be used to supplement graphics.

The principal requirement is that exit and directional signs are clear and unambiguous.

Emergency escape signs

Maintaining Fire Safety in Communal Areas

Access to Competent Advice on Fire Safety Legislation

Landlords and owners of multi-occupancy buildings have a responsibility to maintain fire safety in communal areas. They must appoint someone (a competent person) to provide safety assistance, i.e. guidance on the fire safety measures required by the national legislation and how they should be implemented. Anyone providing this service to a **responsible person** must be fully familiar with fire safety requirements in communal areas.

Co-ordination with Other Occupiers

The **responsible person** will have to "co-ordinate and co-operate" with other responsible persons, either located in the same building or having responsibility for fire safety measures in the building. This may apply where the communal area is part of a development with shops, hotels and other commercial premises, unless there is substantial fire separation between the two and there are no shared escape routes. A key element of this is co-ordination of fire procedures. The difficulties that can arise when a building or its fire safety systems are shared need to be recognised. For example, the detectors needed to operate Automatic Opening Vents (AOVs) in the lobbies to stairways may be part of a fire alarm system covering commercial areas. As the system is common to both, it is important that a single organisation takes responsibility for its testing and maintenance and that there is adequate recourse in contracts and leases to take action if it fails to do this.

Engaging with Occupants

Landlords and others responsible for managing communal areas should seek to engage with the occupants and communicate a number of vital fire safety messages, including:

- How they can prevent fires in the common parts of the building.
- The importance of maintaining security (making sure doors close behind them when they enter or leave) and being vigilant for deliberate fire setting.
- Not to store petrol, bottled gas, paraffin heaters or other flammable substances inside the building and particularly not in communal areas.
- What action they should take if they discover a fire in the communal area.
- What they must do to safeguard communal escape routes, especially taking care to make sure fire doors self-close properly and are not wedged, tied or otherwise held open.

Occupants in a multi-occupancy building should also be aware of what the fire safety policy is on the use of communal areas and ways they can assist the fire and rescue service by not blocking access when parking, and by keeping fire main inlets and outlets, where provided, clear. Specifically targeted campaigns of leafleting and other initiatives by the landlord to promote fire safety may be necessary to keep the message fresh in people's minds, up-to-date and relevant to their particular circumstances. It is important that the needs of other nationalities, visually impaired and disabled occupants are taken into account.

Key Points

Arrangements for managing fire safety in the communal areas of buildings should include the following:

- Developing a fire policy and appointing someone in the organisation to take overall responsibility for fire safety.
- Making sure someone is designated to provide guidance on fire safety measures, and supporting this person with help from specialists, where necessary.
- Co-ordinating and co-operating with other occupiers, particularly on issues such as fire procedures.
- Using handbooks, websites and other media to engage with occupants and communicate vital fire safety messages.
- Providing training to ensure safety officers and other occupants have sufficient fire safety awareness.

- Preparing relevant fire procedures and making everyone aware of them.
- Managing the risk from building works, including adopting a 'hot work' permit system.
- Putting in place programmes for routine inspection, testing, servicing and maintenance of fire safety systems and equipment.
- Arranging similar programmes to monitor the condition of other fire safety measures, such as fire-resisting doors.
- Monitoring the common parts through formal inspections and as part of day-to-day activities by staff.
- Carrying out fire risk assessment reviews to monitor standards.
- Putting in place processes for scrutinising planned alterations in order to consider their impact on fire safety.
- Maintaining suitable records.
- Liaising with the fire and rescue service and encouraging occupants to take up the offer of fire-safety checks by the local fire authority.

STUDY QUESTIONS

10. What are the main factors to consider in providing an adequate means of escape?
11. Explain what is meant by a 'place of relative safety'.
12. Identify the four main purposes of smoke-stop fire-resisting doors.
13. Describe when emergency lighting should be provided.

(Suggested Answers are at the end.)

Emergency Evacuation Procedures

IN THIS SECTION...

- Evacuation procedures are part of the fire emergency plan. They cover how the evacuation of the premises should be carried out, where people should assemble after they have left the premises, what the procedures are for checking whether the premises have been evacuated and the identification of key escape routes.
- Evacuation procedures also include the duties of staff who have specific responsibilities if there is a fire and the arrangements for the safe evacuation of people identified as being especially at risk, such as young persons, those with disabilities or lone workers.
- As soon as premises have been evacuated and all personnel are assembled in their pre-arranged safe areas, fire marshals or other appointed persons should carry out a roll call on the basis of a continually updated register.
- Fire marshals are designated people who, in the event of a fire, search and check their allocated area, ensure that all people have left the building, direct those who have not left the building to an appropriate fire exit and safe assembly point and report that their area has been checked and is clear.
- The aim of a Personal Emergency Evacuation Plan (PEEP) is to provide people who cannot get themselves out of a building unaided during an emergency situation with the necessary information to be able to manage their escape from the building.

Evacuation Procedures and Drills

The **key elements** of a fire emergency plan include:

- The method by which people will be warned if there is a fire.
- What staff should do if they discover a fire.
- How the evacuation of the premises should be carried out.
- Where people should assemble after they have left the premises and procedures for checking whether the premises have been evacuated.
- Identification of key escape routes, as well as how people can gain access to them and escape from them to a place of total safety.
- Arrangements for fighting fire.
- The duties and identity of staff who have specific responsibilities if there is a fire:
  - The incident controller and deputy incident controller.
  - Fire marshals and deputy fire marshals.
  - Roll callers.
  - Supervisors.
- Arrangements for the safe evacuation of people identified as being especially at risk, such as young persons, those with disabilities or lone workers.
- Any machines/processes/appliances/power supplies that need to be stopped or isolated if there is a fire.
- Specific arrangements for high-fire-risk areas.
- Contingency plans for when fire safety systems, such as evacuation lifts, fire detection and warning systems, sprinklers or smoke control systems are out of order.
- How the fire and rescue service and any other necessary services will be called and who will be responsible for doing it.

Identification of key escape routes

- Procedures for meeting the fire and rescue service on their arrival and notifying them of any special risks, e.g. the location of highly flammable materials.

To help people understand the emergency plan (and also the fire risk assessment, as discussed earlier in this element) it is also a good idea to include a building plan with fire-related features marked on it, such as:

- Positions of escape doors.
- Positions of escape routes.
- Fire-resisting constructions.
- Location of refuges and lifts designed to assist those who may need assistance.
- Methods of fighting fire, e.g. numbers and type of fire extinguishers at each location.
- Location of manually operated fire-alarm call points.
- Location of control equipment for fire alarms.
- Location of emergency lighting and exit route signage.
- Location of high-fire-risk areas and processes.
- Location of automatic fire-fighting systems such as sprinklers.
- Location of main electrical supply/isolation switch, main water shut-off valve and main gas and oil shut-off valves.

Training

Training in fire safety procedures is necessary for everybody. It is essential that key personnel who are responsible for implementing safety procedures are given **adequate training** by a competent person in order to perform their duties. This includes:

- Induction training for new employees.
- More specialised training for members of staff with specific safety responsibilities:
  - Fire marshals.
  - People dealing with specialist processes or equipment.
- General training, which should cover:
  - What to do on discovering a fire.
  - How to raise the alarm and what happens when the alarm has been raised.
  - What to do on hearing the fire alarm.
  - The procedures for alerting contractors and visitors including, where appropriate, directing them to exits.
  - The arrangements for calling the fire and rescue service.
  - The evacuation procedures for everyone in the workplace to reach an assembly point at a place of total safety.
  - The importance of reporting to the assembly area.
  - The location and, when appropriate, the use of fire-fighting equipment.
  - The location of escape routes, especially those not in regular use.
  - How to open all emergency exit doors.
  - The importance of keeping fire doors closed to prevent the spread of fire, heat and smoke.
  - Where appropriate, how to stop machines and processes and isolate power supplies in the event of a fire.
  - The reason for not using lifts (except those specifically installed or nominated, following a suitable fire risk assessment).
  - The safe use of highly flammable and explosive substances, as well as the risks from storing or working with them.
  - The importance of general fire safety, which includes good housekeeping.
  - The items listed in the emergency plan.

  - The importance of fire doors and other basic fire-prevention measures.
  - Exit routes and the operation of exit devices, including physically walking these routes.
  - General matters, such as smoking policy and permitted smoking areas or restrictions on cooking other than in designated areas.
  - Assisting disabled persons where necessary.
- Specialist training for fire marshals, incident controllers and deputy incident controllers, which should include:
  - Detailed knowledge of the fire safety strategy of the premises.
  - Awareness of human behaviour in fires.
  - How to encourage others to use the most appropriate escape route.
  - How to search safely and recognise areas that are unsafe to enter.
  - The difficulties that some people, particularly disabled persons, may have in escaping and any special evacuation arrangements that have been pre-planned.
  - Additional training in the use of fire-fighting equipment.
  - An understanding of the purpose of any fixed fire-fighting equipment, such as sprinklers or gas flooding systems.
  - Reporting of faults, incidents and near misses.

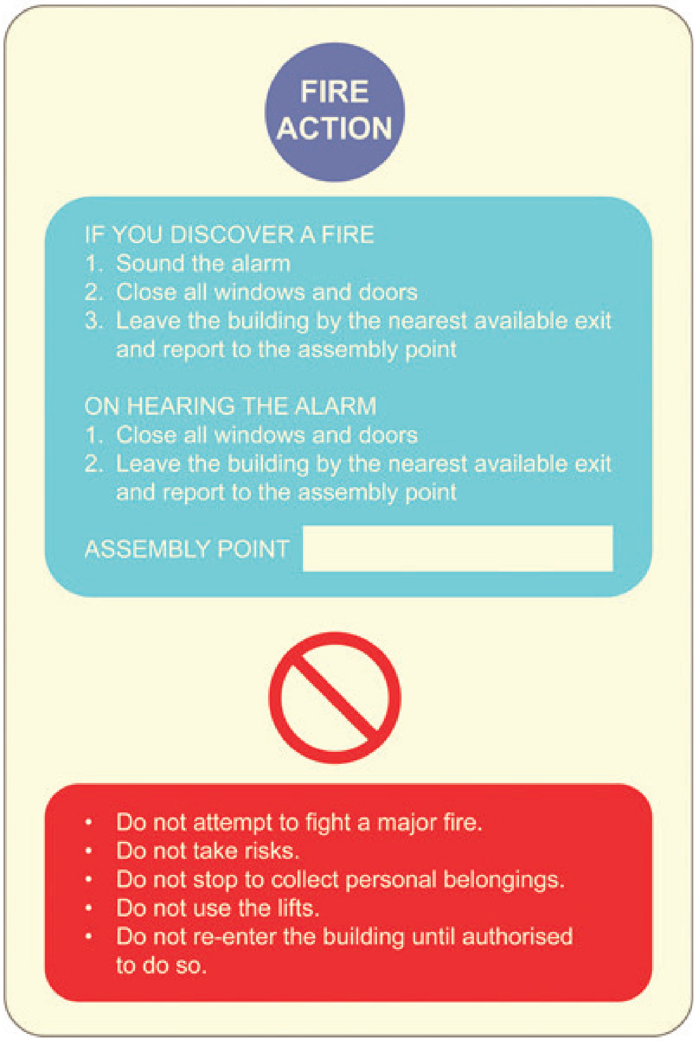
Fire drills should be carried out regularly, simulating conditions that might occur in an actual emergency.

Training, instruction and drills should be recorded in a log or other suitable record, which should be available for inspection.

Examples of matters which should be included in a fire record-keeping book include:

- Date of the instruction or exercise.
- Duration of the instruction or exercise.
- Name of the person giving the instruction.
- Names of the persons receiving the instruction.

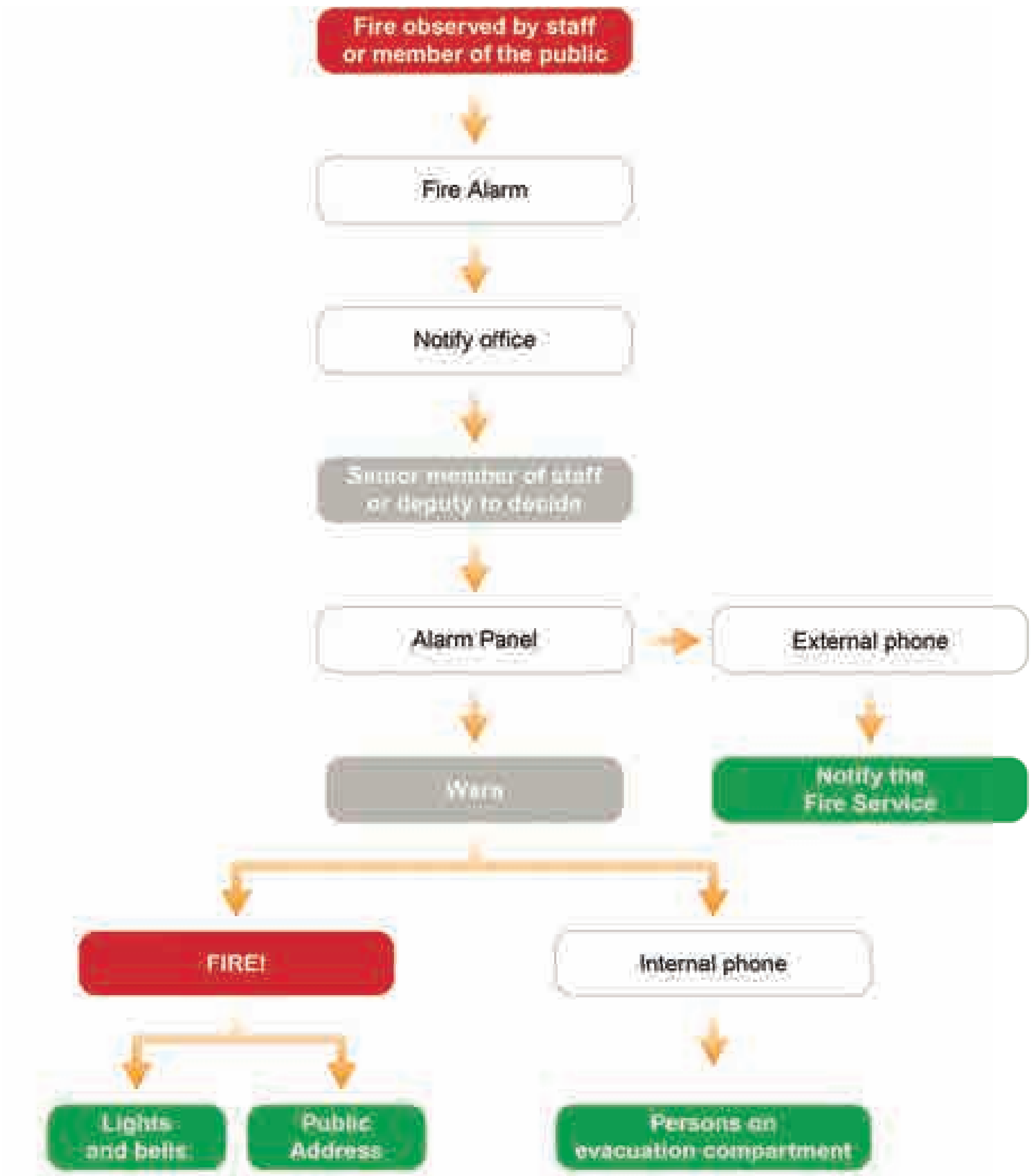
Notices should be displayed in conspicuous positions in the building stating, in concise terms, the action to be taken on discovering a fire or hearing the fire alarm (see the following example).



Fire action sign

Alarm Evacuation and Roll Call

With any building in which a great number of people are present, the procedure must not allow panic, as it will slow evacuation and may cost lives. The evacuation must be orderly and be handled in such a manner that the escape facilities, e.g. capacity of escape routes, can handle the number of people using them.



Alarm procedure

A massed crowd will cause congestion and is likely to slow the flow. The method to be adopted is a **zoned evacuation**, i.e. a compartment at a time. The compartments must be **evacuated in sequence** - with the compartment at highest risk being evacuated first. Sounding an alarm throughout the building would not achieve this and may slow total evacuation.

Staff duties (shops, public buildings):

- Detailed members of staff shepherd the public to the escape route.
- Senior members of staff search all the floors, WCs, etc.
- Members of staff keep exits open and clear.

- A responsible member of staff should meet the fire service on arrival and inform them of all relevant details.
- On leaving the premises, ensure all doors and windows are closed.

As soon as the premises have been evacuated and all personnel are assembled in their pre-arranged safe areas, fire marshals or other appointed persons must carry out a **roll call** on the basis of a continually updated register (the compilation of which will be a line management function). The roll must include staff, visitors, contractors, etc.

If anyone is not accounted for, the fire officer in charge must be notified as soon as the fire services arrives.

In the case of premises where there is random public access (shops, etc.), it may be necessary for the fire service to undertake a search.

Provision of Fire Marshals and their Role

Fire marshals:

- Are appointed to assist with the evacuation procedure.
- Require more comprehensive training, as detailed previously.
- Roles include:
  - **Helping** any members of the public, visitors and/or disabled persons leave the premises.
  - **Checking** designated areas to ensure everyone has left.
  - **Using** fire-fighting equipment.
  - **Liaising** with the fire and rescue service.
  - **Shutting down** vital or dangerous equipment.
  - Performing a supervisory/**managing** role in any fire situation.

Fire marshals in action

TOPIC FOCUS

Fire Marshal Systems

The **operation of the system** is as follows:

- The building is split into small areas of responsibility.
- Each area is allocated to a specific fire marshal.
- Fire marshals are designated people who, in the event of a fire:
  - Search and check their allocated area.
  - Ensure that all people have left the building.
  - Direct those who have not left the building to an appropriate fire exit and safe assembly point.
  - Report that their area has been checked and is clear.

The **benefits of the system** include:

- The use of trained persons who are familiar with the premises to evacuate other people who may not be familiar with the premises.
- Marshals can compensate for any adverse human behaviour which might hinder or delay the evacuation.

Personal Emergency Evacuation Plans (PEEPs)

The aim of a Personal Emergency Evacuation Plan (PEEP) is to provide people who cannot get themselves out of a building unaided during an emergency situation, with the necessary information to be able to manage their escape from the building.

Individuals with a **hearing** impairment may take longer to be alerted, and the **visually** impaired may have greater difficulty finding their way out of a building. These issues need to be considered in the emergency evacuation plan for those persons.

To execute the evacuation plan, special aids may be needed such as:

- **Personal trembler alarms**, which "vibrate" at the same time as the alarm.
- **Buddy system**, where someone is allocated the task of helping the person with a sensory impairment.
- **Visual alarms** for the **hearing-impaired**, such as a flashing beacon.
- **Tactile/Braille** signs for the **visually impaired**, providing the person can locate the sign and is able to read Braille.

> **MORE...** www.
>
> Detailed advice and guidance on implementing a fire risk management plan can be found in the series of UK guidance documents available from:
>
> www.gov.uk/workplace-fire-safety-your-responsibilities/fire-safety-advice-documents.

Persons with severe **mobility** impairment may require assistance during a fire evacuation from building design elements and accessories such as:

- **Evacuation lifts** designated for the use of the disabled, which continue to operate during the fire.
- **Evacuation chairs** – lightweight, manoeuvrable, specialised wheeled chairs for evacuation down stairs and along corridors.
- **Refuges** – fire-protected areas (minimum 30 minutes' fire resistance) which offer **temporary** relative safety where a disabled person has to wait for assistance for full evacuation or needs to rest. Refuges are generally located within a protected stairwell and close to an evacuation lift/chair.

Disabled persons may require a Personal Emergency Evacuation Plan (PEEP)

> **MORE...** www.
>
> The ILO Action Checklist for Fire Safety (part of the Programme on Safety and Health at Work and the Environment (SafeWork) provides a useful method to check that arrangements cover all the essential requirements. This checklist is a management tool to implement practical actions to improve fire protection at the workplace. The checklist considers the following topics:
>
> - Measures to minimise fire risks.
> - Preparing for fire emergencies.
> - Training.
>
> The checklist is designed essentially for small and medium-sized enterprises, but is applicable to all workplaces and is available at:
>
> www.ilo.org/safework/info/publications/WCMS_194782/lang--en/index.htm

STUDY QUESTIONS

14. Identify the issues to be covered during a training session on emergency procedures.
15. Explain the operation and benefits of a fire marshal system.
16. Describe the special aids that might be required in order to execute the Personal Emergency Evacuation Plan for a person with severe sensory impairment.

(Suggested Answers are at the end.)

Summary

The Identification of Hazards and the Assessment of Risk from Fire

We have:

- Considered fire hazards and the assessment of risk.
- Outlined the five steps to fire risk assessment:
  - Identify fire hazards.
  - Identify people at risk.
  - Evaluate, remove, reduce and protect from risk.
  - Record, plan, inform, instruct and train.
  - Review.

Fire Detection and Alarm Systems and Procedures

We have:

- Examined the common fire detection and alarm systems and procedures, including types of fire detector - ionisation, optical, radiation and heat detectors - which are activated by changes in the physical environment.
- Noted that alarm systems fall into three main categories: manual, manual/electric and automatic.

Fixed and Portable Fire-Fighting Equipment

We have:

- Outlined the main types of fixed fire-fighting systems available, including sprinklers, drenchers, total flood systems and deluge systems.
- Identified the main types of extinguishing agent used in fixed installations as water, foam, carbon dioxide, halon and dry powder.
- Considered that fire-fighting equipment should be sited in an easily seen and reached position and regularly inspected and maintained. We also noted there should be suitable training provided for persons required to use this equipment.
- Highlighted the potential environmental damage that can result from contaminated fire-fighting water run-off, meaning that sites should consider the polluting effects of fire in their emergency plans.

Means of Escape

We have:

- Identified the factors which require particular consideration for the provision of safe means of escape, including the nature of the occupants, the number of people attempting to escape, the distance they may have to travel to reach a place of safety, and the size and extent of the 'place of safety'.
- Considered the general requirements for a safe means of escape, including travel distances, stairs, passageways and doors, emergency lighting and signs.
- Outlined the requirements for maintaining fire safety in communal areas, including access to competent advice on fire safety legislation, co-ordination with other occupiers and engaging with occupants to communicate fire safety messages.

Emergency Evacuation Procedures

We have:

- Recognised that evacuation procedures are a part of the emergency plan, which covers:
  - How evacuation should be carried out, where people should assemble, how evacuation of the premises is checked and identifies the key escape routes. These factors should be tested using emergency drills.
  - The duties of staff who have specific responsibilities if there is a fire, including arrangements for the safe evacuation of people especially at risk and taking roll calls.
- Identified fire marshals as designated people who, in the event of a fire:
  - Search and check their allocated area.
  - Ensure that all people have left the building.
  - Direct those who have not left the building to an appropriate fire exit and safe assembly point.
  - Report that their area has been checked and is clear.
- Considered the provision of Personal Emergency Evacuation Plans (PEEPs) for anyone who cannot get themselves out of a building unaided during an evacuation.

Exam Skills

QUESTION

Workers in a vehicle maintenance workshop undertake spray-painting of vehicles using a solvent-based paint with a low flash point.

Outline the measures to be taken to ensure that the risks associated with the spray-painting activity are adequately controlled. **(20)**

Approaching the Question

- Read the question carefully – there is a lot of really important information here for you! This question format can be daunting, but read it carefully before dismissing it - it should be straightforward once you work out what's being asked.
- There are 20 marks available for this question, so you would be expected to provide at least 20 pieces of information to hope to gain full marks.
- Remember if you don't outline but simply "give" or "identify", you won't gain enough marks – you need to show that you understand the risks posed by the activity and can identify suitable controls.

An outline plan for this question would need to include: fire risk assessment – the process, properties of paints, fire issues, control hierarchy, spills, emergencies, ventilation, training.

Try to write your own answer to this question now, then come back and look at the guidance and advice below.

Suggested Answer Outline

The examiner would be looking for depth in the answer – the following points could have been included. (Remember, these would need to be expanded into "outlines" in order to gain good marks.)

- Identify the need to conduct a fire risk assessment.
- The fire risk assessment should look at who may be affected, how harm can occur, duration/frequency of tasks and controls. It should also evaluate the level of risk.
- Identify the information required to undertake the fire risk assessment, including using MSDSs.
- Identify possible ignition sources to ascertain risk of fire and explosion.
- Control measures to be adopted may include:
  - Looking at alternative methods of painting.
  - Considering substitution with a less flammable paint if elimination of the solvent can't be achieved.
  - Minimising quantities of flammable materials in the workshop.
  - Design and construction of the workplace to manage the fire/explosion risks (materials, construction methods).
  - Storage – self-contained, fire-resistant, secured access, spills, lids.
  - Containers – non-spill, use of lids.
  - LEV – enclose (or partially enclose) the process, look at venting and the type of electrical equipment.
  - Procedures – use of equipment, cleaning of spray guns, dealing with fires/spills/containment, etc.
  - Fire detection – automatic systems, nuisance trigger of systems, maintenance.

- Fire-fighting – suitable numbers and types of extinguishers.
- Training – fire-fighting, cleaning of guns, use of PPE, fire issues, emergencies.
- Fire management – escape routes, assembly points, drills, fire marshals, roll call.
- Communication – plans, escape, signage, procedures, PPE.
- Appointment of competent persons to manage fire risks.
- Prohibition of eating, drinking and smoking in the workplace.
- Provision of suitable PPE – anti-static footwear (testing of), overalls (anti-static), glasses/goggles and RPE if required.

Example of How the Question Could be Answered

In order to manage the fire risks from spray-painting of vehicles using a solvent (low flash point) paint, you would need to manage the risks in the following manner:

- *A risk assessment should be carried out to determine the hazardous properties and controls associated with the paints. Information can be obtained from the material safety data sheets.*
- *A fire risk assessment should be carried out to identify the potential fuels (paints and thinners) and possible ignition sources, including heat and static. The risk assessment would also identify those at risk, evaluate current controls and propose additional control measures.*
- *Possible control measures include:*
  - *Elimination of the solvent by using a water-based paint alternative. This may be possible but could result in longer drying times and different paint finishes.*
  - *Substitution of the paint with a solvent-based material which is less flammable – this may be easier to achieve than using a water-based paint but will still result in residual hazards. Consideration should be given to the cleaning materials that are used, e.g. gun washing stations, which may still contain flammable materials.*
- *If these measures aren't reasonably practicable to implement then you would need to look at managing the risk with implementation of appropriate LEV to remove fumes from the work area to prevent build-up of fire/explosion risks, identification and control of ignition sources and ensuring they do not produce either sparks or heat to cause an explosion/fire risk.*
- *Other controls would be minimising quantities of materials used/sprayed or stored in the work area and storing small quantities of materials needed for each shift in a locked, flame-resistant cabinet in the workroom. Larger quantities of material should be stored securely in a fire-resistant store outside and away from the workplace (locked and controlled so as to reduce the risk of arson, and ventilated to prevent the build-up of vapours).*
- *When using and dispensing materials there should be adequate emergency spill containment facilities in the event of a release. The materials should be used in a well ventilated area with LEV provided to reduce vapour concentration and reduce operator exposure to the solvents.*
- *Equipment used in the area should be suitable for use in a flammable atmosphere.*
- *Emergency procedures would need to be developed, e.g. fire and spill response, containment to prevent environmental releases.*
- *Employees in the area would need to be trained in the safe use of the equipment, the emergency procedures and the risk of ignition of the flammable environment. If PPE is required they should also be trained in its use.*

Reasons for Poor Marks Achieved by Exam Candidates

- Lack of knowledge of fire management.
- Insufficient depth, with lists produced rather than outlines.

Element IC4

The Storage, Handling and Processing of Dangerous Substances

Learning Outcomes

Once you've read this element, you'll understand how to:

1. Outline the main physical and chemical characteristics of industrial chemical processes.
2. Outline the main principles of the safe storage, handling and transport of dangerous substances.
3. Outline the main principles of the design and use of electrical systems and equipment in adverse or hazardous environments.
4. Explain the need for emergency planning, the typical organisational arrangements needed for emergencies and relevant regulatory requirements.

Contents

Industrial Chemical Processes

IN THIS SECTION...

- The rate of a reaction will usually increase with **temperature** and **pressure**. A **catalyst** will affect the rate of a chemical reaction without being changed itself.
- **Exothermic** reactions are accompanied by the **evolution of heat**, e.g. combustion of propane or the polymerisation of methyl isocyanate.
- A runaway reaction is an exothermic reaction where the heat generated continues to increase the temperature, accelerating the reaction out of control, e.g. Bhopal in 1984.

Introduction

All chemical reactions involve **changes in energy**, usually evident as heat. Reactive chemical hazards invariably involve the release of energy in a quantity or at a rate too great to be dissipated by the immediate environment of the reacting system, so that destructive effects appear. It is essential for a process designer to understand the nature of the reactive chemicals involved in a process.

Careful control of chemical reactions

Effects of Temperature, Pressure and Catalysts

The rate of a reaction will increase exponentially with increase in **temperature**; in practical terms an increase of 10°C roughly doubles the reaction rate in many cases. This has often been the main contributory factor in cases where inadequate temperature control has caused exothermic reactions to run out of control.

Things can be made worse in closed systems at relatively high **pressures** and/or temperatures. In high-pressure autoclaves, for example, the thick vessel walls and generally heavy construction necessary to withstand the internal pressures implies high thermal capacity of the equipment. Rapid cooling of such vessels to attempt to check an accelerating reaction is impracticable, so bursting discs or other devices must be fitted as pressure reliefs to high-pressure equipment.

Substances which are highly reactive or unstable when subject to heat, pressure, mechanical force or on contact with other chemicals represent a potential source of explosive energy. Acetylene, for example, has a tendency to decompose exothermically and result in explosions or detonations. The character and course of the explosion depend on many factors. Pressures in excess of 10 times the initial pressure can result from acetylene explosions and pressures above 50 times the initial pressure have arisen with detonations.

> **DEFINITION**
>
> **CATALYST**
>
> Any agent (usually a substance) which, when added in very small quantities, notably affects the rate of a chemical reaction without itself being consumed or undergoing a chemical change. Most catalysts accelerate reactions but a few retard them (negative catalysts or inhibitors).

Light can act as a catalyst (although it is not a 'substance' as such) in both the visible and ultra-short wavelengths, e.g. in photosynthesis and other photochemical reactions.

The activity of a solid catalyst is often centred on a small fraction of its surface, so the number of active points can be increased by adding promoters which increase the surface area in some way, e.g. by increasing porosity. Catalytic activity is decreased by substances that act as poisons which clog and weaken the catalyst surface, e.g. lead in the catalytic converters used to control exhaust emissions.

Catalysts can be highly specific in their application, and are essential in virtually all industrial chemical reactions, especially in petroleum refining and synthetic organic chemical manufacturing.

There are many organic catalysts that are vital in the metabolic processes of living organisms. These are called enzymes and are essential, e.g. in digestion.

Heat of Reaction

Exothermic Reactions

An exothermic reaction is a reaction accompanied by the **evolution of heat**, such as a combustion reaction.

Exothermic reactions must be carefully controlled and monitored to ensure there is no failure of the cooling or stirring systems. Quantities should be kept to a minimum and suitable screening provided. No operation of this kind should be entrusted to anyone apart from a highly skilled and competent chemist knowledgeable in the dangers involved and the precautions to be taken.

