
Safety in health-care laboratories



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Introduction

This manual is intended for health-care laboratory workers and those responsible for laboratory administration and planning. It provides guidelines for health and safety in the work environment, and caters to all laboratory activities except in major areas of microbiology.

The manual is not intended to be a complete treatise on safety in the laboratory; it offers a pragmatic approach to the problems encountered in routine practice. References are made to the *Laboratory Biosafety Manual*, relevant WHO and other publications. Where local or national regulations and guidelines exist, these should also be consulted and would take precedence.



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1. The laboratory safety programme

The laboratory safety programme is designed to prevent injury to and illness in all laboratory personnel—medical, technical and ancillary—and to protect other people with right of entry, e.g. hospital tradesmen, industrial service engineers, nurses and patients. All laboratory personnel have a responsibility to adhere to and enforce the programme at all times and should avoid complacency.

Properly designed, the organization of the safety programme permits the management to share and assign responsibility for accident prevention and ensure compliance with safety standards by the staff. The relevant components of the safety programme must be included in every laboratory.

Occupational injuries and illnesses may result from:

- bad practices;
- ignorance;
- inexperience;
- failure to follow established procedures.

Overcrowding, heavy workloads, incorrectly installed and poorly-maintained equipment and badly-designed premises are frequent contributing factors.

The essential objectives of the safety programme are:

- appropriate design of premises;
- safe management of the laboratory environment;
- effective training of staff.

Despite the prominence given in present-day scientific literature to the transmission of the hepatitis B virus (HBV) and human immunodeficiency virus (HIV) and the serious consequences of infection by these agents in laboratory personnel, they represent only a small proportion of potential hazards in the laboratory. Important as these are, it is unwise to concentrate solely on the elimination of such infectious hazards.

There is a common pattern in the mechanism of injury regardless of the nature of the primary injurious stimulus. For example, chemical substances and microbiological agents share portals of entry: the mouth, lungs, skin and eyes.

The terminology used is also common:

- **hazard**: an inherent property capable of causing harm to humans and the environment, e.g. a corrosive chemical;
- **risk**: the probability that there will be harmful effect to humans and the environment, e.g. a corrosive chemical causing burns to the hand;
- **means of control**: a measure that eliminates or minimizes exposure to a hazard, e.g. protective gloves.

Safety systems must be designed to neutralize hazards, reduce exposure and thus

risk, and should be supplemented by management systems or physical barriers that reduce the probability of unwanted consequences.

The sources of hazard in the laboratory include:

- people
- environment
- fabric and fittings
- equipment and furniture
- reagents
- specimens and cultures
- waste.

The basic principles of laboratory safety are the need to protect the worker, the environment and the work.

While safety is a managerial line responsibility which may be assigned to senior staff, there must be no confusion about the direction of the assignment nor of accountability. The Laboratory Director is ultimately responsible for overall safe performance and cannot simply delegate this to a safety officer or safety committee. The attitude of supervisors and, in turn, those of the workforce is, however, of great importance. The Laboratory Director should define and accept responsibility for the safety policy which must be enshrined in the laboratory's operational manual, even if it is ultimately written by the safety officer.

Establishing systems of work

A systematic approach is necessary for the creation of a safe laboratory work environment. The following steps are involved:

Task assessment

A task must be assessed in total: from collection, transportation and receipt of specimens through pre-examination handling, the testing process and any subsequent steps such as disposal of specimens and associated laboratory waste. The tasks of all ancillary staff not directly involved with the specimens must also be assessed, together with the use of machinery, equipment and appliances. This poses five questions:

- how is the task done?
- who does what?
- what is used?
- where is the task performed?
- what can go wrong?

Identification of the hazard

After the task has been examined it is possible to identify any hazard and assess the risks (see Annex 1). Where possible, hazards should be eliminated or contained and risks reduced before a safe system of work is considered reliable.

Defining safe methods

Safety methods can be defined by:

- considering the preparation and level of skill required for the task;
- clearly defining the process sequence within the task;
- specifying safe work methods;
- considering disposal at the end of the task;
- planning methods of access and escape;
- identifying the individual responsible for supervising the task.

Advice should be sought from persons who will be performing the tasks. Their practical knowledge and expertise can help in avoiding specific but unusual hazards.

Details of the task procedure should be written in the form of a Standard Operating Procedure (SOP) (see Annex 2). The language of the procedure should be readily understood by employees and must contain sufficient procedural details to enable a trained person to perform the task without supervision.

Safety rules should be more stringent and protocols more detailed when trained laboratory staff are not available, e.g. when tests are done outside laboratories.

Implementing the system

Agreed and documented systems of work should be available to all staff and must be implemented correctly and consistently. Staff, including managers, supervisors and employees, should be aware of the implementation of a new work practice and be trained in the necessary skills.

Deviations from defined technical procedures are not permissible. When a safety problem is encountered, work must stop until an effective solution is found.

Monitoring the system

This involves three types of checks to ensure that:

- safety procedures are workable and effective;
- employees understand the need for the procedures and find them acceptable;
- changing circumstances and requirements are identified.

Management

The role of the management is to develop strategies that will:

- identify hazards promptly;
- assess risk by a systematic objective procedure;
- define safe work practices which reduce or eliminate hazards;
- stimulate appropriate personal attitudes and skills in the staff through education and training programmes;
- integrate the laboratory safety plan into local strategies for the identification of patients with specific infectious hazards.

While the Laboratory Director has ultimate responsibility for safety practices, the authority for safe operation is delegated through all levels of management.

Safety Officer

The Safety Officer is appointed by and is responsible to the Laboratory Director. The job functions are:

- giving safety advice to the management;
- administering the safety policy;
- assisting in the design and maintenance of the safety programme.

The duties of the Safety Officer entail:

- regular reports on safety status to the Laboratory Director;
- continuous review of the accident prevention programme;
- investigating all laboratory accidents;
- maintenance of accident records;
- coordination of the education programme;
- development of the health surveillance programme;
- regular safety inspections;
- reviewing of new equipment and facilities;
- ensuring compliance with regulations.

Supervisors

Supervisors have the following responsibilities:

- establishment of laboratory work methods;
- assignment of tasks to the work force;
- supervision of the work force;
- monitoring of equipment and facilities;
- motivating staff and ensuring compliance with safety rules.

All these activities involve safety considerations. The supervisor plays a major role because he is in constant contact with the work force.

Safety Committees

If warranted by the staff and if both the employer and employees feel the need for it, a Safety Committee should be set up.

This should include representatives from all grades of employees and be chaired by a senior member of the staff (but not the Laboratory Director). The Committee should meet frequently to review safety policies and suggestions, discuss accident reports and suggest corrective action where necessary. Minutes should be taken and circulated to the staff. Regular on-site inspection of work should be undertaken to identify unsafe practices.

Responsibility

A laboratory safety programme apportions responsibilities, duties and tasks between the management and the work force. Definition, promotion and enforcement of the safety policy, including the appointment of a safety officer and the establishment of a laboratory safety committee are management responsibilities. Compliance with the safety policy requires the full cooperation of the work force. All persons employed in the work environment have responsibilities towards themselves and others (see page 6).

Regardless of how comprehensive the safety procedures are, an employee's safety, irrespective of his/her position in the organizational hierarchy, depends largely on individual conduct. The individual's attitude will determine this, although group attitudes also play an important part. Clearly, the most effective organization encourages highly motivated and competent staff. Though careful employee selection is very important, adequate training also has a major motivating influence.

The employer is responsible for the provision of premises, work environment, plant and work practices to ensure safety of employees and third parties. The plant includes all machinery, equipment and appliances used in the laboratory. Work practices describe the safe use, handling, storage and transportation of articles and substances and the safe performance of laboratory techniques. Substances are any natural or artificial item (chemical or microbiological, in the form of solid, liquid, vapour or gas) used in the workplace.

Work practices must be unambiguously defined in Standard Operating Procedures (SOPs) (see Annex 2).

The Laboratory Director may be an employer or an employee, depending on the circumstances. In the latter capacity, he should provide expert advice to the employer to achieve acceptable standards of health and safety.

In many countries, the safety legislation extends to manufacturers and suppliers of equipment and substances (e.g. chemicals) for use at work. Ideally, all equipment should be designed, constructed and installed so that it poses no threat to health and safety, and should be delivered with unambiguous instructions for correct assembly and safe operation. Hazard warnings, including symbols and risk information applicable during storage, reconstitution or use should be clearly displayed on all labels and product information inserts (see Chapter 8).

The legal basis of health and safety

The objective of the safety legislation is to protect workers, other persons and the environment from the damaging effects of substances hazardous to health and/or work procedures. Legislation already exists in many countries although the requirements may differ from country to country. There is a tendency for legislation to change from prescriptive principles to a process of self-regulation.

The identification of hazards and assessment of risks within the laboratory environment is central to the self-regulatory process. A risk which may be accepted as minimal under certain circumstances may be quite unacceptable under others. For example, chemical risks inherent in the use of a toxic disinfectant may in some circumstances be far outweighed by the benefits of its use in controlling a serious microbiological hazard. The phrase "as far as is reasonably practicable" occurs frequently in UK legislative documents and illustrates a good approach to risk management. It must not be viewed as a convenient escape clause for poor quality risk appraisal; it implies a balanced and informed assessment of the degree of hazard benefit set against potential control measures and takes into account factors such as cost, time, inconvenience and effect on productivity. Only when the risk is insignificant can there be justification for not seeking to eliminate it.

An important component of risk assessment is the degree of consequential injury which follows from exposure to the hazard. This can range from mild skin irritation or rhinorrhoea to death. Clearly the injury potential will have a major effect on permissible exposure to the hazard.

General principles of national policy concerning occupational safety and health at work are given in Article 4 of Convention 155, of the *Convention Concerning Occupational Safety and Health and the Working Environment* passed by the General Conference of the International Labour Organization (ILO) (1). These are:

- “1. Each member shall, in the light of national conditions and practice, and in consultation with the most representative organizations of employers and workers, formulate, implement and periodically review a coherent national policy on occupational safety, occupational health and the working environment.
- “2. The aim of the policy shall be to prevent accidents and injury to health arising out of, linked with or occurring in the course of work, by minimizing, so far as is reasonably practicable, the causes of hazards inherent in the working environment. Many nations have specific legal requirements regarding occupational health and safety and managers should develop laboratory health and safety guidelines in the light of such requirements.”

Safety standards

Written safety standards may emerge as a result of national laws or international directives that may be published by national or international authorities including professional bodies. Such standards have different legal weight depending on their origin. National statutory regulations will clearly carry the force of law. Codes of practice occupy an intermediate position representing advice from a competent authority or professional body. While being admissible in evidence, they may not carry the force of law, but may establish exemplary standards on which judicial decisions may be based. Finally, guidelines are purely advisory and generally will have no substance nor backing in law although they too may establish exemplary standards. Failure to implement the requirements of such standards carries penalties determined by:

- the legal status of the document;
- peer group pressure and/or lowering of professional reputation as a result of failure to practice in accordance with professional standards;
- civil liability, i.e. as a result of legal action started by aggrieved individuals resulting in damages for negligence;
- criminal sanction, e.g. prosecution followed by fines and/or imprisonment;
- loss of accreditation or licence to work (see page 8).

General civil liability

Where a suitable legal framework exists, liability may arise from two sources. The first, called duty of care, is the responsibility owed by every individual to his colleagues and clients, i.e. patients, health-care workers, visitors to the laboratory, etc. This may be assessed judicially at three levels:

- adherence to Standard Operating Procedures;
- the individual's standing in the laboratory hierarchy (the more senior the post, the greater the responsibility);
- the standard expected from individuals of similar standing.

Personal liability may also arise under the law of contract. In this case employees have specified duties which the employer expects from them. If these duties are not fulfilled, the individual is in breach of contract and liable in law.

2. Safety training

The aim of a laboratory safety programme is to establish safe work practices. Training is an important part of this and should begin on the first day of employment before employees commence practical laboratory work. Training, however, is a continuous process throughout an individual's working life.

Initial training

The general principles embodied in the initial training of the new employee should:

- foster correct attitudes to safe working practices;
- instil basic safety principles (concepts of hazard recognition, risk reduction, physical and administrative barriers);
- teach basic principles of personal hygiene;
- develop basic manipulative skills according to safe practice (the operation of simple laboratory equipment, e.g. centrifuges, routine decontamination and spillage-cleaning procedures);
- teach safe use of facilities (e.g. electrical services) and correct action in emergencies;
- encourage the habit of using safety information.

The initial training of workers should include avoidance of risk of exposure to hazardous chemicals, ionizing radiation, infectious material, etc. as appropriate. Hazards and precautions should be stressed to reassure the worker of the relatively minor nature of risks, provided adequate precautions are taken.

The content and detail of the training programme (aims and objectives) should be laid down in a procedure manual which is readily available for reference. All training sessions should be documented and a record of attendance kept.

Trainers

Designations should be allotted to all individuals with a teaching/training role and their responsibilities clearly defined. Trainers should have an appropriate technical background and should be well aware of educational methods. They should be given sufficient time and resources to prepare their programmes, to adapt to changing methods and to maintain their own level of competence. As far as possible, they should have day-to-day practical experience of their subject.

Retraining and monitoring existing staff

The continuing education and training of existing employees is important to keep them abreast of the safety implications of changing technology, legal and other requirements, and improvements in safety practices. Documentation and records of attendance at training sessions should be kept.

The safety practices of employees should be monitored regularly. The safety officer and supervisors should pay constant attention to the extent to which safety precautions are followed. When breaches in recommended practice are detected, the employee should be advised, retrained in correct methods and required to follow them. Disciplinary action may be required for any employee who persistently refuses to observe Standard Operating Procedures (SOPs).

Regulatory requirements

In some states there are regulatory requirements that have a safety content. Failure to satisfy these requirements may result in loss of accreditation or licence to work and will effectively close the laboratory. Regulatory systems may require some or all of the following:

- identification of high-risk job categories;
- employee specification for high-risk jobs;
- development of Standard Operating Procedures for all high-risk procedures;
- specifications for education and training;
- engineering controls, e.g. fume cupboards, biological safety cabinets, ventilation systems, etc.;
- safe work practices;
- personal protective clothing and equipment;
- employee health and immunization programmes;
- record keeping.

The International Labour Organization (ILO) provides guidance on the legal responsibilities of employers (1).

Training methods

Three distinct phases should be considered in the design of a training programme:

- planning
- delivery
- assessment.

Failure in any one of these will invalidate the programme.

Planning

This involves defining the trainees' educational background, previous work experience and training requirements.

Delivery

There are several effective training methods and a correct choice is important. The best methods maximize the students' retention of material during training and subsequently in the laboratory.

While the lecture is the traditional method of imparting the foundations of knowledge, interactive seminars and workshops foster individual student attention and participation. Where the development of manipulative skills is necessary, laboratory exercises should be organized. These give students opportunities to use methods and

instruments under direct instruction and supervision, thus permitting immediate correction of faulty performance. The correct use of mechanical pipettes and bench-top centrifuges can be taught most effectively this way. The creation of job cards (written or pictorial instructions in the form of checklists or charts) can avoid complex narrative and aid understanding.

The selection of appropriate training aids is important as they improve communication between the trainer and students, thereby enhancing the learning process. Some examples are:

- printed material
- still photographs
- slides/overheads
- films/videos
- real objects.

Assessment

The programme should be evaluated by asking:

- how well was the content accepted?
- how much information was absorbed?
- has the learning obtained been translated into effective laboratory practice?

Training modules

Training modules should be prepared for each category of staff and should be relevant to their duties. These modules have already been described for workers in microbiological laboratories (2) and are reproduced here, but generalized where necessary to make them applicable for any health-care laboratory.

Module 1—The core module

This is intended to inculcate good laboratory practices in medical, scientific and technical staff.

1. Classification of hazards
 - chemical
 - electrical
 - fire/explosion
 - mechanical/physical
 - microbiological
 - radiation (ionizing and non-ionizing).
2. Hazard, risk and consequences.
3. Concept of “barrier” precautions.
4. Protective clothing.
5. Fume cupboards.
6. Biological safety cabinets.
7. Closed/open procedures.
8. Special precautions for handling blood and body fluids, i.e. “Universal Precautions” (3–5).
9. Principles of waste disposal.
10. Routine decontamination of surfaces and instruments.
11. Spillage control.

12. Laboratory design features.
13. Importance of good "house-keeping".
14. First-aid for laboratory accidents.
15. Transport, mailing and shipping of biological and other hazardous materials.
16. Documentation, i.e. codes of practice, standard operating procedures.
17. Personal hygiene.

Module 2—The safe laboratory environment

This module is in two parts; the first is concerned with planning for safety and the second with organization for safety. Both are designed for the senior medical, scientific and technical staff of the laboratory, and for engineering, architectural and administrative staff who are concerned with construction, maintenance and servicing of buildings.

Part 1

1. Size and distribution of rooms for different purposes; planning and building systems; furniture and permanent equipment.
2. Services: water, gas, electricity; alternative supply arrangements when public services are not available or fail.
3. Hygiene facilities.
4. Ventilation, including that for fume cupboards and biological safety cabinets.
5. Waste disposal.
6. Security against vandalism, theft, unlawful entry, etc.

Part 2

1. Management functions and responsibilities.
2. Duties and functions of the safety committee.
3. Duties and functions of the safety officer.
4. Medical supervision: employment health programme.
5. Safety codes.
6. Safety audits: conduct and content.
7. General safety services, e.g. fire precautions.

Module 3—For support staff

This module is designed for staff who have had no formal laboratory training. There are three categories:

- Group 1* Janitorial and domestic staff whose duties involve disposal of laboratory waste, washing and preparation of glassware and other equipment.
- Group 2* Engineering and maintenance staff who service laboratory facilities and repair equipment.
- Group 3* Staff who receive and send biological specimens; handle request forms and medical records; pack biological materials for mailing and shipping; drive vehicles which convey specimens.

This module should contain instructions on:

1. Relevant chemical, physical, mechanical, electrical and radiation hazards (all groups).
2. Relevant biological hazards and consequences of exposure (all groups).
3. How hazards may be avoided (all groups).

4. Hazards associated with relevant items of equipment (Group 3).
5. Operation, control and testing items of equipment (Group 2).
6. Personal hygiene (all groups).
7. Spillage clean-up procedures (all groups).
8. Hazards associated with transportation (internal and external) of chemical and biological materials (Groups 1 and 3).
9. Role of the safety officer and safety committee (all groups).
10. Individual's rights and responsibilities with regard to health and safety (all groups).

