Environment, Health and Safety Committee [EHSC]

Note On

FIRE SAFETY IN CHEMICAL LABORATORIES

Pre-amble

This Note is designed to provide basic information and advice for RSC members. It may also be useful to others with a particular interest in the subject

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1. INTRODUCTION

Fire safety is a key issue for all chemical laboratories. Since 1985 there have been 114 serious fires in laboratories each of which incurred losses in excess of £50,000. In the period February 1999 to May 2000 there were 8 serious laboratory fires (4 in universities and 4 in schools) which incurred a total loss of £2,875,000. Four of these fires were started deliberately. There have also been numerous minor fires in chemical laboratories. Fires cause fatalities, serious injury and serious disruption to normal work activities.

The Fire Precautions Act 1971 sets out the requirements for general fire precautions in terms of the means of detecting and giving warning in case of fire, the provision of means of escape, the means of fire fighting and the training of staff in fire fighting. The Fire Precautions (Workplace) Regulations 1997 (as amended) include a requirement to undertake an assessment of the fire risks.

The Health and Safety at Work Act 1974 [HSWA] and the Regulations made under it, including the Management of Health and Safety at Work Regulations 1999 [MHSWR] , cover the provision of process fire precautions which are intended to prevent the outbreak of a fire or minimize the consequences should one occur. These precautions include the storage of flammable liquids, the control of flammable vapours, housekeeping, safe systems of work, the control of sources of ignition and the provision of training for employees.

The combined effect of the MHSWR and the Fire Regulations is to require employers to:

- make a fire risk assessment of the workplace referring to the risk of a fire occurring and the risk to all people who may be affected if it does;

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- identify the significant findings of the assessment and the details of anyone who may be especially at risk;

- provide and maintain appropriate fire precautions including emergency and evacuation plans; and

- provide information, instruction and training about fire precautions to anyone who may be affected.

2. FIRE RISK ASSESSMENT

Fire risk assessment is a systematic method of considering fires which might arise both in the workplace and from the work activities and which could cause harm to people. The assessment process can be summarized in five steps:

i. Identification of the fire hazards.
ii. Identification of the people who may be at risk (employees, students, visitors, contractors and members of the public).
iii. Evaluation of the risks arising from the hazards in terms of whether or not the existing precautions are adequate, or whether further action is required to reduce the chance of fire to an acceptable level.
iv. Recording the findings of actions taken as a result of the above and informing employees of the outcomes.
v. Review of the assessment when the situation changes.

If more than five people are employed by an organization then the fire risk assessment must be recorded. It is good practice, however, to keep such records in all circumstances. The assessment will prompt decisions on both the general and process precautions that will be required or will need to be improved. Arising from the assessment an action plan should be established for the elimination or further reduction of the fire risks.

The following sections consider the hazards that are typically encountered in chemical laboratories and the control measures which should be applied.

3. FIRE HAZARDS

Fire hazards in laboratories arise from the storage and use of flammable, explosive and oxidizing substances and fuel gases, and from undertaking hazardous operations.

Flammable substances

There is a high risk of fire in many laboratories because of the storage and use of flammable substances, which may be in solid, liquid or gaseous form.

The magnitude of hazard from flammable substances depends both on their physico-chemical properties and the quantities involved. For a liquid the flashpoint, auto-ignition temperature, explosive limits, vapour density, and ability to accumulate an electrostatic charge are all important. The possibility of such hazards being accentuated through oxygen enrichment should also be considered.

Fire or explosion can occur when flammable vapours are mixed with oxygen or air in proportions within critical values known as the Lower and Upper Explosive Limits (LEL and UEL, respectively). For most solvents the LEL lies within the range 1-5% in air and therefore good ventilation is essential in order to eliminate the risk of forming a flammable or explosive atmosphere when such substances are used. However, it is significant that the LEL is usually considerably greater than the occupational exposure limit for the concentration of vapour in the workroom air.

Vapours from flammable liquids are denser than air and thus tend to sink to ground level where they can spread over a large area. Care should be taken to minimise the production of such vapours and the associated risk of ignition by flashback from a remote source.

Flammable or combustible solids that are often encountered in laboratories include alkali metals, metallic hydrides, some organometallic compounds, phosphorus and sulphur.

Explosive substances and mixtures

The risk of explosions from mixtures of flammable vapours with air has been referred to above. Explosions can also occur when flammable substances are mixed with solid or liquid oxidants and the need for such combinations should always be assessed before proceeding.