Runaway Reactions

Most reactions are exothermic. They tend to accelerate as the reaction proceeds, unless the rate of cooling is sufficient to prevent a rise in temperature. The exponential temperature effect accelerating the reaction will exceed the (usually) linear effect of falling reactant concentration in decelerating the reaction. Where the exotherm is large and cooling capacity is inadequate, the resulting accelerating reaction may proceed to the point of loss of control, and decomposition, fire or explosion may result. Reactions at high pressure may be exceptionally hazardous owing to the enhanced kinetic energy content of the system.

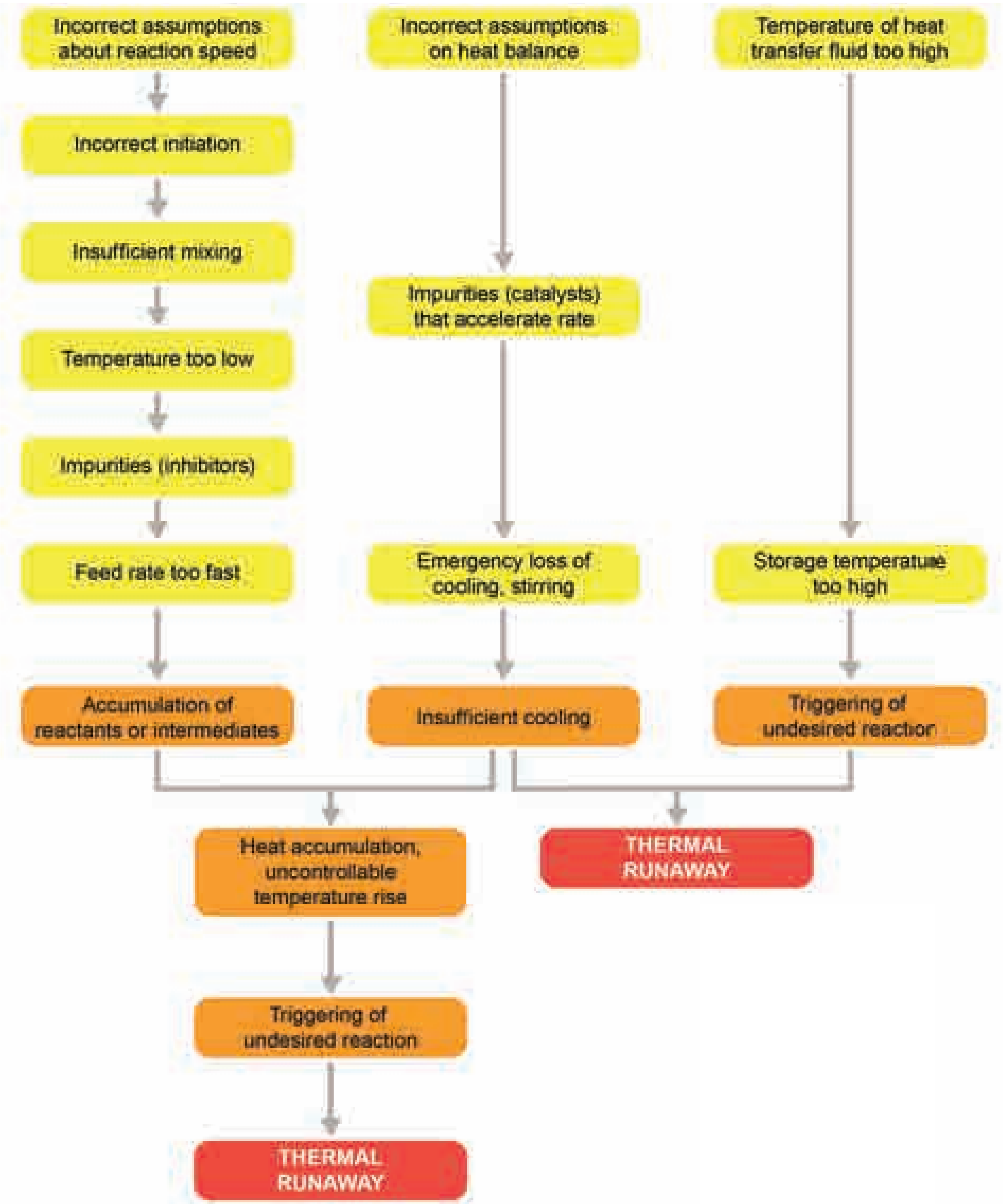
The rate of an exothermic chemical reaction determines the rate of energy release; so factors which affect reaction kinetics are important so far as possible hazards are concerned.

Methods of Controlling Exothermic and Runaway Reactions

Important factors in preventing such thermal runaway reactions are mainly related to the **control of reaction velocity and temperature** within suitable limits. These will include considerations such as:

- Adequate heating and particularly cooling capacity in both liquid and vapour phases of a reaction system.
- Proportions of reactants and rates of addition (allowing for an induction period).
- Use of solvents as diluents and to reduce viscosity of the reaction medium.
- Adequate agitation and mixing in the reaction vessel.
- Control of reaction or distillation pressure.
- Use of an inert atmosphere.

A dangerous runaway reaction is most likely to occur if all the reactants are initially mixed together with any catalyst in a batch reactor, where heat is supplied to start the reaction.



Some causes of runaway in reactors or storage tanks

Many chemical processes require equipment designed to rigid specifications, with sophisticated automatic control and safety devices. With some reactions, it is important to provide protection against failure of cooling media, agitation, control, or safety instrumentation, etc. The reactor itself must be adequately designed for the operating conditions, e.g. pressure, temperature, corrosive environment.

TOPIC FOCUS

The conditions that might give rise to a '**runaway reaction**' include:

- A strongly exothermic reaction process.
- Inadequate provision of cooling.
- Catalysis by contaminants.
- Lack of temperature detection and control.
- Excessive quantities of reactants in the reaction vessel.
- Failure of mixing or agitation.

- **Effects of Thermal Runaway**

  A runaway exothermic reaction can have a range of results from the boiling over of the reaction mass, to large increases in temperature and pressure that can lead to an explosion. Such violence can cause blast and missile damage. If flammable materials are released, fire or a secondary explosion may result. Hot liquors and toxic materials may contaminate the workplace or generate a toxic cloud that may spread off-site.

  There can be serious risk of injuries, even death, to plant operators, and the general public and the local environment may be harmed. At best, a runaway causes loss and disruption of production; at worst it has the potential for a major accident.

- **Effect of Scale**

  The scale with which a reaction is carried out can have a significant effect on the likelihood of runaway. The heat produced increases with the volume of the reaction mixture, whereas the heat removed depends on the surface area available for heat transfer. As scale, and the ratio of volume to surface area, increases, cooling may become inadequate. This has important implications for scale-up of processes from the laboratory to production and should be taken into account, particularly when modifying a process to increase the reaction quantities.

- **Causes of Incidents**

  An analysis of thermal runaways in the UK has indicated that incidents occur because of inadequacies in:

  – understanding of process and thermal chemistry;
  – design for heat removal;
  – control systems and safety systems; and
  – operational procedures, including training.

  These are some of the key factors that should be considered when defining a safe process.

MORE... www.

See:

www.youtube.com/watch?v=C561PCq5E1g)

for a CSB video of thermal runaway at the T2 Laboratories.

Example of Exothermic Reaction

An **exothermic** reaction is a reaction accompanied by the **evolution of heat**, such as a combustion reaction.

Propane is an important fuel gas and reacts exothermically with oxygen. It will burn in excess oxygen with the generation of heat to form water and carbon dioxide.

propane + oxygen → carbon dioxide + water + heat

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

Example of Runaway Reaction

Bhopal, 1984

Methyl Isocyanate (MIC) is an extremely toxic and unstable substance and even in very small quantities is fatal; it is also volatile and unstable at higher temperatures and will break down exothermically to give out large amounts of heat if contaminated. For safe handling, it must be maintained at about 0°C.

On the night of 2-3 December 1984 at the Union Carbide India Limited (UCIL) pesticide plant in Bhopal, Madhya Pradesh, India, during a routine cleaning operation, maintenance workers inadvertently allowed water to enter an MIC storage tank (Tank E610), causing an exothermic, runaway reaction to occur. The MIC boiled and toxic vapour was expelled through the bursting disc vent. A scrubber and flare stack, which might have been able to deal with the release, were shut down at the time so the MIC vapour was discharged directly to atmosphere. The wind carried the plume over the adjacent city of Bhopal where over half a million people were exposed to MIC gas and other chemicals.

STUDY QUESTIONS

1. In general terms, how is the rate of a chemical reaction affected by temperature?
2. What are the two key factors in controlling a thermal runaway?

(Suggested Answers are at the end.)

The Storage, Handling and Transport of Dangerous Substances

IN THIS SECTION...

- The amount of flammable solids or liquids held in a workplace should be limited. Large quantities of flammable substances should be held in suitable stores. Storage may be in:
  - Bulk storage tanks.
  - Intermediate storage vessels.
  - Drums.
- Incompatible materials should be identified and segregated to ensure that they are not allowed to mix and react if a spillage or release occurs.
- Means of controlling spillage should be provided where materials are stored, e.g. an impervious sill or low bund. During filling and transfer, release of vapours should be prevented or kept to an absolute minimum.
- The risks arising from the storage and handling of dangerous substances may be reduced by:
  - Measures to prevent loss of containment or static charge generation during flow through pipelines.
  - Care in filling and emptying containers.
  - Extreme caution in dispensing, spraying or disposing of flammable liquids.
  - The identification of 'zones' which relate to the presence, or possible presence, of flammable atmospheres and suitable electrical equipment that may be used in those zones.
- Carrying goods by road or rail involves the risk of traffic accidents. If the goods carried are dangerous, there is also the risk of an incident, such as spillage of the goods, leading to hazards such as fire, explosion, chemical burn or environmental damage. These risks may be minimised by:
  - Following the key safety principles for loading and unloading of tankers and tank containers.
  - Correct labelling of vehicles and packaging of substances.
  - The importance of driver training programmes and the appointment of a Dangerous Goods Safety Adviser. Storage Methods and Quantities

Storage Methods and Quantities

Wherever possible, the amount of flammable solids or liquids being held in a workplace should be limited to what is required for that day's use. Large quantities of flammable substances should be held in suitable stores, taking into account the need for segregation from incompatible materials. Reduction of inventory to the lowest possible amount is the safest approach to the risk of fire and explosion.

Storage of flammable substances

For the safe storage and handling of flammable liquids:

- Compartmented or separated store; up to four-hour fire resistance.
- Not located where it could hinder the means of escape in the event of a fire.
- The storage should incorporate a means to prevent liquid escapes.
- The store should be located at ground level.

- All ignition sources and combustibles (e.g. rubbish, vegetation) should be eliminated.
- The area should be ventilated to the open air.
- The store and the containers should be marked.

Bulk Storage

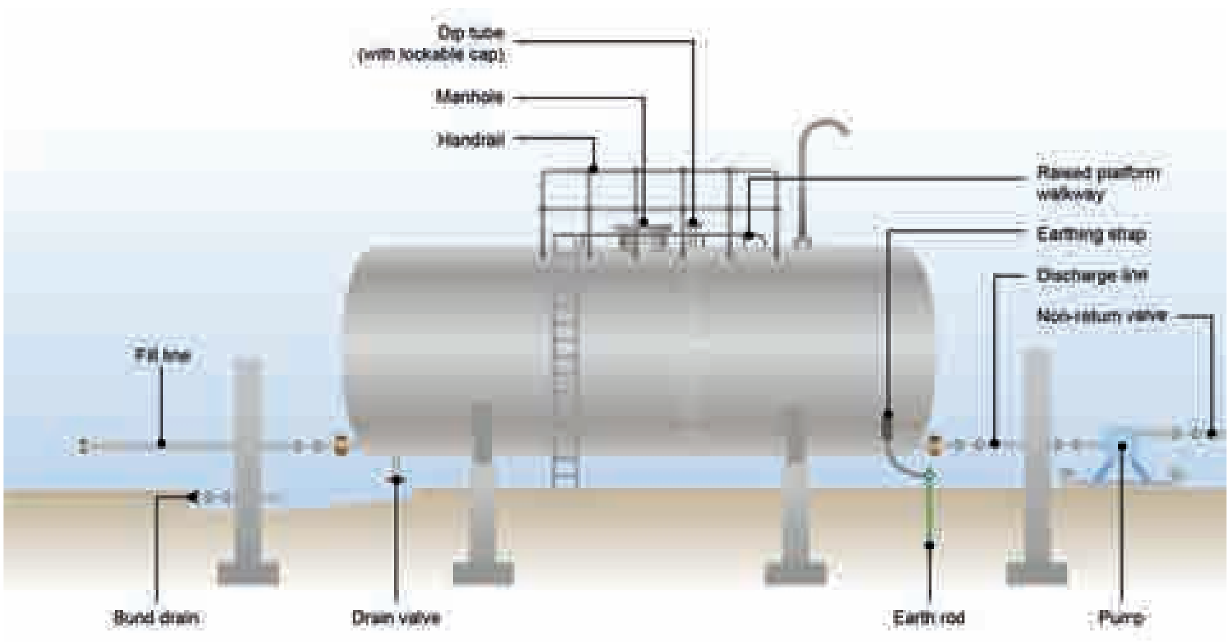
The principal hazards associated with the storage of highly flammable liquids are fire and explosion arising either from:

- Ignition of the liquid.
- Vapour escaping from the installation due to equipment failure or maloperation.
- Exposure of the storage installation to heat from fire in the vicinity.

The storage of highly flammable liquids in fixed bulk tanks is preferable to storage in drums, but this may not always be practicable.

Storage above ground and in the open air is better, because leaks will usually be visible and therefore detected fairly quickly. Moreover, vapours arising from minor leaks will normally be dissipated by natural ventilation. Cleaning, repair work and modifications can also be more easily carried out. Refer to the following figures for more information.

Bulk storage tanks should not be located inside or on the roof of a building.



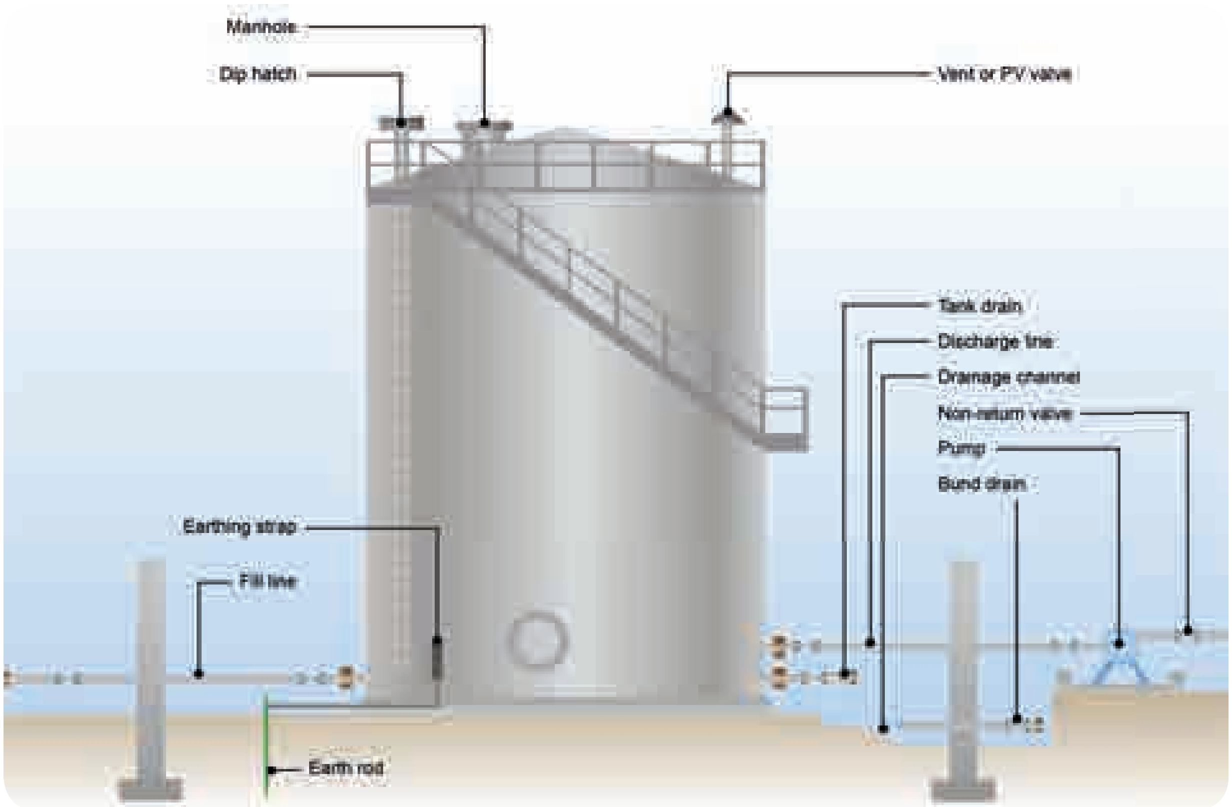
Typical horizontal storage tank

The siting of major installations should take account of the hazard presented to people beyond the site boundary.

MORE... www.

Information on the storage of flammable liquids in tanks can be found in UK guidance HSG176 at:

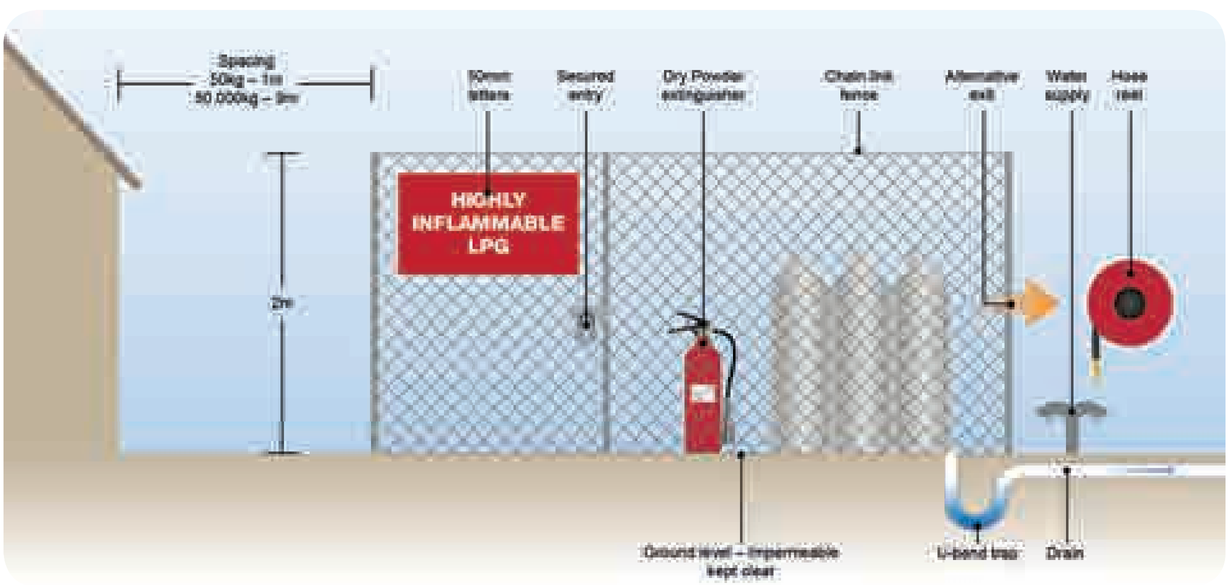
www.hse.gov.uk/pubns/priced/hsg176.pdf



Typical vertical storage tank

Intermediate Storage

Refer to the following figure for storage of LPG cylinders:



Storage of LPG cylinders

Both full and empty cylinders pose a hazard - the safety features apply whatever the state of the cylinders. The store should be outside to allow any gas to dissipate; of course, it should not be possible to ignite any leak and so separation distances between the cylinders and sources of ignition are recommended. These distances are a function of the total quantity of stored gas and the height of the stacked cylinders. Aids to fire-fighting include: dry powder extinguishers, hose reels and water supplies, such as hydrants, for the larger storage areas.

Drum Storage

Drums should be stored outside on an impervious surface (concrete) which is no closer than four metres to any risk, bund or open boundary. If the boundary is an imperforate wall of at least 30 minutes' fire resistance, drums may be stored against it to within one metre of the top. This area should be ramped to contain spills.

Inadequate drum storage

No container should be stored within two metres of any door, plain glazed window, or escape route of a process building.

The storage distances may be reduced if the liquids are stored in a fire-resisting store.

Small containers may be stored in workrooms, provided that:

- The total quantity does not exceed 50 litres.
- When not being used, they are kept in a store of non-combustible construction.

It is common for certain flammable liquids to be stored and transported in drums. Steel was the usual material used in the manufacture of drums, although plastic has become very common.

When drums are used for storage there are a number of points to consider:

- The drums should be stored upright. If stored on their side they must be properly chocked.
- They should be properly marked with signs showing the contents.
- Proper drum-handling equipment should be used – drums should not be rolled.
- They should be periodically examined for damage and removed from service if there are signs of damage.
- They should only be used for substances that they are designed for.

All other safe storage requirements apply.

Specific Locations

If possible, containers should be stored at ground level (singly or in stacks) and in the open air. This is because leaks can be more readily seen and any vapour produced will be dissipated by natural ventilation. Containers should not normally be stored on the roof of a building. If for reasons of space the use of roof-top storage is considered essential, the enforcing authority and the fire authority should be consulted.

Where it is not possible to store containers in the open air, they may be kept in suitable storerooms – preferably separate buildings used only for this purpose. Other materials should not be kept in stores intended only for flammable liquids. Small amounts of flammable liquid may be stored in workrooms in a fire-resisting cupboard or bin.

All containers should be stacked in a safe manner, which:

- Minimises the amount of handling required to find and remove any one of them.
- Allows any leaks to be readily identified and dealt with.

Drums of 200 litres and similar containers should normally be stacked no more than four high and preferably on pallets. If drums are stored on their sides, they should be firmly chocked to prevent movement. All containers should be stacked so as not to obstruct ventilation openings or means of escape.

If containers of flammable liquid are stored near other combustible, toxic, corrosive or oxidising materials, or compressed gases, an assessment of the relative hazards should be carried out, using specialist advice where necessary.

Highly Flammable Liquids (HFLs) and LPGs should be stored in suitable fixed storage tanks, in suitable closed vessels kept in a safe position in the open air, or in suitable closed vessels in workrooms which are either safe by position or are of a fire-resistant structure. Small quantities of liquid may be kept in ordinary workrooms provided they are contained in closed, fire-resisting vessels. In the case of LPG, all such tanks, cupboards and bins should be appropriately marked.

TOPIC FOCUS

To comply with best practice:

- All **HFLs** must be stored safely in one of the following ways:
  - In fixed storage tanks in a safe position.
  - In suitable closed vessels in a safe position in the open air, where necessary being protected against direct sunlight.
  - In suitable closed vessels kept in a storeroom, either safe by position or of fire-resisting structure.
  - In the case of a **workroom** where the aggregate quantity does not exceed **50 litres**, in suitably closed vessels in a suitably placed cupboard or bin that is a fire-resisting structure.
- All **LPGs** are to be stored in one of the following ways:
  - In suitable underground reservoirs or in suitable fixed storage tanks, in a safe position, either underground or in the open air.
  - In suitable movable storage tanks/vessels kept in a safe position in the open air.
  - In pipelines or pumps forming part of an enclosed system.
  - In suitable cylinders kept in safe positions in the open air or, where not reasonably practicable, in a storeroom constructed of non-combustible material, with adequate ventilation, in a safe position, of fire-resisting structure and solely used for the storage of LPG and/or acetylene cylinders.
- Every tank, cylinder, storeroom, etc. used for the storage of LPG to be marked (as above).
- Small **stores of dangerous substances** must also be marked.

The key safety features of a building to be used for the storage of **highly flammable solvents** in 200-litre drums include:

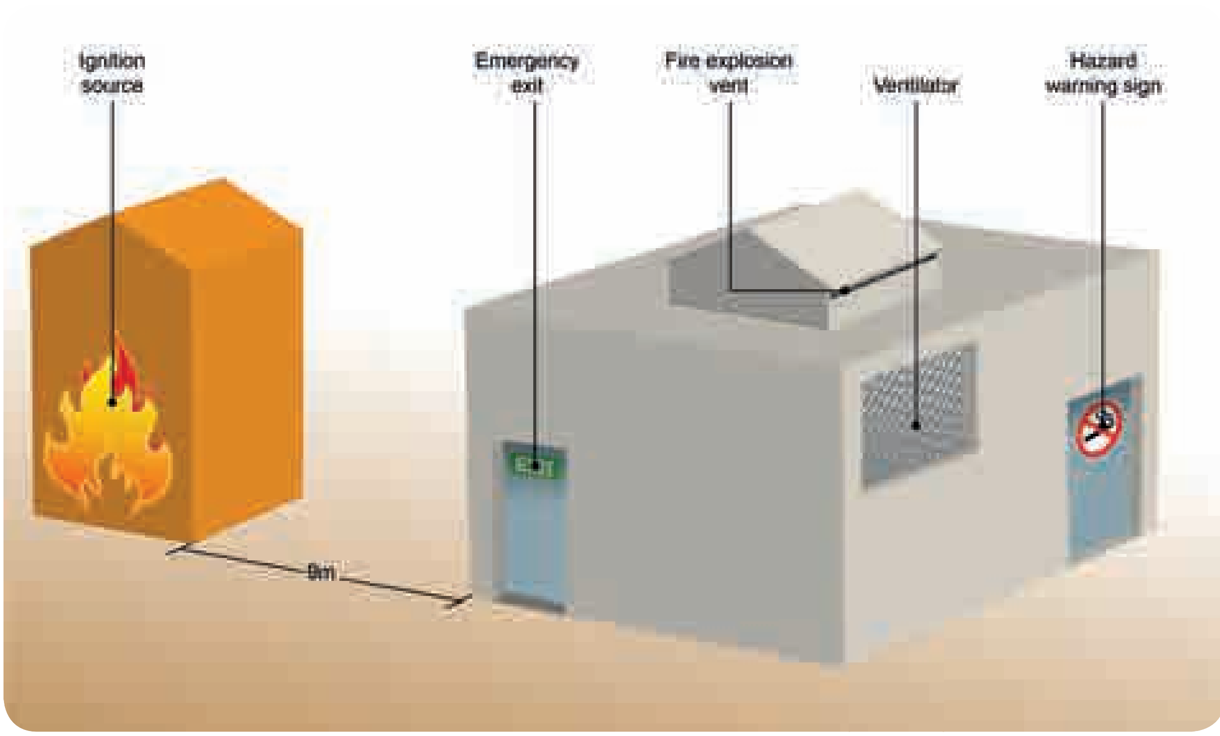
- Bunding to contain spills.
- Impermeable base.
- Non-combustible, fire-resistant construction.
- Lightweight roof or blast panels.
- Security features and warning signs.
- Zone classification.
- Adequate ventilation.
- Segregation of incompatible materials.
- Emergency fire-fighting provision.
- External electrical isolation.
- Adequate separation distance from other buildings.

Storage of Incompatible Materials, Segregation Requirements and Access

There are many substances that may take an active part in fires and explosions. In most cases these materials are only dangerous if heated, exposed to fire or contaminated. In general, all the recommendations relating to storage take the dangers into account.

Any building that is used for storage should be used exclusively for that purpose and:

- Not used for mixed contents – only the hazardous substance.
- Not used for mixing or processing.
- Kept clean and free from rubbish.
- Equipped with non-hazardous heating, e.g. a water system at the correct temperature.
- Separated from fire risks (e.g. by sheet metal) or equipped with fire-resisting walls.
- Ventilated to the open air (as in the following figure).
- Equipped with electrical equipment that is correct for the risk (zone).
- Fire detectors and fixed fire-fighting installations should be considered.



Open air ventilation

The key issue regarding the storage of dangerous substances, which includes hazardous solids as well as flammable liquids and gases, is **segregation**. This is essential to ensure that incompatible materials are not allowed to mix and react, if a spillage or release occurs.

However, **access** to storage facilities for such materials also needs to be considered, with the following issues addressed:

- Suitable signage to warn personnel of the dangerous properties of the stored substances.
- Access limited to authorised persons who have received suitable information, instruction and training in the hazardous properties of the materials, safe handling procedures (including requirements for PPE), and emergency action in the event of spillage or release.

- Suitable security measures to prevent unauthorised access to the stored substances.
- Designated storage arrangements to enable unobstructed access to the stored materials, including:
  - Suitably designed and constructed shelving or racking.
  - Marked walkways and specified storage areas.
  - Clearly designated emergency exits to provide unobstructed egress.

Storage of Toxic and Corrosive Substances

It is hard to generalise too much about the storage requirements for certain types of substance but we will note some points here. If you are involved in arranging for storage of a hazardous substance, you should obtain full details of its characteristics and specific requirements.

The conditions under which reactive chemicals are stored may have a considerable effect on their subsequent utility in reactions, and in some cases potential hazards may arise from inappropriate storage conditions. Two overriding safety principles which we have met before are:

- **Minimising the risk** by using/storing no more of any hazardous substance than is essential.
- **Segregating** substances that may react together to increase the potential hazard, e.g. oxidising agents and reducing agents.

Toxic substances

Toxic materials are those which, under either normal or disaster conditions, or both, can be **dangerous to living things** around them. Such substances can cause serious harm or even death in a relatively small single dose if they enter the body (either by inhalation, ingestion or skin absorption). Carbon tetrachloride (tetrachloromethane), for example, if stored in a poorly ventilated place under standard conditions, can evolve enough vapour to render the storage area toxic. Under disaster conditions of high temperature, if carbon tetrachloride is decomposed it can form significant quantities of the highly toxic phosgene.

It is nearly impossible to seal containers perfectly, so it is realistic always to expect that some of any volatile materials stored will escape into the atmosphere of the storage area. Also, air and atmospheric moisture will come into contact with the contents of imperfectly sealed containers. Some initially well-sealed containers will build up enough internal pressure to break a seal or even burst the sealed unit.

Corrosive materials include acids, acid anhydrides and alkalis. They can destroy living tissue (such as skin or eyes) on contact. Such materials often destroy their containers and get into the atmosphere of a storage area; some are volatile, others react violently with moisture.

- Acid fumes react to evolve toxic fumes with sulphides, sulphites, cyanides, arsenides, tellurides, phosphides, borides, silicides, carbides, fluorides and selenides. They liberate hydrogen on contact with metals and hydrides.
- Alkalis may liberate hydrogen upon contact with aluminium, etc.
- Acid mists or fumes corrode structural materials and equipment, and are toxic to personnel.

Corrosive materials

Implications for Storage of Incompatible Materials and their Segregation

Different categories of materials can react with each other to produce a dangerous condition - it is therefore important to make sure incompatible materials are adequately segregated. The degree of separation depends on the amounts as well as the nature of the compounds, but can vary from little or no separation (the package itself is considered sufficient separation) to an aisle's width (approximately three metres) to a separate building in some cases. Here are some typical implications for storage of corrosives:

MORE... www.

Information on the storage of dangerous chemicals can be found in the **ILO Code of Practice - Safety in the Use of Chemicals at Work** at:

www.ilo.org/safework/info/standards-and-instruments/codes/WCMS_107823/lang--en/index.htm

- There should be sufficient **ventilation** to prevent accumulation of fumes; there must also be **regular inspection**.
- Containers of corrosive materials should be **carefully handled, kept closed and labelled**.
- All **exposed metal** in the vicinity of such storage should be **painted and checked** for weakening by corrosion.
- Corrosive materials should be **isolated** from materials noted above (cyanides, etc.), reaction with which can produce highly toxic fumes.
- Strong acids and alkalis will cause serious burns and eye damage to personnel; adequate protection in the form of gloves, aprons, goggles, etc. should be worn when handling them into and out of storage areas.
- If hydrogen can be evolved, the building should be constructed so that possible hydrogen pockets are eliminated.