Module 4—For safety officers

(but may be useful for members of safety committees)

1. Legal requirements for occupational health and safety.
2. Safety policy documents, Codes of Practice and Standard Operating Procedures.
3. Implementation of safety programmes; the roles and duties of the safety officer and safety committee.
4. Reporting accidents and adverse incidents in routine and emergency situations.
5. Common laboratory accidents and how to avoid them.
6. Emergency protocols.
7. Medical surveillance of staff; employment health programmes, principles and content.
8. Staff relations.
9. Security arrangements against vandalism, theft and unlawful entry.
10. The nature of hazards and consequences of exposure to them.
11. Relevant chemical, physical, mechanical, microbiological and radiation hazards.
12. General principles of hazard control and risk assessment.
13. Decontamination procedures.

Personal hygiene

The principles of personal hygiene should be taught to all new laboratory employees before they commence work in the laboratory. Training in certain standard practices is essential:

- NO eating, drinking, smoking or the application of cosmetics in laboratory work areas nor in any area where workplace materials are handled;
- NO food and drink to be stored in the laboratory (may be stored in the rest area);
- regular handwashing at the end of each job or activity session and immediately after contamination by chemical, biological or other hazardous materials;
- covering cuts and abrasions with waterproof dressings;
- covering patches of eczema or other skin disorders;
- wearing of protective clothing of an approved design, always fastened, within the laboratory work area and removed before leaving the laboratory work area;
- protective clothing not to be kept in personal lockers along with outdoor clothing;
- protective clothing not to be taken home for laundering;
- street clothing to be stored in personal lockers provided for this purpose outside the laboratory work area;
- wearing of pendant jewellery not permitted (staff are advised not to wear any jewellery other than wedding rings).
- children and pets not permitted in laboratory work areas.

Personal protective equipment

Instructions should be given in the use and care of personal protective equipment,

i.e. overalls and laboratory coats, aprons, gloves, eye and face protection masks, ear defenders, and, in some circumstances, respiratory protective equipment (RPE).

Gowns, overalls and laboratory coats

Though gowns, overalls and laboratory coats are a matter of choice they should essentially:

- be made of flame-retarding or non-flammable material;
- cover the neck area, not gape at the knees when the wearer is sitting, and have close-fitting cuffs;

The clothing should be laundered at least once a week. Each worker should have a sufficient number of laboratory clothes so that an immediate change is possible in case of spillage or accident.

Aprons

These are worn over laboratory coats, where necessary, to give further protection against spillage of chemicals and blood. They may be of two types:

- heavy duty rubber, for protection while decanting bulk chemicals;
- light disposable plastic, especially when handling blood.

Gloves

Four kinds of gloves are used:

- heavy duty rubber or leather for handling hot objects and while decanting hazardous bulk chemicals;
- domestic quality for cleaning, washing glassware and disinfection;
- surgeon's, re-usable or disposable, for handling blood, Risk Group 3 materials, and hazardous chemicals at the bench;
- plastic, single-use disposable, for emergencies.

Eye and face protection

Safety spectacles, goggles, vizors and masks are required for different activities:

Safety spectacles

These should be shatter-proof, have side-pieces, and fit over ordinary spectacles. They should be a personal issue and worn as a matter of course, but particularly when chemicals or biological materials are likely to be splashed.

Goggles

Goggles give better protection than safety spectacles for work with hazardous chemicals.

Vizors

Vizors are made of shatter-proof plastic which fit over the whole face, held in place by head straps or caps. Those that curve inwards under the chin give the best protection, e.g. from upward splashes and hot vapours. They should be worn for work with very hazardous chemicals and when autoclaves are unloaded.

Face masks

The surgeon's fabric masks provide little respiratory protection. Better protection, e.g. from the inhalation of powdery material, droplets and aerosols, is provided by compressed paper masks that have flexible metal inserts which allow them to be moulded to the face.

Ear defenders

Although ear defenders are not necessary for ordinary activities, they should be provided where ultrasonic equipment is used.

Respiratory protective equipment

Respiratory protective equipment (RPE) varies from the "gas mask" variety, with interchangeable cannisters for protection against gases, vapours, dusts and microorganisms, to full-face respirators with integral air supply.

They are needed only in high hazard zones and should be personal, fitted to individual, trained users.

Training follow-up procedures

The increased level of safety awareness that exists immediately after training sessions needs to be sustained. For this to be successful positive action is required.

Safety awareness notices should be posted in conspicuous locations and regularly updated to maintain attention. In some countries, multilingual signs may be necessary. Biohazard signs should be posted at the entrance to the laboratory and appropriate hazard symbols displayed at each work station.

Consistent awareness may most readily be achieved by ongoing dialogue between the safety officer and laboratory personnel. Section supervisors should take a prominent part in this process. An active safety committee is also desirable (see page 4).

The regular dissemination of safety information by a series of bulletins or safety promotion programmes is another alternative.

3. Laboratory premises

General design objectives

A well-designed laboratory should provide a safe physical environment and facilitate safe work practices (6-12). To achieve this there should be direct communication and frequent discussions between designers, contractors and those who will occupy the laboratory. The Laboratory Director will have a number of objectives:

- suitability for current work requirements;
- suitability for climatic and geographical conditions;
- adaptability to possible future needs;
- energy efficiency;
- minimum capital and running costs;
- security from unlawful entry and animal pests.

Because of necessity, a number of constraints will be imposed:

- type and range of materials and expertise available;
- national or local building or planning;
- budgetary controls;
- nature of the site;
- relationship or interaction between laboratory-related clinical or other activities.

Each building project is therefore a balance of various objectives and constraints to achieve an optimal design, meeting as many of the initial objectives as possible. Essential health and safety requirements should not be compromised; statutory requirements must be met and basic standards provided that are appropriate to the various laboratory activities and their associated hazards and risks.

The laboratory should provide for the health and safety of its occupants, users and visitors and protect the local and general environment, including adjacent buildings and public places. Planning for such an objective requires knowledge and understanding of relevant legislative controls, laboratory processes and practical safety measures to control them, i.e. the means of eliminating hazards or reducing risks and/or mitigating their consequences.

Laboratory types and classification

There are several different kinds of laboratories. Designs suitable for one may not be satisfactory for another. Even within a laboratory, rooms may serve different purposes and need different designs and services. This is of particular importance in microbiology (see Chapter 7).

The function(s) of the laboratory should therefore be clearly defined early in the planning stage. A general-purpose health care laboratory may require separate facilities for clinical chemistry, haematology, histopathology and microbiology.

Specialized and "containment" laboratories may be required for work with high-risk material. Specimen reception, office, stores and workshop facilities as well as accommodation for patients must be considered. Subsequently, the various processes, materials and equipment can be determined and possible interactions with ancillary working, non-laboratory and social areas examined (8,9). The laboratory may provide services at a national, regional or local level or have associated teaching or research functions. Or it may be a small, single-room laboratory with limited functions.

Some laboratories, e.g. microbiology laboratories, are designed and equipped according to the degree of hazard or risk associated with the organisms, substances or agents to be handled and containment and other safety features selected accordingly. There are formal schemes (1,13-16) that indicate the appropriate design and safety facilities for work with pathogenic organisms that offer differing levels of risk. That of the WHO (2) is shown on pages 54 and 56. Design systems for work with genetically-modified organisms generally follow the same lines. Those for radioactive materials (17) have been adopted by the WHO and other international or national organizations. A similar classification for chemical laboratories has been proposed (18) on the basis of the health, fire and explosion hazards of the substances and processes used therein. More specifically, containment facilities have been established for work with chemical carcinogens (19). Classification schemes are particularly useful to the laboratory designer because the risk-assessment approach matches the degree of hazard to the containment level required and other features necessary to provide a safe working environment.

The laboratory building

The health-care laboratory may occupy part of a hospital building, sharing it with units for in-patient and out-patient treatment. Alternatively, it may be a stand-alone building on a hospital or similar site or be a separate building complex housing research and teaching activities as in a university, medical school or public health laboratory. The building should provide protection against prevailing and anticipated weather conditions including extremes of temperature, rainfall and flooding (12). At the same time it should be designed and constructed according to relevant local or national building codes, particularly with regard to fire safety, the provision of fire-resistant structural elements and adequate means of escape. The last should be adequate for the number of occupants in the building; and located so that all occupied areas are served. Alternative routes of escape should preferably be provided so that people are able to move away from the source of the fire wherever it occurs (see Chapter 4).

In addition to the special requirements for laboratory activities, the internal environment must provide for the comfort of the occupants: extremes of temperature and humidity must be avoided. The provision and maintenance of a comfortable internal environment may require air-conditioning systems for the building as a whole or for selected rooms or areas. These are expensive to install and operate. Passive measures such as a reflective "sunbreaker" shield to protect the interior of the building against direct solar radiation and the careful placement of windows and other openings in the external walls to create cooling air movement are cheaper alternatives. Roofing materials should be heat-reflective and have low thermal capacity and conductivity.

Infestation by animals, birds, and especially insects should be prevented where possible by passive building features including fly-screens or curtains over window openings or doorways, traps or wire-mesh protection for drains and similar piped supply wall openings. Regular removal of waste to refuse and waste storage areas well away from buildings is necessary, and appropriate facilities should be provided.

The overall capital and running costs of the building will be related to its form, i.e. shape and size. In general, a single-storey building is cheapest provided that land is available.

Location of the laboratory

The relative location of the laboratory and its ancillary areas with respect to each other and to the building as a whole must be considered.

- laboratories that have a common function or which share support services or equipment should be grouped together to avoid duplication of facilities and reduce carriage of materials through the building;
- those that require regular deliveries of bulky goods should be located close to the goods receiving area or to a goods lift;
- wherever possible laboratories should be sited away from patient, residential and public areas, although patients may have to attend and provide or deliver specimens;
- laboratories should not be so located in a building that they become thoroughfares or access routes to other areas;
- high-level containment or high-risk laboratories should be located away from patient or public areas and from heavily-used circulation routes;
- services should be located so that maintenance may be carried out with the minimum of disruption to laboratory work;
- laboratories where there is a greater fire risk associated with the use of flammable materials, e.g. histopathology, should be located away from patient or public access areas and flammable material storage facilities to minimize the effect and spread of fire.

Barrier systems

Containment or barrier systems are designed to “contain” or separate the hazard from contact with laboratory workers and with the immediate building or general environment. Barriers may be provided to contain hazardous substances at source, thereby preventing their release into the laboratory. They also include personal protective equipment and administrative controls.

There are thus three tiers of barriers (20):

- *Primary*: around the hazard;
- *Secondary*: around the worker;
- *Tertiary*: around the laboratory.

These are shown in Figure 3.1

Primary and tertiary barriers are relevant to laboratory design as they are provided by equipment, engineering and architectural features. Secondary barriers are concerned with personal protection and hygiene (see Chapter 2).

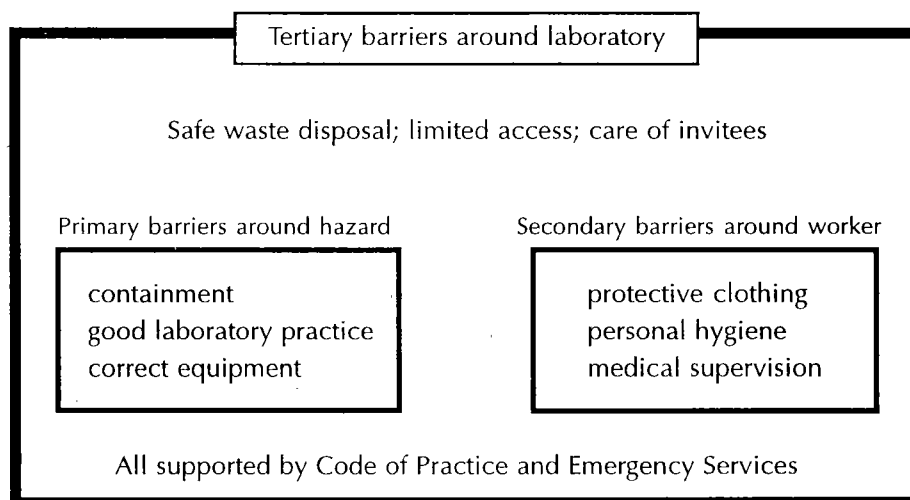
Primary barriers

Primary barriers are intended to:

- keep the hazardous materials (microorganisms) in their containers, preventing their escape;
- prevent or minimize the production of aerosols.

Fig. 3.1. The barrier system for laboratory safety

(Reproduced from reference 20 by permission of the publishers)



Secondary barriers

Secondary barriers are designed to isolate the hazard from the worker and include:

- normal structural elements of the building, e.g. walls, floors and doors which separate one area from another;
- supplementary barriers created by corridors or access rooms where greater separation is required between the laboratory and general circulation areas;
- reinforced, fixed or temporary structural shields or barricades designed to withstand the pressures and fragments generated by explosions or the failure of high-pressure equipment;
- structural shielding to attenuate and contain ionizing and non-ionizing radiation sources;
- systems which create differential air pressures to prevent the movement of airborne hazards from high-risk (contaminated) to low-risk (clean) areas;
- ventilated enclosures such as chemical fume cupboards and biological safety cabinets (which are not interchangeable as they serve quite different purposes);
- barriers which produce structural separation, e.g. enclosed or sealed electrical fittings and equipment to separate the electrical system from contact with highly flammable gases or vapours.

As these involve structural and engineering work they should be considered early in the design stage.

Tertiary barriers

Tertiary barriers include:

- effluent treatment facilities or devices to prevent the escape of hazardous materials from the laboratory building: contaminated or dirty air may be cleaned by water spray or by filtration before being discharged to the outside atmosphere; aqueous wastes may be disinfected by heat or chemical treatment before they are discharged into a public sewer or water course;
- barriers to prevent contaminants from entering the laboratory, e.g. air cleaning plant, showers and facilities for changing into clean or sterile clothing.

Barriers are essential aids to laboratory containment but may create problems by restricting escape from the laboratory in the event of fire or major spillage. They may also impede access by emergency services.

National regulations or codes of practice may define barriers which restrict exposure to hazardous substances by limiting the degree and duration of exposure.

The principles of hazard zoning

In most health-care laboratories, some activities and processes will present greater hazards or risks than others. Some hazards affect only the worker who is directly exposed, e.g. trauma, injuries caused by equipment or needle-stick injuries. Others may affect the entire laboratory and its occupants, jeopardizing their escape from the affected area, e.g. fire, explosion and major spillage or release of toxic, infectious or corrosive materials. The various processes and work stations should be located within the laboratory according to the principles of hazard zoning:

- *Safety Zone*. This includes the primary entrance, circulation areas, offices, stores for non-hazardous materials and washrooms. This should provide unimpeded access to and egress from the laboratory and should be the focal point for fire, personal safety, spillage control and other emergency equipment.
- *Low-hazard Zone*. This zone is for those activities that offer few hazards to personnel and the laboratory as a whole. It should be located between the safety zone and the high-hazard zone.
- *High-hazard Zone*. This is for activities that offer the greatest hazards and risks to the laboratory as a whole. These are farthest from the primary entrance and circulation routes.

Table 3.1 indicates the activities, equipments, etc. appropriate to each zone.

Zones may be separated from each other by partitions or walls into a Containment Laboratory (High-Hazard Zone), a Basic Laboratory (Low-Hazard Zone) and Office area (Safety Zone).

Ventilation requirements

Ventilation of the laboratory is one of the most important design considerations in the provision of a safe working environment. It is also one of the least understood requirements and certainly can be among the most costly to install, maintain and operate. The purposes of the system include the provision of a comfortable internal environment and containment barriers by the extraction and dilution of airborne contaminants.

Local exhaust ventilation

Local exhaust ventilation (LEV) involves the removal of relatively small volumes of contaminated air. The system consists of a partial enclosure or hood, a fan to generate air movement and ducting to convey air from the collection area to a discharge point outside the building. Some systems also incorporate air cleaning equipment, e.g. high-efficiency particulate air filters (HEPA) for the removal of microorganisms, and carbon-filled filters to remove contaminants which may be particles (other than microorganisms), fumes, gases or vapours. Poorly designed LEV systems are common in many laboratories. Sound design requires specialist engineering advice together with a thorough understanding of the nature of the chemical or microbiological hazards involved.

Table 3.1. Hazard zoning in the health-care laboratory

Laboratory activities	Zone classification	Equipment and furniture
Handling and processing high-risk specimens Storage, dispensing and use of highly flammable solvents Dispensing and use of volatile chemical reagents Autoclaving of high-risk samples and material	HIGH-HAZARD ZONE	Microbiological safety cabinets Chemical fume cupboards Flammable solvent and waste storage containers and units Location of compressed or liquefied gas bottles Laboratory autoclave, sterilizer and centrifuge
Activities of low exposure risk, media preparation Processing fixed tissue Use of low-hazard non-volatile reagents Storage of low-to-medium hazardous materials Washing of laboratory apparatus and equipment	LOW-HAZARD ZONE	Wet-work benches for manipulation of low-hazard materials Enclosed analytical and small-scale processing materials and equipment Refrigerated and other storage units and shelving
Activities not involving use of storage of hazardous materials Data storage and retrieval Receipt of specimens	SAFETY ZONE	Write-up desk Laboratory coat pegs Hand wash basin Fire safety, first-aid and spill treatment equipment
DOORWAY		

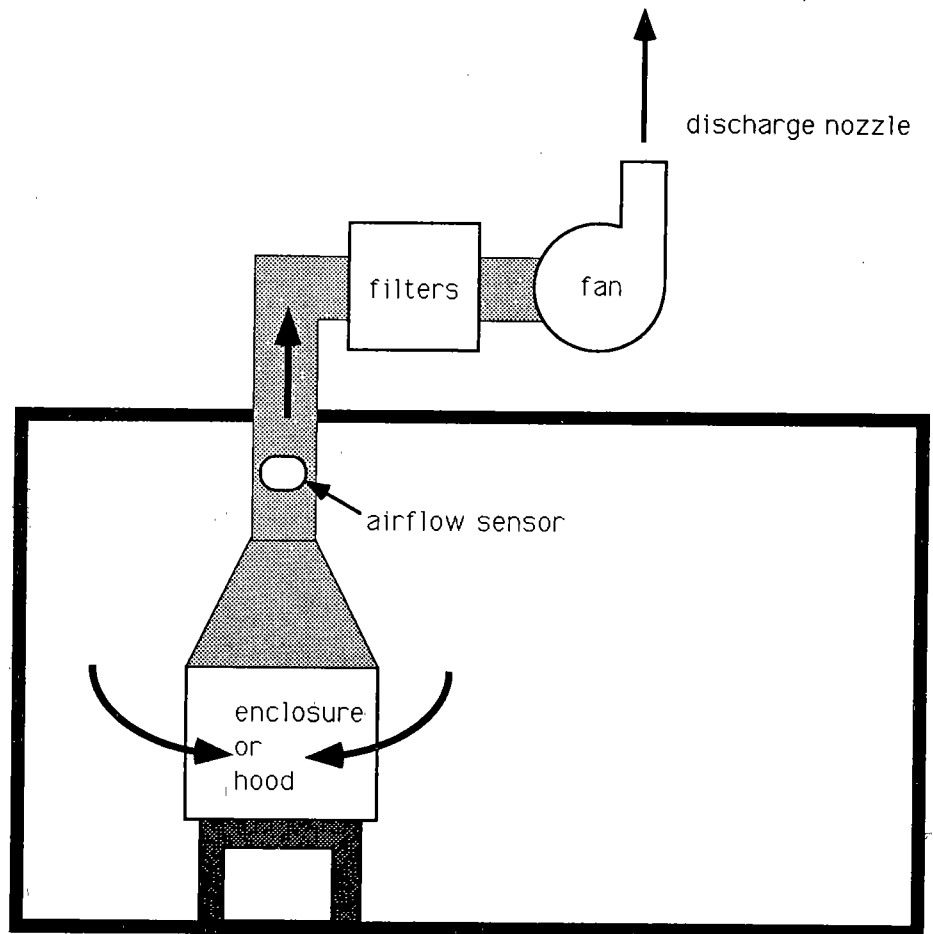
The simplest form of LEV is the capture hood (Fig. 3.2) used to contain and remove the contaminated, hot or malodorous exhausts from equipment such as atomic absorption spectrophotometers and those used in gas chromatography, or from solvent handling areas or dispensaries (21).