Some substances can detonate as a result of friction, shock, heat (eg organic peroxides) or contamination (eg mixtures of perchloric acid with a wide range of materials can be highly unstable). In addition to hazards associated with the handling of these substances it should be remembered that unstable substances may be formed during chemical operations or prolonged storage and appropriate measures should be taken to avoid this happening. For example, certain ethers, alcohols and aldehydes can form peroxides that may detonate during distillation. For this reason bottles of substances prone to peroxidation should not be kept for prolonged periods once they have been opened.

Some substances are inherently unstable and can detonate under certain conditions of pressure and temperature (eg acetylene, carbon disulphide and substances prone to autopolymerisation).

Almost all of the gas now used in laboratories as burner fuel is natural gas (methane) although propane and butane from cylinders may also be encountered. Acetylene, hydrogen and nitrous oxide are also used (eg in atomic absorption equipment where special requirements apply).

Other Combustible Materials

A range of combustible materials, such as paper, cardboard, plastics and other packaging, etc. are often found in laboratories. In the event of a fire these materials along with furniture and construction materials, such as hardboard and chipboard, will contribute significantly to the spread of the fire.

Hazardous Operations

A number of hazardous operations may be undertaken in laboratories that could give rise to fire and explosion risks. These include reactions at either high temperature and/or high pressure and oxidation reactions.

Sources of Ignition

Commonly encountered sources of ignition in laboratories include naked flames (Bunsen and other burners), hot plates, ovens, furnaces, electricity (short circuits, switchgear sparking, faulty wiring/equipment or non-flameproofed equipment), static electricity, high intensity radiation and oxidising agents. Smoking is now generally prohibited in chemical laboratories.

4. FIRE CONTROL MEASURES

Fire Prevention and Precautions

Fire depends on the presence of a fuel, an oxidant (usually air) and normally a source of ignition. Therefore, the prevention of fires relies on eliminating one or more of these. This can best be achieved by a combination of good design and safe working practice.

The design and construction of chemical laboratories is covered in detail in the Building Regulations 1991, various British Standards and other publications. However, it is important that stocks of flammable materials are kept to a minimum, especially those outside approved storage areas. It will often be necessary for solvent stores to be licensed by the local authority. (More information about storage is given below). If a fire occurs it is important to provide containment in order to limit its spread to adjoining areas. Difficulties arise in laboratory buildings because of potential chimney effects created by fume cupboard exhausts and service ducts. Firebreaks are desirable in such ducts and fusible-links dampers may be necessary. With these the damper is held open by a light weight metal link which melts at high temperatures and causes the damper to close.

Ideally at least two protected escape routes should be provided. Emergency exits must be clearly identified by suitable signs and must not be obstructed by furniture or other movable items. Fire Certificates are required for certain classes of premises such as factories.

An appropriate fire detection and fire alarm system should be provided. The location of all fire alarm call points should be clearly marked. Smoke and/or rate of rise heat detectors should be considered, especially in laboratories where equipment is left running unattended. Automatic fire extinguishing systems may also be considered. Portable fire fighting equipment should also be provided. The selection and use of fire extinguishers is considered below.

The design of safe working procedures is as important in fire prevention as the provision of adequate facilities. Reference to safe working procedures is included in various sections below.

Storage of Flammable Substances

Flammable substances must be stored in correctly designed fire-resisting stores. Ideally such stores should be separate buildings in order to minimise the impact of a fire on the main laboratory building. All stores should be clearly marked to indicate their contents and to warn of flammability. Stocks should be controlled, and where possible kept to a minimum, by the careful management of purchase, stock rotation, use and disposal. Access to stores must be restricted to authorised persons who have been instructed in the nature of the hazards and in the safe handling precautions, including procedures in the event of a spillage. All containers must be labelled in accordance with the Chemicals (Hazard Information and Packing for Supply) [CHIP] Regulations (as amended from time to time). The arrangement of materials in stores should be simple and logical (eg alphabetical) and any special requirements for segregation of incompatible materials should be followed.

The fire and explosion hazards involved with the storage of flammable liquids can be minimised by storing these in properly designed containers inside fire resisting store rooms and cupboards and by taking care to prevent or contain spillages during storage and dispensing. Sources of ignition should be removed from stores and no other combustible materials should be kept in them. Adequate provision of absorbent materials, such as vermiculite, must be available to deal with spillages. An appropriate method for disposing of the used absorbent should be arranged. On no account should flammable material be washed down drains if it is spilled.