Leakage and Spillage Containment

Means of **controlling spillage** should be provided, including absorbent granules or other means of clearing up small spills, where appropriate. This may be an impervious sill or low bund, typically 150mm high, big enough to hold 110% of the contents of the largest container. An alternative is to drain the area to a safe place, such as a remote sump or a separator.

Bunding

A bund is an enclosure around a storage facility designed so that, in the event of any leak or spillage from tanks or pipework, it will capture well in excess of the volume of liquids held within the bund area. It is usually designed to hold at least 110% of the contents of the liquid storage vessels, tanks or drums that it surrounds without allowing them to escape. Bunds are usually made of concrete or masonry but can be metal.

Bunds may contain more than one tank and should be designed to hold at least 110% of the capacity of the largest tank within the bund, after making allowance for the space occupied by other tanks. In exceptional cases, where there is no risk of pollution or of hazard to the public, this figure may be reduced to 75%.

A bunded tank

Intermediate lower bunds may be used to divide tanks into groups to contain small spillages and to minimise the surface area of any spillages. This will reduce the maximum size of a bund fire.

Bunds should be substantially impervious to the liquid being stored and designed to withstand the full hydrostatic head. They may be partly below ground level to help provide adequate wall strength. Impact protection, such as crash barriers and bollards, should be provided where necessary.

The height of the bund should take account of the need to ensure adequate ventilation within the bund, ready access for fire-fighting and good means of escape. The height should not normally exceed 1.5m, although in some cases 2m can be used for large tanks. Diversion walls and intermediate lower bunds should not exceed 0.5m unless there are special circumstances, such as sloping ground.

The floor of the bund should:

- Be made of concrete or other material which is impervious to the liquid being stored.
- Have drainage, where necessary, to prevent minor spillages collecting near tanks.

Stone chippings and similar materials may be used providing the underlying ground is impervious. A suitable buried membrane can also be used, as can specially designed systems using the water table to retain liquids not miscible with water.

No vegetation (except short grass) or other combustible material, and no liquid containers or gas cylinders (full or empty) should be stored in the bund or within 1m of the outside of the bund wall. Weedkiller containing sodium chlorate or other oxidising substances should not be used at storage areas or tanker stands because of the increased fire hazard.

The surface of the storage area should be sloped so that any spillage does not accumulate around containers but can drain to an evaporation area (within the storage area or separate from it) or to a sump or interceptor.

Means of removing surface water from the bund should be provided. If an electrically-driven pump is used, the electrical equipment should be of a type suitable for the zone in which it is used.

If a bund drain is used, it should have a valve outside the bund wall, with a system of work in force to ensure the valve remains closed, and preferably locked, except when water is being removed. Surface water from bunds where flammable liquids not miscible with water are stored should be routed through an interceptor, to prevent flammable liquids entering the main drainage system. For liquids miscible with water, special drainage systems may be required.

Many small storage tanks achieve the bund by constructing one tank inside another. This arrangement provides catchment in the event of failure of the storage tank and eliminates the problem of the bund area filling with rain-water.

Filling and Transfer

One of the main dangers associated with the use and storage of flammable liquids is the release of vapours. This must be prevented wherever possible, or at the very least kept to an absolute minimum.

In storage, vapour escape can occur when a substance is decanted into a smaller receptacle for use, allowing vapour to escape. Decanting in a storage area should be avoided.

The preferred method of transfer is by an enclosed pipe network to the point of use. This reduces the possibility of vapour escape and accidental spillage.

A simple filling operation with petrol

CASE STUDY

Texas City (USA) 2005

The explosion and subsequent fire that occurred at BP's refinery in Texas City, Texas, USA, is an example of the consequences of loss of containment resulting in an uncontrolled release of highly flammable liquid.

On 23 March 2005, a series of explosions occurred during the restarting of a hydrocarbon isomerisation unit at BP's refinery in Texas City. A distillation tower flooded with highly flammable liquid hydrocarbons and was over-pressurised, causing a release of liquid from the top of the stack and a cloud of flammable vapour to form over the refinery. A diesel pick-up truck that was idling nearby ignited the vapour, initiating a series of explosions and fires that swept through the unit and the surrounding area.

The US Chemical Safety and Hazard Investigation Board investigating the incident found that approximately 7,600 gallons of flammable liquid hydrocarbons - nearly the equivalent of a full tanker truck of gasoline - were released from the top of the blow-down drum stack in just under two minutes. The ejected liquid rapidly vaporised due to evaporation, wind dispersion, and contact with the surface of nearby equipment. High over-pressures from the resulting vapour cloud explosion totally destroyed 13 trailers and damaged 27 others. People inside trailers were injured as far as 500 feet away from the blow-down drum, and trailers nearly 1,000 feet away sustained damage.

The distillation tower overfilled because a valve allowing liquid to drain from the bottom of the tower into storage tanks was left closed for over three hours during the start-up on the morning of 23 March, which was contrary to unit start-up procedures. The investigation found that procedural deviations, abnormally high liquid levels and pressures, and dramatic swings in tower liquid level were the norm in almost all previous start-ups of the unit since 2000. Operators typically started up the unit with a high liquid level inside and left the drain valve in manual - not automatic - mode to prevent possible loss of liquid flow and resulting damage to a furnace that was connected to the tower. These procedural deviations - together with the faulty condition of valves, gauges, and instruments on the tower - made the tower susceptible to overfilling.

CASE STUDY

Buncefield (UK) 2005

Another example of the serious consequences of loss of containment of flammable liquids is the Buncefield incident, a major fire caused by a series of explosions in the early hours of Sunday 11 December 2005 at the Buncefield Oil Storage Depot, Hemel Hempstead, Hertfordshire, UK. At least one of the initial explosions was of massive proportions and there was a large fire which engulfed a high proportion of the site. Over 40 people were injured but there were no fatalities. Significant damage occurred to both commercial and residential properties in the vicinity and a large area around the site was evacuated on emergency service advice. The fire burned for several days, destroying most of the site and emitting large clouds of black smoke into the atmosphere.

The cause of the incident was the overfilling of a storage tank, allowing fuel to cascade down the side of the tank leading to the rapid formation of a vapour cloud that subsequently ignited, leading to the explosions and fire. The sequence of events was as follows:

- 10 December 2005: Around 19.00, Tank 912 in bund A at the Hertfordshire Oil Storage Ltd (HOSL) West site started receiving unleaded motor fuel from the T/K South pipeline, pumping at about 550m^3/hour.

(Continued)

CASE STUDY

Buncefield (UK) 2005 (Continued)

- 11 December 2005: At approximately midnight, the terminal was closed to tankers and a stock check of products was carried out. When this was completed at around 01.30, no abnormalities were reported.
- From approximately 03.00, the level gauge for Tank 912 recorded an unchanged reading. However, filling of Tank 912 continued at a rate of around 550m^3/hour. Calculations show that at around 05.20, Tank 912 would have been completely full and starting to overflow. Evidence suggests that the protection system, which should have automatically closed valves to prevent any more filling, did not operate.
- From 05.20 onwards, continued pumping caused fuel to cascade down the side of the tank and through the air, leading to the rapid formation of a rich fuel/air mixture that collected in bund A.
- At 05.38, CCTV footage shows vapour from escaped fuel starting to flow out of the north-west corner of bund A towards the west. The vapour cloud was about 1m deep.
- At 05.46, the vapour cloud had thickened to about 2m deep and was flowing out of bund A in all directions.
- Between 05.50 and 06.00, the pumping rate down the T/K South pipeline to Tank 912 gradually rose to around 890m^3/hour.
- By 05.50, the vapour cloud had started flowing off-site near the junction of Cherry Tree Lane and Buncefield Lane, following the ground topography. It spread west into Northgate House and Fuji car parks and towards Catherine House.
- At 06.01 the first explosion occurred, followed by further explosions and a large fire that engulfed over 20 large storage tanks. The main explosion event was centred on the car parks between the HOSL West site and the Fuji and Northgate buildings. The exact ignition points are not certain, but are likely to have been a generator house in the Northgate car park and the pump house on the HOSL West site.
- At the time of ignition, the vapour cloud extended to the west almost as far as Boundary Way in the gaps between the 3-Com, Northgate and Fuji buildings; to the north-west it extended as far as the nearest corner of Catherine House. It may have extended to the north of the HOSL site as far as British Pipelines Agency (BPA) Tank 12 and may have extended south across part of the HOSL site, but not as far as the tanker filling gantry. To the east it reached the BPA site.

There is evidence suggesting that a high-level switch, which should have detected that the tank was full and shut off the supply, failed to operate. The switch failure should have triggered an alarm, but it too appears to have failed.

The UK Health Protection Agency and the UK Major Incident Investigation Board provided advice to prevent incidents such as these in the future. The primary need was for safety measures to be in place to prevent fuel from exiting the tanks in which it is stored. Added safety measures were needed for when fuel does escape, mainly to prevent it forming a flammable vapour and stop pollutants from poisoning the environment.

Handling of Dangerous Substances

Flow Through Pipelines

It is often necessary to move and deliver gases, liquids or solids (powders, etc.) to a particular point as part of a process. One common method of transporting these substances, including dangerous substances, and ensuring that they are isolated from workers, is to send them through enclosed pipelines to the point of delivery or use. Not only is it a convenient method of transporting substances, but the chance of escape and subsequent exposure is reduced when compared with other methods such as containers and drums with opening lids.

The oil industry is one typical example of a process that uses pipelines; the image of a lone pipeline crossing a desert and disappearing into the far horizon is common. At the other end of the spectrum, another example of pipeline use is a hosepipe. While the difference in scale between the two examples is vast, the purpose is the same – to deliver a substance to a desired point. A further example of the use of pipelines in industry is for the purpose of unloading road tankers. Typical substances that may be carried include: petrol, gases, and solids such as flour.


Pipeline transfer

There are a number of issues that need to be considered when using pipelines to transport substances. Depending on the length of the pipeline, the diameter of the pipe and the substance flowing through the pipe, pressure will have to be applied to ensure a satisfactory flow. While this pressure may not always be particularly high, it can cause problems if there is a weakness in the pipeline, particularly at joints and flanges. Any weakness can result in the failure of the integrity of the pipeline, resulting in a release of the substance and a reduction in flow. This may have hazardous results for the process, with a possible lack of feedstock or other important components. Similar problems can arise from a blockage in the pipeline causing over-pressure.

The effects of blockages can be easily demonstrated by standing on a hosepipe and observing the weak points of the system where water leaks out. If there are no weak points and water cannot escape, then the system will eventually fail due to the pressure build-up. Many pipelines have built-in pressure relief systems to deal with these potential problems.

Pressure also affects the flow-rate of the substance. The flow-rate, in turn, is an important factor in the generation of electrostatic charges or 'static electricity'. This is caused by the movement of molecules of dissimilar materials against each other. For example, petrol flowing through a plastic pipe will generate an electrostatic charge, as will a powder such as flour running down a steel chute.

The main danger associated with an electrostatic charge is the possibility of a spark occurring if the charge is not allowed to dissipate to earth. If the spark occurs in an explosive environment, the results can be catastrophic. For example, if all elements of the pipeline, including discharge nozzles, are not equipotentially bonded and earthed, then the charge is quite capable of 'jumping' a gap and producing a spark.

A number of accidents at filling stations have been caused by a static spark between the nozzle of the petrol pump hose and the filler on the car.

When dealing with any type of substance flow through pipelines, it is important to be aware of the possibility of a spark from an electrostatic charge, regardless of the amount of substance and the distance travelled. Bonding and earthing of all parts of a pipeline system is vital to ensure that any charge safely escapes to earth.

Principles in Filling and Emptying Containers

Filling Containers

There are a number of issues to consider when filling containers. Perhaps the most obvious is to ensure that the container that is being used is **suitable** for the substance that is being put into it. Whether it is a small, 'emergency' petrol container or a large acid tank or drum, it is important to ensure that it is designed to accept the substance. It must also be **undamaged**, with no signs of leakage, staining or corrosion.

Once satisfied that the container is suitable, the next step is to determine whether it is **empty and clean**. If it is not, then the previous content must be established. Mixing incompatible substances can lead to uncontrolled chemical reactions. When dealing with volatile substances, it may be necessary to have the container de-gassed and certificated 'clean' prior to filling.

The method of filling has safety implications. The most common methods are:

- **'Top' filling,** which, as the term suggests, is achieved by the use of a hose or tap through an opening in the top of the container (similar to old steam engines being watered). This method of filling is often used when decanting into small containers and drums.
- **'Bottom' filling**, where the substance is delivered into the container under pressure through a closed pipeline. This is a common method of filling road tankers.

Dispensing solvent into a storage drum

Both systems have a degree of risk associated with them:

- Top filling can create 'splash', which can contaminate the surrounding area as well as generating a large electrostatic charge. It will also allow the escape of vapours.
- Bottom filling through a closed system alleviates the problem of vapour escape, but the pressure under which the substance is delivered can cause problems, unless the container is designed to be pressurised and any pressure venting and release devices are functioning properly.

Regardless of the method of filling, care has to be taken to avoid **overfilling**. The consequences of overfilling are potentially enormous and include uncontrolled contamination of the environment and release of vapours. Care should be taken to ensure that the receiving container is large enough to receive the amount of substance that is going to be delivered and that the process is supervised during the delivery process. Bunding and spill control kits should be available in case of a spillage.

The **proper marking** of suitable containers is also important, as unmarked or incorrectly marked containers can lead to tragic accidents, as the following case study illustrates.

CASE STUDY

A young man purchased petrol from a self-service petrol station to use for his motorcycle. The can that he used to obtain and store the petrol had previously contained cooking oil and, when he had used part of the petrol to fill up his motorcycle, the can was left in a cupboard in the kitchen.

Some weeks later, the man's grandmother saw the can in the cupboard and, assuming that it contained cooking oil, attempted to use it to fry food. A fire resulted, in which she was killed and the house destroyed.

If the console operator at the filling station had allowed the grandson to only use an authorised and clearly-labelled petrol container, the accident could have been avoided.

Emptying Containers

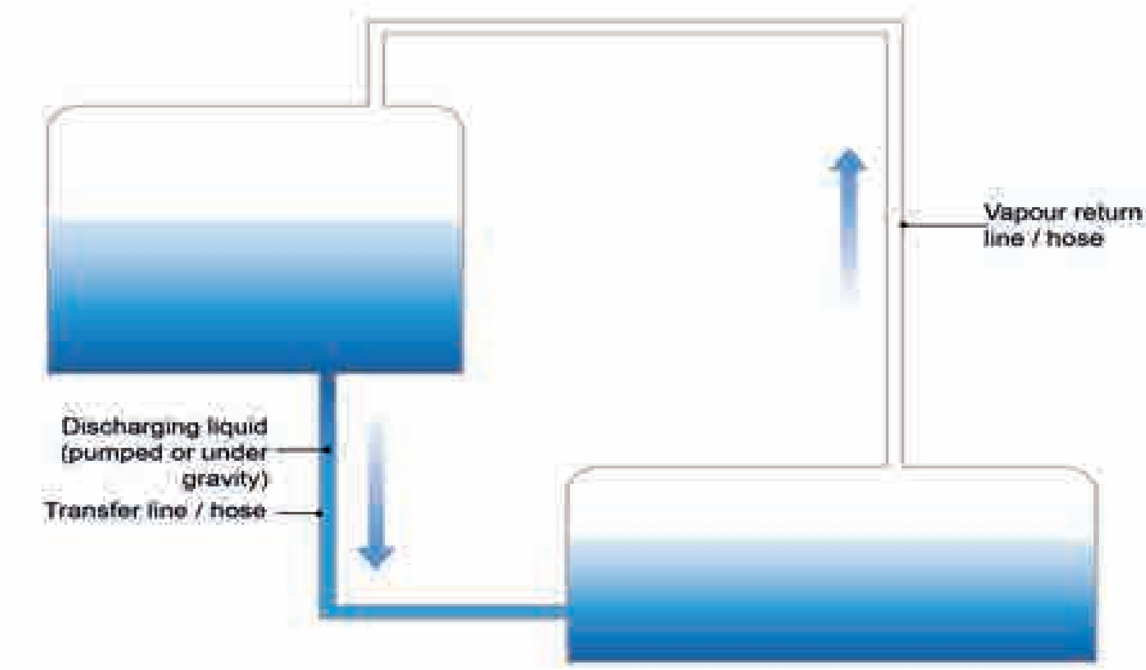
Factors such as spillage, escape of vapour and generation of electrostatic charges are just as relevant when emptying containers. The flow of substance from even a very small container can generate enough electrostatic charge to develop a spark large enough to cause an explosion under the right conditions. Other factors to consider are:

- Nominally Empty Containers

  These are containers that have been emptied of the substance but may still contain vapour. Containers in this condition are potentially very dangerous, and should be closely stoppered until cleaned or disposed of safely. The practice of leaving nominally empty petrol containers open to 'breathe' should be discouraged as the vapour, being heavier than air, will remain in the container and mix with air, making an explosive mixture.

- Implosion of Container

  This can happen as a result of, for example, a liquid being discharged out of the bottom of an otherwise sealed container/tank. If the need to replace the discharging substance with air/vapour (or another medium in certain circumstances) is not taken into account, then a partial vacuum can develop and cause the sides of the container to implode. One way of avoiding this is, of course, to vent the top of the container (e.g. by opening a hatch on the top of a bottom-discharge tanker). Sometimes, though, it is desirable or necessary to use completely closed systems to stop the vapour from escaping. This may be desirable for a variety of reasons, not least of which is environmental protection. In such cases, instead of venting to the atmosphere, a vapour return line is connected between the discharging vessel and the receiving vessel (see following figure). In this way, the liquid being discharged is replaced with the vapour displaced from the top of the receiving vessel. This is the case with road tankers transferring petrol. The vapour return line may be separate from the liquid transfer line or be incorporated within the transfer line.



Transfer of liquid using vapour return valve

- Steam Cleaning

  Implosion can also happen after cleaning if steam has been used. If the container does not allow air in as the steam cools, the reduction of volume of air causes a depression and the possibility of implosion. Hatches on tanks that have been steam-cleaned should be left open until the temperature inside the tank has dropped to a point where implosion will not occur.

Reduction of Risks

In order to reduce the risks associated with the filling and emptying of containers, certain measures, in addition to those already mentioned, should be taken:

- A risk assessment should be carried out.
- All ignition sources should be controlled.
- All personnel involved with the process should be properly trained and supervised.
- Empty and full containers should be segregated.
- All containers should be examined for damage.
- Suitable signs and notices should be displayed.
- Suitable fire-fighting equipment should be available.

Principles in Dispensing, Spraying and Disposal of Flammable Liquids

Dispensing or decanting should generally be avoided. Large volumes are best transferred in closed systems, such as pipelines. Small volumes may be dispensed, but this activity must not be carried out in areas designed for storage of dangerous substances. Such an activity may create a risk of fire involving the stored materials.

Precautions should be taken against:

- Accidental spillage during dispensing, e.g. by using spill trays or other bunding-type arrangements to limit liquid spread.
- Excessive flammable vapour release, by only using tight-head vessels (i.e. narrow orifice containers) that, preferably, are fitted with flame arresters and design features to minimise the build-up of electrostatic charge.

Dispensing should be carried out in a well-ventilated area in order to quickly dilute any escaping vapour concentrations to below the lower explosive limit (LEL). It should also take place away from any ignition source, to prevent fires or explosion. This could include:

- Control of static by using, for example, earthed metal containers and bonding clips prior to decanting.
- Prohibition of smoking.
- Use of non-sparking tools.

Empty, uncleaned containers should be treated as if they are full, as they will contain flammable residues.

Spraying of flammable liquids, such as paints, may easily create a flammable atmosphere – especially when conducted in a confined area with poor ventilation. The vapour concentration may rapidly enter the explosive range. It is therefore essential to control both the vapours and ignition sources during such operations, otherwise the vapour may be ignited, causing a fire or explosion.

Spray-painting furniture parts with a flammable varnish at an assembly line

Usually, spraying operations are conducted in well-ventilated spray booths. The ventilation should be sufficient to dilute the flammable vapours to well below the LEL. The spray booth should be isolated from all ignition sources.

Spray booths are typically classified as zone 1 areas – where an explosive gas/air mixture is likely to be present during normal operation. Any electrical equipment in the booth should therefore take this into account. Liquid movement during spraying, and during filling, emptying, etc. can cause static build-up. Ignition by static discharge is a particular problem, and precautions should be taken against the build-up of static – use of anti-static footwear, clothing and flooring, and the earthing of all equipment.

Waste should be stored appropriately prior to **disposal** – in suitable closed containers that are compatible with the contents. Wastes having different compositions should not be mixed together without regard to possible dangerous reactions. Due account should be taken of the applicable environmental legislation controlling the disposal of waste.

TOPIC FOCUS

The measures that should be taken to control the fire and explosion risks associated with **spray-painting a solvent-based paint with a low flash point** include:

- Fire-resistant workplace construction.
- Use a less flammable, solvent-based substitute paint.
- Reduce the quantity of paints and solvents to a minimum.
- Provide an external, fire-resistant storeroom for paints and solvents with adequate ventilation, located an adequate distance from the workplace.
- Provide local exhaust ventilation.
- Provide dilution ventilation at high and low levels.
- Use intrinsically safe electrical equipment.
- Earth to avoid electrostatic ignition.
- Use conductive footwear and clothing to avoid static build-up.
- Identify the appropriate zone for the work area.
- Use non-spill containers.
- Provide fire-fighting equipment, escape routes and an emergency plan.

Dangers of Electricity in Hazardous Areas

Electricity, and its associated uses, are acknowledged sources of ignition in the workplace and, as such, need to be closely controlled. This becomes even more compelling when electricity is used in areas in which the environment is, or has the capability to be, flammable or explosive. This atmosphere may be caused by vapours from flammable substances, flammable gas or even the presence of dust. Under these circumstances, all of the elements of the fire triangle are present, and fire or explosion would seem to be highly probable. Hazardous area classification enables identification of the specification of suitable electrical equipment that may be used in those zones.

Transport of Dangerous Substances

Carrying goods by road or rail involves the risk of traffic accidents. If the goods carried are dangerous, there is also the risk of an incident, such as spillage of the goods, leading to hazards such as fire, explosion, chemical burn or environmental damage. Most goods are not considered sufficiently dangerous to require special precautions during carriage. Some goods, however, have properties which mean they are potentially dangerous if carried.

Dangerous goods are liquid or solid substances and articles containing them that have been tested and assessed against internationally-agreed criteria (a process called classification) and found to be potentially dangerous (hazardous) when carried. Dangerous goods are assigned the following different classes depending on their predominant hazard:

1. Explosive substances and articles.
2. Gases.
3. Flammable liquids.

4.1 Flammable solids, self-reactive substances and solid desensitised explosives.
4.2 Substances liable to spontaneous combustion.
4.3 Substances which, in contact with water, emit flammable gases.
5.1 Oxidising substances.
5.2 Organic peroxides.

6.1 Toxic substances.

6.2 Infectious substances.

7. Radioactive material.

8. Corrosive substances.

9. Miscellaneous dangerous substances and articles.

UN Recommendations on the Transport of Dangerous Goods – Model Regulations

The *UN Recommendations on the Transport of Dangerous Goods – Model Regulations*, 19th ed., 2015, also known as 'the Orange Book', provide the basis for the development of all international regulations concerning the international transport of dangerous goods, as well as most national legislation. This publication covers all modes of transport – road, sea and air – and the following key areas:

- Classification of dangerous goods.
- Listing.
- Use, construction, testing and approval of:
  - Packaging.
  - Portable tanks.
- Consignment procedures, such as:
  - Marking.
  - Labelling.
  - Placarding.
  - Transport documentation.
  - Emergency response.

The *UN Model Regulations* cover all aspects of transportation necessary to provide international uniformity and a comprehensive, criteria-based classification system for substances that pose a significant hazard in transportation. Material properties addressed include:

- Explosiveness.
- Flammability.
- Toxicity (oral, dermal and inhalation).
- Corrosivity to human tissue and metal.
- Reactivity (e.g. oxidising materials, self-reactive materials).
- Pyrophoric substances (substances that react with water).
- Radioactivity.
- Infectious substance hazards.
- Environmental hazards.

They prescribe:

- Standards for packaging and multimodal tanks used to transport hazardous materials or dangerous goods.
- A system of communicating the hazards of substances in transport through hazard communication requirements which cover:
  - Labelling and marking of packages.
  - Placarding of tanks, freight containers and vehicles.
  - Documentation and emergency response information that is required to accompany each shipment.

The European Agreement

The European Agreement concerning the International Carriage of Dangerous Goods by Road is referred to by the abbreviation ADR, and the agreement concerning rail by RID.

Specific requirements of ADR and RID address issues such as:

- Training requirements.
- Compliance with safety obligations.
- Special requirements relating to the carriage of Class 7 (radioactive) goods.
- Appointment of Dangerous Goods Safety Advisers.
- Reporting accidents or incidents.
- Security provisions.
- Requirements relating to the construction and testing of packaging, receptacles and containers.
- Carriage, loading, unloading and handling.
- Vehicle crew training, equipment, operation and documentation.
- Construction and approval of vehicles.

Additional requirements to ADR and RID include:

- Attendant for, duration of and security for carriage of Class 1 (explosive) goods by road.
- Keeping of consignment information.
- Use of placards, marks and plate markings for carriage, as required nationally.

Key Safety Principles in Loading and Unloading of Tankers and Tank Containers

Road tankers carrying petroleum spirit or other substances are sometimes referred to as 'fixed tanks' or road tank vehicles; the tank is permanently fixed to the vehicle chassis. Tank containers (sometimes called 'ISO tanks' or 'portable tanks') are held in boxed-steel framework. The framework is locked to the vehicle chassis but can be unloaded from the vehicle – this is particularly suited to transfer of tanks between, for example, road vehicle and train, or road vehicle and ship.

A petrol tanker

ADR "Instructions in Writing"

Drivers of tankers must be fully informed of dangers of the materials carried and the emergency action that needs to be taken.

The ADR Instructions in Writing have replaced the previous Tremcard system and are now only required in the language of the driver for the journey.

These instructions must be provided by the carrier to the vehicle crew in language(s) that each member can read and understand before the commencement of the journey. The carrier should ensure that each member of the vehicle crew concerned understands and is capable of carrying out the instructions properly.

Before the start of the journey, the members of the vehicle crew must inform themselves of the dangerous goods loaded and consult the Instructions in Writing for details on actions to be taken in the event of an accident or emergency.

The Instructions in Writing must be kept in the vehicle cab so that they can be easily located by the emergency services in the event of an accident. The driver and the recipient of materials should have written procedures that set out the precautions that need to be taken during loading and unloading. Fire extinguishers should be carried on all vehicles. If substances are flammable or explosive, earth connections should be used during loading and unloading to prevent the possibility of a static spark, and no other sources of ignition, such as smoking materials, should be allowed in the vicinity.

Where bulk storage tanks are used for different substances, there is always the possibility of cross-contamination – a substance being unloaded from a tanker into the wrong bulk tank at a factory. This can be prevented by strict operating procedures and the use of couplings of a different design for each substance. It is also important to ensure that tanks to be filled have enough space to prevent spillage through overfilling.

Labelling of Vehicles and Packaging of Substances

Placarding is the display of hazard warning information, which may contain graphics communicating the hazardous nature of the load for the benefit of the emergency services attending an accident involving the vehicle

Marking is the display of orange reflectorised rectangular plates that may provide information on:

- Emergency action (the emergency action code).
- The material being transported (UN number).
- Address and telephone number of the consignor.

An example used for UK national transport, the "HazChem" panel, is shown below:

> **MORE...** www.
>
> For marking of packages, see *UN Model Regulations* Rev.19, Vol.II, 2015, available under Legal Instruments and Recommendations at:
>
> http://www.unece.org/trans/danger/danger.html

HazChem panel

- The emergency action code (or "HazChem" code) gives advice to the fire authority on action to take.
- The United Nations (UN) number is specific to the substance (or type of substance) being carried.
- The box in the lower right-hand corner identifies the company consigning the load.
- The telephone number is used for contact purposes in an emergency.

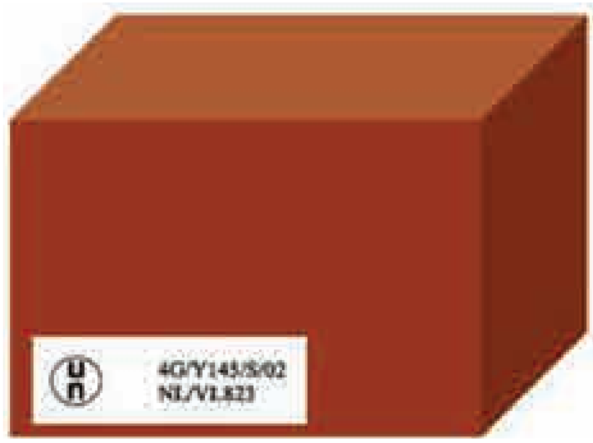
When dangerous goods are transported in packages (rather than in tankers), the package needs to be labelled and marked indicating the hazardous nature of the contents:

- The hazard warning symbol.
- The UN number.

Example of a UN type-approved design

The packaging itself should be of a UN type-approved design:

- Tested and certified and marked as such. Tests include:
  - Stacking.
  - Impact.
  - Internal pressurisation.
- Every package, having passed the UN approval procedure, may carry the "UN" approved symbol (a "u" over an "n" within a circle); this symbol is followed by a code which indicates the standard type of packaging, its performance and approving body.



Example of a UN approval symbol

Driver Training

In Europe, ADR requires all drivers of tankers and tank containers carrying dangerous goods to attend a vocational course of instruction and sit an externally assessed examination – for the classes of goods carried – to obtain a certificate of competency, which is required to be updated at specific intervals.

Drivers of vehicles carrying packaged dangerous goods above certain limits must similarly be vocationally trained and certified.

ADR also requires the appointment of qualified safety advisers, termed **Dangerous Goods Safety Advisers**, who hold a vocational training certificate which covers:

- The types of transport used (road, rail, waterways).
- The types of dangerous goods transported by the employer.

The main duties of the safety adviser are to:

- Monitor legal compliance requirements on the transport of dangerous goods.
- Ensure that an annual report is prepared on the activities of the employer which concern the transport of dangerous goods.
- Provide advice to the employer on the transport of dangerous goods.
- Monitor the employer's arrangements for:
  - Identification of dangerous goods.
  - Requirements for transport vehicle purchase.
  - Checking transport equipment.
  - Training employees.

- Implementing emergency procedures.
- Investigation and preparation of reports on serious accidents.
- Implementation of remedial action following an accident.
- Ensuring compliance with health and safety regulations.

The safety adviser must also ensure that a report is prepared on any accident affecting health and safety that occurs during the transport of dangerous goods.

STUDY QUESTIONS

3. What features should be considered when assessing the suitability of a store for flammable solids?
4. Describe the main means of spillage containment.
5. What are the characteristics of a corrosive substance?
6. What measures should be taken to avoid overfilling with hazardous liquid?
7. In accordance with Hazardous Area Classification (HAC) which zone would spray-paint booths fall under?
8. When selecting a container for filling, what important factors should be checked?
9. Why should dispensing of flammable liquids be done in a well-ventilated area?
10. How can unloading of a substance from a tanker into the wrong storage tank be prevented?

(Suggested Answers are at the end.)