Natural ventilation

The cheapest and simplest method of ventilating the laboratory is by natural means; it relies on external wind pressures and temperature differentials to achieve movement of air into and out of the laboratory through open windows, air-bricks, pass-through ventilation grilles or other openings in the external structure of the building. Natural ventilation is unreliable, however, as it is difficult to control and its effects on the laboratory environment are difficult to predict. Natural air movements may spread contamination from the laboratory into other areas of the building or bring contamination into the laboratory (e.g. exhaust gases from generators).

Fig. 3.2. Components of a laboratory exhaust ventilation system

(Adapted from reference 22 by permission of the publishers)

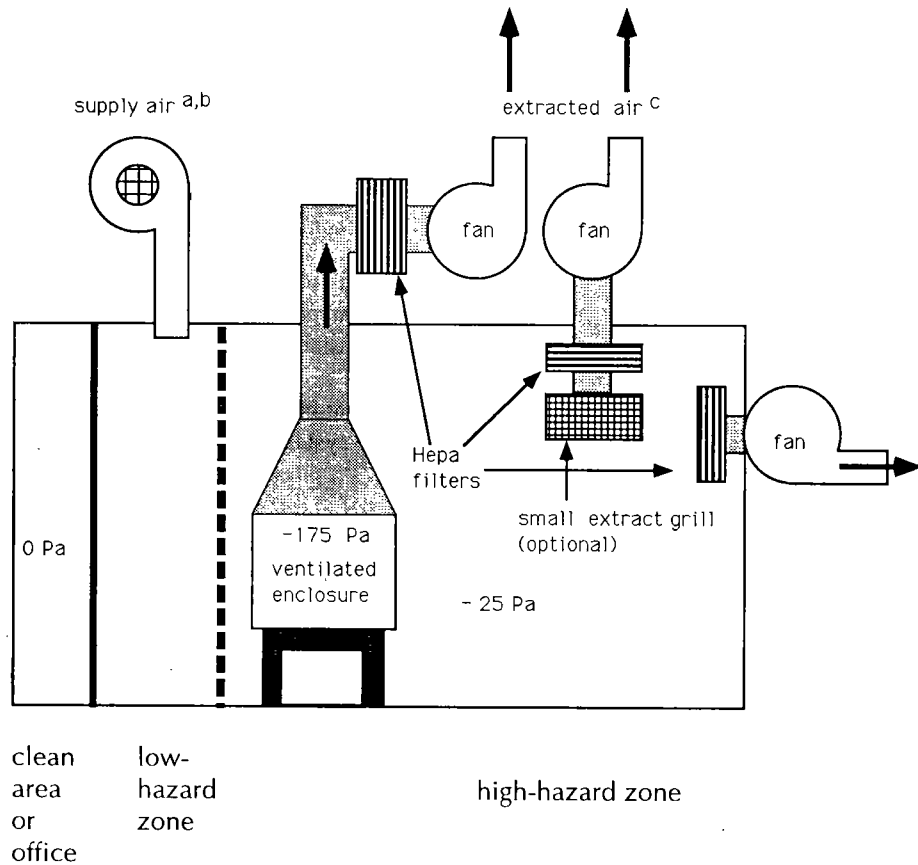


Mechanical ventilation

Mechanical ventilation systems (Fig. 3.3) can supply air of the required quantity and quality to provide for the comfort of the occupants, dilute nuisance contaminants and replace contaminated air removed through LEV systems such as chemical fume cupboards and biological safety cabinets. In conjunction with a controlled exhaust air system, air pressure can be maintained to ensure a differential between the laboratory and its adjoining areas providing a constant air flow into a containment laboratory (negative differential pressure) or a flow from a “clean room” laboratory (positive differential pressure) where a sterile environment with a very low background particle count is required (22,23).

Air supplied to the laboratory should be at low incoming velocity to avoid draughts which would be uncomfortable to the occupants or would disturb the work processes or the containment of ventilated enclosures. Ideally, air should enter the safety or low-risk zone and be extracted from the high-risk zone so that there is a net move-

Fig. 3.3. The role of ventilation in creating a negative pressure containment laboratory (adapted from references 23, 24 by permission of the publishers).



- ^a Supply air may be cleaned and conditioned
- ^b Supply air system may be interlocked with extract to prevent over-pressurization of laboratory and loss of containment
- ^c Air is extracted at about 110% of rate of air supply

ment of air from the clean to contaminated or "dirty" area of the laboratory. The volume of air required will depend on a number of factors:

- the rate at which contaminants are released into the general laboratory environment and their relevant occupational exposure limits or threshold limit values;
- the heat gain from the laboratory, other equipment and solar radiation;
- the number of ventilated enclosures or other LEV systems and the rates of extraction from each;
- the required differential air pressure between the laboratory and adjoining areas;
- the size of the laboratory or laboratory suite and the number of occupants.

Air may be extracted from the laboratory through ventilated enclosures, LEV units, ducts forming part of the whole building air handling system, window or wall-mounted independent fan units or a combination of several of these. In a containment biosafety laboratory (see Chapter 7) or chemical laboratory, the rate of extraction is often designed to exceed the supply rate by about 10% to maintain an air pressure differential lower than that in adjoining areas.

Contaminated air should be discharged so that it will not re-enter or be recirculated in the laboratory, enter adjoining buildings or public areas. Air removed from the laboratory or ventilated enclosures or equipment should preferably be discharged above the highest point of the building; discharges from a lower level should be permitted only for filtered or cleaned air.

The air supply and exhaust systems should be monitored and interlocked so that over-pressurization of the laboratory cannot occur through failure of any component of the extraction system. The supply system must be responsive to changes in the rate of extraction as ventilated enclosures or LEV units are switched on and off; this is achieved by:

- variable speed motors;
- motorized dampers operated by air pressure sensors;
- manually adjustable dampers.

In high-risk laboratories, ventilated enclosures should be connected to the emergency electrical power system to provide continuous containment in the event of a mains power failure.

Mechanical ventilation systems require expert maintenance, especially of the filters, and if fitted, humidifiers, otherwise infectious particles and toxic vapours may be recirculated.

For further information on laboratory ventilation see reference (6).

Access, exits and security

Access to the health-care laboratory should be limited to its staff and others such as cleaners and maintenance workers who are permitted entry if supervised by a trained member of the laboratory staff. Casual visitors should be actively discouraged by a combination of physical barriers and notices. Patients, hospital porters, messengers or others delivering specimens and other items, should be admitted to a waiting room or corridor separated from the main laboratory. A hatchway is useful for the delivery of specimens.

Access to high-level biosafety, chemical and other laboratories should be through a pressurized air-lock corridor or ante-room and not directly from a corridor or general

circulation area. The ante-room may be equipped with washing, showering or clothing change facilities. Doorways are often the most vulnerable point in the laboratory where carefully-designed containment barriers break down. Open doors have the following disadvantages:

- they allow uncontrolled admission of people;
- they permit contaminants to pass into or out of the laboratory;
- they disrupt a carefully balanced laboratory ventilation system;
- they provide no barrier to the spread of fire and smoke through the building.

Doors should therefore be kept closed when the laboratory is occupied and locked when it is vacated. Double key systems, security locks and personal signature devices provide additional protection against unauthorized entry but arrangements must be made so that fire or emergency services can gain access if the laboratory is unoccupied.

Doorways should be wide enough to accommodate the largest items of equipment and provide for the unimpeded escape of occupants in the event of fire. National building and fire safety regulations often specify minimum width requirements and the number and relative position of exit doors. Where the door opens into a circulation or fire-protected escape route it must be of fire-resistant material and self-closing.

Ventilation grilles allowing air to pass into the laboratory from the corridor should not be fitted to such fire doors because of the loss of fire-resistance and to prevent escape of smoke. Doors opening on to corridors should be recessed so that no more than 150–200 mm protrudes. This will reduce the risk of injury to passers-by as a result of collisions and diminish obstruction to corridor traffic. Vision panels are also necessary.

Security measures, i.e. keeping unauthorized people out and preventing the removal of materials or items from the laboratory, often in conflict with the requirements for safety and comfort, and priorities must be discussed and agreed upon locally. Unauthorized or forced entry can be counteracted by:

- reducing the number of entrance doorways into the building;
- providing security guards or surveillance devices;
- reducing the number of unmanned emergency exits from the building;
- fitting alarms to fire-exit doors;
- reducing the number and size of windows;
- fitting locks or grilles.

A security fence around the site perimeter would be an additional deterrent to opportunist intruders.

All exits and escape routes should be clearly sign-posted (see also Fire precautions, Chapter 4).

Space requirements

Space should be provided for storage, circulation routes, fixed items of equipment, furniture and ancillary activities. Offices, libraries, social and catering facilities may also be required.

The minimum space requirement for the laboratory is determined by the:

- number and type of processes or activities;

- number and size of items of equipment;
- number of occupants.

Laboratory space standards should be derived from the ergonomic requirements of the various processes. This includes the size of equipment and furniture and the critical dimensions appropriate to the task to be undertaken at each work station. These functional space requirements must be supplemented by the following:

- special or high-risk procedures;
- storage units including refrigerators and freezers;
- fixed equipment such as ventilated enclosures;
- furnishings, centrifuges and autoclaves;
- circulation areas for the occupants;
- movable equipment and trolleys;
- laboratory services.

There is no international agreement about the provision of work space in laboratories. Floor and bench space depend on activities and equipment. Figures cited vary from metres of bench run per worker to square metres of floor space or cubic metres of total space. As it is difficult to give guidance, readers are referred to other publications (6,10,11) but generous amounts of space foster the safest practices.

Space allocations should be based on systematic analysis of laboratory tasks and other functions rather than on rank or seniority.

Internal surfaces

Internal surfaces, i.e. of floors, walls, and ceilings should be:

- smooth, impervious, free from cracks, cavities, recesses, projecting ledges and other features that could harbour dust or spillage;
- easy to clean and decontaminate effectively;
- constructed of materials that are non-combustible or have high fire-resistance and low flame-spread characteristics.

The floor should be level or variations accommodated by ramps rather than steps: it must have sufficient structural strength for the load put on it, particularly by heavy equipment and storage cabinets; be resistant to foreseeable chemical spills, frequent washing by disinfectants and detergents; have a non-slip surface and be easily repairable. Most of these requirements are met by the use of a sealed concrete floor painted with an epoxy-resin; wooden flooring and floor blocks made from stabilized soil can be covered by a bonded continuous polyvinyl chloride sheet. Washing is made easier if the junction between the floor and walls is coved.

Suitable wall coverings include washable emulsion, water-based gloss, eggshell paint finishes, or epoxy paint systems. Tiled walls may be used in wet or moist areas where frequent or rigorous washing is required provided that a suitable non-porous resin-jointing cement is used to give a smooth surface.

The ceiling finish should be comparable to that used for the walls. Ceilings should be solid; suspended ceilings harbour pests and make decontamination difficult after accidents have occurred.

Services

Most laboratories require centrally or locally provided basic services including electricity, running water, fuel gas and drainage. These may be supplemented as necessary, according to national codes or regulations by piped compressed gases, compressed air, vacuum or steam. Emergency or safety services such as deluge showers and eye-wash stations, fire alarm systems and emergency power supplies may also be included in the laboratory services design specifications.

Service installations should be designed and constructed to facilitate safe access for ease of repair and maintenance.

Electricity supplies

The general principles of electrical safety are discussed in Chapter 5 and only the main requirements are summarized here:

- sufficient socket outlets should be provided for all electrical equipment to be supplied individually, thus avoiding the use of long lengths of flexible cables, extension reels, multiple adaptors or distribution boards;
- socket outlets may be bench, wall or ceiling mounted using a trunking distribution system to allow for flexibility and modification;
- an emergency back-up supply for essential safety equipment, refrigerated storage units and incubators;
- the provision of a separate power circuit or “clean” electrical supply for computers and computer-controlled electronic equipment to prevent mains interference;
- local switches or other means of electrical isolation adjacent to all equipment should be provided unless switched socket outlets are used;
- the mains supply distribution panel, preferably located within the laboratory safety zone, should have all circuit fuses, breakers or isolators clearly labelled with provision for isolating incoming power to the system as a whole or to individual circuits;
- voltage stabilizers and surge devices to protect equipment in areas with fluctuating or intermittent supply.

Lighting

The level of illumination must be sufficient to ensure that laboratory activities can be undertaken safely, general hazards in the laboratory can be seen easily and visual fatigue and discomfort avoided. Inadequate lighting may cause workers to approach the process or equipment too closely thereby exposing them more directly to hazards. Glare caused by excessive contrast between adjacent surfaces, by reflection from bright surfaces or from unscreened lamps may cause distraction as well as visual fatigue. Moving parts of machines may appear stationary if the frequency of the motion corresponds to that of the ac electrical supply or is a sub-multiple of it (i.e. a stroboscopic effect). Certain types of lamps commonly used in laboratories produce harmful ultraviolet radiation, e.g. germicidal, tungsten-halogen and high-pressure mercury discharge light sources.

The general level of illumination at the laboratory bench should be 300 to 500 lux, although higher levels may be required for supplementary tasks. Local lighting may be necessary for visually demanding tasks as in microbiology. Tasks involving accurate colour judgement will require high-colour rendering lamps.

Water supply and drainage

The laboratory will require a reliable supply of running water for washing and cleaning, and as a coolant, solvent or process ingredient. At least two sinks should be provided in each room, one for general laboratory use and the other reserved for hand washing. The supply system should be fed directly from a water main or from a cistern of sufficient capacity to hold a day's requirement so that laboratory activities are not jeopardised by interruption in the public supply. Materials used to construct the supply and drainage systems should be resistant to and not react with chemicals, disinfectants or other materials which may come into contact with them. The supply should be protected against contamination by back-flow or siphonage caused by pressure differentials in directly connected clean and waste systems. The design and construction of the system should avoid excessive multiplication of *Legionella* and other potential pathogens, e.g. from rodents. Bacterial contamination of water systems can be prevented by:

- maintaining hot water tanks and supplies above 50 °C and cold water supplies below 20 °C;
- keeping storage tanks covered and readily accessible for cleaning with drainage points at the lowest possible level;
- keeping pipework as short and direct as possible;
- performing routine checks and maintenance including chemical and thermal disinfection and water treatment to inhibit corrosion, scale formation and sedimentation.

Emergency facilities such as hydraulic hose reels or water sprinkler fire extinguisher systems, drench showers and eye-wash units should be fed from a reliable source with sufficient volume capacity and head of pressure to deal with the emergency.

The drainage system should be capable of conveying contaminated aqueous waste from the laboratory to the public drainage system in pipes and fittings of adequate capacity to handle the maximum foreseeable volume and be constructed of materials with the required heat and chemical resistance. Certain hazardous aqueous wastes have to be treated, neutralized or disinfected before they are discharged into the public drainage system. Plastic materials such as high-density polythene, polypropylene and polyvinyl chloride may be used, but they can soften and sag if exposed for long periods to hot liquids or some organic solvents. Borosilicate glass has very good chemical and heat resistance, is easy to decontaminate, and is transparent thus enabling blockages to be seen readily; it is expensive, however, and difficult to install. Copper or lead pipework must not be used if the effluent contains azides because of the formation and deposition of explosive metallic azides. Stainless steel pipework is susceptible to attack by hydrochloric and other acidic chloride solutions.

Fuel gas

Bunsen or other gas-fuelled burners are required for heat sterilization, to heat experimental apparatus and even for space heaters. Gas may be supplied from a mains service by fixed pipework and outlets or from a liquefied gas bottle or tank located outside the laboratory building. Outlet valves should be of a positive action type and the supply should be fitted with readily accessible isolating stop-cocks or valves and with change-over connections.

Piped compressed gases

Compressed gases, including air or others which may be highly flammable, toxic or corrosive, may be delivered to the laboratory by fixed pipes from supply cylinders or bottles located outside the building. Such installations, although appearing to be inherently safer than keeping compressed gas cylinders in the laboratory, raise a number of design issues:

- the supply and reserve cylinders should be kept in a secure, well-ventilated storage compound where they are protected against extremes of temperature;
- the cylinders should be connected to the delivery pipes by a manifold assembly with pressure regulators and flow-limiting valves; the connections should be clearly and unambiguously labelled even if they have non-interchangeable connectors. Staff responsible for this work should be properly trained;
- the pipes should be run in the open air and their entry into the building should be as near as possible to the laboratory or point of use;
- where pipes are run within the building they should not be located in unventilated service ducts or voids: they should be protected or positioned so that they are not exposed to chemical corrosion, mechanical damage, thermal stress, deposits of oil, grease or uninsulated electrical conductors;
- the materials from which pipes, fittings and valves are constructed should be compatible with the gases they would be carrying: stainless steel is appropriate for high-purity gases and whilst copper pipework may be used for most gases it should not be used for acetylene because a shock-sensitive explosive compound can be formed therein;
- terminal outlets should be clearly labelled and incorporate a pressure regulator or reducing valve;
- terminals carrying flammable gases, including fuel gas, should incorporate a flame arrester device to prevent burn-back;
- the entire system should be pressure- and leak-tested before it is commissioned.

The risks associated with the use of cylinders inside the laboratory (handling, explosion, fire) should be balanced against those inherent in piped supplies.