Flammable liquid stores should be ventilated both at high and low level to prevent the build up of vapours. A sill should be provided at the doorway of the store in order to retain any spillages inside the store. Any electrical equipment such as lights, heaters etc should be of special flameproof construction to prevent vapours being ignited.

No more than 50 litres of flammable liquid should be stored in each room of a laboratory and it should be kept in a fire-resisting cupboard or bin. All such storage cupboards should be clearly marked with their content and its flammability. Shelves in cupboards should be provided with a lip to contain any spillage. The maximum size of any container kept on the bench should be 500ml. Containers kept on the bench should, wherever possible, be stored on a tray to contain any spillage or leakage.

Certain flammable liquids which are petroleum spirit-based and have flash points of 21C or below come within the scope of the Petroleum (Consolidation) Act 1928. This includes many common solvents. Stores for such substances require a Petroleum Licence that should be obtained from the local Fire Authority.

When flammable liquids are transported within the laboratory appropriate carriers should be used for anything other than small glass bottles. Dispensing of flammable liquids from bulk containers should be carried out by trained staff in a safe area. Wherever possible the need for dispensing should be avoided by the purchase of the correct sized containers. As indicated above all containers should be properly labelled.

Where flammable liquids are used steps should be taken to contain or minimise any spillages or loss of containment arising, for example, from fractured glassware, overboiling, loss of cooling to a condenser or inappropriate methods of transferring liquids. In addition to written safe working instructions, it may be appropriate to provide benches with lips or catchment trays to contain spillages and losses of containment.

The storage of volatile, flammable liquids in ordinary refrigerators has led to serious explosions and, consequently only specially designed or modified refrigerators should be used for this purpose.

Cylinders of flammable gases should ideally be stored outside the laboratory in a secure well ventilated compound or storeroom. Gas cylinders should be stored vertical and secured to prevent them falling. Acetylene cylinders must always be kept upright. Full and empty cylinders should be segregated and individual gases kept in separate bays where possible. Flammable gases should be segregated from oxygen and other oxidising gases. Where a gas distribution system is used, manifolds and pipes should be of appropriate material, colour coded and labelled at appropriate points. Pipework and fittings for acetylene should not include any copper, otherwise copper acetylide can form on internal surfaces and could give rise to an explosion risk.

Fuel gases

All fuel gas lines (like other services) should be colour coded for identification and labelled at suitable intervals along their length. Maintenance and repair of gas pipelines and equipment should only be undertaken by trained and competent maintenance staff. The system should be inspected at regular intervals to identify any damage and possible leaks. Particular attention should be given to any flexible tubing (eg from bench cocks to burners) to ensure that it is properly connected and secured.

The main gas supply to each building should be fitted with an easily identifiable and readily accessible control valve to enable authorised persons to isolate the supply to the building. Consideration should be given to interlocking any fire detection system with the automatic shut-off valves on the flammable or oxidant gases supplies. All laboratory staff should be aware of the need to shut off all equipment, including burners and pilot lights, should the gas supply be interrupted for any reason.

Control of Explosive Substances and Mixtures

All explosive or spontaneously combustible substances and mixtures should be stored in accordance with the manufacturer's or supplier's health and safety datasheet. It is good practice to inspect all such materials on receipt for signs of damage or decomposition. Periodic rechecking is also advisable to ensure that there has been no deterioration of the substances or their packaging.

Some substances can be stored safely at normal temperatures but begin to decompose as the temperature increases. It is unsafe to store such substances in areas that are likely to overheat due to direct sunlight, for example. Redundant heating pipes should be isolated to prevent inadvertant reconnection. It may be necessary to use a temperature controlled storeroom or refrigerator and regular checks will need to be done to monitor the temperature to detect any malfunctions that could lead to an increase in the risk of decomposition. Any faults detected should be remedied. There could also be a risk associated with storage at too low a temperature if the substance concerned can separate from a diluent by crystallisation, for example.

Where picric acid is used regular checks should be made on opened bottles to ensure that the solid level is well covered with water. It is also advisable that the outside rim of the bottle is wiped to remove any smears of saturated picric acid solution prior to replacing the closure to prevent it drying out and exploding next time the bottle is opened.