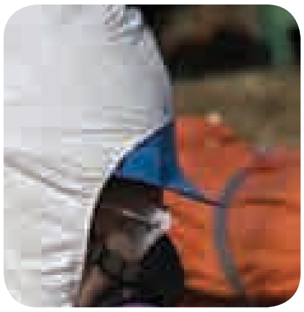
Hazardous Environments

IN THIS SECTION...

- Where electrical equipment may be exposed to hazardous environments, it should be constructed and protected to prevent danger arising from the exposure. This should include:
  - Resistance to mechanical damage.
  - Protection against solid bodies, objects and dusts.
  - Protection against liquids and gases.
- A wet and/or corrosive environment can result in degradation of the electrical installation and damage to the electrical systems in certain workplaces.
- Where flammable atmospheres are present (or likely to occur), particular precautions are necessary to prevent electrically-caused ignition of the atmosphere. Hazardous Area Classification (HAC) identifies those areas in a plant where flammable atmospheres can be found and additionally provides an estimate of how often they may be found there. It is applied to areas where solvent vapours, gases or mists may be found and also where flammable dust clouds can occur.
- HAC zones where flammable atmospheres could occur are defined on the basis of the frequency of the presence of a flammable atmosphere:
  - Zone 0, 1 and 2 for gases, vapours and mists.
  - Zone 20, 21 and 22 for dusts.
- Work involving electrical systems in hazardous environments such as those which are flammable, corrosive, explosive, or involving zones 0, 1 and 2, should be carried out in accordance with a permit-to-work system.
- Pressurised equipment excludes flammable gas from the equipment by achieving a higher pressure inside the equipment than is present in its surroundings. Purging is a method whereby a flow of air or inert gas is maintained in a room or enclosure to reduce or prevent a flammable atmosphere occurring.
- The design of **intrinsically safe equipment** ensures that the energy level is insufficient to produce an incendiary spark.
- **Flameproof equipment** is totally enclosed and the casing must be robust enough to withstand internal explosions without igniting the flammable atmosphere in which the equipment is located.
- **Type 'e' equipment** does not arc, spark or generate temperatures high enough to ignite a flammable atmosphere.
- **Type 'N' equipment** meets less stringent requirements compared with type 'e' equipment and is intended for use in zone 2 applications.

Introduction

Where electrical equipment may be exposed to adverse or hazardous environments, the equipment should be constructed and protected to prevent danger arising from the exposure. The protection required will vary depending on the type of hazard and the degree of risk. It is essential to select the correct type of equipment for the hazardous environment that it might be used in.



Hazardous environment

Principles of Protection

Resistance to Mechanical Damage and Solid Bodies

This includes abrasion, impact, stress, wear and tear, vibration, hydraulic and pneumatic pressure. Mechanical protection may be necessary and may take the form of conduits or armouring to ensure the integrity of basic insulation on conductors.

Protection against Dusts, Liquids and Gases

This includes: liquid immersion, splashing, spraying and condensation and also contamination by liquids and solids. Equipment which is liable to damage by corrosion due to the presence of moisture should be totally enclosed in corrosion-resistant housing which is not vented to the atmosphere. Equipment used in dusty environments should be capable of resisting the entry of dust and dirt where it is likely to cause mechanical or electrical damage. Where accumulations of dirt, etc. are likely, regular inspection and cleaning of the equipment will be necessary. Portable motor-driven equipment with ventilation slots can give rise to the accumulation of dirt and dust.

Protection against Natural Hazards

Adverse weather conditions, including temperature, rain, snow, ice and wind, can create a hazardous environment. Additional protection may include lightning protection and installing weatherproof equipment. It should be ensured that all equipment exposed to external conditions is sufficiently robust to cope with the hazards likely to be encountered.

Natural hazards also include solar radiation, animals and plants. Sufficient protection may be achieved by simply increasing the strength of equipment, such as insulation that can withstand the gnawing of rodents.

Snow can create a hazardous environment

Wet Environments

In certain workplaces, e.g. those carrying out electroplating activities, there may be significant use of conductive and corrosive fluids which can generate humid and corrosive atmospheres. In this type of environment, there will be the risk of corrosion and subsequent damage of any uninsulated or unprotected parts of the electrical system, and also the possibility of ingress of fluids or water vapour into electrical components.

In such an environment, it is essential that all electrical equipment is designed and constructed to withstand this type of hazardous environment.

Selection of Electrical Equipment for Use in Flammable Atmospheres

In situations where flammable atmospheres are present or likely to occur occasionally, particular precautions are necessary to prevent electrically-caused ignition of the atmosphere. Hot surfaces, arcs and sparks associated with electrical equipment can ignite such atmospheres, causing fires and explosions. Careful assessment of locations in which flammable atmospheres are likely to be present is necessary in order that suitable precautions may be taken.

Flammable atmospheres are created by the presence of flammable gases, vapours and dusts. For an atmosphere to be capable of ignition, the concentration of the flammable substance in air must be at a certain level. The ignitable concentration lies between the upper and lower explosive limits (UEL and LEL) of the substance. Mixtures outside this range, i.e. rich and lean mixtures, will not ignite.

Classification of Hazardous Areas and Zoning

Hazardous Area Classification (HAC)

Hazardous Area Classification (HAC) identifies those areas in a plant where flammable atmospheres can be found and additionally provides an estimate of how often they may be found there. It is applied to areas where solvent vapours, gases or mists may be found and also those where flammable dust clouds can occur.

HAC and methods of performing HAC have been around in various national standards for a long time already and, in all European Union countries, HAC is mandatory as the **ATEX Directives** (Atmosphères Explosibles) are incorporated into the national laws of all member states. HAC zones where flammable atmospheres could occur are defined on the basis of the frequency of the presence of a flammable atmosphere:

- Zone 0, 1 and 2 for gases, vapours and mists.
- Zone 20, 21 and 22 for dusts.

Although the zone designations are different for gases and dusts, the actual definitions are essentially identical, as shown in the next section.

Hazardous Area Zoning

Section 7.4.2 of the **ILO Code of Practice - Safety in the Use of Chemicals at Work** requires that areas where flammable atmospheres may occur should be classified according to the degree of probability of a flammable concentration occurring in the area. An example of such zoning from UK regulations follows. You should recognise this list from earlier.

Flammable Vapours

- Zone 0

  A place in which an explosive atmosphere consisting of a mixture with air of dangerous substances in the form of gas, vapour or mist is present continuously or for long periods or frequently.

- Zone 1

  A place in which an explosive atmosphere consisting of a mixture with air of dangerous substances in the form of gas, vapour or mist is likely to occur in normal operation occasionally.

- Zone 2

  A place in which an explosive atmosphere consisting of a mixture with air of dangerous substances in the form of gas, vapour or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

Combustible Dusts

- Zone 20

  A place in which an explosive atmosphere in the form of a cloud of combustible dust in air is present continuously or for long periods or frequently.

- Zone 21

  A place in which an explosive atmosphere in the form of a cloud of combustible dust in air is likely to occur in normal operation occasionally.

- Zone 22

  A place in which an explosive atmosphere in the form of a cloud of combustible dust in air is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

Determining which zone is suitable for different circumstances, and where the boundaries between zones should be drawn, is a complex process which should involve expertise from a number of fields such as safety, production and chemical engineering.

Once the zone boundaries are established, equipment can be selected so that it is suitable for the intended area.

Use of Permits-to-Work

Whenever maintenance or other temporary work of a potentially hazardous nature is to be carried out, some sort of permit-to-work system is essential. Work on electrical equipment or electrical systems comes into this category.

Permits should:

- Define the work to be done.
- Say how to make the work area safe.
- Identify any remaining hazards and the precautions to be taken.
- Describe checks to be carried out before normal work can be resumed.
- Name the person responsible for controlling the job.

Through this process the potential effects of the hazardous environment on the electrical equipment or system in question will be identified and the necessary precautions required will be incorporated into the permit system.

Electrical isolation as part of the permit-to-work system

Principles of Pressurisation and Purging

Pressurised equipment excludes flammable gas from the equipment by achieving a higher pressure inside the equipment than is present in its surroundings. Pressurisation can be achieved by drawing clean air from a safe area or an inert gas into the equipment under positive pressure. The air leaks out from small gaps in the casing of the equipment, preventing the ingress of gas/vapour from the flammable atmosphere. The pressurising equipment must be monitored and interlocked to the supply in order to disconnect it if the air supply fails or the pressure drops.

Purging, as opposed to pressurising, is a method whereby a flow of air or inert gas is maintained in a room or enclosure to reduce or prevent a flammable atmosphere occurring.

Types of Equipment

Intrinsically Safe Equipment

This design ensures that the energy level is insufficient to produce an incendiary spark. Two categories of intrinsically safe equipment exist:

- 'ia' which is more stringent as it allows for two simultaneous faults; and
- 'ib' which allows for only one.

Only 'ia' equipment can be used (exceptionally) in zone 0 if sparking contacts are not part of the equipment. Examples of type 'i' are instrumentation and low energy equipment.

Flameproof Equipment

This equipment is totally enclosed and the casing must be robust enough to withstand internal explosions without igniting the flammable atmosphere in which the equipment is located. Examples of type 'd' equipment are motors, lighting, switchgear and portable handlamps. Due to its robust structure, it is heavy and expensive. It is suitable for use in zones 1 or 2 but is unsuitable for zone 0.

TOPIC FOCUS

Intrinsically safe equipment and flameproof equipment afford protection by different means.

Intrinsically safe equipment:

- Has restricted electrical energy.
- Energy levels are insufficient to produce an incendiary spark.
- Can be used in zone 0 areas.
- Faults may raise energy levels.

Flameproof equipment:

- Allows an explosive mixture to enter the enclosure but the enclosure will withstand the pressure and heat of explosion and the ignition of the surrounding flammable atmosphere is prevented.
- Is not suitable for some combustible powders and dusts.
- Can be used in zones 1 and 2.
- Requires regular maintenance to ensure continuing integrity.

Type 'e' Equipment

This equipment does not arc, spark or generate temperatures high enough to ignite a flammable atmosphere. Examples of type 'e' equipment are induction motors and transformers. Type 'e' equipment may be used in zone 2 areas.

Type 'N' Equipment (Non-Sparking)

Less stringent requirements have to be met by this category as compared with type 'e' equipment above. It is intended for use in zone 2 applications. Examples of type 'n' or 'N' equipment are some solid-state relays.

STUDY QUESTIONS

11. How should electrical equipment, which is liable to be damaged by corrosion from moisture, be constructed?
12. Describe flameproof equipment and identify the zones for which it is suitable.
13. Describe what is meant by 'purging'.
14. Describe a hazardous area classified as 'zone 2'.

(Suggested Answers are at the end.)

Emergency Planning

IN THIS SECTION...

- Organisations need procedures in place to cope with emergencies. Typical emergencies might include:
  - Localised chemical spillage or gas/vapour release.
  - Fire evacuation.
  - First-aid treatment.
  - Bomb threat.
  - Major incident (such as a large chemical vapour release).
- In the event of an emergency, access to first-aid personnel and facilities, means for fighting a fire to ensure that it is extinguished before any serious damage is done, and spill containment to prevent or reduce damage or injury, can mean the difference between life and death.
- An emergency plan is a formal, written document designed to assist management with the control of specific hazards or incidents, to minimise disruption to normal work activities and reduce the impact on the organisation, including post-incident recovery.
- The **ILO Convention on the Prevention of Major Industrial Accidents (C174)** applies to major hazard installations that handle significant quantities of hazardous substances.
- Employers at major hazard installations should produce a documented system of Major Hazard Control, which includes emergency measures and procedures including:
  - The on-site emergency plan, which is principally concerned with the control of an emergency using on-site resources and is produced by the employer.
  - The off-site emergency plan, which is for the protection of the public and the environment and is the responsibility of the authorities.
- Emergency plans should be kept up-to-date to take account of changes on a planned regular basis, as well as when significant changes occur.

Need for Emergency Preparedness Within an Organisation

Emergencies can take many forms and can occur on different scales. Organisations need procedures in place to cope with emergencies. Typical emergency procedures that a company might need to consider include:

- Localised chemical spillage or gas/vapour release.
- Fire evacuation.
- First-aid treatment.
- Bomb threat.
- Major incident (such as a large chemical vapour release).


First-aid treatment

Emergency situations can occur at any time. How an organisation deals with that emergency, however, can dictate whether the emergency turns into a disaster or not. Historically, there have been a number of disasters that could easily have been prevented or where the consequence could have been much less if appropriate safeguards or emergency planning had been in place.

For these reasons it is imperative that all organisations prepare themselves for emergency situations. Action should be considered in terms of:

- Prevention of loss.
- Early warning of loss.
- Minimising the consequences of loss.

Consequence Minimisation via Emergency Procedures

First-Aid/Medical

In the event of an emergency, access to good first-aid personnel and facilities can mean the difference between life and death. While most organisations will have a number of qualified first-aiders, it is desirable for as many employees as possible to have some first-aid training in, for example, artificial respiration, control of bleeding and any other relevant action for hazards in their own particular workplace.

It is important that qualified first-aiders are identified on a notice which is displayed in a prominent place in the workplace. Contact numbers and times should also be displayed and these should be kept up-to-date.

First-aid equipment suitable to the workplace should be available in an easily accessible location. Usually first-aid boxes are adequate and these should be strategically situated around the workplace. Other first-aid items such as eye-washes may be necessary where there is a particular hazard from dust or airborne debris.

It is vital that all first-aid equipment is checked regularly and replenished as necessary. A contents list is useful for ensuring that first-aid boxes are fully stocked.

Fire Fighting and Evacuation

The emergency procedures should:

- Describe how to:
  - Raise the alarm and call the fire service.
  - Tackle a fire or control spills and leaks.
  - Evacuate the site.
- Include arrangements for evacuation of areas in the event of fire or toxic gas emission and specify designated safe areas, assembly points and toxic gas shelters.
- Identify responsible personnel whose duties during area evacuation include:
  - Responsibility for a specific area.
  - Collecting ID badges from plant racks.
  - Ensuring roll calls are undertaken to identify missing persons.
  - Communication of missing persons to central emergency services.

MORE... www.

International Requirements and Standards

The following documents are relevant to this area of the syllabus:

- **ILO Occupational Safety and Health Recommendation R164** (Article 3: First-Aid and Emergency Plans).
- **ILO Convention C161 Occupational Health Services** (for first-aid/medical services).
- **ILO Convention C174 Prevention of Major Industrial Accidents** (1993).
- **ILO Code of Practice on the Prevention of Major Industrial Accidents** (1991) (especially Chapters 1-6).

ILO Conventions, Recommendations and Codes of Practice are available at:

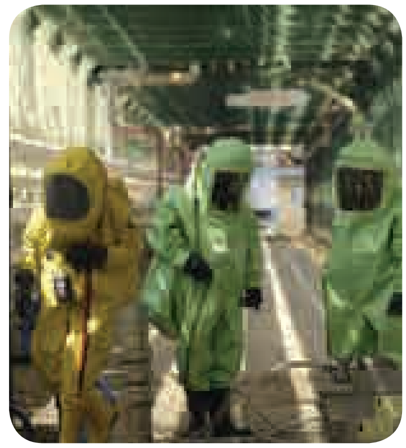
http://www.ilo.org/global/standards/lang--en/index.htm

Spill Containment

There are a number of ways in which a spill can be contained so as to prevent or reduce damage or injury. Most of these relate to the design of the vessel or pipe or surrounding area.

Pressure relief and emergency venting provides protection against over-pressurisation of plant, and may be the last line of defence against failure and uncontrolled loss of containment. Adequate isolation valves should also be provided so that, in the event of a sudden loss, the effects can be mitigated. Where personnel would be exposed to danger when operating the valves manually, the shut-off valves should be remotely operated wherever reasonably practicable.

Suitable bunding around storage vessels will capture some loss safely and act as an indication that the system requires review so as to prevent further loss.


Response to an emergency spill

In addition to the above, good housekeeping in terms of regular checks of the vessels, pipework and any safety features and preventive maintenance should ensure that unplanned spills are prevented.

Development of Emergency Plans

An emergency plan is a formal, written document designed to assist management with the control of specific hazards or incidents, so that minimum disruption to normal work activities will occur and the good name of the company will not be damaged.

When the range of major disruptive circumstances which could arise have been identified, individual emergency plans will then cover the following main points with regard to each of the identified hazards:

- Event.
- Location.
- Potential for harm.
- Existing instructions for dealing with the problem.
- Immediate actions to be taken.
- Control of the event.
- Assessment of the event.
- Response.
- Damage limitation action.
- Recovery plan.

TOPIC FOCUS

The issues that need to be considered in the **development of an emergency plan to minimise the consequences of a major incident in a chemical plant using toxic and flammable substances** include:

- Causes and extent of damage from a major incident.
- Quantities of materials stored.
- Call-out arrangements.
- Resources to deal with the incident, including first-aid and rescue equipment.

(Continued)

TOPIC FOCUS

- Raising the alarm.
- On- and off-site evacuation and shelter arrangements.
- Staff training.
- Notification of, and co-ordination/consultation with, emergency services.
- Search and rescue arrangements.
- Communication issues.
- Business continuity arrangements.
- Control of spillages and pollution and clean-up and decontamination.
- Establishing control centres and making available information, plans and inventories.

Role of External Emergency Services and Competent Authorities in Emergency Planning and Control

In order that such a plan operates smoothly and efficiently, it is important that responsibilities are set down and understood. This will include non-company personnel, as external services such as the following may be involved in both the development and implementation of the plan:

- Police.
- Fire.
- Ambulance.
- Welfare.
- Regulating authorities.
- Local companies.
- Technical expertise.
- Electricity company.
- Gas company.
- Water company.
- Local transport.

Someone within the company should be trained in the responsibility for dealing with the media, as this can have a profound effect on the company's image.

Preparation of Major Accident Hazard Emergency Plans to Meet Regulatory Requirements

The **ILO Convention on the Prevention of Major Industrial Accidents** (C174) is intended to apply to major hazard installations. A major hazard installation (MHI) is defined as an installation that "produces, processes, handles, uses, disposes of or stores, either permanently or temporarily, one or more hazardous substances or categories of substances in quantities which exceed the threshold quantity".

A "threshold quantity" is simply an amount (specific to the substance type) which would trigger inclusion within the major hazard installation regulatory regime. These thresholds are set by national governments, as appropriate; there is no globally agreed figure, but it would typically be a number of tonnes, depending on the hazardous nature of the substances.

The **basic responsibilities of employers at major hazard installations** are to:

- Identify the MHI and notify the "competent authority" (i.e. the relevant government department).
- Produce a documented system of Major Hazard Control, covering:
  - Identification/analysis of hazards and assessment of risks.
  - Technical and organisational measures:
    - **Technical measures**: design, safety systems, construction, choice of chemicals, operation, maintenance and systematic inspection of the installation.
    - **Organisational measures**: training and instruction of personnel, the provision of equipment in order to ensure their safety, staffing levels, hours of work, definition of responsibilities, and controls on outside contractors and temporary workers on the site of the installation.
  - Emergency measures and procedures:
    - This consists of producing an on-site emergency plan (which is periodically tested and evaluated) and providing information to the authorities (so they can produce off-site emergency plans). Employers must consult with relevant authorities and bodies.
    - The on-site emergency plan is principally concerned with the control of the emergency using on-site resources. The employer has responsibility for producing it.
    - The purpose of the off-site emergency plan is for the protection of the public and the environment. The off-site plan is the responsibility of the authorities.
  - Consequence minimisation measures.
  - Consultation with workers and their representatives.
  - Continuous improvement of the system. This should include learning from accidents and near-misses, so it should cover the necessary data-gathering and analysis. The lessons learned should be recorded and also discussed with workers.
- Prepare a safety report (with reviews at planned intervals and also when there are significant changes). The safety report:
  - Is based on the information already described under "documented system", i.e. hazard identification, plans, consequence minimisation, etc.
  - Needs reviewing just like a risk assessment, particularly where there have been significant changes (in the quantities of hazardous substances, etc.), new developments in technical knowledge, at planned intervals (as prescribed) or at the request of the competent authority.
  - Should be made available to the competent authority.
- Inform the competent authority in the event of a major accident and follow this up with a report (causes, consequences, action taken, etc.).
- Inform and train workers.

The **basic responsibilities of competent authorities** with regard to off-site emergency preparedness are to:

- Prepare an off-site emergency plan (for protection of the public and the environment). The off-site plan:
  - Will be based on information provided to the competent authority by the employer on the major hazard installation (and contained in the safety report).
  - Must be kept up-to-date and engage any necessary consultees.
- Inform the public (about safety measures and the behaviour to adopt in an emergency). The information given to the public must also be kept up-to-date.
- Warn the public when a major accident arises.
- Inform other countries (in the event of transboundary incidents).

Preparation of On-Site and Off-Site Emergency Plans

The two emergency plans should be complementary. The on-site plan should include details of the arrangements in place to assist with an emergency off-site. Similarly, the off-site plan should include details of the arrangements for providing assistance for the on-site emergency.

The emergency plan should cover the response required during each phase of the emergency, both immediately and in the longer term. During the first few hours after the accident (the 'critical' phase of an accident response), key decisions must be made quickly and under considerable pressure. A detailed understanding of the likely sequence of events and appropriate actions will help anyone who may be expected to play a part in the response.

On-Site

For simple installations, the plan may consist simply of raising the alarm, putting employees on standby and calling in the external emergency services. For more complex installations, far more will be needed, for example:

- Assessment of the size/nature/likelihood of potential accidents.
- Liaison with external agencies.
- Procedures for raising the alarm and for communications.
- Emergency Control Centre (ECC) - location and organisation.
- Appointment of those with specific duties (incident controller, site main controller, first-aiders, etc.).
- On-site actions (including evacuation and roll-call) during an emergency.
- Off-site actions during an emergency.


Employers have responsibility for on-site emergency plans

The above refer to elements of a documented emergency plan. Practically, the operator will need to:

- Identify the major incident risks on the site (which requires information on the types of chemicals, their effects and properties, together with likely release scenarios).
- Get input from relevant external agencies (fire department, utilities, etc.) to develop a workable plan.
- Make provision for an Emergency Control Centre (ECC). This is often a dedicated building/room in a relatively safe location (i.e. far enough away from the likely starting point of a major incident). As the name implies, this is the focal point for the emergency operations. The ECC should be equipped with ready access to such things as:
  - Site plans.
  - Contact information.
  - Chemical information.
  - Necessary communication equipment (radios, telephones).
- Allocate responsibilities – specific individuals should have clearly defined roles and responsibilities. A hierarchical incident management structure (main controller, incident controller/officer, etc.) should be adopted; this is the model used by the emergency services. Though the roles are clearly defined, the same individual may not always be assigned to a task; instead, there may be a pool of individuals who are available on a rotating "duty manager" basis to provide adequate cover. There should also be out-of-hours call-out arrangements.

  The **incident controller**:

  - Assesses the scale of the incident and initiates the emergency procedures.
  - Directs the proceedings until the arrival of the emergency services (fire department).
  - Directs search/rescue operations.

   - Ensures evacuation of non-essential workers.
   - Sets up communications/operations at the ECC.
   - Assumes the responsibilities of the main controller until they arrive and provides advice to the emergency services (as requested).

  The **site main controller** is responsible for:

   - Deciding whether a major emergency is likely.
   - Controlling operations directly.
   - Continuous review/assessment of developments.
   - In consultation with the incident controller, directing the shutting down/evacuation of parts of the installation.
   - Ensuring casualties receive treatment.
   - Liaising with external authorities.
   - Controlling on-site traffic flow.
   - Ensuring a record of the emergency is maintained as it develops.
   - Dealing with the press (statements, etc.).
   - Post-incident management.

- Provide the necessary equipment, including communication equipment (e.g. radios, in addition to those used in the ECC), spill containment (absorbents, diking equipment), necessary PPE (such as gas-tight chemical suits and breathing apparatus).
- Maintain all the emergency equipment and facilities. These should be in a state of readiness. The nature of emergencies is that they can happen at any time. So, plan for back-up – have spares available in case of failures, make sure stocks are replenished after use (absorbents, air from self-contained breathing apparatus, etc.).
- Train emergency personnel and practise the plan. People are naturally uncertain and confused early in an emergency, where there may be little information and lots of things happening. This is especially true when the plan and/or equipment is unfamiliar; uncertainty can allow an emergency to spiral out of control. The plan should not just be a written document that is only ever brought out in an emergency; personnel should be trained to be familiar with the procedures and their part in them. This will involve practising the plan on a regular basis.
- Test and review the plans regularly (at least every three years), especially if there are significant changes which might affect them. Clearly, a good opportunity to review the plans is after a practice, when feedback from participants in a debrief can identify significant deficiencies in workability (e.g. over-complicated communications or command structure causing confusion).
- For extended emergencies, consider arrangements for welfare facilities (including outside catering) and also relief of staff who were first on the scene. A major incident may not only be physically demanding for emergency responders, but can also be mentally and emotionally draining for decision-makers higher up the chain of command.
- Ensure that the plan is flexible enough to cope with unforeseen issues/events and the fluid nature of emergencies. More information will become available as the emergency develops, so plans may have to be adapted.
- Appoint and train people with the specific responsibility of managing the press.
- Consider business recovery/continuity issues – a major incident can destroy a factory. Many businesses do not recover after a major fire. Depending on the business risk, a contingency plan (e.g. to transfer production temporarily to another site) may also be needed.

Off-Site

There clearly needs to be co-ordination between the on-site and off-site emergency plans, since the two must come together during an emergency. Much of the information required by local authorities to prepare the off-site emergency plan (the nature of the risks and likely extent of the consequences) will come from the assessment carried out as part of the on-site plan (and detailed in the safety report). The authorities need to consider the potential effects on people and the environment in order to put mitigation and remedial measures in place. Off-site plans should contain details of:

Rescue arrangements within the emergency plan

- Organisation – command structures, warning systems, names of site main controllers, ECC, etc.
- Communications – identifying the personnel involved and contact details.
- Specialised emergency equipment – heavy lifting gear, etc.
- Specialised knowledge – expertise that may be needed.
- Nature of chemical risks on the site.
- Arrangements for obtaining weather information.
- Humanitarian arrangements – transport, emergency feeding, evacuation, first-aid, etc.
- Getting information to the public – dealing with the media and local inhabitants.
- Arrangements for collecting information on the developing emergency (to identify the cause) and for reviewing the plan.

Ongoing Monitoring and Maintenance of Emergency Plans

Just like reviewing risk assessments and other such things, emergency plans need to be kept up-to-date, to take account of changes. This should be done on a planned, regular basis, as well as when significant changes occur (increased inventory, new hazards, etc.). A good time to re-appraise is also after a rehearsal/test debrief. No plan is ever perfect. Testing often reveals problems with the plans, such as uncertainty of roles or poor communications.

STUDY QUESTIONS

15. Draw up an emergency plan for dealing with victims of an explosion in a factory manufacturing paints and varnishes.

16. As safety practitioner for a large organisation with premises on a number of different sites, you are responsible for the emergency evacuation procedures. Explain how you would:

    (a) Develop and plan these procedures.

    (b) Ensure that all employees know the procedures.

    (c) Monitor the effectiveness of the procedures.

(Suggested Answers are at the end.)

Summary

Industrial Chemical Processes

In particular, we have:

- Considered how temperature, pressure and catalysts can impact on the rate of reaction.
- Examined exothermic reactions (those emitting heat) and also the exothermic runaway reaction.
- Identified ways of controlling the temperature and pressure of a reaction.

The Storage, Handling and Transport of Dangerous Substances

We have:

- Discussed the way in which dangerous substances should be stored safely, with particular reference to:
  - Storage of incompatible substances and segregation requirements.
  - Containment of leaks or spillages.
- Identified the main principles for the safe handling of chemicals with reference to:
  - Flow through pipes.
  - Filling and emptying containers.
  - Dispensing, spraying and disposal of flammable liquids.
  - Dangers of electricity in hazardous areas.
- Identified the main principles associated with the transport of chemicals, including:
  - Loading and unloading tankers.
  - Labelling vehicles.
  - Packaging substances.
  - Driver training.
  - Role of the Dangerous Goods Safety Adviser.

Hazardous Environments

We have:

- Outlined the principles of protection for electrical equipment used in hazardous environments, particularly wet environments and flammable atmospheres.
- Considered the classification of hazardous areas using zoning.
- Identified the need for a permit-to-work in certain situations.
- Considered the benefits of pressurisation and purging of electrical equipment in a hazardous environment.
- Identified the different types of equipment suitable for use in hazardous environments:
  - Intrinsically safe equipment.
  - Flameproof equipment.
  - Type ‘e’ equipment.
  - Type ‘N’ equipment.

Emergency Planning

We have:

- Identified the need for emergency preparedness in an organisation.
- Considered the ways in which preparation can ensure consequences of an emergency situation can be minimised, including planning for:
  - First-aid/medical provision.
  - Fire evacuation.
  - Spill containment.
- Outlined the development of:
  - Emergency plans, including liaison with external emergency services and competent authorities.
  - Major accident hazard emergency plans.
  - On- and off-site emergency plans, including monitoring and maintenance.
  -

Exam Skills

QUESTION

The transfer of an extremely flammable liquid from a bulk storage tank to a road tanker may generate static electricity. **Outline** the design features which would reduce the risk of ignition of the extremely flammable liquid vapour due to static electricity. **(10)**

Approaching the Question

This looks like a complicated question, but don't be put off – it isn't as bad as it looks!

Re-read this section of material, thinking about the terms included in the question and getting them clear in your mind.

Suggested Answer Outline

You would need to show the examiner that you understand how the build-up of static electricity occurs, such as movement of liquid causing static build-up, splash filling, pumping of liquid, transport movement, etc.

Typical controls could include:

- Regulating pumping rate and transfer speed, as slow rates reduce build-up of static.
- Earth bonding the tanker, transfer pipework, valves, pumps and tank (and all other equipment).
- An interlock system to ensure earthing is in place before pumping.
- Using sub-surface discharge pipework inside the tank to avoid splash filling.
- Eliminating any possible contamination (i.e. from the presence of water in the pipeline).
- Installing only equipment suitable for use in a flammable atmosphere in the installation (including electrical equipment, such as lighting, and mechanical equipment, such as pumps).
- Providing a vapour return system where the displaced vapour from the tank is returned to the tanker rather than being released to atmosphere.
- Providing a nitrogen blanketing system on the road tanker.
- Providing appropriate instrumentation (i.e. to detect earth leakage and automatically shut down the system).
- Providing anti-static clothing/footwear and provision for testing of these.

HINTS AND TIPS

Remember, examiners can ask any questions based on the syllabus and related to the Learning Outcomes. Although you may not use these types of processes yourself, you could still get an exam question on them, so you need to be prepared for this.

Example of How the Question Could be Answered

In order to manage the risk of ignition due to static electricity, you would need to identify how the risk of static can be implemented into the process of transfer of extremely flammable liquids.

Static electricity can occur in a number of ways – operators building up a charge on overalls/clothing, the liquid sloshing around in the tanker during delivery to the site and building up a charge (the movement of electrons causes static charge to be raised in the liquid), pumping the liquid between the bulk tank and the road tanker.