Equipment and furniture

The designer's and planner's concern is with the suitability of equipment and furniture for its intended use, its location within the laboratory and provision of necessary services, e.g. supply of electricity. The specific problems of equipment-related hazards are considered in Chapter 6. The essential considerations are:

- choice of material for work surfaces depends on whether it needs to be resistant to chemicals, disinfectants, detergents, high and low temperatures, abrasion and impact, as well as ease of cleaning or decontamination. The surface should be sufficiently durable to withstand heavy use;
- under-bench units or cabinets may be floor-standing, fitted with castors, suspended or cantilevered from the bench frame. The design should permit easy floor cleaning and decontamination beneath the units and facilitate the interchange of units to give flexibility for activity needs;
- the work surface and frames of benches and tables should be sufficiently strong and stable to carry the equipment load;
- furniture should be ergonomically designed with respect to the height and reach of the average operator and whether they are seated or standing: the relative positioning of furniture and equipment should reflect activities which are related or sequential to one another;

- shelves and over-bench cupboards should be low enough for their contents to be easily reached;
- the colour and surface texture of furniture and equipment should be chosen to reduce glare and reflection and to enhance environmental comfort and morale: where possible neutral colours should be chosen;
- large equipment and furniture should be placed where they do not compromise the circulation and emergency routes, disturb air flow to ventilated enclosures, or cast shadows on work surfaces.

Storage facilities

Space should be allocated within the laboratory for adequate and safe storage of frequently used items; otherwise, stores will encroach into the work areas, passageways and corridors. Highly flammable liquids and gases, and other combustible materials such as paper and plastic goods, combine to create a significant risk to the laboratory in the event of fire. Storage of materials in passageways and corridors impedes movement and may be the cause of "collision" accidents. For these reasons and to prevent the accumulation of little-used materials, it is advisable that storage facilities are provided for restricted quantities of frequently-used items consistent with daily requirements. Quantities in excess of these should be confined to a storeroom outside the laboratory or kept in a separate building. Laboratory storage facilities include under-bench units, drawers and shelves for chemical reagents and solvents, equipments, disposables and other consumables.

Special storage requirements are needed for the following:

- compressed gas cylinders (see page 27) which are kept in the laboratory should be restricted to those gases in actual use or connected to a system or item of equipment awaiting use. Cylinders should be secured to a stable fixture or placed in a cylinder trolley. Ventilated gas cylinder cabinets are available which protect the cylinder against physical damage and fire and laboratory personnel against gas leaks;
- highly flammable liquids, other than reagent bottles of 500 cc capacity or less, should be stored in fire-resistant cabinets with lipped shelves; cabinets should not have ventilation grilles or other openings because they destroy the fire resistance and integrity and allow solvent vapour to escape into the laboratory. Such chemicals should not be stored in domestic refrigerators or freezers because of the risk of fire or explosion initiated by sparks from thermostats;
- volatile hazardous or obnoxious chemicals or those with high vapour pressures should be stored in a ventilated cabinet which has an exhaust to the outside; they should not be stored in fume cupboards;
- toxic chemicals including scheduled or listed poisons and drugs and "notorious" chemicals which are widely recognized as poisonous by non-laboratory staff should be kept in a secure, locked store within the laboratory and be accessible only to authorized users.

Storage of chemicals

With few exceptions, chemicals kept in the laboratory are hazardous (e.g. toxic, corrosive, flammable). Quantities should be restricted and controlled to limit any loss or damage due to fire or spillage of substances hazardous to the environment as well as the occupants of the building.

Stored chemicals should be protected against laboratory activities, extremes of temperature and the possibility that they might be knocked over or broken. Bottles con-

taining hazardous chemicals should be kept in a secondary outer container or on chemically-resistant trays or lipped shelves at low levels. Incompatible chemicals are those which react together violently or release highly toxic or flammable products. They should be kept apart in separate storage units or cabinets in separate areas of the laboratory or, if in small quantities, in robust double containers. (Listed incompatibilities for individual chemicals are given in Annex 3.) Hazardous chemical storage cabinets should be located in the high-risk zone of the laboratory but not immediately adjacent to high-risk activities or processes.

Biological and clinical specimens and materials

Temperature-controlled storage facilities, including cold rooms, freezers or refrigerators, are necessary for the storage of biological and clinical materials to prevent deterioration and the growth of unwanted organisms. Domestic freezers and refrigerators are suitable for the storage of biological specimens but those used for particularly delicate organisms or important specimens should be connected to a socket outlet provided with an emergency back-up supply or be fitted with power failure alarms. Unless spark-proofed, domestic equipment should not be used to store specimens preserved in low flashpoint solvents.

Laboratory waste

Storage facilities should be set aside for laboratory waste prior to treatment and disposal either within the laboratory or elsewhere. Suitable leak-proof or fire-resistant containers should be provided to allow for the segregation of chemical residues, used solvents, infectious or contaminated materials, etc. The various kinds of laboratory waste are considered in Chapter 12.

Emergency and other safety provisions

All laboratories should have contingency plans for dealing with accidents and natural disasters—fire, flood, storm, earthquake, etc.

These plans should include the following:

- list of emergency services—medical, engineering, supply services;
- identification of high-hazard zones;
- list of at-risk personnel;
- list of hospitals, doctors and treatment facilities;
- sources of drugs, vaccines and special equipment.

Notices should be displayed prominently giving the following information and telephone numbers:

- the laboratory itself (emergency services may not know where it is);
- fire service;
- ambulance service;
- medical and first-aid services;
- laboratory director and safety officer;
- police;
- water, gas and electricity services;
- engineer.

Appropriate facilities and services should therefore be provided and include:

- emergency or secondary electrical supplies from a stand-by generator or batteries to power essential safety and other equipment, at least for a limited time period, e.g. emergency lighting, security alarm systems, fire alarm and detection systems, ventilated enclosures and temperature-regulated equipment in high-level containment laboratories;
- fire alarms, smoke detectors, sprinklers, extinguishers and fire blankets (see Chapter 4);
- first-aid equipment;
- spill kits for the containment, treatment and removal of biological, chemical or radioactive materials;
- emergency telephone or alarm to summon assistance or the emergency services;
- a clearly labelled and accessible safety panel containing stop-cocks, valves or switches to isolate all mains or piped services to the laboratory.

Modernizing existing premises

The principles outlined in this chapter apply equally to the refurbishment of an existing laboratory. Most laboratories have a finite life span and although minor modifications may be made at frequent intervals, the accommodation and services will need eventual replacement to cope with new work processes, altered staffing, outdated or inadequate electrical and mechanical services and plants. Major refurbishment programmes provide the opportunity to assess the health and safety needs of new processes and review continuing activities. Existing laboratories and their equipment, furniture and fittings may require extensive cleaning and decontamination before stripping out and reconstruction can begin.

Refurbishment programmes are not without their particular problems:

- design and construction may be entrusted to in-house staff with little or no experience of the high-technology requirements of modern laboratories;
- partial refurbishment of buildings may accidentally create incompatibilities of equipment and services;
- refurbishment of laboratories in old buildings imposes severe constraints on the availability and adequacy of general building services and plants.

Useful information and advice on modernization and refurbishment of laboratories has been published (6-8).

4. Fire in the laboratory

The fire-risk in health-care laboratories arises mainly from the presence of materials that are highly flammable (i.e. easily set on fire) or combustible (i.e. capable of or used for burning) and the availability of a number of ignition sources.

If a fire spreads beyond the laboratory it threatens the remainder of the building, adjoining premises and many more people. Laboratory fires also present risks to fire fighters and the environment through the release of infectious, radioactive or toxic materials or the contamination of debris by such materials.

For prevention purposes fires are grouped into four broad classes according to the nature of the combustible material and the ignition source:

- Class A:* These are due to ordinary combustible materials such as paper and wood.
- Class B:* These involve highly flammable liquids and gases such as petroleum products, alcohols and fuel gases.
- Class C:* These are fires of electrical origin or those which arise from electrical equipment.
- Class D:* These involve combustible or highly reactive metals such as sodium.

The prevention of laboratory fires requires a basic understanding of the mechanism of the combustion process and the behaviour of fire, coupled with knowledge of the fire-related properties of potential fuels.

Definitions

Several terms are used to indicate the minimum temperature at which self-sustained combustion can be initiated for a given fuel.

Flashpoint

This is the lowest temperature at which a liquid fuel gives off sufficient vapour to form a flammable vapour-air mixture which momentarily flashes when a small pilot flame is applied. The most hazardous liquids are those with flashpoints below ambient temperature because they will rapidly evaporate from open vessels, even those kept in refrigerators or freezers (see page 28). Conversely, liquids with flashpoints appreciably above ambient may require much higher temperatures before flammable vapours are formed.

Ignition temperature

The ignition temperature is that at which a vapour or gas-air mixture will ignite when a pilot ignition source, usually a small flame or electrical spark, is applied.

Auto-ignition temperature

The auto-ignition temperature is that at which the fuel will ignite without the application of a pilot source.

Fire point

The fire point is the lowest temperature at which a liquid fuel produces sufficient vapour to give sustained combustion when a pilot ignition flame is applied. (The term Fire Point may also be used to define the location of fire extinguishers and alarm points.)

Limits of flammability

The limits of flammability are the minimum and maximum concentrations, measured as the percentage by volume of vapour or gas in air, between which ignition and sustained combustion can occur. The *Lower Flammable Limit* is the minimum concentration or quantity of vapour or gas in air, at normal temperature and pressure, which is capable of self-sustaining combustion when ignited.

Vapour density

The vapour density is the weight of a volume of gas or vapour compared with the weight of an equal volume of air at normal temperature and pressure. High vapour density materials are likely to concentrate at low levels whereas low vapour density materials tend to diffuse rapidly until equilibrium is reached. The vapour density of a fuel provides information on the relative concentrations of ignitable vapour or gas at the floor or ceiling level within the laboratory.

These various properties express the potential fire hazard and so reflect the relative risk of fire occurring in a particular laboratory or during a process. Other factors such as the availability of ignition sources, ambient temperatures and process conditions are also important and will modify the fire-risk assessment for any given fuel.

Values of these basic properties for some commonly-used chemicals are shown in Table 4.1. The exact numerical values depend on the method of measurement and small variations from those cited in the table may be found in other publications.

Table 4.1. Flammable limits of some chemicals

Chemical	Flashpoint (°C)	Flammable (% by volume) (Air=1)	Vapour density (Air=1)	Fire hazard
Acetic acid (glacial)	40	5.4–16.1	2.07	Flammable
Acetone	-18	2.6–12.8	2.00	Highly flammable
Ethanol (absolute)	13	3.3–19.0	1.59	Highly flammable
Ethanol (70%)	21	3.6–15.0	1.58	Highly flammable
Ethyl ether	-45	1.9–48.0	2.55	Extremely flammable
Isopropyl alcohol	14	2.0–12.0	2.10	Highly flammable
Methanol	12	6.0–36.0	1.11	Highly flammable
Toluene	4	1.3–7.0	3.14	Highly flammable
Xylene	27–32	1.1–7.0	3.66	Flammable

The combustion process

Under appropriate conditions, fire results from the combination of a fuel and oxidant in the presence of a source of ignition. The fuel may be a flammable or combustible solid, liquid or gas, while the oxidant most commonly involved is oxygen since it makes up 20.9% by volume of air. Ignition sources may take many forms but they all possess the ability to supply thermal energy to a combustible or flammable substance. Combustion is a vapour or gas phase, exothermic (heat-releasing) oxidation reaction and so an essential prerequisite for fire involving solids or liquids is the production of vapours and gases from the initial fuel.

This process, which involves thermal decomposition without oxidation of solids and some liquids, produces a combustible vapour. In most cases further heat is then needed to activate or energize the components that make up the flammable vapours and gases and the oxygen molecules to enable the chemical process of combustion between them to proceed. Once initiated, sufficient heat is released which raises the temperature of neighbouring molecules to a point where they also undergo reaction so that the combustion process is self-sustaining. The initial or primary fire transfers heat by radiation, convection and conduction to unheated fuels and materials which in turn ignite and burn, thus spreading the fire from its point of origin. The fire will continue to burn until:

- (i) all the fuel is consumed;
- (ii) there is insufficient oxygen to sustain combustion;
- (iii) the combustion process is stopped by appropriate and adequate extinction methods.

Laboratory fuels and ignition sources

In health-care laboratories fires are most likely to arise as a direct consequence of the use of materials and equipment.

The most hazardous of these materials are highly flammable or extremely flammable liquids, i.e. those with flashpoints below the ambient temperature. These include:

- methanol, ethanol and other alcohols;
- diethyl ether, toluene, acetone and various combinations of these and other chemicals such as alcohol-based stains, fixatives (Carnoy's fixative—3:1 methanol:acetic acid), and the commonly used 70% ethanol or propanol disinfectants;
- fuel gases such as butane, methane and propane [supplied as gases or as liquefied petroleum gas, (LPG)], acetylene and hydrogen (supplied in compressed gas cylinders).

The ignition sources may be obvious:

- oxidant gases;
- Bunsen burners or other naked flames;
- kerosene and gas-operated ovens;
- appliances with hot surfaces or heating elements;
- boilers, incinerators and their flues;
- lighters and matches used by smokers.

The ignition sources that are not immediately obvious include:

- arcing or sparking when electrical circuits are made or broken, e.g. switches in lighting or power supplies;

- temperature control (thermostat) devices;
- static electricity discharges to earth;
- overheating in faulty electrical equipment;
- overloading of electrical circuits by connecting too many appliances to a single socket outlet or conductor or the use of electric motors or other components which are not maintained or are deprived of adequate ventilation (see Chapter 5).

The laboratory may be at risk from fires that occur in any other part of the building or even outside it and the fire safety strategy should consider these possibilities.

Assessing the fire-risk of laboratory chemicals

Fire-risk may be defined as the probability of a fire occurring. The magnitude of the risk is assessed with regard to the extent of damage and loss of life which it may cause. Laboratories are often classified as high fire-risk areas because of the presence of easily-ignitable flammable substances although the likelihood of fire in any situation depends on a number of factors. These include certain physical and chemical properties of the flammable substances themselves and the proximity of ignition sources. Fire damage will depend on the quantities of fuel involved, the ease with which it can spread within the laboratory or building and the presence of early detection and extinction devices or systems. In the laboratory the major fire hazard is created by the use and storage of flammable liquids near:

- electrical equipment;
- open flames;
- hot surfaces.

For laboratory activities involving flammable or combustible materials the risk of fire is largely due to the creation of flammable vapour-air mixtures and their likely contact with ignition sources. The ability of fuels to vaporize or ignite under particular circumstances depends on their chemical and physical properties. For liquids, gases and to a lesser extent solids, these hazards can be evaluated and quantified by a number of measurable basic properties.

Reducing the risk of fire

Reducing the risk of fire in the health-care laboratory requires incorporation of the elements of fire prevention and fire protection. The former seeks to reduce or eliminate the likelihood of fire by controlling fuels and ignition sources; the latter is concerned with the reduction of damage when fire occurs.

The basic aims of a fire prevention strategy are to:

- avoid the formation of any flammable gas or vapour mixture;
- prevent contact between any flammable gas or vapour-air mixture and any ignition source.

These aims may be realized by the following measures:

- use of non-flammable materials or substances;
- where this is not possible, use of materials or substances that offer the least fire hazard or the least tendency to volatilize at ambient temperature, e.g. solvents or reagents of high, rather than low flashpoints or substances with high rather than low boiling points;
- use of the smallest practical quantities and keeping laboratory-held stocks to the minimum;

- use of mechanical or natural ventilation to prevent the accumulation of flammable gases or vapours in the air at concentrations above the lower flammable limit; the position of any ventilation exhaust or supply grilles in the laboratory will be determined by the vapour density of the substances involved; the majority of commonly-used solvent vapours are more dense than air and so require ventilation at or near floor level for effective dilution;
- prevention of the evaporation or release of liquids or gases into the laboratory by keeping containers and vessels securely capped or closed, whenever possible, or by handling flammable liquids only in an effective exhaust cupboard or hood or in a well-ventilated area of the laboratory;
- removal of all potential ignition sources from areas of the laboratory where they may come into contact with flammable substances. Sources include open flames, electrical or other equipment with heating elements, hot surfaces or components that generate sparks (including domestic-style refrigerators; see page 49); a no-smoking policy is obligatory;
- recognition of static electricity discharges as sources of ignition; these can easily cause serious fires, particularly during the dispensing of highly flammable solvents from large metal containers into small ones. Where practicable, containers should be electrically bonded or connected to each other and earthed (grounded) to discharge any accumulated static charge;
- prevention or restriction of the dispersal or spillage of highly flammable liquids by the provision of lipped trays, shelves, sills or storage facilities that contain and confine the liquid and reduce its rate of evaporation;
- separation of flammable vapours or gases from potential ignition sources either by: (i) distance—allow at least 2 m separation between open containers of flammable solvents and Bunsen or other flames, or (ii) fire-resistant enclosures or structures.

Fire protection

Preventive measures can reduce the likelihood of laboratory fires but the risks cannot be removed entirely. It is necessary, therefore to provide measures, both active and passive, to protect the occupants, the building and its contents from the effects of fire. These should be consonant with national fire safety precautions and codes of practice.

Passive fire protection

Passive protection comprises the structural precautions that are designed to contain fire and ensure that adequate means of escape are provided for the occupants of the building. This is met by using non-combustible building materials or those that are fire-resistant (i.e. resist penetration by flame or smoke for a specified time period) and by designing the building in such a way that there is effective separation of high-risk laboratory areas from other areas.

Escape routes

National building and fire safety codes usually require a number of escape routes of specified minimum width and travel distance from the laboratory to any final exit according to the size of the building, configuration, number of occupants and the fire-risk. Each laboratory should have a minimum of two exit doors well separated from each other. In a single-storey building at least one of these doors should lead directly to the outside, although windows which can be opened can also be used as exits in an emergency. In a multi-storey building the laboratory exits will generally lead to a corridor and thence to one or more staircases which should be separated from the corridor at each storey by fire-resistant doors to prevent the spread of toxic

smoke throughout the building. Arrows painted on the floors leading to fire exits are recommended.

Fire resistance

The principle of fire resistance applies both to the design and construction of laboratory buildings and the need to contain highly flammable materials safely within the specified rooms. Protection against fire is improved by the use of fire-resisting or non-combustible building materials and components such as structural beams, columns, supporting walls, floors and ceilings that reduce the risk of the spread of fire from one area to another and preventing rapid collapse of the structure. The fire resistance rating of the different structural components and the methods of construction are usually established by regulatory requirements.