Where perchloric acid has been used for metal alloy analysis over a long period, the fume cupboard extraction ducting may harbour significant amounts of perchlorates. Special precautions should be taken when inspection or maintenance of the ducting is undertaken in order to prevent explosions.

It is important that any explosive substances and materials which are surplus or which can no longer be kept safely are disposed of in a safe manner. Advice on the disposal of such materials should be obtained from the supplier and information should be kept readily available for use in an emergency.

Control of Other Combustible Materials

The amount of combustible material such as paper and packaging should be kept to minimum. All refuse and discarded paper and packaging should be removed on a regular basis. Particular care should be taken when disposing of oily or solvent soaked wipers or rags to prevent spontaneous combustion or the ignition of the residual solvent vapours.

Electrical Equipment

The Electricity at Work Regulations 1989 require that “any electrical equipment which may reasonably foreseeably be exposed to any flammable or explosive substance, including dusts, vapours or gases, shall be of such construction or as necessary protected as to prevent, so far as reasonably practicable, danger arising from such exposure”.

The extent to which explosive atmospheres arise from vapours or gases in most laboratories is usually limited. In any case it should often be possible to avoid siting electrical equipment in the hazardous zone.

In the event that electrical equipment is within the hazardous zone there are a number of techniques or concepts of protection that can be applied. These are ways of preventing ignition which are defined in relevant UK standards. They include ‘intrinsically safe’, ‘specially protected’, ‘flameproof’, ‘pressurised’, ‘increased safety’, ‘type N’, ‘oil immersed’ and ‘powder filled’. The type of equipment required must be matched with the hazard zone. Categories of hazard zone are also defined in UK standards. They are :

- Zone 0 - explosive gas/air mixture is present continuously or for long periods;
- Zone 1 - explosive gas/air mixture is likely to occur in normal operation; and
- Zone 2 - explosive gas/air mixture is not likely to occur in normal operation but if it does it will be only for a short period.

In laboratories explosion protection may be needed in measurement and control applications. In such circumstances the intrinsic safety concept may prove to be the most flexible and economic. Intrinsic safety is achieved by restricting the electrical energy in that part of the electrical system that is in the hazardous zone so that it is insufficient to ignite the gas or vapour.

Electrical equipment for use in hazardous zones should be certified as being designed and constructed to comply with an appropriate standard. The need for suitably protected equipment extends to cables, their termination and glands. If due attention is not paid to these matters the integrity of the equipment itself will be lost.

Potentially explosive atmospheres that arise as a result of flammable dust in air will also require appropriately protected electrical equipment. The problems are not quite so complex and the solution is based primarily on limiting the external surface temperature and ensuring that dust cannot enter enclosures.

Control of Hazardous Operations

Whilst this section refers primarily to oxidation reactions the guidance given is equally applicable to other types of reaction that involve fire and explosion hazards. The scale of all oxidation work, unless known to be safe, should be kept to a minimum. Staff should know the flammable limits of gaseous mixtures and, if possible, should aim to work well outside the flammable or explosive range. It should be remembered that changes of temperature or pressure modify these ranges.

The maximum possible energy release and the rate of release should always be considered. Where the apparatus is not capable of containing such release it should be placed within an adequate enclosure from which personnel are excluded throughout the period of risk. Safe operating procedures should be introduced and should include the siting of controls outside the enclosure and, if appropriate the provision of interlocks.

When flammable gases are taken outside the enclosure (eg for analysis or to exhaust) they must be made safe, for example by dilution with an inert gas to below the Lower Explosive Limit. Mixing of gases should be carried out inside the enclosure. Appropriate pressure relief vents and flame traps should be incorporated in the apparatus and adequate maintenance procedures must be adopted.

When transferring solids to vessels traces of the solid should not be left on the vessel walls. Vapours may be ignited by pyrophoric materials such as Raney Nickel, platinum, cobalt, manganese and palladium. Many materials not normally pyrophoric may become so when present in a finely divided state.

Unstable peroxides may be formed as by-products or intermediates in liquid-phase oxidations, eg when certain ethers or aldehydes are oxidised. The person in charge of such experiments should, where possible, determine the acceptable upper limit for peroxide concentration. The concentration of peroxide should be monitored to ensure that it remains below the limit.

The person in charge should make regular checks to ensure that the nature and degree of any explosion hazard does not exceed those for which the protective equipment was designed.