To manage the risks, you would need to look at a number of options:

- *Avoid charge build-up by reducing the flow rate of the liquid, as static build-up is increased as the flow increases. Static is also generated as liquid is poured; so using sub-surface discharge legs into the tank (rather than splash filling) would prevent static build-up.*
- *Dissipate the charge before it builds up to a dangerous level. This can be achieved in a number of ways:*
  - *Ensure that transfer pipework is manufactured of a conductive material and is earthed to the tanker and the tank.*
  - *Ensure that earth bonding of transfer lines, pipework, valves and vessels is tested to ensure charge build-up is discharged safely to earth, possibly with the use of a meter/indicator to monitor charge build-up and inhibit the process when the charge approaches danger levels.*
  - *Install test stations to check conductivity of footwear used on site.*
  - *Finally, anti-static overalls/footwear for operators could be used, together with test stations to check for conductivity.*

Reasons for Poor Marks Achieved by Exam Candidates

- Demonstrates a lack of understanding of the principles of static protection.
- Refers to earthing and bonding but little else.
- Suggests controls which are procedural rather than "design features", as requested.
- Doesn't provide an "outline", as required by the question.

Element IC5

Work Equipment

Learning Outcomes

Once you've read this element, you'll understand how to:

1. Outline the criteria for the selection of suitable work equipment for particular tasks and processes to eliminate or reduce risks.
2. Explain how risks to health and safety arising from the use of work equipment are controlled.
3. Explain safe working procedures for the maintenance, inspection and testing of work equipment according to the risks posed.
4. Explain the role of competence, training, information and supervision in the control of risks arising from the installation, operation, maintenance and use of work equipment.
5. Outline the maintenance, failure modes and prevention strategies when working with pressure systems.

Contents

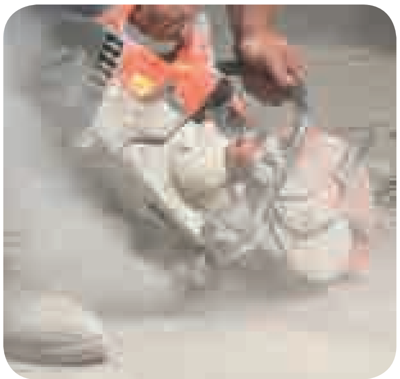
Selection of Suitable Equipment

IN THIS SECTION...

- The selection of suitable work equipment for particular **tasks** and **processes** makes it possible to reduce or eliminate many risks to the health and safety of people in the workplace.
- Equipment should be suitable, by **design**, **construction** or **adaptation**, for the actual work it is provided to do.
- **Energy or substances** used or produced by equipment may present a risk to safety or health and should be supplied and/or removed in a safe manner.
- Well-designed layout of controls will reduce the ergonomic and anthropometric strains on the operator that could affect the type and frequency of operator errors.
- One of the most effective ways of reducing the risk of harm from machinery is to eliminate, or reduce, the need for interaction between the operator and the machine.
- The size of openings, height of barriers and distance from danger are important considerations in safeguarding work equipment, as they affect whether a person can come into contact with dangerous parts of machinery.

Suitability for Task, Process and Environment

The selection of suitable work equipment for particular tasks and processes makes it possible to reduce or eliminate many risks to the health and safety of people in the workplace. This applies both to the use and maintenance of the equipment.



Suitable equipment for the operation?

When selecting work equipment, employers should also consider environmental conditions, such as:

- Lighting, temperature and humidity.
- Problems such as accelerated wear and exposure to wet or cold, which might be caused by using the equipment outside in poor weather conditions.
- Other work being carried out in the vicinity that may be causing noise, vibration or dust emissions, which may affect the operation.
- The activities of people who are not at work but who may be affected by noise, dust or fumes produced by the operation of the equipment

Employers must assess the location where the work equipment is being used and take account of any risks that may arise from the particular circumstances. The risks involved may mean that work equipment may not be able to be used in a particular place. For example, electrically-powered equipment is not suitable for use in wet or flammable atmospheres unless it is designed for this purpose. In such circumstances, employers should consider selecting suitably protected electrical equipment or alternative pneumatically- or hydraulically-powered equipment.

Suitability of Design, Construction and Adaptation

Equipment should be:

- Suitable, by **design, construction or adaptation**, for the **actual work it is provided to do.**
- Used in accordance with the manufacturer's specifications and instructions.

Means to Supply Energy or Substances

Another factor to consider when determining the suitability of work equipment is the possibility that energy used or produced by the equipment - such as electrical or mechanical energy - may present a risk to safety or health.

Similarly, any substances used or produced by the equipment - such as fuels or process materials - may introduce similar risks.

Ergonomic, Anthropometric and Human Reliability Considerations

Layout and Operation of Controls and Emergency Controls

Before designing equipment or machinery, it is important to know what it is required to do; the control panel is no exception. Indeed, due to the effect that it can have on an individual's health, it is even more important to know how the individual will interface with the machine. The use of task analysis will assist in this process of identification.

For the man-machine (ergonomic) relationship to be effective, the human element needs to receive information relating to the process, performance and adverse conditions that require action (including emergency situations). In order to do this and so that the necessary action is taken, the design of the interface has to take into account the human characteristics (anthropometrics) that will allow the information to be received, processed and acted upon. The information can be received in a number of ways but generally it is either **visual** or **audible**.

There are several types of control available for any piece of machinery. What is important is that the chosen control is appropriate for the operation of the machine and that it does its job effectively and with minimum opportunity for error. Important criteria that controls should meet are as follows:

- Clearly visible.
- Appropriately marked.
- Positioned for safe operation.
- Designed so that movement of the control is consistent with the effect required.
- Located outside the danger zone, except for certain controls, e.g. emergency stop.
- Positioned so that their operation cannot cause additional risk.
- Designed to prevent unintentional operation.
- Made to withstand foreseeable strain, particularly in the case of emergency controls.
- Starting of the machine can only be by means of the control, particularly after adverse conditions, e.g. a power cut.
- Stopping devices should be fitted.
- Emergency stopping devices should be fitted, clearly marked and to work effectively.
- The control must override any part of the system except the emergency control.
- Any fault or failure must not lead to danger.
- Interactive software must be user-friendly to the operator.

Controls have a number of characteristics that need to be taken into account. Remember that they are the prime man-machine interface and must be appropriate for the operator. For example, it is not appropriate to install a lever that requires the operator to use his/her full body weight while in the sitting position; this would make operation difficult, if not impossible. The following is a list of control characteristics:

- Displacement (either linear (up and down or side to side) or angular (rotational)).
- Operating force.

- Friction, inertia or drag.
- Number of positions.
- Direction of movement.
- Predetermined stops (detents).
- Appropriate identification.
- Compatibility with displays.
- Size.

Each of the above characteristics will, to a greater or lesser extent, affect the choice of the controls for any specific task.

Another important aspect for the selection of appropriate controls is their **location**. Key factors in this are:

- Number of controls - the fewer there are, the lower the chance of the wrong one being operated.
- Arrange controls to encourage a range of postures for the operator, which allow movement to keep the body 'fresh'.
- Arrange controls so that the sequence of operations is in an arc, so that the control layout is representative of the process.
- Where large forces are required to be exerted, use foot pedals or have power assistance.
- Have a clear distinction between normal and emergency controls.
- Keep consistent groupings of displays and controls; ideally the display should be above the control.
- Prevent accidental operation (for example, being knocked by an elbow, etc.) by:
  - Recessing the control.
  - Orientating the control so that the normal direction from which any accidental activation may occur will not cause it to be operated.
  - Covering the control with a hinged cover.
  - Locking the control.
  - Operationally sequencing a set of controls.
  - Increasing control distance.

Selection of the appropriate control-type is therefore important from an operational viewpoint.

The following table summarises the types of control and their characteristics:

Characteristics and uses of controls

Control Type	Use at Speed	Accuracy	Mounting Space Required	Use in an Array	Ease to Check Reading in Array
Toggle switch	Good	Good	Small	Good	Good
Rotary switch	Good	Good	Small	Good	Fair
Push button	Very good	Very poor	Small	Good	Poor
Rotary selector	Good	Good	Medium	Good	Good
Knob	Fair	Fair	Small-medium	Poor	Good
Handwheel	Poor	Good	Large	Poor	Poor
Crank	Fair	Poor	Medium-large	Poor	Poor
Lever	Good	Fair	Large	Good	Good
Foot pedal	Good	Poor	Large	Poor	Poor

Many systems do not just have one control and/or indicator, but a number of them on the same control panel. These will be arranged into an 'array', which introduces further problems. The effectiveness of controls in arrays is given in the table above.

Some key points relating to arrays are:

- Keep the control next to the indicator that gives the reading of its output so that the effect of operation of the control can be easily monitored.
- Have switches all set the same way, e.g. 'up' for off and 'down' for on (this reflects the stereotyping obtained by individuals from switching domestic lights on and off).
- Arrange for knobs all to increase by turning the same way.
- If a bank of dials is introduced, have them so that they all point the same way when normal. Any abnormal reading then stands out by position rather than the operator having to read all the dials.
- Where dials all have differing locations in the 'normal' position, then colour code the dial face to show when the needle is outside the norm. A glance will then highlight whether further attention to this particular information is required.
- Identify stereotypes for controls and take these into account. (Remember that countries have different stereotypes and machines may be different, e.g. a light switch in the USA is on when 'up' rather than 'down' as in the UK.)
- Controls need to be located so that there is enough space between them that they can be grasped and operated.
- Well-designed layouts of controls will assist in the introduction of a man-machine interface that will not impose undue pressures and strains on the operator that could affect operator error type and frequency.

Reducing the Need for Access

One of the most effective ways of reducing the risk of harm from machinery is to eliminate, or reduce, the need for interaction between the operator and the machine. Two successful methods used in industry for achieving this are:

Automation in the car industry

- **Automation**

  In certain operations - usually routine, repetitive tasks - it is possible to replace workers with automatic systems such as robots, automatic guided vehicles, etc. These computer-controlled devices carry out the tasks without the associated human failings of fatigue, misjudgement or lapse of concentration. While an automated system requires maintenance of the machinery and the operating software, the day-to-day interaction is reduced to a minimum. Further control can be achieved by restricting access to automated areas, and the use of suitable safeguarding such as fencing, interlocking gate locks, pressure mats, etc.

- **Remote Systems**

  This simply refers to the operation of a system or single piece of machinery by a person, or persons, who may not be in close proximity to that equipment. Practically everybody is familiar with the TV remote control which allows all functions to be carried out from the other side of the room. The same principle of 'remote control' is used in many different industrial settings, from simple arrangements, such as a pendant control for an overhead crane, to more complex control rooms from which all routine operations are controlled and monitored. The obvious advantage is in segregating the operator from the immediate working area. However, total reliance on the controls could be seen as a disadvantage.

While it is clear that both of these systems can play a large part in reducing regular interaction (and therefore the risk of injury), maintenance, repairs and servicing still need to be carried out. It is important to have rigorous procedures to cater for these activities.

Size of Openings, Height of Barriers and Distance from Danger

An operator can come into contact with dangerous parts of machinery in two ways: either by reaching over the protective structure, or putting part of their body through an opening in the protective structure.

The dimensions given in the following tables are based on anthropometric considerations. They relate the:

- Size of the opening to the dimension of the body part to be excluded.
- Height of the barrier to reach distance.
- Distance from danger to possible access by fingers or limbs.

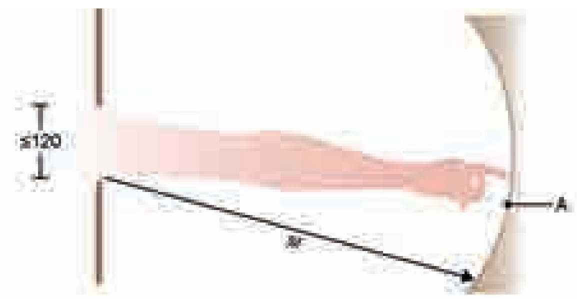
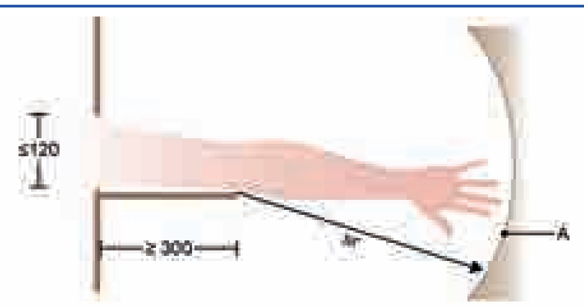
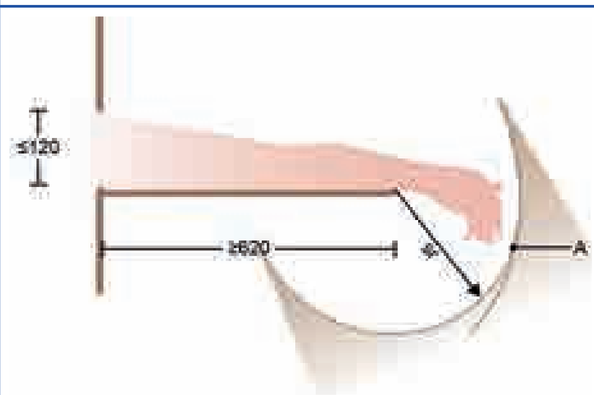
The tables that follow are included purely to illustrate these principles.

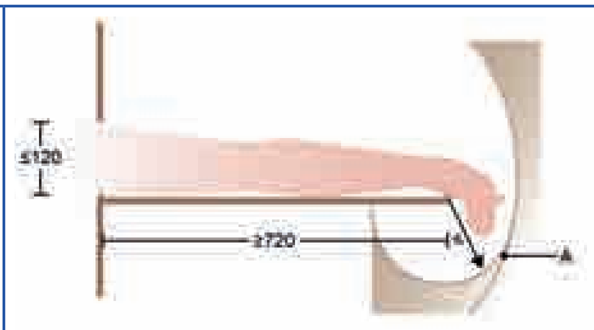
Size of Openings

Arms or fingers can go through openings. Where the arm can go through the opening to reach around, the clearances are as shown in the following table:

Clearance through openings

Dimensions in millimetres

Limitation of Movement	Safety Distance (sr)	Illustration
Limitation of movement only at shoulder and armpit	≥ 850	
Arm supported up to elbow	≥ 550	
Arm supported up to wrist	≥ 230	

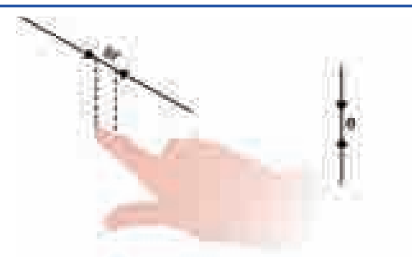
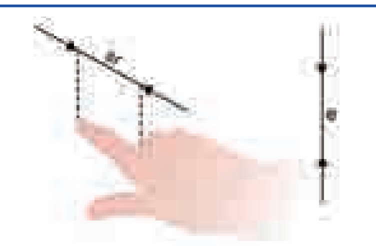
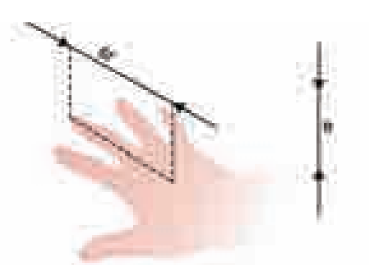
Arm and hand supported up to knuckle joint	≥ 130	

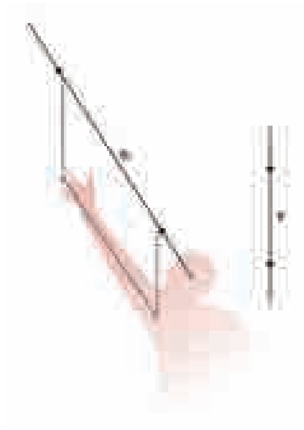
A: Range of movement of the arm

Where **fingers** can go through the opening, the clearances required to prevent contact with the dangerous part are illustrated in the following table:

Clearance for fingers

Dimensions in millimetres

Part of Body	Illustration	Opening	Safety Distance (sr)		
			Slot	Square	Round
Fingertip		e ≤ 4	≥ 2	≥ 2	≥ 2
		4 < e ≤ 6	≥ 20	≥ 10	≥ 10
Finger up to knuckle joint		6 < e ≤ 8	≥ 40	≥ 30	≥ 20
		8 < e ≤ 10	≥ 80	≥ 60	≥ 60
		10 < e ≤ 12	≥ 100	≥ 80	≥ 80
		12 < e ≤ 20	≥ 900*	≥ 120	≥ 120
or Hand					

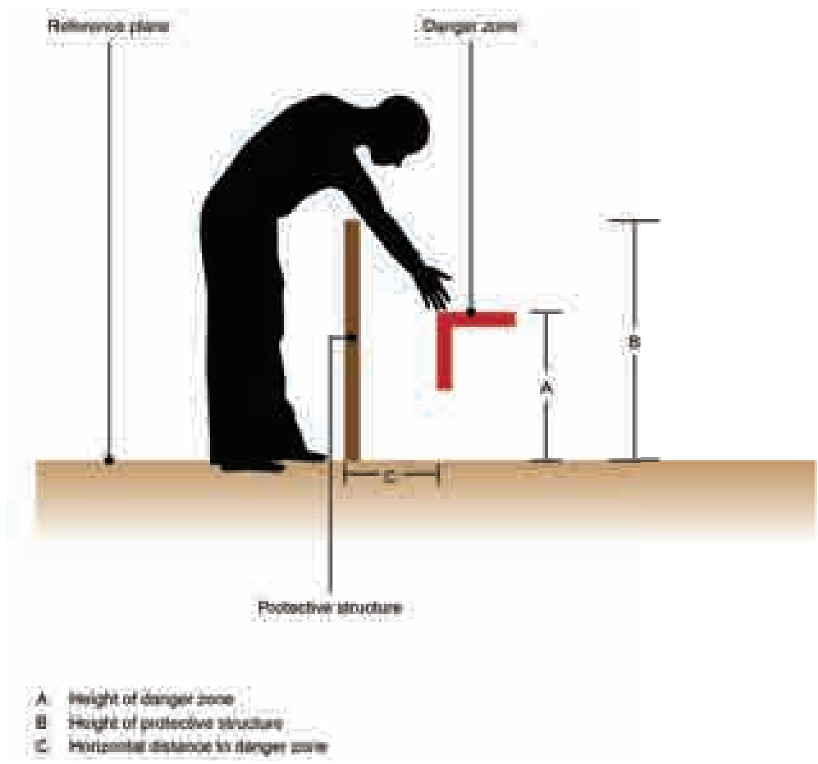
Arm up to junction with shoulder		$20 < e \le 40$	≥ 900	≥ 550	≥ 120
		$30 < e \le 100$	≥ 900	≥ 900	≥ 900

* If the length of the slot opening is ≤ 40mm the thumb will act as a stop and the safety distance can be reduced to 120mm.

Where movement is restricted in some way by part of the protective structure, then dimensions may be reduced.

Height of Barriers

It may be that the danger is above or below the level of the person's shoulder, i.e. with the arm horizontal. As the arm would swing in an arc, the horizontal distance could be reduced, which is shown in the charts. The next figure shows the key dimensions referred to in the following tables.



Key dimensions for the height of barriers

Distance from Danger

The decision on minimum guarding distance is made on the basis of the risk from the danger that is to be avoided. Where the risk is low or high, the relevant distances are shown in the tables that follow.

Minimum distance for low risk

Dimensions in millimetres

Height of Danger Zone	Height of Protective Structure [1]								
	1,000	1,200	1,400	1,600	1,800	2,000	2,200	2,400	2,500
	Horizontal Distance to Danger Zone								
2,500	-	-	-	-	-	-	-	-	-
2,400	100	100	100	100	100	100	100	100	-
2,200	600	600	500	500	400	350	250	-	-
2,000	1,100	900	700	600	500	350	-	-	-
1,800	1,100	1,000	900	900	600	-	-	-	-
1,600	1,300	1,000	900	900	500	-	-	-	-
1,400	1,300	1,000	900	800	100	-	-	-	-
1,200	1,400	1,000	900	500	-	-	-	-	-
1,000	1,400	1,000	900	300	-	-	-	-	-
800	1,300	900	600	-	-	-	-	-	-
600	1,200	500	-	-	-	-	-	-	-
400	1,200	300	-	-	-	-	-	-	-
200	1,100	200	-	-	-	-	-	-	-
0	1,100	200	-	-	-	-	-	-	-

[1] Protective structures less than 1,000mm high are not included because they do not sufficiently restrict movement of the body.

Minimum distance for high risk

Dimensions in millimetres

Height of Danger Zone	Height of Protective Structure [1]									
	1,000	1,200	1,400[2]	1,600	1,800	2,000	2,200	2,400	2,500	2,700
	Horizontal Distance to Danger Zone									
2,700	-	-	-	-	-	-	-	-	-	-
2,600	900	800	700	600	600	500	400	300	100	-
2,400	1,100	1,000	900	800	700	600	400	300	100	-
2,200	1,300	1,200	1,000	900	800	600	400	300	-	-
2,000	1,400	,1300	1,100	900	800	600	400	-	-	-
1,800	1,500	1,400	1,100	900	800	600	-	-	-	-
1,600	1,500	1,400	1,100	900	800	500	-	-	-	-
1,400	1,500	1,400	1,100	900	800	-	-	-	-	-
1,200	1,500	1,400	1,100	900	700	-	-	-	-	-
1,000	1,500	1,400	1,000	800	-	-	-	-	-	-
800	1,500	1,300	900	600	-	-	-	-	-	-
600	1,400	1,300	800	-	-	-	-	-	-	-
400	1,400	1,200	400	-	-	-	-	-	-	-
200	1,200	900	-	-	-	-	-	-	-	-
0	1,100	500	-	-	-	-	-	-	-	-

(1) Protective structures less than 1,000mm high are not included because they do not sufficiently restrict movement of the body.

(2) Protective structures lower than 1,400mm should not be used without additional safety measures.

STUDY QUESTIONS

1. Identify five criteria that machinery controls should meet.
2. What precautions can be taken to prevent accidental operation of a machine?

(Suggested Answers are at the end.)

Risks to Health and Safety Arising from the Use of Work Equipment

IN THIS SECTION...

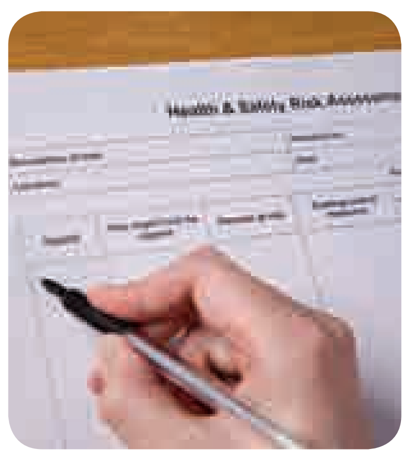
- The employer should ensure that work equipment is:
  - Suitable.
  - Safe for use.
  - Maintained in a safe condition.
  - Inspected.
  - Accompanied by suitable safety measures.

  Risk assessment and the implementation of appropriate controls are the means by which this is achieved.
- The risks associated with the use of work equipment can arise from its integrity, location, purpose, incorrect installation or re-installation, deterioration or other exceptional circumstances which could affect its safe operation.
- The risk control hierarchy relating to work equipment involves:
  - Eliminating the risks.
  - Employing 'hardware' (physical) measures, such as the provision of guards.
  - Employing 'software' measures, such as safe systems of work and the provision of information, instruction and training.

The Need for Work Equipment Risk Assessments

To make sure that work equipment is **correctly selected and safely used**, there are **two important considerations**:

- Management duties covering the selection of suitable equipment, maintenance, inspection, specific risks, information, instructions and training and the conformity of work equipment with standards for product safety.
- Physical requirements for issues such as the guarding of dangerous parts, the provision of appropriate stop and emergency stop controls, stability, lighting and suitable warning markings or devices.



Work equipment risk assessment

In broad terms, the employer should ensure that work equipment is:

- Suitable for the intended use.
- Safe for use, maintained in a safe condition and, in certain circumstances, inspected to ensure this remains the case.
- Used only by people who have received adequate information, instruction and training.
- Accompanied by suitable safety measures, e.g. protective devices, markings, warnings.

This may be achieved through risk assessment and the implementation of appropriate controls.

We will examine next what this risk assessment process needs to consider.

Risks Associated with Using Work Equipment

The risks to health and safety arising from work equipment should be assessed, taking into account matters such as the type of work equipment, substances and electrical or mechanical hazards to which people may be exposed. There are three aspects that are useful to consider in this process:

- Initial Integrity

  Equipment should be suitable, by design, construction or adaptation, for the actual work it is provided for to do. When first providing work equipment for use in the workplace, the employer should make sure that it has been made to the requirements of any prescribed standards. Adequate operating instructions should be provided with the equipment, as should adequate information about residual hazards such as noise and vibration. The equipment should also be checked for obvious faults.

- Location where it will be Used

  The location in which the work equipment is to be used should be assessed, to take account of any risks that may arise from the particular circumstances. Such factors can invalidate the use of work equipment in a particular place. For example, electrically-powered equipment is not suitable for use in wet or flammable atmospheres, unless it is designed for this purpose. As mentioned previously, in such circumstances suitably protected electrical equipment or alternative pneumatically - or hydraulically - powered equipment would be a better choice.

  In addition, work equipment itself can sometimes cause risks to health and safety in particular locations which would otherwise be safe. A petrol engine generator discharging exhaust fumes into an enclosed space is an example of this.

- Purpose for which it will be Used

  This requirement concerns each particular process for which the work equipment is to be used and the conditions under which it will be used. The equipment should be suitable for the process and conditions of use, for example:

  - A circular saw is generally not suitable for cutting a rebate, whereas a spindle moulding machine would be suitable because it can be guarded to a high standard.
  - Knives with unprotected blades are often used for cutting operations where scissors or other cutting tools could be used, reducing both the probability and severity of an injury.

The risk assessment process for work equipment will also need to consider any risks arising from its **initial installation** and any subsequent **re-installation**. For example, risk assessment of any equipment that needs to be repeatedly installed then dismantled will need to consider this aspect.

Another consideration is **deterioration** of the equipment during use, either from defects, damage or wear, or possibly from the nature of the environment in which it is used, which could result in an unacceptable risk.

The risk assessment should also identify any exceptional circumstances which could affect the safe operation of the work equipment.

Risk Control Hierarchy

Risk control measures for work equipment follow the same principle as for all risk control strategies and are set out in the Topic Focus box below.

5.2 Risks to Health and Safety Arising from the Use of Work Equipment

TOPIC FOCUS

The **hierarchy of controls** for work equipment:

- **Remove all risk by design**, i.e. introduce **intrinsic safety**.
- Use **fixed enclosed guards**; fixed guards have no moving parts which can fail or be abused.
- Use **other guards**, including movable guards, adjustable guards, automatic guards and fixed guards which are not fully enclosing.
- Use **protection devices** which do not prevent access but do prevent motion of the work equipment when close, e.g. pressure mats, infrared beams.
- Use **protection appliances** which hold or manipulate the workpiece, keeping the operator away from danger, e.g. a push-stick on a circular saw.
- Provide **information, instruction, training and supervision**, which is always important and is a requirement no matter what guarding arrangements are in place. It is particularly important when the risk cannot be adequately eliminated by the above controls, e.g. a hand-held electric drill.
- Use **Personal Protective Equipment (PPE)**.

These control measures can be simplified into the following strategy:

- Eliminate the risks created by the use of work equipment through careful selection.
- Employ 'hardware' (physical) measures such as:
  - Suitable guards.
  - Protection devices.
  - Markings and warning devices.
  - System control devices, e.g. emergency stop buttons.
  - Personal protective equipment.
- Employ 'software' measures such as:
  - Following safe systems of work.
  - Ensuring maintenance is only performed when equipment is shut down.
  - Provision of information, instruction and training.

PPE used in conjunction with work equipment

A combination of these measures may be necessary depending on the requirements of the work, the assessment of the risks involved, and the practicability of such measures.

STUDY QUESTIONS

3. Outline the factors that need to be considered when identifying the risks associated with the use of work equipment.
4. Outline the three aspects that should be considered in assessing the risks to health and safety arising from work equipment.
5. Describe the three elements of the risk control hierarchy relating to work equipment.

(Suggested Answers are at the end.)

Maintenance, Inspection and Testing

IN THIS SECTION...

- Maintenance of work equipment can expose those carrying out the work to a range of different hazards. Key precautions include risk assessment to enable suitable control measures to be put in place, the use of trained, competent maintenance workers, measures such as permit-to-work, ensuring suitable means of access, and physical isolation of the equipment.
- The three principal strategies for ensuring well-maintained equipment are:
  - Planned preventive maintenance.
  - Condition-based maintenance.
  - Breakdown maintenance.
- Factors to consider in developing a planned maintenance programme for safety-critical components include:
  - Importance in the process.
  - Failure during the production process.
  - Machine complexity.
  - Relationship with other machines.
  - Availability of replacement equipment.
  - Identification of critical components.
  - Environmental factors.
  - Maintainability within the design of the machine.
- Maintenance is so fundamental to ensuring the safety of work equipment that in some countries there may be statutory duties relating to the maintenance of work equipment.
- Work equipment should be inspected at appropriate times or suitable intervals to ensure that health and safety conditions are maintained and that any deterioration can be detected and remedied in good time. The factors to be considered in determining inspection regimes include:
  - The type of equipment.
  - Where it is used.
  - How it is used.
- As part of an inspection, a functional or other test may be necessary to check that the safety-related parts are working as they should be and that the work equipment and relevant parts are structurally sound.
- The aim of Non-Destructive Testing (NDT) is to test without having to destroy the integrity of the material or the component. A number of NDT techniques are available, each with its advantages and limitations:
  - Dye penetrant.
  - Acoustic emission.
  - Ultrasonic.
  - Radiography (gamma and x-ray).
  - Eddy current.
  - Magnetic particle.

Radiography can be used for Non-Destructive Testing (NDT)

Hazards and Control Measures Associated with the Maintenance of Work Equipment

Maintenance of work equipment can expose those carrying out the work to a number of different hazards. Due to the varied amount of tasks that come under the wide umbrella of maintenance, ranging from repairing and replacing broken items to cleaning and painting, it is important that a thorough assessment of the work to be carried out is made prior to the work commencing.

Maintenance of work equipment

- It is common for maintenance workers to be exposed to a number of **hazardous substances**, such as: fuels, oils and greases, paints, cleaning solvents and acids. Exposure to fibrous dust is also a common hazard when repairing or replacing friction linings such as those found on brakes and clutch mechanisms.
- Due to the nature of the work, it is often necessary to **remove the safeguarding** to gain access to the parts requiring attention, which means exposing workers to the dangerous parts of the machinery. Inadvertent start-up of the machine during maintenance work is an ever-present danger.
- Maintenance workers may be required to carry out work in places where it is **not certain what the hazards will be**. A failed or broken-down piece of machinery may not have failed safely, and there is the possibility of stored pressure or energy. Equipment failure may result in sharp shards of metal from broken parts and these can cause deep cuts, which are often contaminated with oil or grease. It is also possible for parts of failed equipment to collapse or fall without warning.
- It is often necessary to carry out work in areas with restricted space, poor access, limited lighting and little or no ventilation. Maintenance work is often carried out in **unpleasant working conditions**. Due to the nature of the work, repairs undertaken in cold, wet, muddy conditions, particularly on construction sites, and this can increase the risk of injury.
- The **repair work to be carried out can increase the risks**, particularly where it is necessary to:
  - Carry out hot work, such as welding, grinding, burning, etc. with the associated hazards of fire, noise, glare, heat and possibly the depletion of oxygen.
  - Use electrical tools, especially in inclement conditions or in flammable atmospheres.
- **Carrying out running adjustments and checks following repairs** often requires the equipment to be energised and this presents additional hazards, particularly where the checks are carried out with safeguarding removed.