If there is a fire adjacent to the health-care laboratory, fire-resistant containers or storage facilities will protect highly flammable solvents, cylinders of compressed gases, toxic chemicals, culture stocks, clinical samples and records against ignition. Storage cabinets or boxes for keeping flammable solvents in the laboratory, including used solvents, should be of mild steel or thick plywood with close-fitting doors or lids and lipped shelves to retain any spillage. They should not have ventilation grilles or slots which will allow vapours to escape into the laboratory. The fire-resistance rating of the cabinet should be sufficient to prevent the ignition of the contents by a nearby fire, and give sufficient time to enable occupants to evacuate the immediate area, or permit the fire to be extinguished. An effective method of increasing the fire rating is by the application of fire-retarding paint and by fitting seals around door edges which expand when heated and provide a seal between the door and its frame.

Fire-resisting storage cabinets should be placed away from potential ignition sources and doorways. Ideally, flammable liquid storage cabinets and containers should be kept in an outside store, shielded from the sun, rain or ground-water, ventilated to the open air at both high and low level, and secured against unauthorized access.

Active fire prevention

Damage or loss caused by fire can be minimized by early detection and the use of fire-extinguishing equipment.

Fire detection and alarm systems

The earlier a fire can be detected the easier it is to extinguish. The occupants in any laboratory or work area will usually sense a fire by sight, smell or radiated heat but automatic sensors are still necessary in potentially unoccupied areas. There is little sense, however, in fitting an automatic fire detection system in a remote laboratory or building unless fire fighters can be in attendance in a matter of minutes or the system also incorporates automatic extinguishing devices.

Automatic fire detectors sense fire by responding to heat, radiation, smoke, flames and/or combustion gases. They should be capable of distinguishing a fire from variations in the ambient temperature. In a laboratory the most useful types are smoke and temperature rate-of-rise detectors. The former respond to smoke particles produced by the fire and the latter to rapid increase in ambient air temperature. Solvents such as toluene and xylene burn to give dense black smoke which is quickly detected by a smoke detector whereas alcohol fires produce virtually no smoke and may not be detected. Detectors may be located in high-risk areas such as stores and laboratories where large quantities of flammable solvents are kept and handled, but it is equally important to protect fire escape staircases and corridors.

Fire alarms are necessary to alert the occupants of the building to fire. Alarms may be activated by an automatic fire detection system or by the occupants of the building. Bells or sirens may be sounded from a press button or switch with an easily broken glass cover although in a small building a hand bell or gong struck with a hammer may be sufficient to warn all the occupants. Fire alarm signals should be audible throughout the building and this determines the number and position of the bells, sirens or other alarms. The alarm points should be located along escape routes from the building to discourage occupants from walking towards a fire.

The occupants of the laboratory should know how and where to activate fire alarms and what action to take when the alarms are sounded. These instructions should be rehearsed during periodic fire drills or practices and essential instructions provided in all laboratories in the form of "Fire Action Notices".

Fire extinguishers

Extinguishing agents act by removing one or more of the essential ingredients (air, fuel and heat) from the combustion process. The most important consideration while selecting from the many types and models of fire extinguishers is the type of fire. This is based on the substances involved (see Chapter 8 and Annex 3). The means of delivery of the agent varies from sprinkler or flooding systems to hand-held portable extinguishers. The minimum requirement for the laboratory are buckets containing sand, dry soil or water, a fire blanket and one or more fire extinguishers. If the laboratory forms part of a large building there may also be a requirement for fire hoses. In a high-risk area or to protect particularly expensive equipment, a simple automatic system which incorporates a fire sensor device to actuate discharge of the extinguishing agent may be necessary.

Sand or soil buckets are useful for containing and extinguishing fires involving free-flowing liquids; they are cheap and can be easily replenished after use. Fire blankets provide the easiest means of extinguishing fire on personal clothing although they may also be used to smother fires in small open containers. They should be made of material that does not burn readily, such as heavy cotton.

Table 4.2 shows the various extinguishing agents commonly available in portable extinguishers, the types of fires for which each is recommended and other factors to be considered in selecting the most appropriate one.

Table 4.2. Types of fire extinguishers

Agent	Type of fire*	Comments
Water	Paper, wood, fabric	Not suitable for liquid fires nor on live electrical equipment
Foam	Contained liquids	Not on live electrical equipment; not suitable for free-flowing liquids
CO ₂	Liquid and electrical	Not suitable for paper or metal fires, limited cooling effect so re-ignition may occur
Halon	Liquid and electrical	Some halons and their combustion products are corrosive or toxic
Dry powder	Liquid and electrical	Good general-purpose agent, leaves powder residue after application

*Fire and extinguisher classifications are based on the fuels involved; national schemes vary but fires are commonly grouped according to: solid fuels (paper, timber, fabrics, etc.); liquids; gases; live electrical equipment or appliances; or metals.

Extinguishers for general fire protection should be placed in conspicuous positions near the laboratory exit or in adjoining corridors serving a number of laboratories or rooms. Where there are significant fire risks, such as laboratories or stores containing highly flammable liquids, the appropriate extinguishers should be installed nearby. Extinguishers are generally labelled or rated according to their capacity and the type of fire for which they are recommended.

The number of extinguishers required in each situation will depend on the total floor area, the fire hazard and volume of highly flammable liquid present. National codes or recommendations should be cited for specific guidance but each laboratory should have at least one extinguisher suitable for Class B (liquid) fires and one for electrical fires together with a water bucket.

There should be a regular programme for inspection and testing of fixed and portable fire extinguishing equipment. Deficiencies identified by the inspection should be made good without delay.

Instruction and training in fire safety

Instruction and training should be given to all laboratory workers and other staff who share the building. This should include details of the basic combustion process, how fires start, spread and can be prevented. Staff should be trained to recognize and evaluate fire hazards and plan their work in such a way so as to reduce the risk of fire. They also need to know what action to take when fires occur. Instructions should be given in brief and simple language on:

- raising the alarm;
- summoning the fire brigade or other assistance;
- when and how to tackle the fire;
- evacuation of the laboratory or building;
- appropriate exit routes and safe assembly areas.

The staff should be informed of and understand the reasoning behind laboratory rules for fire prevention, including the correct handling and storage of highly flammable liquids, the need to keep fire doors closed and emergency routes and exits unobstructed. These matters and the procedures to be followed in the event of fire, should be covered in readily understandable written handouts and verbal instructions given during the worker's first day in the laboratory. Practice is necessary to ensure that the staff are familiar with and follow these various procedures. Practice drills should be organized at least twice a year partly to test the alarm system and its audibility throughout the building and to ensure that the evacuation is prompt and effective. For further information about laboratory fires see references (24-29).

5. Electrical safety

A safe and reliable electrical supply is essential for the health-care laboratory. All such laboratories will have electrically-powered equipment and lighting. Even the smallest laboratory will have portable equipment that requires batteries. Laboratory workers should therefore be aware of the hazards of electrical systems and the means of controlling them, including appropriate earthing (grounding) of electrical equipment and sufficient earthed (grounded) outlets to avoid using temporary and often unsafe additional connections.

Detailed considerations of the principles and practice of electrical engineering are outside the scope of this publication.

Electrical systems

In most laboratories electricity will be supplied from an electricity generating station. A local generator fuelled by gasoline or diesel oil may be provided as a back-up source should the mains supply fail. In isolated laboratories the primary supply will be a local generator. Solar energy may be the source in some laboratories. In some installations there may be a transformer to reduce the voltage or smooth out surges which affect equipment performance. Some equipment may have an integral battery which provides a back-up supply.

Hazards of electricity

Fires of electrical origin

Fires caused by electricity are considered in Chapter 4, but the important mechanisms are listed here:

- overheating of cables and electrical equipment due to overloading of conductors;
- overheating due to thermostat failure and lack of an over-temperature cut-out device;
- leakage currents due to inadequate insulation;
- auto-ignition due to overheating of flammable materials placed too close to or inside electrical equipment which in normal operation becomes hot;
- ignition of flammable material by electrical sparking or arcing.

Electric shock

An electric shock may be nothing more than a mild tingling sensation but can be a more painful stimulus resulting in total loss of muscle control and death. The nature and severity of injury depends on the magnitude, duration and path of the electric current through the body and, in the case of alternating current, its frequency.

The effects of electrical shock are most acute around a frequency of 50 Hz. Suscepti-

bility is greatest if a person is in good electrical contact with earth, such as in damp or wet conditions. Hot environments, where people may perspire present an increased risk because the insulating protection afforded by clothing may be reduced by its dampness. In a laboratory, electric shocks, however mild, can also generate other hazards by causing a reflex "startle reaction" which may cause the victim to lose control of a chemical or biological substance with which he is working. The treatment of electrical shock is considered in Chapter 12.

Electrical discharge

Electrical discharge, i.e. sparks and arcs, may ignite flammable vapours, causing explosions and fires. Severe arcing and sparking can generate ultraviolet (UV) radiation which damages the skin and eyes. Electrical discharge is accompanied by ozone production. This can build up in a confined space and become a respiratory hazard. It can also accelerate the breakdown of insulating materials.

Other electrical hazards

Electrical burns can be caused by the heating effect arising from the passage of an electric current through the body. These most commonly affect the skin at the point of contact with the electrical conductor (see First-aid, Chapter 12).

Exposure to high frequencies, e.g. radio frequencies, including microwaves, may cause electrical burns. If electrical equipment (e.g. switchgear, motors and power cables) is subjected to excessive currents there may be an explosion.

Control of electrical hazards

Important factors to consider are:

- design of systems;
- design and construction of equipment;
- commissioning;
- use;
- maintenance;
- repair;
- modification.

General precautions against electric shock are:

- selection of equipment suitable for the application and the environment;
- good installation practice;
- regular, scheduled maintenance;
- careful use in accordance with the manufacturer's instructions.

Protection against electric shock from equipment is achieved by using:

- extra-low voltage equipment;
- reduced voltage equipment;
- double insulated or all-insulated construction;
- earthing (grounding) and protection by an automatic disconnection device;
- electrical separation from the mains and earth.

Design of systems

In the planning of an electrical installation consideration should be given to the energy requirements (wattage) of all the equipment and plant that is to be used. It is prudent to allow between 25–30% extra capacity to allow for future expansion. Laboratories should be provided with sufficient socket outlets to enable each item of equipment to be powered directly without the improper use of multiple adaptors or extension leads. The use of these devices can result in overheating and the risk of fire. Moreover, such practices encourage the accumulation of trailing leads which can be an impediment to safe movement within the laboratory.

A fully earthed (grounded) installation is recommended and earth leakage circuit breakers (residual current detectors or ground fault interrupters) or similar devices should be provided. Ideally the voltage available at socket outlets should be the lowest compatible with available equipment. Wherever possible, every equipment should have an efficient and safe means of isolating it from the electrical supply; this should be readily accessible.

Back-up generators are often required, in the event of mains supply failure, to power safety equipment such as fume cupboards and biological safety cabinets. The electrical installation should be provided with an automatic start-up and change-over facility. It is important that a generator is compatible with the load it is to supply, particularly with regard to voltage, the rated output of the unit (kVA), connections and earthing. A generator may introduce hazards. Care is needed in the use and storage of gasoline (see Storage of flammable chemicals, Chapter 8). The exhaust gases from a generator may enter the laboratory thus endangering laboratory workers and other persons. Appropriate siting is important in the interest of safety.

Design and construction of equipment

Electrically-operated equipment should be designed and manufactured to comply with appropriate local safety requirements. The recognized standard is that of the International Electrotechnical Commission (30) and useful information is available in other publications (31,32).

When equipment is purchased compatibility with local voltages and frequencies should be specified.

Commissioning

New, modified or repaired equipment should not be put into routine use until a competent person (e.g. a trained electrician) has carried out prescribed electrical safety tests and has satisfied himself that the equipment is safe to use. Basic tests are:

Measurement

- earth bonding;
- insulation resistance;

Inspection

- proper fusing;
- damage;

- signs of overheating;
- proper connections;
- colour coding of wiring.

Use of equipment

Users of equipment should be trained in its proper use and should handle it carefully in such a way that electrical safety is not compromised. In particular, it should not be dropped nor carried by supply cables. Splash-proof or non-sparking (intrinsically safe) equipment may be required for some applications. If conducting liquid is accidentally spilled on to equipment the latter should be disconnected from the electrical supply and carefully dried. It should not be re-used until a competent person has passed it to be fit for use.

Maintenance, repair and modification

Only competent persons should be permitted to carry out this work on electrical equipment and circuitry. Unauthorized work should be forbidden.

6. Equipment-related hazards

Equipment-related accidents are common in laboratories. To reduce them four important factors should be considered:

- ergonomics;
- hazards of particular types of equipment;
- causes of accidents;
- management of equipment.

Fire and electrical hazards are covered in Chapters 4 and 5 respectively.

Ergonomic factors

Ergonomics (also known as human factors engineering) has been defined as the science of fitting the equipment, or the task, to the worker. The safety objective is to take account of human limitations and not to require a worker to adapt to the equipment or workplace environment that happens to be available when the task is being planned. Failure to achieve these objectives can arise from:

- poor equipment design which does not take into account available skills and conditions of use;
- equipment incompatible with size, shape and anatomical proportions of workers;
- need for frequent lifting or moving of heavy equipment;
- repetitive movements.

Back problems are common occupational disabilities and may result from uncomfortable chairs, benches at the wrong height and moving and lifting heavy loads.

Trolleys should be provided for moving gas cylinders (see page 28) and other heavy loads.

Repetitive movements may cause strain injuries such as arthritis or synovitis (32).

Hazards of particular equipment and materials

Centrifuges

The biggest threat from centrifuges, both to the user and to others in the vicinity, comes from the rotation assembly (the rotor and its accessories). The most important safety requirement is a strong guard barrier around the rotation assembly to prevent the projection of disruption debris into the laboratory. Accidents caused by the breaking up of centrifuge heads are often violently explosive. Wherever possible, and especially for large equipment, there should be a control switch for the centrifuge located far enough from it so that it can be switched off in an emergency. Most accidents are caused by misuse, such as:

- failure to balance the load;
- failure to locate the trunnions and buckets properly, sometimes because the centrifuge is placed too high for the user to see inside the bowl;
- over-enthusiastic use of the speed control causing too rapid an acceleration rate.

Faulty components also contribute. For example, rotor failure is usually initiated by cracks or fissures. These may be caused by corrosion or mechanical damage. Corrosion usually starts at high stress areas and often in places where dirt accumulates: the bottoms and sides of buckets and cups are common sites. As a result of corrosion, small holes (pitting) may arise on the surface of rotors if anodizing is lost. It is important not to use alkaline solutions which attack anodized areas. Saline, used for red cell washing, and reagents used for preparing material for culturing tubercle bacilli (oxalic acid, sodium hydroxide and sulphuric acid) have also been implicated (32).

Because of the potentially lethal nature of rotor failure, ultracentrifuges require special attention. They should be used only by trained staff in accordance with the manufacturer's instructions.

The International Federation of Clinical Chemistry (IFCC) guidelines for selection and use of centrifuges (33) are recommended.

Moving parts

Exposure to drive belts, chains and pulleys, e.g. on vacuum pumps, and moving parts of centrifuges can result in injury to the hands and fingers. Equipment should be provided with physical barriers (fencing) to prevent users from exposure to moving parts.

Autoclaves and pressure vessels

There are three important hazards: failure to sterilize; pressure; and unloading.

Failure to sterilize

Infected material may not be made safe, leaving staff at risk. Inadequate venting of the chamber of a pressure-controlled autoclave is a significant cause. The temperature in the load chamber should be monitored by thermocouples; that recorded or registered in the drain may be very much lower than that of the load (10). Time is also important: the effectiveness of the sterilization process is determined by the *Holding Time at Temperature* (HTAT), i.e. taken from the time when the temperature of the load reaches the required level (see Chapter 7).

The pressure vessel hazard

Small autoclaves and pressure cookers: User error is an important factor in the safe operation of small autoclaves, media preparation and pressure cookers. The following precautions should be taken:

- the manufacturer's instructions should be observed;
- the vessel should be inspected daily for signs of corrosion and the vent for evidence of blockage;
- only replacement parts supplied by the manufacturer should be used;
- all bottle caps should be loosened;
- an adequate volume of water should be placed in the vessel each time it is used;

- the vessel should not be allowed to boil dry nor be left unattended while in use.

Large autoclaves: All large and conventional autoclaves should be fitted with a safety interlock that prevents the opening of the door until the temperature in a sealed container has fallen to 80 °C. The following steps will reduce pressure hazards:

- inspection of door seals for damage;
- checking the load to ensure that all screw caps are loose and that the head space in each bottle is 1/3 of the capacity;
- there are no cracked or defective bottles;
- displaying a warning notice if sealed containers are unavoidable and if the load is exceptionally large;
- correct procedure for closing the door;
- safety mechanism is not over-ridden;
- closing the main steam valve at the end of the run and opening the air break and exhaust valves before opening the door.

The unloading hazard

After removal from an autoclave, bottles can explode before they have been allowed to cool down, causing injury to operators.

The risks may be reduced by:

- wearing insulated gauntlet gloves and a visor when unloading;
- opening the door by only 12–30 mm and then leaving the autoclave for 15 min to accelerate further cooling of the load before unloading; during these operations the door should, as far as possible, be kept between the body of the operator and the chamber contents;
- avoiding mechanical and thermal shocks (from cold, draught, etc.) to the load;
- when possible, leaving large loads, or loads made up of large unit volumes, overnight in a locked autoclave to cool;
- using culture media containers that are as small as is compatible with efficiency and convenience of use.

Loading and unloading autoclaves, especially the vertical type, can induce back strain. Horizontal models are preferable, and are best loaded and unloaded from a trolley. Large modern autoclaves have integral trolley-loading facilities.

Although not a hazard, unpleasant odours may result from autoclaving large amounts of pathological material and permeate the whole building. Therefore, proper ventilation should be provided.

Sharp and pointed objects

Cuts, punctures and other skin injuries caused by sharp or pointed objects are very common. The following items have been implicated:

- hypodermic and other needles;
- blades;
- broken glass;
- glass capillaries;
- metal shelving;
- metal doors of chemical storage cabinets;
- autoclave buckets;
- paper and computer cards.

While cuts and punctures may not be serious in themselves, damaged skin is a significant portal of infection, notably for hepatitis B and immunodeficiency viruses and may permit the entry of chemical agents into the body. Contamination of work surfaces with blood is common and provides a source of infection.

Steps should be taken to limit the presence and use of sharp and pointed instruments in health-care laboratories to situations where there is no alternative. The accessible edges and corners of metallic equipment should be smoothed with a file or padded with suitable material. Glass edges should be fire-polished wherever possible. Pipette fillers need to be chosen and fitted with care to avoid breakage of glass pipettes. Care is needed in laboratories where slides and cover glasses are washed for re-use.