Fire Fighting Equipment

All employees must be trained to react promptly to any fires that break out in the laboratory. The first priorities must be to raise the alarm and to evacuate the building. Extinguishers are provided to put out small fires or to contain large fires whilst other occupants escape from a room or building to a place of safety. If there is any doubt about the ability to extinguish a fire then escape is the only option.

All fire extinguisher points should be clearly labelled, preferably above the height of any obstruction, and information on the use of each type of extinguisher should be given. It is essential that a sufficient number of suitable extinguishers is available and that employees are familiar with their use and limitations. Periodic refresher training should also be given on the use of extinguishers.

The choice of fire extinguisher depends on the nature and the scale of the laboratory operations. For small laboratory fires which involve flammable liquids (Class B fires) the choice of portable extinguishers lies among vaporising liquids, carbon dioxide and dry powders. In most laboratories the first two are likely to be preferred. Any of them may be used on electrical fires. Irrespective of the choice of extinguisher everyone should be evacuated from the location at which a fire has occurred because the products of combustion of even commonplace materials may be highly toxic.

Fires involving large quantities of contained flammable liquids are best extinguished with foam or dry powder. For fires involving spilled or running flammable liquids dry powder is the most suitable extinguisher. Foam should not be used on electrical fires.

For fires involving solid materials such as wood or paper (Class A fires) water is the preferred extinguishing medium because of its cooling power. Water should not be used on fires involving electrical equipment and care should be taken in laboratories where water-reactive chemicals are in use. Nevertheless, water extinguishers should always be available to complement other types of extinguisher.

Fires involving gases or vapours (Class C fires) can be very difficult to fight as extinguishing the flame can allow the accumulation of a dangerous gas/air mixture which is liable to re-ignite or even explode should it reach an ignition source. The supply of gas should be isolated before the flame is extinguished with a suitable extinguishing medium such as dry powder or foam.

Particular risks are associated with fires involving water-reactive substances such as certain metals, metal hydrides or metal alkyls (Class D fires). Special powders are available for use in such situations.

Some laboratory operations are best protected by fixed extinguishing systems, which may be activated automatically or operated manually. Extinguishing media used include water sprays, halons and carbon dioxide. The protection of employees must always be carefully considered whenever fixed automatic systems are installed, bearing in mind the potentially asphyxiating properties of such systems. It should be noted that halons used in existing fixed systems may no longer be available because of their potential effect on the ozone layer.

Fire blankets should be kept available for use where people may have their clothes on fire. Such blankets should be of an adequate size (minimum 0.9m X 0.9m; maximum 1.8m X 1.8m). Fire blankets can also be effective for dealing with small fires.

All fire fighting equipment should be inspected by a competent person at least annually. Once an extinguisher has been used it should be refilled or replaced immediately.

Training and evacuation

Fire instructions giving details of actions to take in the event of a fire should be displayed in all rooms and at all exits. This information should also be included in the health and safety policy and, if appropriate, in the safety manual and employee handbook. Line managers should make the evacuation arrangements appropriate to each area and regular evacuation exercises should be undertaken and recorded. Instructions should be given about turning off equipment if it is appropriate and safe to do so prior to evacuating. All persons given special responsibility for evacuation procedures should have deputies who should be available to act in their absence. Fire alarms should have a distinctive sound and should be audible in all areas of the laboratory. Alarms should be tested on regular basis, preferably at least once a month so that over a year each call point is tested at least once.

Fire escape routes and fire exits should be clearly marked by suitable signs and wherever practicable emergency lighting should be provided. Fire escape routes and exits should be kept clear and unobstructed at all times. All members of staff should be aware of the locations at which they should assemble after evacuation and all assembly points should be clearly marked. Procedures should be established to ensure that all personnel, visitors and contractors are accounted for after and evacuation. Special arrangements should be made to ensure the safe evacuation of any disabled persons. If personnel are not accounted for after an evacuation, in no circumstances should members of staff re-enter the laboratory to search for them. The Fire Brigade should undertake this task if, and when, it is safe to do so.

Fire Records

A Fire Log book should be maintained in which records are kept of all fire training (including evacuation drills), all inspections and tests of fire detection equipment, fire fighting equipment, fire alarms and emergency lighting and all checks of fire doors and fire escape routes. Keeping a Fire Log is a legal requirement in all premises with Fire Certificates and is best practice in all laboratories.

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