From this limited list it is apparent that the risks associated with maintenance work can be higher than for normal day-to-day operation of the equipment.

To reduce the risk of injury while maintenance work is being carried out, it is necessary to undertake a thorough risk assessment to enable suitable control measures to be put in place. Referring to, and adhering to, manufacturers' information should be part of the overall control strategy, as should the use of trained, competent maintenance workers. A permit-to-work may often be necessary as part of the safe system of work. Prevention measures might include:

- Suitable means of access.
- Physical isolation of the equipment.
- Portable lighting (a torch or low-voltage lamp may often be sufficient) where necessary.
- Ventilation, including Local Exhaust Ventilation (LEV).
- Use of suitable tools (possibly substituting electrically-powered tools with pneumatic tools in certain environments).

- Not carrying out work in situ (i.e. with the items in their original position) and instead removing items to be worked on in a more suitable location. Blocking or shoring-up moving parts to prevent unexpected movement.
- Providing suitable protective equipment to reduce the effects of hazardous substances, sharp objects, hot surfaces, etc.

This list is not exhaustive, as each job will present its own problems. It is only by taking a logical approach to the situation that an acceptable degree of risk reduction can be achieved.

Maintenance Strategies and Options

There are three main strategies for maintenance of work equipment which we will consider in more detail below.

Planned Preventive Maintenance

The basis of routine maintenance is that equipment is inspected and vulnerable parts are replaced at regular intervals or after a certain number of hours of use. How frequently should this maintenance be done? If it is done too frequently, the equipment will run effectively but the maintenance costs will be very high. If it is done too infrequently, the maintenance cost will be low but the system will be subject to failures.

If breakdowns are to be avoided, some form of planned maintenance is essential. Such a system allows machine servicing to be planned to minimise lost production time.

Planned maintenance is based on the fact that any machine or plant item consists of various components, each of which has a definable working life. These can be classified into one of the following four item types:

- **Maintainable**: a maintainable item is one that will last for many years if serviced regularly; e.g. an item that requires regular lubrication (such as a gearbox).
- **Replaceable**: a replaceable item is one with a limited life which should be replaced at regular intervals if sudden and possibly disastrous failures are to be avoided, e.g. a drive belt.
- **Inspectable**: an inspectable item also has a limited life, but potential failure can be identified by some form of measurement; e.g. play in a bearing or wear on electrical contacts.
- **Long-life**: a long-life item is one that is likely to last for many years without failure, because it is not subject to any appreciable wear, vibration or stress; e.g. a machine baseplate.

Preventive maintenance is regular maintenance carried out in order to reduce the probability of problems occurring. Such work should be timed to occur when operations will not be disrupted. Preventive maintenance has long been recognised as extremely important in the reduction of maintenance costs and improvement of equipment reliability. In practice it takes many forms. Two major factors that should control the extent of a preventive programme are the:

- Cost of the programme compared with the carefully measured reduction in total repair costs and improved equipment performance.
- Percentage utilisation of the equipment maintained.

If the cost of preparing for a preventive maintenance inspection is essentially the same as the cost of repair after a failure, accompanied by preventive inspections, the justification is small.


Planned preventive maintenance in progress

If, on the other hand, breakdown could result in severe damage to the equipment and a far more costly repair, a scheduled inspection time should be considered.

Ideally, you should take advantage of a breakdown in some component of the line to perform vital inspections and replacements, which can be accomplished in about the same time as the primary repair. This would ensure preventive maintenance is carried out without discontinuing operations unnecessarily.

TOPIC FOCUS

The advantages and disadvantages of the operation of a **planned preventive maintenance system** include:

Advantages

- Safer operation.
- Reduced downtime and lost production.
- Increased reliability of equipment.
- Failure rate predictions.
- Rapid turnaround of parts.
- Maintenance carried out at times of least disruption.
- Reduced risk from planned maintenance operations.

Disadvantages

- Over-maintenance, with reduced efficiency.
- High costs of parts still with useful life.
- Management time for planning and operating schedules.
- Over-familiarity with tasks leading to complacency.
- Higher skill level.
- Increased storage requirements for spare parts.

The benefits of planned preventive maintenance include:

- **Legal benefits** - to demonstrate that the employer has taken appropriate steps to meet his legal obligations to maintain safe plant and a safe place of work.
- **Business benefits** - an effective maintenance strategy will improve both reliability and the image of the company with customers. Well-maintained work equipment will also be more likely to produce output goods within the tolerances required by the contract; e.g. worn dies on a moulding machine will produce items which, being outside the tolerances, must be rejected. Well-maintained work equipment reduces the chance of accidents, which in turn reduces the potential for injuries and subsequent cost implications. With a regime which ensures that repairs are dealt with efficiently and effectively, staff become less likely to use substandard equipment and are more likely to report damage or defects.

  This improves the safety culture of the company and will reflect in areas outside those relating to machinery, in that the general attitude to all matters relating to safety is improved.

From all this, it is clear that positive returns are available from effective maintenance.

TOPIC FOCUS

Factors to consider when introducing a planned preventive maintenance system include:

- Failure-rate predictions.
- Manufacturers' data.
- Spare parts required.
- Downtime of plant during maintenance. Information from condition monitoring.
- Equipment needed.
- Training of associated staff.
- Maintenance schedules and frequency.
- Systems for non-routine/breakdown maintenance.
- Systems of work.
- Record keeping/maintenance logs.

Condition-Based Maintenance

Condition-based maintenance relies on monitoring the condition of safety-critical parts and carrying out maintenance whenever it is necessary to avoid failure. Maintenance is performed after indicators show that equipment is going to fail or that equipment performance is deteriorating.

Condition-based maintenance should improve system reliability, since maintenance is carried out before failure. It should also decrease maintenance costs, avoiding both unnecessary and breakdown maintenance. Since fewer operations are carried out, there should also be a lower chance of errors occurring during maintenance.

However, the primary disadvantage is the cost arising from setting the system up to monitor parameters such as vibration, temperature, and also non-destructive testing techniques. In addition, unpredictable maintenance periods can cause costs to be divided unequally and the system will increase the number of parts that need maintenance and checking.

Condition-based monitoring involves routine checking of the condition of safety-critical parts. For example, whenever a car is serviced, the remaining thickness of brake linings/shoes and tyre tread depth will be monitored.

Where safety-critical parts could fail and cause the equipment, guards or other protective devices to fail and lead to immediate or hidden potential risks, a formal system of condition-based maintenance is likely to be necessary.

Breakdown Maintenance

When equipment failure does not have a major effect on production or safety and may be tolerated until repair, then the positive decision to use this as an option can be valid. The strength of this system is that it has a minimal cost in relation to a maintenance resource. The weakness is that the equipment is out of use during a possibly extended breakdown period and that repair has to be arranged. The effect on the equipment may be such that, depending on what has failed, the damage may reduce the effective working life.


Breakdown maintenance

Factors to be Considered in Developing a Planned Maintenance Programme for Safety-Critical Components

Whatever the chosen maintenance strategy, it needs to consider a number of factors that may, at times, be in conflict with each other. However, weighing up the factors will help management decide the best strategy to choose. The factors outlined below are 'strategic' (i.e. top-level) factors, which have to be identified and assessed in relation to the role of the machinery under consideration.

- Importance in the Process

  Any strategy adopted should reflect whether the equipment has a critical and central role. For example, if all production depends on a conveyor moving components from one stage of production to the next and if without that conveyor production stops, the maintenance strategy must ensure the minimum downtime during the production process.

- Failure During the Production Process

  This sort of strategy will normally be a more costly option in terms of time and effort, and will have to be balanced against the loss due to production breakdown.

- **Machine Complexity**

  Any piece of machinery will have a number of components, any of which may fail. Some are more difficult to gain access to than others and the potential time delay in repair must be considered. Certain components may be so inaccessible that replacement or repair requires total strip-down of the machine. Consequently, some of the maintenance strategies available may not be an appropriate choice. An example is the replacement of an armature within an electric motor, where the amount of stripping-down justifies that the bearings, etc. are checked at the same time.

- **Relationship with Other Machines**

  In a production line, failure of one machine may cause total failure of the entire line. The position and effect of a possible failure has to be considered, so the best option for an individual machine may not be the best option for the overall production line. In such cases, the production line should be regarded as a single entity in the first instance, with the individual machines being considered separately when reviewing implementation within the chosen maintenance strategy.

- **Availability of Replacement Equipment**

  Maintenance strategy selection is varied when it is possible to replace failed equipment with functional equipment held 'in store' for such an occasion. The availability of the replacement, the work involved in fitting it and getting operational, are factors which must be taken into account, along with the availability of maintenance capability to undertake the work, as detailed below.

  This is an option frequently used for small machines with low purchase cost, where it is possible to have replacements available. For example, on construction sites, 110v electric hand tools are usually available as replacements (either on-site or with quick delivery) for failed units, with the failed unit normally being returned to a workshop for repair.

- **Identification of Critical Components**

  Within any machine there is a number of key components which will have a major effect on the failure mode of the machine. The identification of such components is important when deciding on the maintenance strategy to be adopted.

  For example, if studies show that in a particular make of pump it is the armature which fails regularly, then:

  - The strategy chosen must target that component.
  - The maintenance strategy of the other components should be considered in relation to the strategy chosen for the armature; such as full pump maintenance at the time of the armature being attended to, rather than at a lesser frequency which the other components would normally dictate.

Planned preventive maintenance for safety-critical components

- **Environmental Factors**

  Machine characteristics can be considerably altered by the environment in which the machine is required to work. Environmental factors can include: heat, cold, dampness, dust, vibration and vapours. Electrical power supply reliability should be examined, as power fluctuations may influence machine operation.

- **Maintenance Capability Within the Company**

  Since any maintenance strategy has to be implemented, the resource requirements – in terms of time and skill – have to be taken into account. It is inappropriate to consider a strategy if the resources are not available to implement it.

- **Maintainability Within the Design of the Machine**

  The manufacturer has to make provision for maintainability, taking into account the following factors:

  – Accessibility of internal parts.
  – Ease of handling and human capabilities.
  – Suitable choice of workplaces.
  – Limitations on the number of special tools and equipment.
  – Ease of supervision.

- **Unknown Factors**

  People generally believe that they are aware of the factors which affect equipment. In practice, many rely on information from records or by discussion, making the information second- or third-hand. In addition, the reliability of this information, e.g. consistency of completion of records or reporting of failures, must be assessed to ensure that a strategy decision is being made on accurate information. This is the most common failing in selection of the most suitable maintenance strategy. Operatives, for example, may find that an electrical hand tool regularly fails due to the power lead being loose in the socket as a result of poor design. It is not normally reported, as the fixing of the machine is carried out by the operator, who simply pushes the nuisance lead back in and does not bother with a 'boring' reporting process. Review of the record for failures would not reveal the true downtime of the machine.

Need for the Maintenance of Work Equipment

We have discussed the types of maintenance already. "Inspection" is what is done in-between thorough examinations (discussed later) and generally involves visual checks (and possibly tests). It can usually be done by the operator/user.

Maintenance is so fundamental to ensuring the safety of work equipment and so many accidents have occurred as a result of lack of maintenance that in some countries there may be statutory duties relating to the maintenance of work equipment. For example, there are a number of pieces of UK legislation that require inspection and/or maintenance to be undertaken and recorded for particular types of equipment, such as:

- **Provision and Use of Work Equipment Regulations 1998 (PUWER)** – maintenance and inspection of work equipment in general.
- **Lifting Operations and Lifting Equipment Regulations 1998 (LOLER)** – inspection of lifting equipment.
- **Pressure Systems Safety Regulations 2000 (PSSR)** – maintenance of pressure systems.
- **Electricity at Work Regulations 1989** – maintenance of electrical systems.

Maintenance is required for lifting equipment

Hired Work Equipment

Hired or leased equipment may also need to comply with any applicable legal requirements. Organisations hiring or leasing equipment will need to be assured that companies supplying such equipment are doing so in accordance with any statutory duties.

Arrangements will need to ensure that:

- Local policies and risk assessments adequately cover leased and loaned work equipment.
- Only reputable hire outlet shops are used, which can demonstrate appropriate inspection and maintenance standards.
- Hired work equipment is maintained while in use.

Inspection Regimes

To ensure that health and safety conditions are maintained and that any deterioration can be detected and remedied in good time, work equipment should be inspected at appropriate times or suitable intervals. A useful criterion to determine whether inspection is necessary is if there could be a significant risk resulting from incorrect installation, deterioration or as a result of exceptional circumstances that could affect the safe operation of the work equipment.

The purpose of an inspection is to identify whether the equipment can be operated, adjusted and maintained safely and to ensure that any deterioration (e.g. defect, damage, wear) can be detected and remedied before it results in unacceptable risks.

Inspection of work equipment

The extent of the inspection required will depend on the potential risks from the work equipment and will need to consider:

- The type of equipment:
  - Are there safety-related parts which are necessary for safe operation of the equipment, e.g. overload warning devices and limit switches?
- Where it is used:
  - Is the equipment used in a hostile environment where hot, cold, wet or corrosive conditions may accelerate deterioration?
- How it is used:
  - The nature, frequency and duration of use will determine the extent of wear and tear and the likelihood of deterioration. Equipment that is regularly dismantled and re-assembled will require inspection to ensure that it has been installed correctly and is safe to operate.

The inspection itself may vary from a simple visual external inspection to a detailed comprehensive inspection, which may include some dismantling and/or testing.

The frequency of inspections for work equipment needs to be determined by a risk assessment, using the knowledge and experience of persons who are competent to determine the nature of the inspection, what it should include, how it should be done and when it should be carried out. Experienced, in-house employees such as a department manager or supervisor may be able to do this. They should know what will need to be inspected to detect damage or faults resulting from deterioration. They should also be able to determine whether any tests are needed during the inspection to see if the equipment is working safely or is structurally sound.

Need for Functional Testing of Safety-Related Parts

As part of an inspection, a functional or other test may be necessary to check that the safety-related parts are working as they should be and that the work equipment and relevant parts are structurally sound.

Safety-related parts might include:

- Interlocks and protection devices associated with an interlocked guarding system on the dangerous parts of a machine.
- Controls and emergency controls necessary for the general safe operation of the equipment.

So, for example, a dangerous machine such as a power-operated paper-cutting guillotine should be subjected to:

- Daily operator checks on interlocking or photoelectric guards.
- Monthly operator checks on sweep-away guards.

- Six-monthly inspections of all safety components, such as brakes, clutches, interlocks, switches and cams, carried out by a competent guillotine engineer.

To check that relevant parts are structurally sound, non-destructive testing of safety-critical parts might be required.

The need for any testing should be decided by the competent person who determines the nature of the inspection.

Advantages and Disadvantages of Non-Destructive Testing

Principles and Application

The aim of Non-Destructive Testing (NDT) is to test without having to destroy the integrity of the material or the component.

NDT can easily be incorporated within a quality control regime during the manufacture of components, with the advantage that substandard components are rejected at the earliest possible stage of production. Savings are therefore generated by not having work undertaken on components that will subsequently be rejected.

A number of NDT techniques are available, which are described below. Each has its limitations in use and it is important to understand the principles and limitations of each of the methods.

Functional testing of safety systems

Non-destructive techniques involve leaving the test piece undamaged. Many of the techniques can be undertaken on-site. The selection of the particular technique for a specific situation is important, as it needs to take into account the limitations and weaknesses of each technique in order for there to be confidence in the results obtained.

Dye Penetrant

This technique involves the use of dye penetrant to highlight the defect so that a visual inspection can be made. The surface of the material to be tested is first cleaned thoroughly, including the removal of any lubricant in the form of oil or grease. In an on-site location, this is carried out using a solvent cleaner to remove any traces of grease. The dye is then applied, normally by spraying, and this penetrates into any surface crack. After a period of time the excess is wiped off. To make the dye visible, it is 'developed' by spraying with a developer which is naturally white but absorbs the dye from the defect, giving an indication on the surface as to the location of any defects at which to direct visual or other examinations.

Acoustic Emission

Acoustic Emission (AE) is the production of sound waves when a material undergoes internal change as a result of an external force. Elastic energy is released by a material as it undergoes deformation or fracture. Typical emission frequencies of these elastic waves are 100kHz to 1MHz. Mechanical loading on a component can generate elastic waves caused by small surface displacement of the material. The rapid release of energy within the material can be detected as cracks grow, fibres break or other damage occurs in the stressed material.

Small-scale damage is detectable long before failure, so AE can be used as a non-destructive technique to find defects during structural proof tests and plant operation. The technique can also be used to study the formation of cracks during a welding process, as opposed to locating them after the weld has been formed with the more familiar ultrasonic testing technique.

Emissions are detected by an ultrasonic transducer probe in close contact with the material surface and transmitted to a receiving instrument, which records and displays their frequency, amplitude and duration. If the characteristics of sounds normally emitted from the material are known, then abnormal ones can be identified. If more than one probe is used, the location of the source of abnormal emission can be determined.

Typical applications of the Acoustic Emission principle in testing materials include:

- Examination of the behaviour of materials such as metals, ceramics, composites, rocks, and concrete to examine crack propagation, fatigue, stress corrosion or creep.
- Non-destructive testing during manufacturing processes.
- Continuous monitoring of metallic structures.
- Periodic testing of pressure vessels, pipelines, bridges, cables.

Ultrasonic

This method involves the use of a generator transmitting ultrasound waves into a material and detecting them when they are reflected from within the material. It is analogous to the geological mapping process that uses reflected shock waves to interpret discontinuity phenomena underground.

The ultrasound waves are generated in a head that is placed upon and moved across the surface, generally with some form of lubricant (e.g. water) to minimise any air gap. The ultrasound travels into the material and is 'bounced' back to a receiver mounted in the head. The output is read on an oscilloscope. The equipment must be calibrated to the full depth of the material before starting. Any defect will cause a variation in the return signal and this can be interpreted to indicate the depth of the defect, so the technique can detect defects within the material that do not show on the surface.

Radiography

This process requires a source of gamma or x-rays, which are allowed to pass through the material and onto a strip of film. The radiation triggers a reaction in the film emulsion which, when developed, shows where the material is sound and also where any discontinuity/defect exists within the material. (The developed result is known as a 'radiograph'.)

This is an important method where a permanent record of the inspection is required. It is used extensively in steel fabrication, particularly in highly specified situations such as welds on oil rigs, pipework and reactor vessels.

Eddy Current

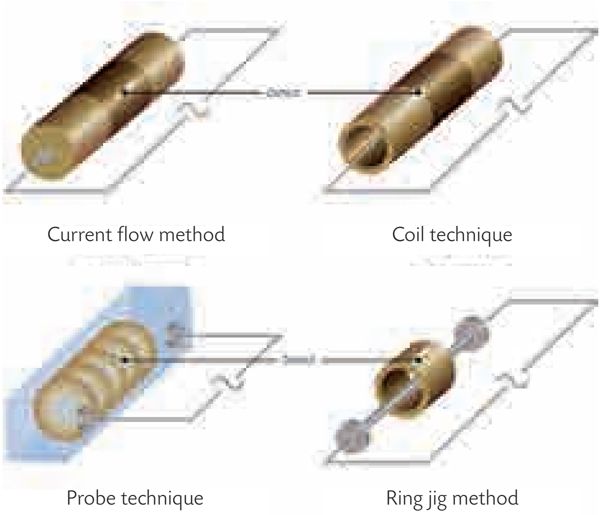
When a high-frequency AC current is passed through a coil, it sets up alternating magnetic fields. If the coil is placed next to the surface of an electrically-conducting material, it sets up eddy currents in the material. Any discontinuity in the surface causes a variation of the eddy current. If another coil is placed adjacent to the first, it can detect the changes in the eddy current, indicating the location of a defect. These changes can be calibrated and used to determine the depth of any defect.

Eddy current testing

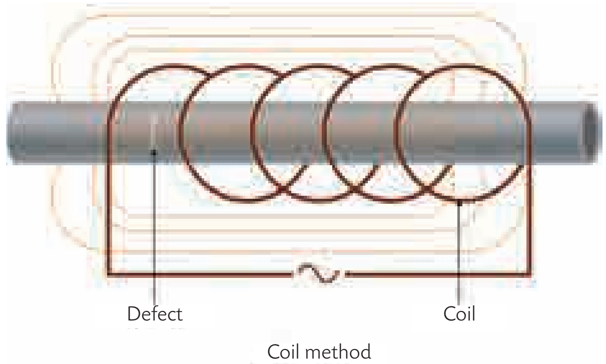
Magnetic Particle

This technique works by magnetising the component and applying magnetic particles or ink. Any defect in the component will show, as it distorts the magnetic field and the particles lie 'differently'. The defect tends to cause a concentration of the magnetic field, which attracts more particles to it than to the surrounding material.

The magnetic field may be applied using AC currents in one of a number of possible ways, as shown in the following figures:



Circular magnetisation for longitudinal cracks



Magnetisation for transverse cracks

Summary of Advantages and Disadvantages

The table that follows summarises the NDT methods available, together with their advantages and disadvantages.

Summary of NDT methods

Test	Advantages	Disadvantages
Dye Penetrant	Cheap and convenient. Superior to visual examination. For all non-porous materials.	Surface defects only. Defects must be open to the surface.
Acoustic Emission	Can be used to study the formation of cracks during a process and precisely locate the source.	Relies on complex equipment and skilled operators.
Ultrasonic	Precise location of internal and external defects. Sizing of many defects possible.	Expensive equipment. Dependent on a skilled operator and a power supply.
Radiography	Permanent, pictorial, easily interpreted images obtained. Locates majority of internal defects.	Safety hazards. Expensive x-ray sets. Thickness limits (more so with x-rays). Power supply required.
Eddy Current	Rapid detection of surface or sub-surface flaws. Can measure depth of shallow flaws.	Cannot operate close to other free surfaces, e.g. thin sheet. Cannot find deep flaws. Requires power source.
Magnetic Particle	More sensitive than dye penetrant. Can also find sub-surface defects.	Ferrous metals only. Cannot find defects at any significant depth. Requires power source.

STUDY QUESTIONS

6. Outline a range of precautions that might be required to reduce the risk of injury while maintenance work is being carried out.

7. Outline the:

   (a) **advantages** and

   (b) **disadvantages**

   of the operation of a planned preventive maintenance system.

8. Outline the factors to be considered in developing a planned maintenance programme for safety-critical components.

9. Describe the factors to be considered when determining inspection regimes for work equipment.

10. Describe the principle of operation of ultrasound as a non-destructive testing method.

11. Choose two other forms of non-destructive testing (i.e. not including ultrasound). For each of the two NDTs chosen, outline the advantages and disadvantages.

(Suggested Answers are at the end.)

Competence, Training, Information and Supervision in Relation to Work Equipment

IN THIS SECTION...

- **Competence** is defined as the ability to undertake responsibilities and perform activities to a recognised standard on a regular basis. It is a combination of skills, experience and knowledge.
- **Training** is an important component of establishing competence but is not sufficient on its own.
- Circumstances when training is likely to be required include:
  - Induction.
  - Changes in work activities.
  - Introduction of new technology or new equipment.
  - Changes in systems of work.
  - Refresher training.
- Groups of people having specific training needs include supervisors and young and vulnerable persons.
- In deciding on the appropriate level of supervision for particular tasks, the level will depend on the risks involved as well as the competence of employees to identify and handle those risks.
- There are specific training needs specified for certain hazardous types of work equipment such as chainsaws, woodworking machines, power presses and abrasive wheels.
- The employer is responsible for providing adequate health and safety information or, if necessary, written instructions for safe use of work equipment.
- Information should be easy to understand and written instructions should be available to the people using the work equipment and other appropriate people.

Training and Competence

Competence can be defined as the ability to undertake responsibilities and perform activities to a recognised standard on a regular basis. It is a combination of skills, experience and knowledge.

Training is an important component of establishing competence but is not sufficient on its own. For example, consolidation of knowledge and skills through training is a key part of developing competence.

Competence is a combination of skills, experience and knowledge

Circumstances when Training is Likely to be Required

It is important that all persons who use work equipment receive adequate health and safety training in how to use the work equipment, the risks associated with such use and the precautions that need to be taken.

The requirements for adequate training will vary according to the job or activity and the work equipment, but in general it will be necessary to:

- Evaluate the existing competence of employees to operate the work equipment in use.

- Evaluate the competence employees will need to manage or supervise the use of work equipment.
- Train the employees to make up any shortfall between their existing competence and that required.

Circumstances when training is likely to be required include: at induction; where there are changes in work activities; where new equipment or technology is introduced; where the system of work changes; and when refresher training is needed.

- Induction

  Training needs are likely to be greatest on recruitment. Recruitment and placement procedures should ensure that employees have the necessary abilities to do their jobs safely or can acquire them through training. New recruits need basic induction training in how to work safely, as well as arrangements for first-aid, fire and evacuation.

- Changes in Work Activities

  Additional training is required if the risks to which people are exposed change due to a change in their work activities. Consequently, people changing jobs or taking on extra responsibilities need to know about any new health and safety implications.

- Introduction of New Technology or New Equipment

  The risks to which people are exposed may change due to the introduction of new technology or new equipment. Again, persons employing new processes or new work equipment also need to know about the health and safety implications of such changes.

- Changes in Systems of Work

  Even if work activities and work equipment remain unchanged, it is likely that monitoring of health and safety standards and revision of risk assessments will result in improvements to systems of work, which will need to be implemented through revised training of the relevant workforce.

- Refresher Training

  Refresher training should be provided if necessary, because skills decline if they are not used regularly. A key example of this is people who deputise for others on occasions, who will probably need more frequent refresher training than those who do the work regularly.

Groups of People Having Specific Training Needs

Supervisors

In addition to the requirement to train users of work equipment, the employer also has a responsibility to ensure that any employees who supervise or manage the use of work equipment receive adequate health and safety training in how to use the work equipment, the risks associated with such use, and the precautions that need to be taken.

Young and Vulnerable Persons

Training and proper supervision of young people is particularly important because of their relative immaturity and unfamiliarity with the working environment. Induction training is of particular importance since all employees should be competent to use work equipment safely regardless of their age.

There may be national legislation relating to young people which sets out specific requirements for their training. For example, in the UK, the **Management of Health and Safety at Work Regulations 1999 (MHSWR)** contain specific requirements relating to the employment of young people (under the age of 18), requiring employers to assess risks to young people before they start work, taking into account their inexperience, lack of awareness of potential risks and their immaturity.

Competence, External and Self-Supervision

The relationship between competence, external (imposed) supervision and self-supervision is illustrated in the following diagram:

Levels of supervision
Source: HSG65 Successful health and safety management (2nd ed.), HSE, 1997 (now superseded)

The current version of HSG65 (third edition, 2013) adopts a Plan, Do, Check, Act approach and makes reference to extensive HSE guidance on competence, available at:

www.hse.gov.uk/managing/competence.htm

Deciding on the appropriate level of supervision for particular tasks will depend on the risks involved, as well as the competence of employees to identify and handle those risks. Consequently, external supervision will be needed if employees are new to a job, undergoing training or doing jobs which present special risks. Some supervision of fully competent individuals will always be needed to ensure that standards are being met consistently.

MORE... www.

Further information can be found in HSG65 *Managing for Health and Safety,* available at:

www.hse.gov.uk/pubns/priced/hsg65.pdfpriced/hsg65.pdf

Circumstances where there are Specific Training Needs for Certain Hazardous Types of Work Equipment

We have already noted how important it is that all persons who use work equipment receive adequate health and safety training in how to use the work equipment, the risks associated with such use and the precautions that need to be taken. For certain hazardous types of work equipment, there are specific training needs, as outlined below.

5.4 Competence, Training, Information and Supervision in Relation to Work Equipment

Self-Propelled Work Equipment

As with the training required for all work equipment, the training standard required for operators of self-propelled work equipment should be adequate in ensuring the health and safety of other workers and anyone else who may be affected by the work. The Approved Code of Practice (ACoP) and guidance to the UK **Provision and Use of Work Equipment Regulations (PUWER)** specifically imposes minimum training obligations in relation to driver training and states:

"You should ensure that self-propelled work equipment, including any attachments or towed equipment, is only driven by workers who have received appropriate training in the safe driving of such work equipment."

There is a further ACoP and guidance for those using lift trucks. This supports the **PUWER** ACoP in dealing specifically with the training for rider-operated lift trucks and states that:

"Employers should not allow anyone to operate, even on a very occasional basis, lift trucks... who has not satisfactorily completed basic training and testing as described in this ACoP, except for those undergoing such training under adequate supervision."

Source: HSE WAIT Tool (www.hse.gov.uk/work-at-height/wait/mewp-multi.htm)

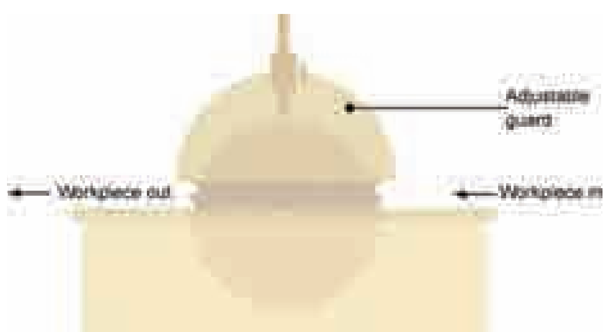
Those providing the training are also required:

- to have undergone appropriate training in instructional techniques and skills assessment, and
- to have sufficient industrial experience and knowledge of working environments to put their instruction in context.

Chainsaws

Chainsaws are potentially dangerous machines which can cause major injury if used by untrained people. Anyone who uses a chainsaw at work should have received adequate training and be competent in using a chainsaw for that type of work. The training should include:

- Dangers arising from the chainsaw itself.
- Dangers arising from the task for which the chainsaw is to be used.
- The precautions to control these dangers, including relevant legal requirements.



Circular saw

Woodworking Machines

The risks associated with the use of woodworking machinery are high, since it relies on high-speed sharp cutters to do the job. In many cases, these cutters are exposed to enable the machining process to take place. Additionally, many machines are still hand-fed.

Machine operators, those who assist in the machining process, and those who set, clean, or maintain woodworking machinery, should be provided with training.

All training schemes should include the following elements:

- **General** – instruction in the safety skills and knowledge common to woodworking processes.
- **Machine-specific** – practical instruction in the safe operation of the machine, including in particular:
  - The **dangers** arising from the machine and any limitations to its use.
  - The main **causes of accidents** and relevant **safe working practices**, including the correct use of guards, protection devices, appliances and the use of the manual brake where fitted.
- **Familiarisation** – on-the-job training under close supervision.

Power Presses

Power presses are among the most dangerous machines used in industry. Amputation or serious injury can result from accidents caused by trapping between the tools of a power press, and the guarding mechanisms are subject to continuous wear.

Power press

Persons appointed to inspect power presses require training, which includes suitable and sufficient practical instruction in relation to each type of power press and guard and/or protection device used.

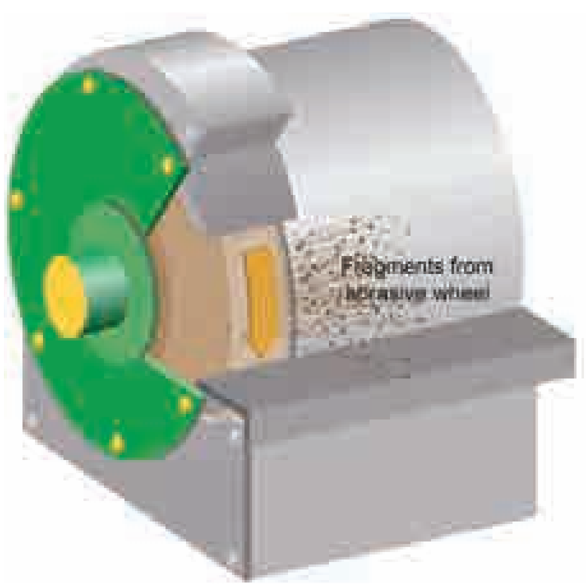
Press operators are most likely to need training when they are recruited. However, training is also required if:

- The risks to which people are exposed change.
- New equipment or technology is introduced.
- The system of work changes.