There should be an established procedure for dealing with broken glass. Strong rubber or leather gloves should be available for this purpose. Safe handling and disposal of contaminated sharp objects such as used hypodermic needles are described in Chapters 7 and 11.

Gas cylinders

The compressed gas cylinder is a good example of an inherently unstable item. It is very heavy and can cause injury if it falls from the vertical position or rolls along the ground. When in use or being stored upright it should always be secured to a reliable fixture, such as a laboratory bench. Injuries to feet and legs can arise when gas cylinders are being moved. Reducing valves can be damaged or even broken off. This type of damage can result in sudden release of gas with the result that an uncontrolled projectile, with great injury potential is produced. The hazard is exacerbated if flammable or toxic gas is involved (24,32).

Purpose-built trolleys should always be used to move compressed gas cylinders.

Collapse of supporting structures

In addition to posing a mechanical hazard, collapse of supporting structures, such as benching and shelving, may lead to the release of toxic or flammable material stored thereon.

Prevention requires good design and construction as well as regular inspection.

Unstable equipment

Although some items of equipment, such as refrigerators and incubators, are not inherently unstable, they may topple over if placed on benches that are too narrow. Centrifuges in particular need adequate bench space. Apart from causing personal injury, hazardous substances may be spilled or released.

Such equipment requires sufficient bench space.

Radiation

The hazards of ionizing radiation are dealt with in Chapter 9. Some equipment-related non-ionizing radiations, i.e. heat, ultraviolet light (UV) and laser light may be a problem in health-care laboratories. There is some doubt about the risk to health of radiations from visual display units (VDUs) (see page 47).

Heat

Large autoclaves and large biochemical analysers which incorporate flame photometers and some heating baths may radiate so much heat that the environmental temperature is considerably raised. While heat stress is unlikely under these circumstances, working conditions may become uncomfortable and air-conditioning is desirable. Hot surfaces that do not appear to be hot, e.g. the surface of a bench top autoclave, may offer a skin-burn hazard to the user. The temperature of accessible parts that may be touched inadvertently should therefore not exceed 100 °C and the temperature of metal handles should not exceed 55 °C (32).

Ultraviolet light

Germicidal ultraviolet (UV) sources, e.g. at 100–280 nm, have been installed in some biological safety cabinets and culture media plate-pouring machines. Over-exposure may cause conjunctivitis. If it is necessary to provide equipment with a germicidal UV light source, interlocking should be provided to prevent exposure to users. Microscopes used with UV lamps should be shielded to prevent eye exposure.

Laser light

Lasers are used in some blood cell counters and cell-sorting instruments. They can cause eye lesions, depending on the power, density, wavelength, duration of exposure and size of the retinal image, but there is no evidence of risk to operators provided that the equipment is used in accordance with the manufacturer's instructions.

Visual display units (VDUs)

Also known as visual display terminals, these are widely used in health-care laboratories and some concern has been expressed about possible health effects, especially on pregnant women, including those associated with the emission of electromagnetic radiations (EMR). A WHO Working Group (34) concluded that the levels of EMR and the low-frequency pulsed field and electrostatic fields are generally either not detectable or are insignificant compared with the recognized hazard threshold. It also agreed that ergonomic factors (see page 43) may be responsible for some of the problems reported by VDU users.

There has been concern about incidents of spontaneous abortions among VDU users and of congenital defects in their children. Studies carried out so far have not provided conclusive evidence of adverse effects in pregnancy but this does not necessarily mean that using VDUs is absolutely safe. Further studies are being done but in the meantime steps should be taken to avoid excessive discomfort and fatigue in pregnant women using VDUs.

Explosions

Some equipment-related hazards result from chemicals that are used in processes, e.g. azides, perchloric acid and picric acid (see Chapter 8 and Annex 3). Others result from the build-up of pressure, e.g. use of autoclaves, culture media preparators, pressure cookers and microwave ovens. Reagent reservoirs from which liquid is delivered under high internal pressure may burst and special plastic-coated bottles, that are resistant to bursting, should be used. Glass reagent bottles used to store chemicals which may build up pressure, e.g. sodium hypochlorite and fuming nitric acid should

be provided with caps which incorporate a pressure relief facility (see Chapter 8). Glass vacuum desiccators may implode; they should always be placed inside a protective cage when evacuated.

Audible noise

It is unlikely that the noise level in a health-care laboratory will be high enough to pose a risk of noise-induced hearing loss. However, high levels may be a source of annoyance to workers, cause loss of concentration that may affect safety, and induce psychological stress symptoms. A noise level not exceeding 65 dB, or lower if required by local regulations, is recommended and every effort should be made to reduce noise levels in the health-care laboratory, e.g. by siting noisy equipment such as air compressors outside the laboratory.

Ultrasonics

Ultrasonic cell disruptors and cleaning baths may pose a significant threat to hearing unless they are placed in soundproof cabinets or ear defenders are worn. Some bench-top cell disruption equipment is provided with soundproofing by the manufacturers. Ear defenders should be worn when hand-held equipment is used. If the hands are likely to be immersed, rubber gloves should be worn while ultrasonic cleaning baths are in use. If bare hands are immersed the user may develop petechial lesions and allergic dermatitis may occur if the bath contains a detergent or caustic cleaning material.

Ultrasonic equipment may produce aerosols from the liquids that are in use. If inhaled, these aerosols may cause damage or infection of the respiratory tract. Where there is a risk of harmful aerosol production, e.g. disruption of pathogenic micro-organisms, the equipment should be operated in a biological safety cabinet or fume cupboard.

Infection

Sharp or pointed edges can transmit infection (see pages 45 and 54). Infectious aerosols, droplets and splashing may be produced by some items of equipment capable of introducing large amounts of energy into liquids being processed, e.g. mixers, blenders, ultrasonic devices and centrifuges (1,10,32), thereby creating a risk of microbial transmission by airborne and surface contamination. Mixers, blenders and ultrasonic devices should be operated in biological safety cabinets when there is a risk of infectious aerosol production. When infectious materials are centrifuged, sealed buckets should be used.

Equipment as reservoirs of infection

Shared equipment, e.g. microscopes, can present a risk of transmission of infection (35,36) and should be cleaned and disinfected regularly. No equipment should be maintained or repaired in the laboratory or sent outside unless it has been decontaminated by the laboratory staff and supporting documentation is available.

Portable or stationary eye-wash stations for first-aid irrigation of eyes that have been splashed with chemicals may be contaminated with opportunist pathogens such as pseudomonads and free-living amoebae. Microbiological monitoring of these appliances is desirable and they should be regularly disinfected, e.g. with a solution

containing approximately 25 ppm of free chlorine. Single-use eye-wash obviates infection hazards.

Examples of infection hazards associated with particular items of equipment and suitable precautions are given below.

Automated chemistry analysers — sample probes may produce droplets;
— shielding may be necessary;
— wiping probes may contaminate fingers;
— needlestick injuries may arise.

Remedy: Take care and wear gloves.

Microhaematocrit centrifuges — cuts and stabs caused by broken glass capillary tubes.

Remedy: Handle fragments with forceps.

— clay slabs used to seal tubes may become contaminated with blood and contain fragments of glass.

Remedy: Avoid finger contact and replace frequently.

Cryostat microtomes — unfixed tissue may contain pathogens.

Remedy: Do not use pressurized freezing propellants because infected spray and droplets may be produced. Wear gloves and take care when changing microtome knives.

Causes of equipment-related accidents

Examples of causes of equipment-related accidents (32) are:

Faulty design or construction

Electrical fires in incubators — no over-temperature cut-out;
Electrical shock — failure to provide reliable grounding (earthing).

Remedy: Specify compliance with standards, e.g. IEC (30).

Improper use

Centrifuge accident — failure to balance buckets on swing-out rotors.

Remedy: Train and supervise staff.

Anaerobic incubator explosion — use of incorrect gas.

Remedy: Train and supervise staff.

Improper adaptation

Explosion in domestic vacuum flask — improper transport of liquid nitrogen.

Remedy: Use of specially-designed equipment.

Explosion in domestic-type refrigerator — not sparkproofed and used to store diethyl ether with leaking screw cap.

Remedy: Store low flashpoint solvents and extracts only in sparkproofed refrigerators.

Lack of proper maintenance

Fire in flame photometer

— incorrect re-assembly of components during maintenance.

Remedy: Train and supervise staff.

Fire in oxygen reducing valve

— failure to replace sintered metal filter.

*Remedy: Institute a maintenance programme in accordance with manufacturers' recommendations.***Management of equipment**

Some common factors in equipment-related accidents have been identified (32). These are:

- inferior quality or worn out equipment;
- inadequacies of and mistakes in servicing;
- use of unsuitable or incompatible ancillary equipment;
- inadequate knowledge of or training in the use of the apparatus or system involved.

Accordingly, five activities which are essential features of equipment management have been proposed (32):

- selection of equipment;
- acceptance procedure;
- training;
- servicing (maintenance, repair and modification);
- replacement policy.

The various mishaps in health-care laboratories that have been described above will amply justify these features. It is therefore recommended that these principles of equipment management are adopted in all health-care laboratories.

Table 6.1 lists the equipment that may create hazards and how such hazards may be eliminated. Table 6.2 lists the safety equipment.

Table 6.1. Equipment that may create hazards

Equipment	Hazard	How to eliminate or reduce the hazard
Hypodermic needles	Accidental inoculation, aerosol or spillage	<ul style="list-style-type: none"> • Do not recap or clip needles. • Use a needle-locking type of syringe to prevent separation of the needle and syringe, or use a disposable type where the needle is an integral part of the syringe unit. • Use good laboratory techniques, e.g. <ul style="list-style-type: none"> – Fill the syringe carefully to minimize air bubbles and frothing of inoculum. – Avoid using syringes to mix infectious liquids; if used, ensure that the tip of the needle is held under the surface of the fluid in the vessel and avoid excessive force. – Wrap the needle and stopper in a cotton pledget moistened with an appropriate disinfectant before withdrawing the needle from a rubber-stoppered bottle. – Expel excess liquid and air bubbles from the syringe vertically into a cotton pledget moistened with an appropriate disinfectant or into a small bottle containing cotton

Equipment	Hazard	How to eliminate or reduce the hazard
Hypodermic needles (<i>continued</i>)		<ul style="list-style-type: none"> • Use a biological safety cabinet for all operations with infectious material • Restrain animals while they are being inoculated. Use blunt needles or cannulas for intranasal or oral inoculation. Use a biological safety cabinet. • Autoclave after use and ensure proper disposal.
Centrifuges	Aerosols, splashing and tube breakage	<ul style="list-style-type: none"> • Use sealable buckets (safety cups).
Ultra-centrifuges	Aerosols, splashing and tube breakage	<ul style="list-style-type: none"> • Install HEPA filter between centrifuge and vacuum pump. • Maintain log book of operating hours for each rotor and a preventive maintenance programme to reduce risk of mechanical failure. • Load and unload buckets in a biological safety cabinet.
Anaerobic jars	Explosion, dispersing infectious materials	<ul style="list-style-type: none"> • Ensure integrity of wire capsule around catalyst.
Dessicators	Implosion, dispersing glass fragments and infectious materials	<ul style="list-style-type: none"> • Place in a stout wire cage.
Homogenizers, tissue grinders	Aerosols and leakage	<ul style="list-style-type: none"> • Operate and open equipment in a biological safety cabinet. • Use specially designed models that prevent leakage from rotor bearings and O-ring gaskets or use a stomacher. • Before opening the blender bowl wait for 10 minutes to allow the aerosol cloud to settle. Refrigerate to condense aerosols.
Sonicators, ultrasonic cleaners	Impaired hearing, dermatitis	<ul style="list-style-type: none"> • Ensure insulation to protect against subharmonics. • Wear gloves for protection against high-frequency and detergent action on skin.
Culture stirrers, shakers, agitators	Aerosols, splashing and spillage	<ul style="list-style-type: none"> • Operate in a biological safety cabinet or specially designed primary containment. • Use heavy duty screw-capped culture flasks, fitted with filter-protected outlets, if necessary, and well secured.
Freeze-driers (lyophilizers)	Aerosols and direct contact contamination	<ul style="list-style-type: none"> • Use O-ring connectors to seal the unit throughout. • Use air filters to protect vacuum lines. • Use a satisfactory method of decontamination, e.g. chemical. • Provide an all-metal moisture trap and a vapour condenser. • Carefully inspect all glass vacuum vessels for surface scratches. Use only glassware designed for vacuum work.
Domestic-type refrigerators	Provide ignition sources (thermostats, light switches, heater strips, etc.) that can ignite vapours from stored flammable solvents	<ul style="list-style-type: none"> • Place warning sign on domestic-type refrigerators: "Do not store flammable solvents in this refrigerator." • Modify by relocating manual temperature controls to the exterior of the cabinet and sealing all points where wires pass from the refrigerator compartment. <p>Note: Self-defrosting refrigerators cannot be modified in this way.</p>
Water-baths and Warburg baths	Growth of microorganisms Sodium azide forms explosive compounds with some metals	<ul style="list-style-type: none"> • Regular cleaning and disinfection. • Do not use sodium azide for preventing growth of organisms.

Source: WHO Laboratory Biosafety Manual

Table 6.2. Equipment design to eliminate or reduce hazards

Equipment	Hazard corrected	Safety features
Biological Safety Cabinet		
Class I	Aerosol and spatter	<ul style="list-style-type: none"> • Minimum inward air flow (face velocity) at work access opening. Adequate filtration of exhaust air.
Class II	Aerosol and spatter	<ul style="list-style-type: none"> • Minimum inward air flow (face velocity) at work access opening. Adequate filtration of exhaust air.
Class III	Aerosol and spatter	<ul style="list-style-type: none"> • Maximum containment.
Spatter shield	Spatter of chemicals	<ul style="list-style-type: none"> • Forms screen between operator and work.
Pipetting aids	Hazards from pipetting by mouth, e.g. ingestion of pathogens, inhalation of aerosols produced by mouth suction on pipette, blowing out of liquid or dripping from pipette, contamination of suction end of pipette	<ul style="list-style-type: none"> • Ease of use. • Control contamination of suction end of pipette, protecting pipetting aid, user and vacuum line. • Can be sterilized. • Control leakage from pipette tip.
Loop micro-incinerators	Spatter from transfer loops	<ul style="list-style-type: none"> • Shielded in open-ended glass or ceramic tube, heated by gas or electricity.
Leakproof vessels for collection and transport of infectious materials for sterilization	Aerosols, spillage and leakage	<ul style="list-style-type: none"> • Leakproof construction with lid or cover. • Durable. • Autoclavable.
Autoclaves; manual or automatic	Infectious material (made safe for disposal or re-use)	<ul style="list-style-type: none"> • Approved design. • Effective heat sterilization.
Screw-capped bottles	Aerosols and spillage	<ul style="list-style-type: none"> • Effective containment.
Vacuum line protection	Contamination of laboratory vacuum system with aerosols and overflow fluids	<ul style="list-style-type: none"> • Cartridge-type filter prevents passage of aerosols (particle size 0.45 μm). • Overflow flask contains appropriate disinfectant. Rubber bulb may be used to close off vacuum automatically when storage flask is full. • Entire unit autoclavable.
Goggles or safety spectacles	Impact and splash	<ul style="list-style-type: none"> • Impact-resistant lenses (must be optically correct or worn over corrective spectacles). • Side shields.
Face shield	Impact and splash	<ul style="list-style-type: none"> • Shields entire face. • Easily removable in case of accident.

Source: WHO Laboratory Biosafety Manual

7. Microbiological hazards

Microbiological hazards and the prevention of laboratory-acquired infections are dealt with in the WHO Laboratory Biosafety Manual (2), which is a key volume for all health-care laboratory workers engaged in microbiology. Workers in other health-care laboratory disciplines, however, are also exposed to infections from pathological materials and this chapter outlines the principles of biosafety and describes the universal precautions that should be used in the handling of pathological specimens. For further details the WHO Laboratory Biosafety Manual (2) and other publications (3–5,10,13–16) should be consulted.

The International Biohazard sign

The International Biohazard sign (Fig. 7.1), which has black lettering on a yellow background, should be exhibited on the doors of any laboratory that handles pathogenic microorganisms or materials that may contain them.

Fig. 7.1. International Biohazard symbol



Routes of infection

Microorganisms may enter the human body through the lungs, the mouth, the skin and the eyes. Other routes are unlikely in the health-care laboratory.

Through the lungs

Infected aerosols and airborne particles are often generated during laboratory manipulations, especially in microbiology. Inhalation of these may initiate infection.

Through the mouth

Bad practices such as mouth pipetting, eating, drinking and smoking in the laboratory and poor hygiene (not washing the hands) may transfer microorganisms to the mouth.

Through the skin

The two main routes are accidental puncture by hypodermic needles ("needlestick") and through cuts and abrasions; including those that are not visible to the naked eye.

Through the eyes

Rubbing the eyes with infected (unwashed) hands may transfer microorganisms to the eyes, where they may penetrate the thin mucous membrane.

All these risks can be minimized, if not prevented, by good laboratory practice, the correct use of equipment and a high standard of personal hygiene, as indicated elsewhere in this Manual and its companion volume, the WHO Laboratory Biosafety Manual (2).

Risk Groups of microorganisms

Experience has taught that some microorganisms, and therefore the laboratory specimens that contain them, are more dangerous to handle in the laboratory than others or are more likely to cause severe infection in laboratory workers. Assessment of the relative risk of handling infectious agents has led to the adoption of a scale consisting of four Risk (or Hazard) Groups, ranging from the least (Group 1) to the most (Group 4) hazardous to laboratory workers and the community. Several classification systems have been proposed (13–16) but that formulated and currently used by the WHO (2) is shown in Table 7.1. Other systems use the same principles but there are variations in the wording.

Table 7.1. Classification of microorganisms on the basis of risk

Risk Group 1 (no or very low individual and community risk)

A microorganism that is unlikely to cause human or animal disease.

Risk Group 2 (moderate individual risk, low community risk)

A pathogen that can cause human or animal disease but is unlikely to be a serious hazard to laboratory workers, the community, livestock or the environment. Laboratory exposures may cause serious infection, but effective treatment and preventive measures are available and the risk of spread of infection is limited.

Risk Group 3 (high individual and community risk)

A pathogen that usually causes serious human or animal disease but does not ordinarily spread from one infected individual to another. Effective treatment and preventive measures are available.

Risk Group 4 (high individual and community risk)

A pathogen that usually causes serious human or animal disease and can be readily transmitted from one individual to another, directly or indirectly. Effective treatment and preventive measures are usually not available.

Source: WHO Laboratory Biosafety Manual

The assignment of a pathogen to a particular Risk Group depends on several factors which may differ according to:

- the intrinsic pathogenicity of the organism;
- incidence of the organism in the community;
- mode of transmission (aerosol, arthropod vector) and host range;
- existing levels of immunity;
- availability of effective preventive and therapeutic measures;
- geographic and climatic conditions;
- local standards of hygiene.

The WHO has not proposed lists and recommends that the health authorities of each country should make lists of bacteria, viruses and other organisms in each Risk Group in the light of these factors and according to the local circumstances. In addition, some organisms may be placed in differing Risk Groups according to the manipulations involved and the volume or amount of material handled.

There is no international agreement on the composition of such lists and while most states have compiled their own, some have adopted those of other states or organizations. Most lists also specify or make recommendations about vaccination and the wearing of gloves for handling particular organisms.

Biosafety or containment levels

It is obvious that work with organisms in different Risk Groups requires different conditions for containment, i.e. ensuring that the organisms do not escape from their specimens, culture vessels or the laboratory.

There are four Biosafety or Containment Levels (1–4), each designed for work with organisms of the corresponding Risk Groups. These are shown in Table 7.2, which includes examples of laboratories, practices and equipment. Table 7.3 summarizes the requirements of each level.

In the WHO classification (2), laboratories working with organisms in Risk Groups 1 and 2 (Biosafety Levels 1 and 2) are grouped together as Basic Laboratories, while those working with Risk Groups 3 and 4 (Biosafety Levels 3 and 4 respectively) are classed as Containment and Maximum Containment Laboratories. In some countries Basic Laboratories are described as P1 and P2 (P stands for Physical Containment), P3 is used for Containment, and P4 for Maximum Containment Laboratories.

Biosafety Level 1 (BSL 1)

This is appropriate for handling organisms of Risk Group 1, which do not cause disease in healthy adult humans. Such work can be conducted on an open bench without any containment equipment. BSL 1 laboratories are appropriate for teaching (without using patient specimens).

Biosafety Level 2 (BSL 2)

This level is applicable to most diagnostic activities involving clinical specimens containing pathogens of Risk Group 2. It corresponds to the WHO Basic Laboratory. With good microbiological techniques and universal precautions (see page 60) clinical specimens containing the majority of human pathogens, may be safely manipulated on the open bench. This also applies to most activities involving blood, body fluids or

Table 7.2. Relationship of Risk Groups to Biosafety Levels, practices and equipment

Risk Group	Biosafety Level	Examples of laboratories	Laboratory practices	Safety equipment
1	Basic Biosafety Level 1	Basic teaching	GMT ^a	None; open bench work
2	Basic Biosafety Level 2	Primary health services; primary-level hospital; diagnostic, teaching and public health	GMT plus protective clothing; biohazard sign	Open bench plus BSC ^b for potential aerosols
3	Containment Biosafety Level 3	Special diagnostic	As level 2 plus special clothing, controlled access, directional air flow	BSC and/or other primary containment for all activities
4	Maximum Containment Biosafety Level 4	Dangerous pathogen units	As level 3 plus airlock entry, shower exit, special waste disposal	Class III BSC or positive pressure double-ended autoclave, filtered air

^a GMT, good microbiological technique

^b BSC biological safety cabinet

Source: WHO Laboratory Biosafety Manual

Table 7.3. Summary of Biosafety Level requirements

	Biosafety Level			
	1	2	3	4
Isolation of laboratory	No	No	Desirable	Yes
Room sealable for decontamination	No	No	Yes	Yes
Ventilation:				
inward air flow	No	Desirable	Yes	Yes
mechanical via building system	No	Desirable	Desirable	No
mechanical, independent	No	No	Desirable	Yes
filtered air exhaust	No	No	Yes	Yes
Double-door entry	No	No	Yes	Yes
Airlock	No	No	No	Yes
Airlock with shower	No	No	No	Yes
Effluent treatment	No	No	No	Yes
Autoclave:				
on site	Yes	Yes	Yes	Yes
in laboratory room	No	No	Yes	Yes
double-ended	No	No	Desirable	Yes
Biological safety cabinets				
Class I or II	No	Yes	Yes	Desirable
Class III	No	No	Desirable	Yes

Source: WHO Laboratory Biosafety Manual

tissues that may contain HBV or HIV. However, manipulations which involve techniques with a high aerosol potential should be conducted in a biological safety cabinet (see below).

Biosafety Level 3 (BSL 3)

This level is applicable to diagnostic work involving organisms of Risk Group 3 or high concentrations of Risk Group 2 pathogens. It corresponds to the Containment Laboratory in the WHO nomenclature. BSL 3 also applies to diagnostic activities on blood or other body fluids which are more likely to produce aerosols and cause infection by the airborne route. In most clinical laboratories, BSL 3 activities can be conducted in a separate room equipped with a Class 1 or Class II biological safety cabinet.

Biosafety Level 4 (BSL 4)

This is intended for work with viruses in Risk Group 4. It corresponds to the WHO Maximum Containment Laboratory. These laboratories are usually separate buildings with strictly controlled access and equipped with Class III biological safety cabinets. Only specially trained staff are allowed to work in such laboratories.

Biological safety cabinets

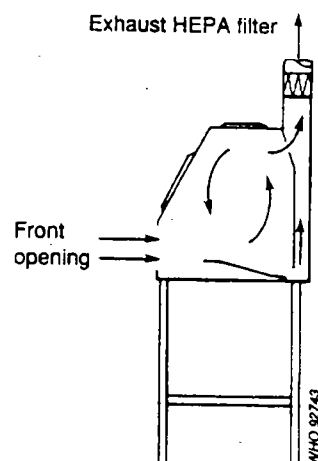
There are three classes of biological safety cabinets. These cabinets are described briefly here, but for their final choice, siting and installation other publications should be consulted (37–42).

Class I biological safety cabinet

A Class I biological safety cabinet (Fig. 7.2) is an open-fronted, ventilated cabinet that provides personal protection to the operator by an inward air flow that is not circulated. It is fitted with an High Efficiency Particulate Air (HEPA) filter to protect the environment from microorganisms released during manipulations within the working space.

Fig. 7.2. Schematic diagram of a Class I biological safety cabinet

(Source: reference 2, reproduced by permission of the Minister of Supply and Services, Canada)



Class I cabinets may be used for work with low- or moderate-risk organisms (Risk Groups 2 and 3). Although they protect the operator they do not protect the material (product) within the cabinet from contamination.

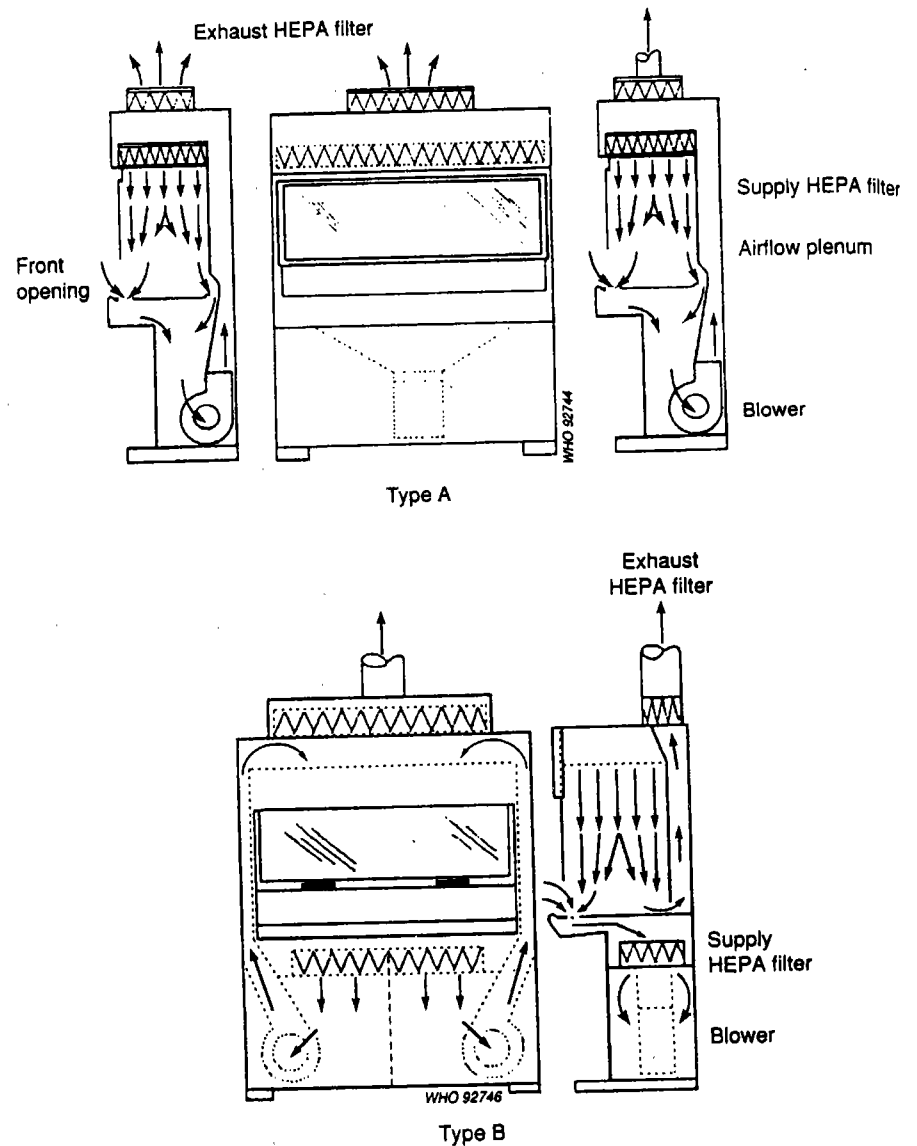
Class II biological safety cabinet

A Class II biological safety cabinet (Fig. 7.3) is an open-fronted, ventilated cabinet that gives personal protection to the operator and the material (product). There is an inward air flow and HEPA-filtered supply and exhaust air. There are two types of Class II cabinets:

- Class II, type A normally used in microbiology filters and recirculates 70% of the air.
- Class II, type B cabinets, which filter and recirculate only 30% of the air are used while working with radioactive and carcinogenic substances.

Fig. 7.3. Schematic diagram of a Class II biological safety cabinet

(Source: reference 2, reproduced by permission of the Minister of Supply and Services, Canada)



Class II, type A biological safety cabinets may be used for work with low- or moderate-risk organisms (Risk Groups 2 and 3). As they protect both the operator and the material (product) within the cabinet from contamination they are particularly useful for work with tissue cultures.

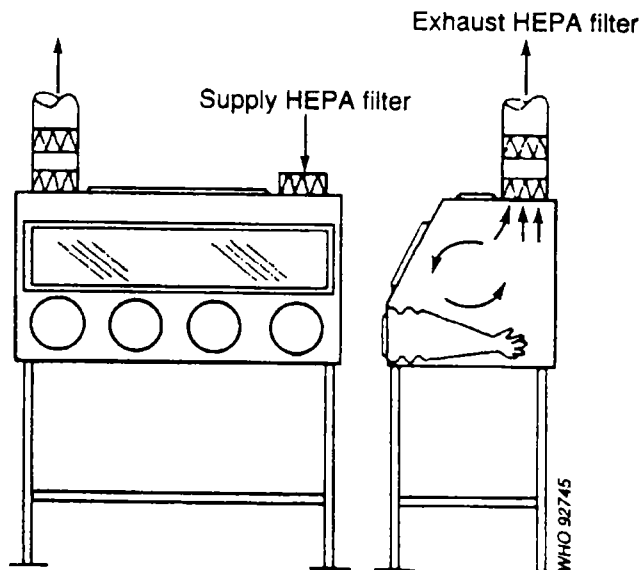
Class III biological safety cabinet

A Class III biological safety cabinet (Fig. 7.4) is a totally enclosed, gas-tight ventilated cabinet maintained under negative pressure. Both supply and exhaust air is HEPA-filtered. Exhaust air is usually passed through two HEPA filters in series. Work is done with long-sleeved rubber gloves which are integral with the cabinet carcass.

Class III cabinets are used for high-risk (Risk Group 4) agents and provide a total barrier between the operator and work. Flammable gases should not be used in these cabinets.

Class III cabinets may be fitted with dunk tanks for external disinfection of containers that are passed in and out of the working space. They are often connected in lines by sealable ports and a terminal autoclave may be included in the line.

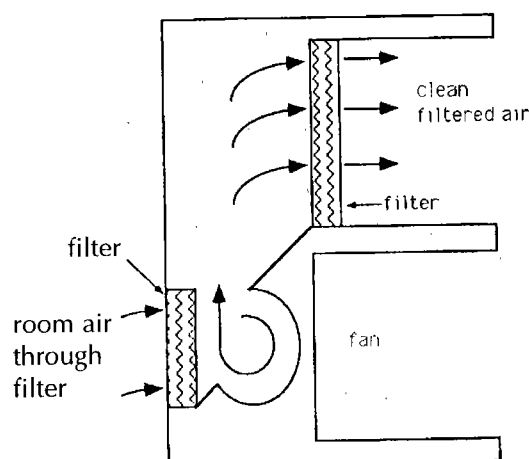
Fig. 7.4. Schematic diagram of a Class III biological safety cabinet
(Source: reference 2, reproduced by permission of the Minister of Supply and Services, Canada)



Laminar flow cabinets

There is often confusion between biological safety cabinets and laminar flow cabinets or workstations. Biological safety cabinets are designed to protect the worker (and sometimes the work); laminar flow cabinets are designed to protect the work only and offer no protection to the worker (10,43). A typical laminar flow cabinet is shown in Fig. 7.5. These cabinets have no place in laboratories where infectious materials are handled. They are useful, however, in the preparation of culture media and sterile solutions.

Fig. 7.5. Schematic diagram of a laminar flow clean air workstation
(Adapted from reference 44 by permission of the authors)



Universal Precautions

Universal precautions were originally devised to protect health-care workers from infection with bloodborne diseases (3–5). The principles are:

- all blood specimens are treated as potentially infectious irrespective of the source and laboratory findings;
- all blood-stained equipment and equipment that has been used to handle blood is treated as potentially infectious.

These precautions should be applied in laboratories by:

- wearing gloves for handling all blood specimens;
- wearing gloves for handling specimens and materials that contain or might contain organisms in Risk Group 3 and, if recommended in national lists, those in Risk Group 2.

All other precautions against infection, as detailed in this and the *WHO Laboratory Biosafety Manual (2)* should also be followed.

Sterilization and disinfection

Sterilization implies the killing of all living organisms and is usually accomplished by heat, e.g. in an autoclave or hot air oven.

Disinfection implies killing or rendering pathogenic microorganisms inactive. Most disinfection methods employ chemicals.

The hazards of using autoclaves are described on pages 44–45. Ovens are outside the scope of this book. For further information about sterilization one of the standard textbooks should be consulted (44,45).

Chemical disinfectants

The disinfectants used in the health-care laboratory vary in their ability to kill bacterial spores, fungi and certain viruses but all are active against vegetative bacteria.

Table 7.4. Properties of some laboratory disinfectants^a

	Active against							Inactivated by					Toxicity		
	Fungi	Bacteria		Mycobacteria	Spores	Lipid viruses	Non-lipid viruses	Protein	Natural materials	Synthetic materials	Hard water	Detergents	Skin	Eyes	Lungs
		Gram-positive	Gram-negative												
Phenolic compounds	+++	+++	+++	++	-	+	v	+	++	++	+	C	+	+	-
Hypochlorites	+	+++	+++	++	++	+	+	+++	+	+	+	C	+	+	+
Alcohols	-	+++	+++	+++	-	+	v	+	+	+	+	-	-	+	-
Formaldehyde	+++	+++	+++	+++	+++ ^b	+	+	+	+	+	+	-	+	+	+
Glutaral	+++	+++	+++	+++	+++ ^c	+	+	NA	+	+	+	-	+	+	+
Lodophors	+++	+++	+++	+++	+	+	+	+++	+	+	+	A	+	+	-

^a +++ good; ++ fair; + slight; - nil; v depends on virus; C cationic; A anionic; NA not applicable.
^b above 40 °C. ^c above 20 °C. Source: Adapted from reference 10 by kind permission of the publishers.

Some are toxic to the skin, eyes or lungs and care is needed in handling them. Eye protectors and gloves should be worn when chemical disinfectants are diluted for use. Table 7.4 gives the properties of some laboratory disinfectants.

Although different compounds and formulations may have specific applications, the "universal" disinfectant used in the health-care laboratory is chlorine, normally as sodium hypochlorite solution. Commercial formulations vary in the amount of available chlorine. Commercial solutions and household bleaches may contain 50 g/L (50 000 ppm). The final concentration for "clean" situations, i.e. general laboratory use is 1 g/L (1000 ppm) and the hypochlorite should be diluted to 1/50 with water. For blood spillages and blood-contaminated objects a stronger solution containing 5 g/L (5000 ppm) should be used, made by diluting the hypochlorite to 1/10 with water. Dilute hypochlorite solutions lose their activity when stored and solutions for use should be made up daily. Other chlorine-releasing compounds are available and are listed, along with the appropriate dilutions, in Table 7.5.

For further information on disinfectants see the *WHO Laboratory Biosafety Manual* (2) and other publications (44-46).

Table 7.5. Other chlorine-releasing compounds and recommended dilutions

	"Clean" conditions ^a	"Dirty" conditions ^b
Available chlorine required	0.1% (1 g/L)	0.5% (5 g/L)
Sodium hypochlorite solution (5% available chlorine)	20 mL/L	100 mL/L
Calcium hypochlorite (70% available chlorine)	1.4 g/L	7.0 g/L
NaDDC powder (60% available chlorine)	1.7 g/L	8.5 g/L
NaDDC tablets (1.5 g available chlorine per tablet)	1 tablet/L	4 tablets/L
Chloramine (25% available chlorine)	20 g/L	20 g/L

^a After removal of bulk material. ^b For flooding, e.g. on blood or before removal of bulk material. Source: *WHO Laboratory Biosafety Manual*

8. Chemical hazards

Many of the chemicals used in health-care laboratories are intrinsically hazardous. But familiarity with them and failure to recognize the hazards may lead to careless handling, incorrect storage and disposal procedures and therefore the likelihood of risk of exposure to their toxic effects and to fires or explosions. A systematic risk reduction strategy for hazardous chemicals depends largely on:

- recognition of the hazards;
- evaluation of the risks;
- provision and use of appropriate safety precautions.

Chemicals can cause injuries or damage due to:

- immediate (acute), delayed (chronic or latent) or cumulative toxicity;
- corrosive effects;
- explosion and fire;
- adverse environmental effects.