Training is also required for people who supervise or manage the use of power presses. Such training should include the safe operation of the press and the risks posed to the person carrying out the work (e.g. the press operator, setter or appointed person), as well as the quality of the inspection and test carried out by the appointed person.

Abrasive Wheels

One of the main risks associated with the use of abrasive wheels is injury resulting from breakage. Accident statistics indicate that nearly half of all accidents involving abrasive wheels are due to an unsafe system of work or operator error. Consequently, training is required both in the use and in the mounting of abrasive wheels.



Abrasive wheel

Any training programme should cover at least the following:

- Hazards and risks arising from the use of abrasive wheels and the precautions to be observed.
- Methods of marking abrasive wheels with their type, size and maximum operating speed.
- How to store, handle and transport abrasive wheels.
- How to inspect and test abrasive wheels for damage.
- The functions of all the components used with abrasive wheels, such as flanges, blotters, bushes and nuts.

- How to assemble abrasive wheels correctly to make sure they are properly balanced and fit to use.
- The proper method of dressing an abrasive wheel.
- The correct adjustment of the work rest on pedestal or bench grinding machines.
- The use of suitable personal protective equipment, e.g. eye protection.

Information Required for the Safe Use and Operation of Work Equipment

The employer has to ensure that all persons who use work equipment, and also those who supervise or manage it, have adequate health and safety information, or if necessary, written instructions on the use of the work equipment.

Providing information for the safe use and operation of machinery

This information should cover:

- All health and safety aspects arising from the use of the work equipment.
- Any limitations on these uses.
- Any foreseeable difficulties that could arise.
- The methods to deal with those difficulties.
- Any additional information obtained from experience of using the work equipment.

Consequently, the employer has to make available all relevant health and safety information and, where appropriate, written instructions on the safe use and operation of machinery to their workforce. Workers should have easy access to such information and instructions and be able to understand them.

Such written instructions can include the information provided by manufacturers or suppliers of work equipment, such as:

- Instruction sheets, manuals or placards.
- Warning labels.
- Training manuals.

They can also include in-house instructions and instructions from training courses.

Easily Understandable Information and Instructions

Information and instructions should be easy to understand. Written instructions should be available to the people directly using the work equipment and also other appropriate people such as maintenance staff.

Supervisors and managers also need access to the information and written instructions. The amount of detailed health and safety information they will need to have immediately available for day-to-day running of production lines will vary, but it is important that they know what information is available and where it can be found.

Information can be verbal where this is considered sufficient but, where there are complicated or unusual circumstances, the information should be in writing. Other factors that need to be taken into consideration include:

- The degree of skill of the workers involved.
- Their experience and training.
- The degree of supervision.
- The complexity and length of the particular job.

The information and written instructions should:

- Be in clear English and/or other languages if appropriate for the people using them.
- Be set out in a logical order, with illustrations where appropriate.
- Use standard symbols should be used where appropriate.

Special arrangements may be needed for employees with language difficulties or with disabilities which could make it difficult for them to receive or understand the information or instructions.

DEFINITION

WARNINGS

It may be necessary for work equipment to incorporate warnings or warning devices for reasons of health and safety.

If so, these warnings should be unambiguous, easily perceived and easily understood.

Examples include:

- Notices such as:
  - Positive instructions (e.g. 'hard hats must be worn').
  - Prohibitions (e.g. 'not to be operated by people under 18 years').
  - Restrictions (e.g. 'do not heat above 60°C').
- Warning devices which are:
  - Audible (e.g. reversing alarms on construction vehicles).
  - Visible (e.g. a light on a control panel that a fan on a microbiological cabinet has broken down or a blockage has occurred on a particular machine).
  - An indication of imminent danger (e.g. a machine about to start) or development of a fault condition (e.g. pump failure or conveyor blockage indicator on a control panel).
  - The continued presence of a potential hazard (e.g. hotplate or laser on).

STUDY QUESTIONS

12. Explain the difference between competence and training.
13. Outline the main circumstances when training is likely to be required.
14. Explain the relationship between competence, external (imposed) and self-supervision.
15. Explain why woodworking machine operators require specific training and what such training should include.
16. The employer has to ensure that all persons who use work equipment, and also those who supervise or manage it, have adequate health and safety information or, if necessary, written instructions on the use of the work equipment. What should this information cover?
17. Outline, with examples, the types of warnings or warning devices that might be needed for health and safety purposes in relation to work equipment.

(Suggested Answers are at the end.)

Pressure Systems

IN THIS SECTION...

- A pressure system is a means of storing and transporting energy for use in the workplace.
- Three types of pressure system are commonly defined:
  - A system comprising a pressure vessel, its associated pipework and protective devices.
  - Pipework, with its protective devices, to which a transportable pressure receptacle is connected.
  - A pipeline with its protective devices.

  All of the above must contain (or be liable to contain) what is sometimes called a 'relevant fluid' (e.g. steam).
- Pressure systems may require a written scheme of examination.
- The mechanisms of mechanical failure that lead to a loss of containment include: excessive stress; abnormal external loading; overpressure; overheating; mechanical fatigue and shock; thermal fatigue and shock; brittle fracture; creep; hydrogen attack; and corrosive failure.
- A strategy to prevent the failure of pressure systems should include: design and construction; repair and modification; information and marking; safe operating limits; written scheme of examination; maintenance and record keeping; and the requirement for competent persons.

Definition of a Pressure System

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Pressure system

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All of the above must contain (or be liable to contain) what is sometimes called a 'relevant fluid' (e.g. steam).

What is considered a 'relevant fluid' for the purposes of any local regulations is likely to vary in detail. However, as an example, here is what is considered within the scope of the term in the UK **Pressure Systems Safety Regulations 2000**.

Examples of pressure systems and equipment are:

- boilers and steam heating systems;
- pressurised process plant and piping;
- compressed air systems (fixed and portable);
- pressure cookers, autoclaves and retorts;
- heat exchangers and refrigeration plant;
- valves, steam traps and filters;
- pipework and hoses; and
- pressure gauges and level indicators.

DEFINITION

RELEVANT FLUID

This means:

(a) steam; or

(b) any fluid or mixture of fluids which is at a pressure greater than 0.5 bar above atmospheric pressure, and which is:

(i) a gas; or

(ii) a liquid which would have a vapour pressure greater than 0.5 bar above atmospheric pressure when in equilibrium with its vapour at either the actual temperature of the liquid or 17.5 degrees Celsius; or

(c) a gas dissolved under pressure in a solvent contained in a porous substance at ambient temperature and which could be released from the solvent without the application of heat

Types of Inspection, Frequencies and Statutory Basis for Examination of Pressure Systems

Good practice for pressure vessels, pipework and protective devices is presented in UK legislation - the **Pressure Systems Safety Regulations 2000**. These Regulations place obligations on anyone who manufactures or constructs a new pressure system, and anyone who repairs or modifies a new or existing pressure system or part of it, to ensure that no danger will arise when it is operated within the safe operating limits specified for that plant.

The other main requirements of the Regulations are that the user must:

- Establish the safe operating limits of the system.
- Have a written scheme of examination for the system.
- Maintain the system.
- Have operating instructions and ensure that the system is only operated in accordance with the instructions.

The concept of the written scheme of examination is important. It should be compiled before a pressure system can be operated. Details of the pressure vessels, protection devices and pipework should be included in the scheme. It should specify the nature and frequency of examinations and the measures necessary to prepare the system for safe examination.

A report of the periodic examination by the competent person should be given to the user or owner of the system within 28 days. However, if there is imminent danger from the continued operation of the system, the report should be provided within 14 days and a copy should be provided to the enforcing authority. The UK Regulations also require that records are retained.

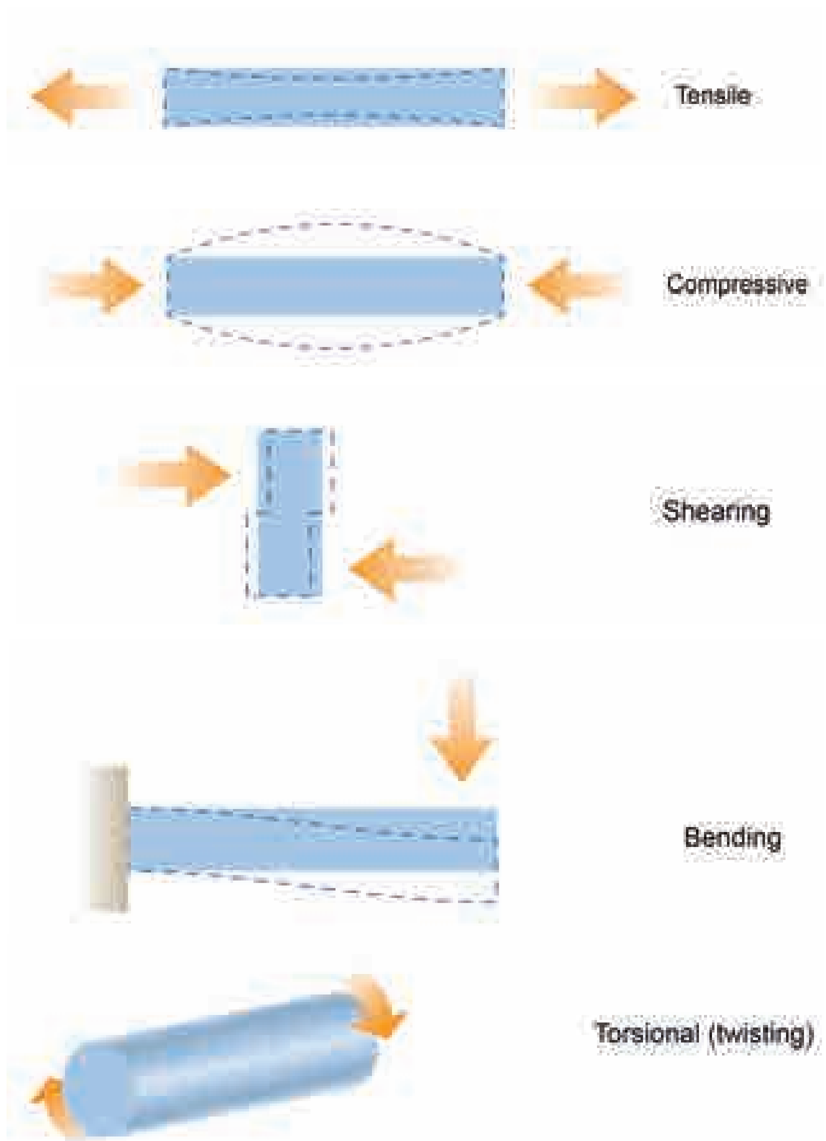
Mechanisms of Mechanical Failure that Lead to a Loss of Containment

There are many ways in which vessels, pipework and equipment in a system can suffer wear, tear and failure in the materials of their construction, including: creep, stress, stress-corrosion cracking, thermal shock, and brittle fracture.

Forces on Materials

Any force imposed on an item made from any material is resisted by the internal structure of that material, and this internal force is equal and opposite to the force applied.

- Pulling (stretching) a material is known as a tensile force.
- Pushing a material is known as a compressive force.
- A force not applied in line is called a shear force.
- External forces can be bending forces.
- Twisting forces are known as axial or torsional forces.



Main categories of stress

Excessive Stress

When material is heated, it expands. If this expansion cannot occur because the material is constrained, it will impose a stress on the material. When a system is installed, filled and pressurised for the first time, the various parts will move slightly and 'settle in'. If this is prevented by pipework being tightly clamped in place and is not free to expand, the system will become stressed and this could lead to failure. Residual stresses from manufacturing will produce the same effect and it is difficult, when investigating failure, to determine which of the two has caused the failure.

> **DEFINITIONS**
>
> **STRESS**
>
> The force applied per unit area.
>
> **STRAIN**
>
> The fractional distortion due to stress (e.g. the amount the material stretches compared to its original size).

Abnormal External Loading

This comes about by external forces being applied to the system, e.g. a ladder being rested against pipework or a vehicle impacting a pipe rack.

Overpressure

The major causes of overpressure include:

- Operating problems or mistakes, such as an operator mistakenly opening or closing a valve to cause the vessel or system pressure to increase. For example, they may adjust a steam regulator to give pressures exceeding the Maximum Allowable Working Pressure (MAWP) of a steam jacket.
- Equipment failures, e.g. a heat exchanger tube rupture that increases the shell side pressure beyond the MAWP.
- Process upset, e.g. a runaway reaction causing high temperatures and pressures.
- External heating, such as a fire that heats the contents of a vessel, giving high vapour pressures, and...
- Utility failures, such as the loss of cooling or the loss of agitation causing a runaway reaction.

Overheating

This occurs when the system runs faster than designed and the pressure relief system fails to work, e.g. an oil-burning boiler running at full pressure due to failure of the thermostatic controls. When this occurs, flames impinge directly onto the boiler tubes (over-firing) and a combination of low water flow and excessive temperature may mean an explosion would occur if the safety valve fails to function. Boilers may suffer this by having low water levels (boiler BLEVE).

Mechanical Fatigue and Shock

This is caused by the physical movement of parts of the system, setting up fatigue failure. An example of this is the bellows failure at Flixborough (mentioned in Element IC2) in that the bellows eventually could not withstand the movement. Movement may be caused by the effects of movement of the fluid, particularly if it flows in 'pulses', e.g. water hammer. Shock failure is similar to that of external loading but applied very rapidly.

Thermal Fatigue and Shock

This is caused by the constant changes in temperature from hot to cold and vice versa. These changes have the effect of making the material expand and contract, which sets up cyclic stress reversal, leading to fatigue failure.

Brittle Fracture

This is caused by cold changing the characteristics of the material from which the system is made, e.g. polymer seals need to be selected with care as their use in 'cold' systems makes the material brittle and liable to failure.

Creep

At normal temperatures, and within the elastic region, materials will often develop their full strain as soon as the stress is applied. However, at elevated temperatures and with a constant load/stress applied close to the elastic limit, the material may continue to deform slowly over time. This is essentially a slow process of plastic deformation, and is referred to as **creep**. The extent to which creep acts is dependent on two main factors: **time**, as creep is a slow process, and **temperature**, as creep can be accelerated by increasing the temperature. Creep is therefore a major factor in hot, high-pressure environments such as boilers.

Creep is not a true mode of failure as the failure will occur as either brittle or ductile, depending on the type and properties of the parent material. It is included as it is a specific factor that has to be considered, particularly as it is time-dependent.

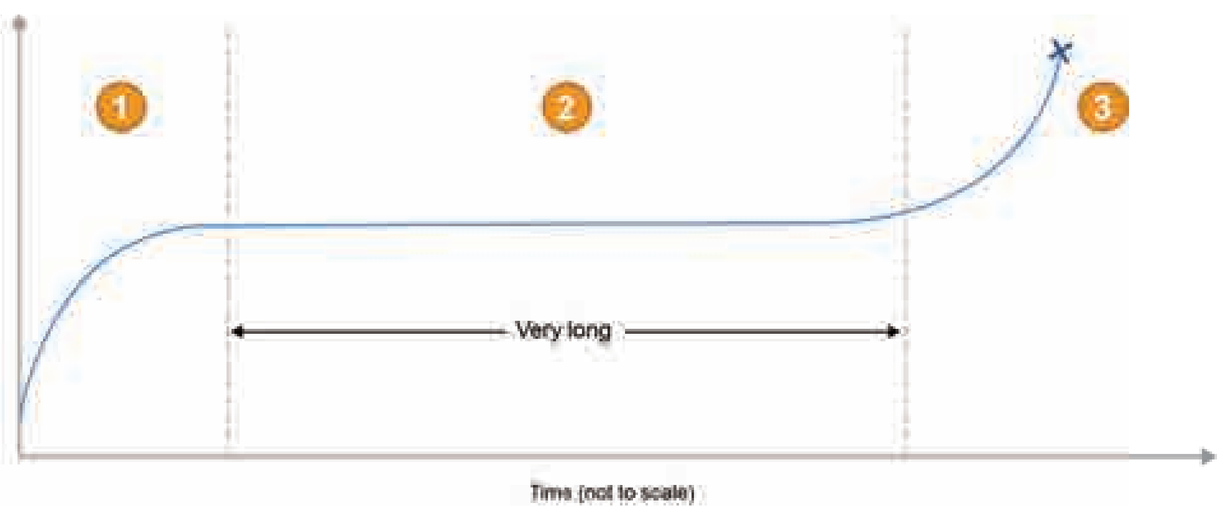
DEFINITION

DUCTILITY

A ductile material has the capacity to deform permanently (e.g. stretch, bend, or spread) in response to stress. Most common steels, for example, are quite ductile and hence can accommodate local stress concentrations. Brittle materials, such as glass, cannot accommodate concentrations of stress because they lack ductility, and therefore fracture easily. When a material specimen is stressed, it deforms elastically at first; above a certain deformation, called the elastic limit, deformation becomes permanent.

Ductile fracture or failure is a type of materials failure which is characterised by extensive deformation or 'necking'. This usually occurs prior to the actual fracture. The term 'ductile rupture' refers to the failure of highly ductile materials. In such cases, materials pull apart instead of cracking. In ductile fracture, there is absorption of massive amounts of energy and slow propagation before the fracture occurs.

Investigation into creep has shown that it occurs in three general stages, as shown in the following figure (which shows strain (at constant load and temperature) against time):



Creep curve

In the initial stage (1), which is called primary creep or transient creep, the rate is initially rapid but then slows down to a constant rate (2) of secondary creep. Eventually this moves into (3) tertiary creep where the rate increases rapidly until failure. This transition between secondary and tertiary creep is believed to be caused by the formation of small internal cavities or localised necking, which cause the stresses to be increased in other areas, leading to an increase in the strain. Once this occurs, the rate of creep increases considerably (see figure above).

Creep can lead to the failure of pressure systems from fractured steam pipes or cracks developing in boiler heater tubes. It is primarily controlled by design and the choice of materials, e.g. chrome-molybdenum steels have low creep characteristics.

Hydrogen Attack

This is a particular problem within steel steam-boiler tubes when the pH drops below normal levels. In such cases, water reacts with the steel under high temperature conditions to produce hydrogen (corroding the iron in the process). The hydrogen then further reacts with carbides in the steel and decarbonises it (forming methane gas). The result is two-fold:

- Loss of material due to corrosion.
- Loss of strength due to hydrogen attack – micro-cracking.

Corrosive Failure

This is caused by substances in the relevant fluid attacking the material from which the system is made. This is usually because of impurities within the fluid, as the system has to be designed to take the fluid. Boilers or other systems using water are particularly susceptible, especially where the system supply has to be regularly replenished. Corrosive failure will often occur inside the system, making detection difficult, so the examination process must set up a means of detection.

CASE STUDY

The following incidents illustrate the mechanism of corrosive failure and the circumstances in which it can occur.

- **Piping Failure – External Corrosion Problem**

  A failure occurred on a 10" high pressure (475 psig) process gas line in a high volume process system.

  The hydrocarbon release was very large and the vapours found an ignition source almost immediately, resulting in a large and intense initial fire. Over many years of operation (and moisture entrapment from rain and summer sweating) the pipe suffered external corrosion with irregular pitting and eventually the pipe ruptured.

- **Corrosion Fatigue Failure of Tubes in Water Tube Boilers**

  Information on three relatively recent failures associated with water tube boilers, caused by corrosion fatigue of the outer water wall tubes, can be found at:

  www.hse.gov.uk/comah/alerts/corrosion.htm

Prevention and Testing Strategy

The key points in a prevention strategy are:

- Fit safety devices.
- Operate the system within the limits specified.
- Undertake a thorough inspection of the full system.
- Undertake more regular inspections between thorough inspections.
- Use Non-Destructive Testing (NDT) techniques to determine what is happening inside the system.

Design and Construction

Designers and manufacturers must consider at the manufacturing stage both the purpose of the plant and the means of ensuring compliance with any relevant legislation.


Thorough inspection of the full system

The designer, manufacturer, importer or supplier should consider and take due account of the following, where applicable:

- Expected working life (the design life) of the system.
- Properties of the contained fluid.
- All extreme operating conditions, including start-up, shutdown and reasonably foreseeable fault or emergency conditions.
- The need for system examination to ensure continued integrity throughout its design life.
- Any foreseeable changes to the design conditions.
- Conditions for standby operation.
- Protection against system failure, using suitable measuring, control and protective devices as appropriate.
- Use of suitable materials for each component part.
- External forces expected to be exerted on the system, including thermal loads and wind loading.
- Safe access for operation, maintenance and examination, including the fitting of access (e.g. door) safety devices or suitable guards, as appropriate.

Repair and Modification

When designing any modifications (including extensions or additions) or repairs to the pressurised parts of the system, whether temporary or permanent, the following should be taken into account:


Modifications to pressurised systems

- The original design specification.
- The duty for which the system is to be used after the repair or modification, including any change in relevant fluid.
- The effects any such work may have on the integrity of the pressure system.
- Whether the protective devices are still adequate.
- Continued suitability of the written scheme of examination.

Information and Marking

Adequate information about any pressure system should be made available to users/owners by designers, suppliers or those who modify or repair equipment. Basic information about pressure vessels should be permanently marked on the vessel. The information required is:

- The manufacturer's name.
- A serial number.
- Date of manufacture.
- The standard to which the vessel was built.
- Maximum and minimum allowable pressure.
- Design temperature.

Additional information about pressure vessels and information relevant to the whole system should be provided in writing.

It is not possible to give a complete list of all the additional information which might be necessary, but the following items should be considered where relevant:

- Design standards used and evidence of compliance with national/European/international standards or documentation showing conformity.
- Design pressures (maximum and minimum).
- Fatigue life.
- Design temperatures (maximum and minimum).
- Creep life.
- Intended contents, especially where the design has been carried out for a specific process.
- Flow rates and discharge capacities.
- Corrosion allowances.
- Wall thickness.
- Volume capacities, especially for storage vessels. Depending on the intended contents, these may be expressed as maximum volume, pressure or filling ratio.
- Materials of construction.

Safe Operating Limits

Designers, manufacturers and suppliers should be responsible for providing adequate information about the system or its component parts. The user/owner should not operate the system or allow it to be operated before the safe operating limits have been established.

Written Scheme of Examination, Maintenance and Record Keeping

It is the responsibility of the user/owner to select a competent person, capable of carrying out the duties in a proper manner, with sufficient expertise in the particular type of system. In some cases, the necessary expertise will lie within the user/owner's own organisation.

The term 'competent person' is used in connection with two distinct functions:

- Drawing up or certifying schemes of examination.
- Carrying out examinations under the scheme.

The competent person can be from within the user/owner's organisation or from outside, and should have sufficient understanding of the systems in question to enable that person to draw up schemes of examination or certify them as suitable.

Users should select a competent person to carry out the required duties.

Before a pressure system is operated, the user/owner should ensure that a **written scheme of examination** has been prepared. It should be drawn up by a competent person, or someone other than a competent person, who is certified as suitable by a competent person.

Responsibilities may be summarised as follows:

- The user/owner ensures the scope of the scheme is appropriate, i.e. which parts of the system are covered (with advice, if necessary, from a suitably experienced adviser).
- The competent person specifies the nature and frequency of examinations and any special measures necessary to prepare the system for safe examination.

The purpose of **maintenance** is to ensure the safe operation and condition of the system.

The type and frequency of maintenance for the system should be assessed and a suitable maintenance programme planned.

A suitable system for **recording and retaining information** about safe operating limits and any changes to them should be used. Whatever method is used, the information should be readily available to those people who need it, including the competent person responsible for the examinations in accordance with the written scheme.

For mobile systems, the owner should provide the user with a written statement detailing the safe operating limits or ensure that this information is clearly marked on the equipment.

Competent Persons

Pressure systems can be divided into three categories:

- Minor systems include those containing steam, pressurised hot water, compressed air, inert gases or fluorocarbon refrigerants, which are small and present few engineering problems. The pressure (above atmospheric pressure) is less than 20 bar and the temperatures in the system should be between -20°C and 250°C.
- Intermediate systems include most storage and process systems which do not fall into either of the other two categories.
- Major systems are those which, because of their size, complexity or hazardous contents, require the highest level of expertise in determining their condition. They include steam-generating systems where the individual capacities of the steam generators are more than 10MW, large pressure vessels and chemical reaction vessels.

The level of expertise required by the competent person depends on the size and complexity of the system in question.

STUDY QUESTIONS

18. List the various mechanisms of mechanical failure that could lead to a loss of containment in a pressure system.

19. Outline the elements of a strategy to prevent failure of pressure systems.

20. What basic information about pressure vessels should be permanently marked on the vessel?

(Suggested Answers are at the end.)

Summary

Selection of Suitable Equipment

We have:

- Considered the suitability of work equipment with reference to:
  - Task, process and environment in which it will be used.
  - Design, construction and adaptation of equipment for the work it will be used to do.
  - Energy and substances required or produced by equipment must be provided or extracted by safe means.
- Identified the ergonomic, anthropomorphic and human reliability considerations, including the design of controls and emergency controls and the need to reduce access wherever possible.
- Considered the ways in which people may come into contact with work equipment and ways to minimise this risk:
  - Size of openings.
  - Height of barriers.
  - Distance from danger.

Risks to Health and Safety Arising from the Use of Work Equipment

We have:

- Explained the need for risk assessment of work equipment.
- Identified the risks associated with work equipment relating to:
  - Initial integrity.
  - Where it will be used.
  - Purpose for which it will be used.
- Considered risks that could arise from:
  - Incorrect installation or re-installation.
  - Deterioration.
  - Exceptional circumstances which could affect the safe operation of the work equipment.
- Identified the hierarchy of controls for work equipment:
  - Remove all risk by design.
  - Use fixed enclosed guards.
  - Use other guards which are not fully enclosing.
  - Use protection devices (which do not prevent access but do prevent motion of the work equipment when close).
  - Use protection appliances which hold or manipulate the workpiece (keeping the operator away from danger).
  - Provide information, instruction, training and supervision.
  - Use Personal Protective Equipment (PPE).

Summary

Maintenance, Inspection and Testing

We have:

- Identified the hazards and control measures associated with maintenance of work equipment.
- Considered the strategies and options for maintenance, including the factors to consider and advantages and disadvantages of:
  - Planned preventive maintenance.
  - Condition-based maintenance.
  - Breakdown maintenance.
- Considered the factors relevant to developing a preventive maintenance programme for safety-critical components:
  - Importance in the process.
  - Failure during the production process.
  - Machine complexity and relationship with other machines.
  - Availability of replacement equipment.
  - Identification of critical components.
  - Environmental factors.
  - Maintenance capability and design of the machine.
  - Unknown factors.
- Noted, as an example of statutory duties for maintenance, those that exist in UK law under **PUWER**, **LOLER**, **PSSR**, and the **Electricity at Work Regulations 1989**.
- Outlined the requirement for inspection of work equipment and the need for functional testing of safety-related parts.
- Considered the operation of the principal non-destructive testing techniques, which are dye penetrant, acoustic emission, ultrasonic, radiography (gamma and x-ray), eddy current and magnetic particle.

Competence, Training, Information and Supervision in Relation to Work Equipment

We have:

- Defined training and competence and considered the circumstances where training will be required:
  - Induction.
  - Changes in work activities.
  - Introduction of new technology or equipment.
  - Changes in systems of work.
  - Refresher training.
- Considered the groups of people in a workplace who have specific training needs, e.g. supervisors, young and vulnerable people, etc.
- Identified the relationship between competence and external supervision.
- Outlined the circumstances where specific training needs are required by hazardous work equipment.
- Examined the information required for the safe use and operation of work equipment, which should cover health and safety aspects arising from the use of the work equipment, any limitations on its use, difficulties that could arise and the methods to deal with them.
- Noted that information and instructions regarding the operation and use of work equipment must be readily comprehensible to those concerned.

Pressure Systems

We have:

- Defined pressure systems.
- Considered the types of inspection, frequencies and statutory basis for examination of unfired pressure systems.
- Outlined the mechanisms of mechanical failure that lead to a loss of containment, which include:
  - Excessive stress.
  - Abnormal external loading.
  - Overpressure.
  - Overheating.
  - Mechanical fatigue and shock.
  - Thermal fatigue and shock.
  - Brittle fracture.
  - Creep.
  - Hydrogen attack.
  - Corrosive failure.
- Examined a strategy to prevent the failure of pressure systems, which should consider:
  - Design and construction.
  - Repair and modification.
  - Information and marking.
  - Safe operating limits.
  - Written scheme of examination.
  - Maintenance and record keeping.
  - The requirement for competent persons.

Exam Skills

QUESTION

Outline the practical control measures that can be taken to minimise risk when operating a bench-mounted circular saw. **(10)**

Approaching the Question

The last question we attempted may have looked daunting, but hopefully you will now feel more confident at tackling these. This is another example of a short, compulsory answer question. Remember that you need to average 50% across all of these questions to have a great chance of passing the exam, and that most people will have stronger and weaker questions. When revising, focus on the areas that you know are weaker – it may be easier to revise material that you are confident with but it won't give you the maximum benefit from your study efforts.

Allow yourself 15 minutes (time yourself!) and write a full answer. Remember, your answer should be an "outline".

Suggested Answer Outline

The examiner would require you to address the issues of machinery safety principles in relation to a bench saw. Remember, they can ask you about any item of equipment so be prepared for something you may not have seen. Picture the issues and apply the basic principles of safety management.

The examiner would be looking for ten of the following points to be addressed:

- Use of an adjustable top guard which is set to the correct height for the workpiece. (The need to ensure correct operation and/or adjustment of the top guard should be mentioned.)
- A fixed guard should be used to protect the portion of the blade beneath the bench.
- The use of a push-stick to feed material being sawn.
- Provision of adequate distance away from the blade when a person is removing cut materials from the table – this may be achieved by extending the table so that they are standing far enough away to avoid contact with the blade.
- The correct positioning of the riving knife.
- Ensuring correct selection, maintenance and adjustment of the blade.
- Training and competence of those working with the equipment.
- Provision of LEV to remove the dust generated (maintained in good order and inspected).
- Provision of adequate workspace around the equipment so that people can move freely without trip hazards, etc.
- Provision of adequate heat and lighting.
- Provision of one or more emergency stop devices which are clearly marked.
- Provision of local isolation devices for maintenance.
- Installation of the machine on a firm, level surface.
- Implementation of safe systems of work for safe use of the equipment – this includes training operators in these systems.
- Development of maintenance procedures, to check the guards are in place and used correctly and that the machine and LEV are in good working order, together with the training of maintenance personnel.
- Provision of PPE, e.g. dust masks, hearing protection and goggles if required.

Example of How the Question Could be Answered

Typical practical controls used with a bench-mounted circular saw include the following:

- *An adjustable guard to protect the saw blade on the cutting part of the blade. The adjustable guard is set by the trained operator so that the smallest part of the blade possible is exposed.*
- *A fixed guard around the portion of the blade beneath the table to ensure that it is totally enclosed.*
- *The operator will also need to feed the material past/through the blade, so either a feed device would be needed, or a remote device for pushing material through the blade (e.g. a push-stick) would need to be considered, to prevent access to the blade while it is rotating.*
- *The size of the table should also be designed to make access to the blade difficult from the reach point of view.*
- *The aspect of maintenance of the machine would need to be addressed, as the blade and LEV system will need access from a trained, competent member of staff, so local lockable isolation needs to be provided, clearly signed and accessible, along with a maintenance procedure detailing the safe system of work to be deployed when working on the machine.*
- *The machine will produce a significant amount of noise, vibration and dust, so effective control is required on these issues, including LEV, noise and vibration reduction/damping techniques along with any necessary PPE required to operate the equipment – eye protection, noise and dust.*
- *A safe system of work will be needed for operation of the bench saw, and appropriate levels of supervision, training and information and instruction will be needed on the hazards, controls, and systems of work to be followed.*
- *Finally you would need to check that all controls (emergency stops, stop/start, guards, etc.) meet the relevant standards.*

Reasons for Poor Marks Achieved by Exam Candidates

An exam candidate would achieve **poor marks** for not expanding on anything more than the use of guards and a push-stick – possibly due to not being able to picture the equipment and relate to the controls.

Unit IC - Part 1

Suggested Answers

No Peeking!

Once you have worked your way through the revision questions in this book, use the suggested answers on the following pages to find out where you went wrong (and what you got right), and as a resource to improve your knowledge and question-answering technique.

Element IC1: Workplace Welfare Requirements and Specific Workplace Issues

Question 1

- Sound construction.
- Adequate strength and stability.
- Not being overloaded.
- Free from holes, slopes, uneven or slippery surfaces.
- Holes, bumps or uneven areas made good.
- Slopes not being steeper than necessary.
- Slopes and ramps used by people with disabilities provided with a handrail.
- Surfaces likely to get wet or subject to spillages should be of a type which does not become unduly slippery (slip-resistant coating).
- Floors near to machinery slip-resistant and kept free from slippery substances.
- Arrangements to minimise risks from snow and ice.
- Kept free of obstructions which may present a hazard or impede access.
- Effective drainage should be provided where a floor is liable to get wet.

Question 2

- Methodology is based on using a pendulum Coefficient of Friction (CoF) test.
- Pendulum CoF test is based on a swinging, imitation heel which sweeps over a set area of flooring in a controlled manner:
  - Slipperiness of flooring has a direct and measurable effect on the pendulum test value.
- CoF results can be used to provide information on:
  - Different CoF values between one surface and another.
  - Effects of contamination on surfaces in terms of CoF.
- Pendulum results should be interpreted using:
  - High slip potential 0-24
  - Moderate slip potential 25-35
  - Low slip potential 36 +
- On a dry or wet surface, values of 36 or more (equivalent to a CoF of 0.36) are currently accepted to indicate satisfactory slip resistance.
- Further tests are carried out after contamination of the test surface with any expected contaminant:
  - Allows an insight into the actual CoF experienced in everyday working situations.

Question 3

Whenever there is a risk which has not been avoided or controlled by other means, e.g. by engineering controls and safe systems of work.

Question 4

Prohibition – round with white background and red border and diagonal red bar.

Mandatory – round with blue background and white symbol.

Safe condition – square or rectangular with white symbols on green background.

Warning – triangular black border with black pictogram on yellow background.

Question 5

The specific risks associated with confined spaces are: fire and explosion, increase in body temperature, asphyxiation, drowning and entrapment in a free-flowing solid.

Question 6

The atmosphere in a confined space can be harmful to workers due to: a lack of oxygen, build-up of toxic gas or build-up of flammable gas.

Question 7

A worker can enter or work in a confined space without BA if:

- Effective steps have been taken to avoid ingress of dangerous fumes.
- There is a Confined Spaces Permit-to-Work in place.
- All electrical, mechanical, chemical, heat and other sources have been isolated.
- Sludge or other deposits have been removed.
- The workplace has been cleaned, drained and purged as necessary, for the type of work to be carried out and entry to be made.
- The space contains no material liable to give off fumes.
- The space has been adequately ventilated and tested for fumes.
- There is an adequate supply of respirable air.
- The space has been certified as being safe for entry without breathing apparatus.

Question 8

BA sets, resuscitators, means of summoning help (radios, klaxons), life-lines, oxygen.

Question 9

The adverse effects of weather on a structure could include:

- Expansion and contracting of materials caused by heat.
- Ingress of moisture causing deformation, flaking, erosion, corrosion, etc.
- Structural problems caused by high winds.

Question 10

Four reasons for ground subsidence are: overloading, change in water content, the presence of mines and tunnels, and excavations.

Question 11

Sagging roof, bulging walls, signs of flaking masonry, collapsed walls, signs of corrosion on brickwork, dampness, dry or wet rot, gaps around window or door frames, uneven floors.

Question 12

Injury or death resulting from people falling from height, or objects falling from height onto people below.

Question 13

Examples include:

- Avoid: use long-handled tools to clean windows rather than climbing a ladder.
- Prevent: use additional equipment with permanent guardrails, e.g. tower scaffolds.
- Minimise: use personal protective equipment, such as a fall-arrest system.

Question 14

(a) Some of the hazards a lone worker might encounter could be:

- Working at height off of temporary access equipment, such as portable ladders or trestles.
- Restricted access and egress.
- Confined spaces.
- Dangerous machinery.
- Dangerous chemicals, dusts or biological hazards.
- Electricity.
- Flammable or explosive substances.
- Very cold or very hot environments.
- Heavy objects which are too large for one person.
- Violent or aggressive patients or clients.
- Violent or aggressive animals on farms or in zoos.
- Dangerous road conditions such as snow, ice, low sun or other, aggressive drivers.

(b) Risks a lone worker may face could be:

- Falling from height.
- Becoming trapped or engulfed in a liquid or free-flowing solid such as rice or grain.
- Being overcome or asphyxiated by fumes in a confined space.
- Becoming entangled in machinery.
- Being burned or overcome by dangerous chemicals or their fumes.
- Being electrocuted.
- Being burned or involved in an explosion.
- Suffering from heat exhaustion or hypothermia.
- Damaging limbs, muscles or bones lifting heavy objects.
- Being attacked by violent or aggressive patients or clients.
- Being attacked or savaged by violent or aggressive animals.
- Suffering injuries as a result of being involved in a road traffic accident.

Lone workers also face the risk of physical and mental problems due to the nature of their role.

Question 15

Control measures might include:

- Ensuring risk assessments identify lone working tasks on and off site and the potential hazards.
- Eliminating the hazards of working alone by using a buddy system. People should work in pairs at difficult or out-of-the-way sites, including home and community visits.
- Information on high-risk geographical areas or jobs should be given to staff (particularly new members) and records of staff whereabouts should be kept. Safe completion of jobs should be reported.
- Good communications at all times: mobile telephones and two-way radios can be useful in some cases.
- Electronic and visual monitors, which can also offer some protection.
- The introduction of a Personal Alarm Security System (PASS).
- Alarms: many counter, service and care workers have access to panic buttons and a range of other emergency, personal distress and violent attack alarms are available.
- Reorganise the way jobs are done to provide a safer system of work.
- Review procedures regularly to make sure they are working.
- The necessity for handling cash or dangerous materials should be continually reassessed.

When carrying out a lone working risk assessment, employers should ask the following questions:

- Can the risks of the job be adequately controlled by one person?
- Is there a risk of violence?
- Are women especially at risk if they work alone?
- Are young workers especially at risk if they work alone?
- Is the person medically fit and suitable to work alone?
- What training is required to ensure competency in safety matters?
- How will the person be supervised?
- What happens if a person becomes ill, has an accident, or there is an emergency?

Employers have a duty to provide first-aid facilities and welfare arrangements and ensure the safety of lone workers.

If national governments are signatories to the International Labour Organisation (ILO) then *Occupational Safety and Health Convention C155* and *Recommendation R164* will be the main source of direction for the provision of first-aid for lone workers. The ILO also produces guidance documents such as *The Organisation of First-Aid in the Workplace* to assist employers in this duty.

Suitable equipment, facilities and training should also be provided under C155 as well as C119 (Guarding of Machinery Convention) and C148 (Working Environment (Air Pollution, Noise and Vibration)), to ensure lone workers are able to work in safety.

For all jobs, the national laws that apply to other exposed workers such as entry into confined spaces, electricity, VDU and PPE, also apply to the lone worker.

Article 11 of Convention C155 also requires that all accidents, near-misses and incidents of violence should be recorded and studied at regular intervals to prevent further occurrences.

Free-to-download guidance documents and leaflets are also available on the UK HSE website (www.hse.gov.uk) to help employers who might have lone workers.

Element IC2: Fire and Explosion

Question 1

- Flash point is the lowest temperature at which sufficient vapour is given off to flash, i.e. ignite momentarily, when a source of ignition is applied.
- Auto-ignition temperature is the lowest temperature at which the substance will ignite without the application of an ignition source.

Question 2

With the flash point of petrol being so low, under normal conditions it will always be giving off sufficient vapour to be above the fire point. Any source of ignition is therefore liable to result in fire.

Question 3

Confined Vapour Cloud Explosion (CVCE), Unconfined Vapour Cloud Explosion (UVCE) and Boiling Liquid Expanding Vapour Explosion (BLEVE).

Question 4

A CVCE occurs if a flammable vapour cloud is ignited in a container, e.g. a process vessel, or in a building, so that it is confined. Pressure can build up until the containing walls rupture. A UVCE results from the release of a considerable quantity of flammable gas or vapour into the atmosphere and its subsequent ignition.

Question 5

A primary explosion occurs in part of a plant, causing an air disturbance. The air disturbance disperses dust and causes a secondary explosion, which is often more destructive than the primary explosion.

Question 6

When placed in a fire situation, unprotected steel will rapidly lose its designed shape and therefore its strength. In a fire, a steel beam will expand and push the columns out, causing the floor slabs to collapse onto the floor below. This floor, not being strong enough to carry the extra load placed on it, also collapses. In a multi-storey building the effect is often that the whole building collapses floor by floor. The steelwork can also spread heat by conduction, causing the fire to spread.

Question 7

The paint, when exposed to excessive heat, bubbles; this gives additional protection to the covered timber.

Question 8

The spread of fire within a building can be minimised by compartmentation and the use of suitable fire-resistant walls, floors and fire doors.

Question 9

Fire-stopping can be described as preventing the spread of smoke and flame by placing obstructions across air passageways. Ventilation ducts and gaps around doors must have the facility to be stopped in the event of a fire. This can be achieved by the use of baffles, self-closing doors and intumescent material which expands when subject to heat, sealing the opening.

Question 10

Any four of the following features should be considered:

- Wherever possible, they should be isolated from other buildings.
- Buildings should preferably be one storey high.
- If inside, the vulnerable area of the building must be reinforced.
- The rest of the areas of the plant must be protected (a blast wall is needed).
- Sufficient explosion venting to avoid structural damage from overpressure must be provided.
- Hot gases from the explosion must be vented to the outside atmosphere to prevent secondary fires.

Other features are safe escape routes in case of an explosion/fire, fire-resistant construction materials, fire-resistant doors and good electrical insulation.

Question 11

- Zone 0 is classified as a place in which an explosive atmosphere consisting of a mixture with air of dangerous substances in the form of gas, vapour or mist is present continuously or for long periods of time or frequently.
- Zone 20 is classified as a place in which an explosive atmosphere in the form of a cloud of combustible dust in air is present continuously or for long periods or frequently.

Question 12

Consideration must be given to ensuring that any fluids (gas or liquid) that may escape when a bursting disc fails are safely vented away from the operator.

Question 13

Bursting discs are the weakest point in the system – they are designed to fail and so avoid mechanical damage to the rest of the system.

Element IC3: Workplace Fire Risk Assessment

Question 1

- Smoke inhalation, triggering conditions such as asthma.
- Inhalation of superheated air, causing burning and failure of the lungs.
- Suffocation or respiratory difficulties caused by depletion of oxygen.
- Poisoning by inhalation of toxic gases given off by combustion products.
- Burning by heat, flames or explosion.
- Injury from falling or collapsing structures.
- Falls from a height while attempting to escape.
- Crushing injuries caused by panic or stampede.
- Injury from broken and flying glass.
- Mental or physical trauma.
- Death.

Question 2

A fire risk assessment should adopt a structured approach that ensures all fire hazards and associated risks are taken into account:

- Identify fire hazards – look for all the sources of ignition, fuel and oxygen that together might cause fire.
- Identify people at risk – anyone who may be affected, not just workers, e.g. maintenance staff, contractors, cleaners, security guards, etc. Visitors, members of the public and those who may be at particular risk (e.g. young or inexperienced workers, people with mobility or sensory impairment, etc.) must also be considered.
- Evaluate, remove, reduce and protect from risk – through the use of:
  - Preventive measures to remove or reduce the risk of fire breaking out (e.g. effective control of ignition sources, appropriate storage of flammable materials, good housekeeping, maintenance and inspection of equipment, etc.).
  - Protective measures to remove or reduce people being harmed in the event of a fire occurring (e.g. provision of automatic detection and alarm systems, adequate means of escape, fixed and portable fire-fighting equipment, etc.).
- Record, plan, inform, instruct and train – significant findings of the assessment should be recorded; emergency plans should be developed; appropriate information and instruction should be provided to relevant persons; appropriate training should be provided.
- Review – the fire risk assessment should be reviewed regularly to take account of such things as new or changed fire hazards; after a significant or major incident; after a significant change in the workplace, etc.

Question 3

The four types of detector commonly used are:

- Ionisation smoke detectors.
- Optical detectors.
- Radiation detectors.
- Heat detectors.

Question 4

Regular tests of an alarm system serve to check the circuits and to familiarise staff with the call note.

Question 5

Manual alarm systems are suitable for small workplaces.

Question 6

The five classes of fire are:

- A - Solids (organic solids).
- B - Flammable liquids and liquefiable solids (subdivided into those miscible with water and those which are not).
- C - Gases and liquid gases.
- D - Flammable metals.
- F - Cooking fat fires.

Question 7

The colour-coding of fire extinguishers and the types of fire that they are suitable for are as follows:

- Water - Red - Class A fires.
- Foam - Cream - Classes A and B fires.
- Dry Powder - Blue - Classes A, B and C fires.
- Carbon Dioxide - Black - Class B and electrical fires.
- Wet Chemical - Yellow - Class F fires.

Question 8

Starvation refers to the removal of the fuel part of the fire triangle. This can be achieved by taking the fuel away from the fire, taking the fire away from the fuel and/or reducing the quantity or bulk of fuel available. Materials may therefore be moved away from the fire (to a distance sufficient to ensure that they will not be ignited by any continuing radiant heat) or a gas supply may be turned off.

Question 9

While dry powder and carbon dioxide may be used to knock the flame down, there is a risk of a build-up of gas if it cannot be turned off. In some situations, it may be preferable to allow the fire to continue and to call the fire service.

Question 10

The main factors to consider for an adequate means of escape are the:

- Nature of the occupants, e.g. mobility.
- Number of people attempting to escape.
- Distance they may have to travel to reach a place of safety.
- Size and extent of the place of safety.

Question 11

A place of relative safety exists where a fire door is placed between people and the fire. Once within this place, the structure will protect people from smoke and heat while they make their way to a place clear of risk.

Question 12

Fire-resisting doors (smoke-stop) are used to:

- Break corridors into sections and thereby reduce the area of smoke-logging.
- Separate stairs from the remainder of the floor area.
- Confine an outbreak of fire to its place of origin.
- Keep escape routes free of smoke for long enough to permit evacuation of occupants.

Question 13

Emergency escape lighting should be provided in those parts of buildings where there is underground or windowless accommodation, core stairways or extensive internal corridors. Generally, the need for such lighting will arise more frequently in shops than in factories and offices, because of the greater likelihood of people in the building being unfamiliar with the means of escape.

Question 14

The following topics should be covered in each training session, with practical exercises where possible:

- Action to take on discovering a fire.
- How to raise the alarm and the procedures this sets in motion.
- Action to be taken on hearing the fire alarm.
- Procedures for alerting members of the public including, where appropriate, directing them to exits.
- Arrangements for calling the fire and rescue service.
- Evacuation procedure for everyone in the premises to an assembly point at a place of safety.
- The importance of reporting to the assembly area.
- Location and use of fire-fighting equipment.
- Location of escape routes, including those not in regular use.
- How to open all escape doors.
- The importance of keeping fire doors closed.
- How to stop machines and processes and isolate power supplies where appropriate.
- The reason for not using lifts (except those specifically installed or nominated, following a suitable fire risk assessment).
- The safe use of highly flammable and explosive substances, as well as the risks from storing or working with them.
- The importance of general fire precautions and good housekeeping.
- The items listed in the emergency plan.
- The importance of fire doors and other basic fire-prevention measures.
- Exit routes and the operation of exit devices, including physically walking these routes.
- General matters, such as smoking policy or restrictions on cooking.
- Assisting disabled persons where necessary.

Question 15

The **operation** of the system is as follows:

- The building is split into small areas of responsibility.
- Each area is allocated to a specific fire marshal.
- Fire marshals are designated people who, in the event of a fire:
  - Search and check their allocated area.
  - Ensure that all people have left the building.
  - Direct those who have not left the building to an appropriate fire exit and safe assembly point.
  - Report that their area has been checked and is clear.

The **benefits** of the system include:

- The use of trained persons who are familiar with the premises to evacuate other people who may not be familiar with the premises.
- Marshals can compensate for any adverse human behaviour which might hinder or delay the evacuation.

Question 16

To execute the Personal Emergency Evacuation Plan special aids may be needed, such as:

- **Personal trembler alarms**, which "vibrate" at the same time as the alarm.
- **Buddy system**, where someone is allocated the task of helping the person with a sensory impairment.
- **Visual alarms** for the **hearing-impaired**, such as a flashing beacon.
- **Tactile/Braille** signs for the **visually impaired**, providing the person can locate the sign and is also able to read Braille.

Element IC4: The Storage, Handling and Processing of Dangerous Substances

Question 1

The rate of a reaction will increase exponentially with increase in temperature; in practical terms, an increase of 10°C roughly doubles the reaction rate in many cases.

Question 2

Important factors in preventing thermal runaway reactions are mainly related to the control of reaction velocity and temperature within suitable limits.

Question 3

A suitable store for flammable solids should:

- Only be used as a store.
- Be used only for hazardous substances.
- Not be used for mixing or processing.
- Be kept clean.
- Contain a non-hazardous heating system.
- Be separated from fire risks.
- Be ventilated to open air.
- Use correct electrical equipment.
- Have fire-detectors and fixed fire-fighting installations where necessary.

Question 4

This may be an impervious sill or low bund, typically 150mm high, and big enough to hold 110% of the contents of the largest container.

Question 5

Corrosive materials include acids, acid anhydrides and alkalis. They can destroy living tissue (such as skin or eyes) on contact. Such materials often destroy their containers and get into the atmosphere of a storage area; some are volatile, others react violently with moisture.

Question 6

To avoid overfilling, care should be taken to ensure that the receiving container is large enough to receive the total amount of substance that is going to be delivered. The process must be supervised throughout the filling and delivery process.

Question 7

Spray booths are typically classified as zone 1 areas – where an explosive gas/air mixture is likely to be present during normal operation.

Question 8

The container being used should be **suitable** for the substance that is being put into it. It must also be **undamaged**, with no signs of leakage, staining or corrosion.

Question 9

Dispensing should be done in a well-ventilated area in order to quickly dilute any escaping vapour concentrations to below the lower flammable limit.

Question 10

This can be prevented by strict operating procedures and the use of couplings of a different design for each substance.

Question 11

Equipment which is liable to damage by corrosion due to the presence of moisture should be totally enclosed in corrosion-resistant housing which is not vented to the atmosphere.

Question 12

Flameproof equipment is totally enclosed and the casing must be robust enough to withstand internal explosions without igniting the flammable atmosphere in which the equipment is located. Examples of type 'd' equipment are: motors, lighting, switchgear and portable handlamps. Due to its robust structure, it is heavy and expensive. It is suitable for use in zones 1 or 2, but is unsuitable for zone 0.

Question 13

Purging is a method whereby a flow of air or inert gas is maintained in a room or enclosure to reduce or prevent a flammable atmosphere occurring.

Question 14

Zone 2 classification is given to an area in which an explosive atmosphere consisting of a mixture with air of dangerous substances in the form of gas, vapour or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

Question 15

An emergency plan for dealing with victims of an explosion in a factory manufacturing paints and varnishes would have to consider the following:

- Treatment of the injured people on site.
- Transportation of the injured people to hospital.
- Evacuation of the building and site.
- Containment of the fire (to prevent further damage/injury from fumes, etc.).

The emergency plan would outline the actions required immediately after the explosion. For example, these could include:

- Raise the alarm (contact emergency services, e.g. fire department, police and ambulance).
- Evacuate the building/site.
- Advise the local community to keep windows closed, etc.
- Consider evacuation of local houses.
- Seal off other supplies to prevent further explosions/spread of fire.

Considerations relating to dealing with the victims of the explosion would include ensuring that adequate first-aid facilities and first-aiders are available.

Once the site has been made safe and the victims have been looked after, the company then has to start considering its recovery plan.

Details of the emergency plan should be shared with the local emergency services and other relevant external bodies such as the water company and environmental authorities. Information relating to the types of chemicals stored, and any fumes likely to come off as a result of fire, explosion or spillage, should be identified.

Question 16

(a) The emergency evacuation procedures for each site should be developed by considering the types of hazards that are present, e.g. dangerous substances, and the types of emergency situations that could occur, e.g. fire, explosion, flood, etc. Consideration must also be given to whether an emergency on site could affect neighbouring houses or the environment. Once these have been determined, safe routes for evacuating the buildings at each site must be identified, ensuring that the routes give adequate protection against the types of emergency that could potentially occur. Additionally, a safe 'muster point' must be identified to where people on site must evacuate. The names of people on-site authorised to set emergency procedures in motion, and the people in charge of and co-ordinating the on-site mitigatory action, must be identified. All this would be completed in liaison with the local emergency services and external bodies, where appropriate.

(b) All employees must be trained in the emergency procedures and this will be a part of the induction training. Refresher training will also be carried out at regular intervals (e.g. annually). Written notices of the procedures will be displayed at appropriate points throughout the workplace. Where employees work at more than one site, they will receive a briefing for each site.

(c) The effectiveness of the procedures will be monitored by having practice evacuations of each site and by questioning employees as to what they understand the procedures to be. This questioning could be included in a health and safety audit.

Element IC5: Work Equipment

Question 1

Any five from the following criteria:

- Clearly visible.
- Appropriately marked.
- Positioned for safe operation.
- Designed so that movement of the control is consistent with the effect required.
- Located outside the danger zone, except for certain controls, e.g. emergency stop.
- Positioned so that their operation cannot cause additional risk.
- Designed to prevent unintentional operation.
- Made to withstand foreseeable strain, particularly emergency controls.
- Fitted with dials, etc. if required for safe operation.
- Starting of the machine can only be by means of the control, particularly after adverse conditions, e.g. a power cut.
- Stopping devices should be fitted.
- Emergency stopping devices should be fitted, clearly marked and to work effectively.
- The control must override any part of the system except the emergency control.
- Any fault or failure must not lead to danger.
- Interactive software must be user-friendly to the operator.

Question 2

A number of precautions to prevent accidental operation can be taken:

- Recessing the control.
- Orientating the control so that the normal direction from which any accidental activation may occur will not cause it to be operated.
- Using two-handed controls and shrouded start buttons and pedals.
- Covering the control with a hinged cover.
- Locking the control.
- Operationally sequencing a set of controls.
- Increasing control distance.
- Ensuring that any starting that is initiated from a keyboard or other multifunction device, should require some form of confirmation in addition to the start command, and the results of the actuation should be displayed.

Question 3

The factors that need to be considered when identifying the risks associated with the use of work equipment include:

- Initial integrity.
- The location where it will be used.
- The purpose for which it will be used.
- Incorrect installation or re-installation.
- Deterioration.
- Other exceptional circumstances which could affect its safe operation.

Question 4

- Initial integrity:
  - Equipment should be suitable, by design, construction or adaptation, for the actual work it is provided for to do. When first providing work equipment for use in the workplace, the employer should make sure that it has been made to the requirements of any prescribed standards.
- The place where it will be used:
  - The location in which the work equipment is to be used should be assessed to take account of any risks that may arise from the particular circumstances.
- The purpose for which it will be used:
  - This requirement concerns each particular process for which the work equipment is to be used and the conditions under which it will be used. The equipment should be suitable for the process and conditions of use.

Question 5

- Eliminate the risks created by the use of work equipment through careful selection.
- Employ 'hardware' (physical) measures such as:
  - Suitable guards.
  - Protection devices.
  - Markings and warning devices.
  - System control devices, such as emergency stop buttons.
  - Personal protective equipment.
- Employ 'software' measures such as:
  - Following safe systems of work.
  - Ensuring maintenance is only performed when equipment is shut down.
  - Provision of information, instruction and training.

Question 6

Precautions might include:

- Plan the work carefully before the start.
- Produce a safe system of work.
- Ensure maintenance staff are competent.
- Provide suitable and safe means of access to all parts of the equipment.
- Physical isolation of the equipment.
- Release any stored energy in lines or pumps.
- Use portable lighting (a torch or low-voltage lamp may often be sufficient) where necessary.
- Ventilation, including local exhaust ventilation (LEV).
- Use of suitable tools (possibly substituting electrically-powered tools with pneumatic tools in certain environments).
- Carrying out work during 'down time' or at quiet periods.
- Not carrying out work in situ and instead removing items to be worked on in a more suitable location.
- Blocking or shoring-up moving parts to prevent unexpected movement.
- Providing suitable protective equipment to reduce the effects of hazardous substances, sharp objects, hot surfaces, etc.

Question 7

(a) Advantages:

- Safer operation.
- Reduced downtime and lost production.
- Increased reliability of equipment.
- Failure-rate predictions.
- Rapid turnaround of parts.
- Maintenance carried out at times of least disruption.
- Reduced risk from planned maintenance operations.

(b) Disadvantages:

- Over-maintenance, with reduced efficiency.
- High costs of parts still with useful life.
- Management time for planning and operating schedules.
- Over-familiarity with tasks leading to complacency.
- Higher skill level.
- Increased storage requirements for spare parts.

Question 8

Factors to be considered in developing a planned maintenance programme for safety-critical components include:

- Importance of the component in the overall process.
- Relative importance of failure during the production process.
- Machine complexity.
- Relationship with other machines.
- Availability of replacement equipment.
- Identification of critical components.
- Environmental factors.
- Maintenance capability within the company.
- Maintainability within the design of the machine.
- Unknown factors.

Question 9

The factors to be considered when determining inspection regimes for work equipment include:

- The type of equipment:
  - Are there safety-related parts which are necessary for safe operation of the equipment, e.g. overload warning devices and limit switches?
- Where it is used:
  - Is the equipment used in a hostile environment where hot, cold, wet or corrosive conditions may accelerate deterioration?
- How it is used:
  - The nature, frequency and duration of use will determine the extent of wear and tear and the likelihood of deterioration. In addition, equipment regularly dismantled and re-assembled will require inspection to ensure that it has been installed correctly and is safe to operate.

Question 10

This method involves the use of a generator transmitting ultrasound waves into a material and detecting them when reflected from within the material. It can be compared to the geological mapping process that uses reflected shock waves to interpret discontinuity phenomena underground. The ultrasound waves are generated in a head that is placed upon and moved across the surface, generally with some form of lubricant (e.g. water-based lubricant) to minimise any air gap. The ultrasound travels into the material and is 'bounced' back to a receiver mounted in the head.

The output is read on an oscilloscope. The equipment must be calibrated to the full depth of the material before starting. Any defect will cause a variation in the return signal and this can be interpreted to indicate the depth of the defect, so it can detect defects within the material that do not show on the surface.

Question 11

As an example, if you have chosen radiography and dye penetrant, the advantages and disadvantages might look like this:

Test	Advantages	Disadvantages
Radiography	Permanent, pictorial, easily interpreted images obtained. Locates majority of internal defects.	Radiation safety hazards. Expensive X-ray sets. Thickness limits (more so with X-rays). Power supply required.
Dye Penetrant	Cheap and convenient. Superior to visual examination. For all non-porous materials.	Surface defects only. Defects must be open to the surface.

Question 12

Competence can be defined as the ability to undertake responsibilities and perform activities to a recognised standard on a regular basis. It is a combination of skills, experience and knowledge.

Training is an important component of establishing competence but is not sufficient on its own. For example, consolidation of knowledge and skills through training is a key part of developing competence.

Question 13

Circumstances when training is likely to be required include:

- On joining an organisation (induction).
- On promotion (particularly into a managerial or supervisory role).
- Changes in or taking on new work activities.
- If the risks to which people are exposed change due to a change in their working tasks.
- Introduction of new technology or new equipment into the workplace.
- Changes in systems of work.
- Refresher training for routine or specialist roles.

Question 14

Where an activity is carried out by highly competent staff and the degree of risk is low, then self-supervision will be adequate. However, where competence levels are low and the work activity involves a significant level of risk, then close supervision will be required to ensure that the work is carried out safely. Some supervision of fully competent individuals will always be needed to ensure that standards are being met consistently.

Question 15

Woodworking machine operators require specific training because the risks associated with the use of woodworking machinery are high. The machines rely on high-speed sharp cutters to do the job and in many cases those cutters are exposed to enable the machining process to take place. Additionally, many machines are still hand-fed.

All training schemes should include the following elements:

- General - instruction in the safety skills and knowledge common to woodworking processes.
- Machine-specific - practical instruction in the safe operation of the machine, including in particular:
  - The dangers arising from the machine and any limitations as to its use.
  - The main causes of accidents and relevant safe working practices, including the correct use of guards, protection devices, appliances and the use of the manual brake where fitted.
- Familiarisation - on-the-job training under close supervision.

Question 16

This information should cover:

- All health and safety aspects arising from the use of the work equipment.
- Any limitations on these uses.
- Any foreseeable difficulties that could arise.
- The methods to deal with them.
- Any additional information obtained from experience of using the work equipment.

Question 17

Types of warnings or warning devices include:

- Notices such as:
  - Positive instructions (e.g. 'hard hats must be worn').
  - Prohibitions (e.g. 'not to be operated by people under 18 years').
  - Restrictions (e.g. 'do not heat above 60°C').
- Warning devices which are:
  - Audible (e.g. reversing alarms on construction vehicles).
  - Visible (e.g. a light on a control panel that a fan on a microbiological cabinet has broken down or a blockage has occurred on a particular machine).
  - An indication of imminent danger (e.g. a machine about to start) or development of a fault condition (e.g. pump failure or conveyor blockage indicator on a control panel).
  - The continued presence of a potential hazard (e.g. hotplate or laser on).

Question 18

The various mechanisms of mechanical failure that could lead to a loss of containment in a pressure system include:

- Excessive stress.
- Abnormal external loading.
- Overpressure.
- Overheating.
- Mechanical fatigue and shock.
- Thermal fatigue and shock.

- Brittle fracture.
- Creep.
- Hydrogen attack.
- Corrosive failure.

Question 19

The key points in a prevention strategy are:

- Fit safety devices.
- Operate the system within the limits specified.
- Undertake a thorough inspection of the full system.
- Undertake more regular inspections between thorough inspections.
- Use Non-Destructive Testing (NDT) techniques to determine what is happening inside the system.

Question 20

The information required is:

- The manufacturer's name.
- A serial number.
- Date of manufacture.
- The standard to which the vessel was built.
- Maximum and minimum allowable pressure.
- Design temperature.