In general, personal injuries that arise from exposure (inhalation, ingestion or skin contact) to chemicals are called *health hazards*. Damage to buildings and their contents by chemicals are *safety hazards*. Personal injuries may also arise from fires and explosions. A substance may offer both kinds of hazards, e.g. a corrosive chemical may injure both people and property; and many solvents are both toxic and highly flammable.

Definitions and classification

Chemical hazards may be defined and classified according to schemes used for the transportation and shipment of dangerous substances, mixtures or preparations. Various schemes have been proposed (47–57). Other schemes define and rate various hazards according to the degree of danger. In one such scheme (27), substances are listed as *Health, Fire, and Instability/Reactivity* hazards on a numerical scale of 0–4, where 0 = no unusual hazard, 1 = minor, 2 = moderate, 3 = severe and 4 = extreme hazard. Another scheme (51) assigns toxic, fire, explosion and reactivity hazards on the basis of low (1), medium (2) and high (3) effects.

The toxic effects of chemicals may be further divided and defined on the basis of their ability to cause specific types of disease or affect particular organs or bodily functions:

Allergenic substances are recognized by the immune system as antigens and cause allergic or hypersensitive contact which may lead to dermatitis; inhalation leads to asthma and related conditions.

Carcinogens are substances that cause or statistically increase the risk of cancer, usually but not exclusively after repeated long-term exposure. Carcinogens are classified on the basis of epidemiological, animal and experimental studies (52) as: Group

1 (carcinogenic to humans), Group 2A (probably carcinogenic to humans), Group 2B (possibly carcinogenic to humans), Group 3 (not classifiable), and Group 4 (probably not carcinogenic to humans). The evidence on which such classifications are made is regularly reviewed and updated.

Reproductive toxins include *mutagens* which can induce mutations of the germ cells, leading to genetically-induced malformations, spontaneous abortion or death of the offspring of the exposed individual.

Teratogens can damage the fetus, causing congenital malformations or death. Exposure during pregnancy may result in cancer in the offspring many years later.

Routes of exposure

The knowledge of the ways in which exposure may occur is important in reducing that exposure and assessing its effects. Exposure may occur in several ways:

Inhalation

Chemicals deposited in the respiratory tract may cause irritation, allergic sensitization, respiratory diseases or cancers. They may cause systemic poisoning if absorbed through the mucous membranes.

Contact with skin and eyes

Skin contact may cause chemical burns or dermatitis. Splashing into or rubbing the eyes may result in conjunctivitis.

Absorption through skin or eyes

Even if there is no immediate local effect, absorption may result in systemic poisoning.

Swallowing

Chemicals may be ingested as a result of aspiration during mouth pipetting, by placing articles in the mouth, and the consumption of contaminated food and drink in the laboratory.

Injection

Small, but significant amounts of chemicals may be injected when the skin is punctured by sharp objects such as needles, probes and knives.

Chemical hazard information

Information about the hazards of individual chemicals is provided by labels on the containers and packages, suppliers' data sheets and reference books (53–57). The hazards, etc. of some chemicals commonly used in health-care laboratories are detailed in Annex 3.

Labels on containers usually indicate the general nature of the contents by standard warning symbols (Fig. 8.1) together with the numbers of Risk and Safety Phrases. These numbers are keys to the particular dangers and necessary safety precautions. Risk Phrases apply to substances listed under the European Community's Directives on the *Classification, Packaging and Labelling of Dangerous Substances Regulations* (47), usually known as 'CPL'. The list is printed in several languages. Safety Phrases are supplementary to Risk Phrases. Both are available from the WHO. The label should also indicate fire safety, (flashpoint, flammability limits, auto-ignition temperature and fire extinguisher media (see Chapter 4), first-aid, reactivity, handling, storage, spillage and disposal information.

Copies of data sheets should be kept on file and be available to all members of the staff. In the health-care laboratory most chemicals are used as reagents in established techniques and the hazards should be predictable. In some circumstances, however, unforeseen risks may arise from the inadvertent mixing or accidental misuse of chemicals. Dangerously unstable chemicals and mixtures of incompatible substances should be avoided or additional precautions taken. Examples of these are:

- formation of shock-sensitive explosive peroxides when dimethyl ether and other ethers are exposed to sunlight;
- production of chlorine gas from mixtures of bleach and acids;
- formation of explosive products when sodium azide meets metals such as copper and lead;
- the vigorous base-catalysed reaction between acetone and chloroform;
- violent boiling when water is added to sulphuric acid.

Measurement and quantification of chemical hazards

Hazard measurement and quantification are necessary to provide evidence of the existence and extent of any particular hazard. It is often possible to determine the magnitude, in absolute or relative terms, of a chemical hazard by reference to some property or the extent of its interaction with a target organism under standard conditions. Such information provides guidance on the selection of the least hazardous chemical for a particular activity.

Fire hazard

The relative magnitude of the fire hazards posed by flammable chemicals may be determined by comparison of their flashpoints, ignition temperatures, flammability and vapour pressures (see Chapter 4).

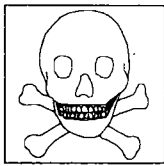
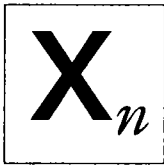
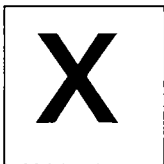
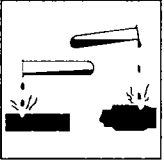
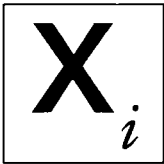



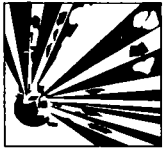

Toxicity

For most chemicals the identification and possible quantification of health hazards are based on tests with animals, cell cultures or microorganisms, and extrapolation of these results to humans may be difficult or unreliable. A further complication is that toxic effects may be observed for only one route of exposure or dose. There are two commonly used indicators of the health hazards of chemicals:

Lethal Dose 50 (LD₅₀)

This is the minimum dose which, when given by a specific route, causes the death of 50% of animals in a group of the same species. LD₅₀ values are expressed as dose per unit body weight (mg/Kg) according to the species and route of administration.

Fig. 8.1. Classification of chemical hazards and hazard symbols*

Hazard	Characteristic property	Hazard symbol
Toxic	Ability to cause death or serious health risk following exposure by inhalation, ingestion or absorption through the skin. Effects may be acute, occurring within a short time after exposure, chronic as a result of long-term exposures or latent characterized by a long period between exposures and effect.	
Very toxic	Ability to cause death or extremely serious acute or chronic health effects following exposure by any route.	
Harmful	Ability to offer limited health risks following exposure by any route.	
Corrosive	Ability to destroy outer body tissues and internal tissue on exposure by inhalation, ingestion or skin contact or with the ability to materially damage inanimate substances.	
Irritant	Ability to cause inflammation of body tissue following immediate, prolonged or frequent contact with the skin or mucous membrane.	
Extremely flammable	A liquid having flashpoint below 0 °C and boiling point less than or below 35 °C.	
Highly flammable	A substance which readily ignites and burns, e.g. any liquid having flammable flashpoint of less than 21 °C; any substance which on contact with air or water ignites spontaneously or evolves highly flammable gases; any gaseous substance which is flammable at normal pressure.	
Flammable	A liquid with flashpoint between 21 °C and 55 °C.	
Explosive	Any substance which may explode when heated or when subject to shock or friction.	
Oxidizing	Any substance which produces heat, or evolves oxygen in contact with other substances causing them to burn strongly or become spontaneously combustible.	

*Based on the EC classification and labelling scheme

Lethal Concentration 50 (LC_{50})

This is the equivalent indicator of toxicity where the route of exposure is inhalation (of gas, vapour or dust). The concentration of the chemical is given in parts per million (ppm) or weight per unit volume of air (mg/m^3).

The usefulness of LD_{50} and related tests as indicators of toxicity is questionable because of variations in the observed effects and measured values for different species and routes of administration, and the difficulty in evaluating long-term or chronic, cumulative or carcinogenic effects. Nevertheless, these tests are widely used for hazard ratings and classification schemes on the basis that the lower the lethal dose the greater is the hazard.

Table 8.1 shows the numerical criteria for classifying chemicals as very toxic, toxic or harmful (47). Table 8.2 gives a general classification of toxicity ratings based on the lethal doses for various routes of exposure.

The terms *corrosive* and *irritant* indicate the potential of a chemical to injure the skin or other tissues at the point of contact. Currently there is no index of the relative degrees of hazard or classification of such chemicals although the severe consequences of skin and eye contact with concentrated acids, bases and phenols are well known.

Table 8.1. Numerical criteria for toxicity classification

Category	LD_{50} mg/Kg (oral, rat)	LD_{50} mg/Kg (percutaneous, rat or rabbit)	LC_{50} mg/L (4 h, rat)
Very toxic	<25	<50	<0.5
Toxic	>25–200	50–400	>0.5–2
Harmful	>200–2000	400–2000	>2–20

Source: Adapted from reference 47

Table 8.2. General classification of toxicity ratings

Toxicity rating	LD_{50} (oral, rat) mg/Kg	LD_{50} (4 h, rat) ppm	LD_{50} (skin, rabbit) mg/Kg	Descriptive term
1	<1	<10	<5	Extreme
2	1–50	10–100	5–43	High
3	50–500	100–1000	44–340	Moderate
4	500–5000	1000–10000	350–2810	Slight
5	5000–15000	10000–100000	2820–22600	Practically non-toxic
6	>15000	>100000	>22600	Relatively harmless

Variations on this classification scheme appear in national regulations and voluntary codes

Sources: Hathaway GJ, Proctor NH, Hughes JP, Fischman ML. In: *Proctor and Hughes' chemical hazards of the workplace*, 3rd ed. New York, Van Nostrand Reinhold, 1991.

Carson PA, Numford CJ. *The safe handling of chemicals in industry*, Essex, Longman, 1988.

References 56, 57 by kind permission of the publisher.

Occupational Exposure Limits; Threshold Limit Values

These are concentrations of airborne chemicals to which persons may be exposed without significant risk of adverse health effects. The limits are expressed as parts per million (ppm) or mg/m³ of air, averaged over a stated reference period—an 8 h day or 40 h week for long-term or average exposures, and 10–15 min periods for short-term exposures or as a maximum concentration that should not be exceeded.

These limits are not indices of health hazards or toxicity, nor do they represent divisions between 'safe' and 'hazardous' concentrations. They provide guidance about tolerable levels for most people and can represent minimum standards of workplace hygiene. They are used as qualitative indicators of approximate hazard wherein high values imply a low health risk and *vice versa*.

Table 8.3 gives a rough classification scheme that facilitates comparison of the hazards of inhaling different chemicals.

Table 8.3. Classification of inhalation hazards

Relative hazard	Exposure limit (ppm)*
Slight	>500
Moderate	100–500
High	<100
Severe	<5

* conversion factor for exposure limits are:

$$\text{mg/m}^3 = \text{ppm} \times \text{molecular weight}/24$$

Source: Adapted from reference 51 with kind permission of the publisher.

The 'Hazard Diamond'

The 'hazard diamond' label designed by the US National Fire Prevention Association (29) indicates, by numbers within a coloured diamond-shaped sign, the flammability, health hazard, reactivity and special precautions of the chemical in the container (Fig. 8.2). It may be used on bottles, containers and bulk carriers.

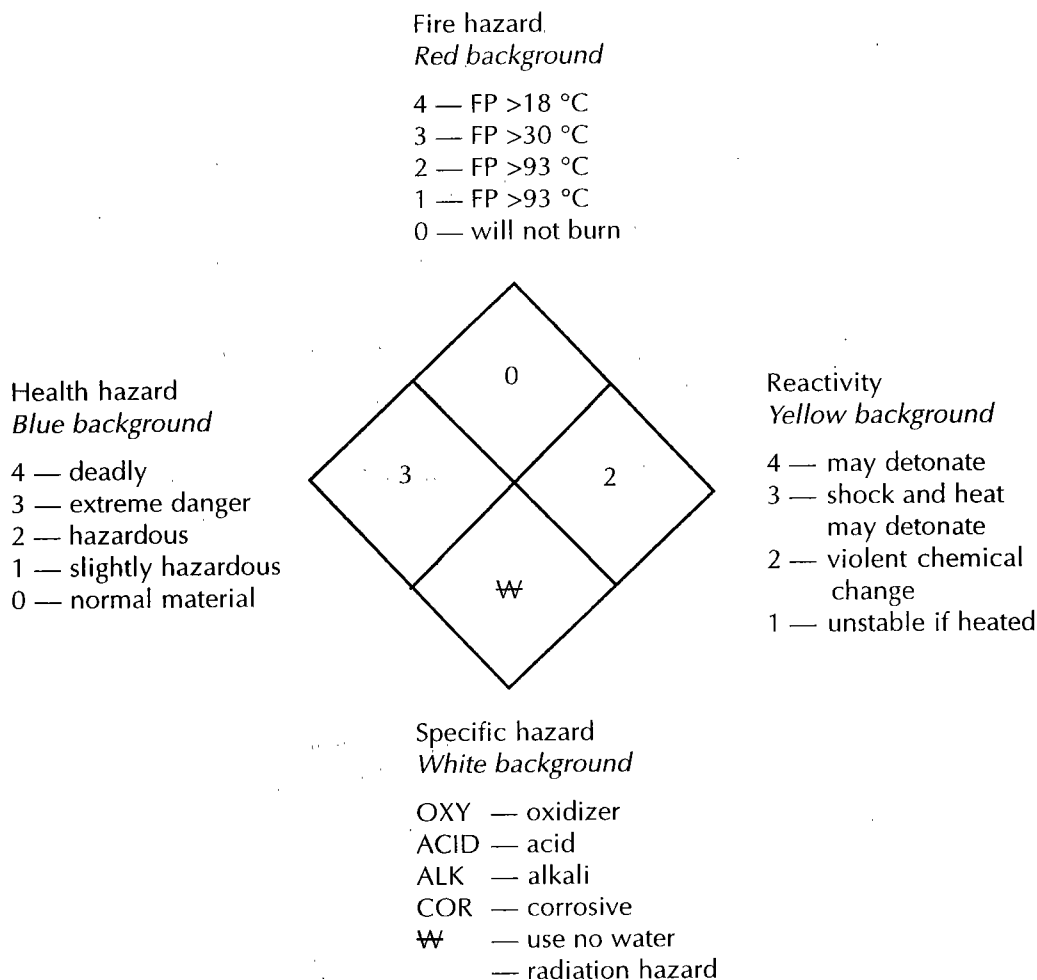
Risks associated with chemicals

The risk of injury or disease caused by toxic or hazardous chemicals expresses the probability or likelihood that harm will occur and the extent of that harm. The probability of being exposed to chemicals in the laboratory, i.e. the potential for exposure, depends on:

- the nature of the process;
- the physical form and properties of the substance, including its volatility and concentration;
- the efficiency of containment, partial containment or devices, including personal protective equipment;
- the frequency and duration of the activity.

The extent of harm, i.e. the consequences of exposure, will depend on these factors but will be determined by:

Fig. 8.2. The "hazard diamond" (US National Fire Association)
(Adapted from reference 29. The example given is sulphuric acid)



FP—Flashpoint; figures have been changed from °Fahrenheit to °Celsius.

- the intrinsic hazard of the chemical;
- the concentration of the chemical and amount or dose absorbed by the body, or in contact with it, including the time during which the exposure occurs;
- the parts of the body which are exposed to the chemical;
- the possibility of synergistic effects, whereby the harm caused by exposure to several chemicals is greater than that expected from each one individually.

The degree of risk associated with typical laboratory activities involving toxic chemicals should be evaluated before the work is started so as to determine the level or type of containment needed to obviate the risk, or to ensure that it is so reduced that there will be no significant adverse health effects. This evaluation should include the delivery, storage and disposal of chemicals and the consequences of foreseeable accidents such as spillage.

Annex 3 lists the hazards and precautions to be taken in the handling of some commonly-used laboratory chemicals.

Reducing risks

Risks may be reduced by controlling the substances used, technical processes and containment.

Substance control

This may be achieved by:

- using non-hazardous or low-hazard materials instead of hazardous ones;
- using pure reagents, as impurities may be toxic or reactive;
- using aqueous solutions wherever possible or otherwise selecting solvents of low toxicity and flammability ratings or lowest vapour pressures;
- selecting chemicals that are most easily contained or give limited contamination if released;
- purchasing, storing and using the smallest quantities of chemicals consistent with technical methods;
- clearly labelling all reagent bottles with name and hazard warning;
- replacing stoppers immediately after use, keeping bottles and containers closed when not in use; opening closed containers with care to release internal pressure safely.

Process control

Most investigations in health-care laboratories follow well-established protocols, but reagents may be made on site in which case the equipment used may be controlled by:

- avoiding unnecessary manipulations, e.g. by purchasing 'ready-to-use' reagents and kits;
- using only glassware that is in good condition and which is decontaminated and cleaned immediately after use. Plastic chemical containers and apparatus reduce breakages;
- using suction devices ('pipettors') instead of mouth pipetting;
- using large funnels and spillage catchment trays when pouring from bulk containers.

Containment control

This involves care and correct use of fume cupboards and local ventilation equipment (see Chapter 3).

Storage and disposal of chemicals

These are considered in Chapters 3 and 11.

Spillages and leakages

Chemical spillages can contaminate laboratory furniture and equipment. People may be contaminated directly or indirectly by contact with contaminated surfaces. First-aid treatment of affected persons is described in Chapter 12.

Treatment of spillages should be considered during the risk evaluation process. Hazard data sheets will often give advice on dealing with spillage of specific chemicals.

Spillage preventing equipment should be placed strategically and includes the following:

- protective clothing, including aprons;
- eye and face protection (see pages 12–13);
- buckets, mops and scoops or pans;
- stiff card for collecting the spillage into a scoop or pan;
- inert absorbent substances, e.g. sand, kieselguhr (diatomite), paper or gelling material.

The general procedures to contain spillages and leaks are:

Non-volatile, non-flammable liquids

These may be confined by placing dry sand or absorbent paper at the edges of the spillage to prevent spread; and then adding further sand or absorbent paper to soak up the liquid. Spillage control powders are available, which, if sprinkled on a liquid, form a gel which is easier to deal with. The absorbed spillage may then be collected in a scoop or pan and disposed off. Thereafter the area should be washed with several changes of water.

Volatile or highly flammable liquids

These are best removed by encouraging evaporation after extinguishing all flames, removing ignition sources and opening all windows.

Acids and alkalis

These should not be neutralized *in situ* but collected as described for non-volatile liquids with a suitable absorbent and transferred to a leak-proof container for neutralization in a safe place.

Solids

Solids should be moistened with water to reduce dust and collected for disposal in a pan or scoop.

Leakages from gas cylinders

If leakage from a flammable gas cylinder occurs, all flames should be extinguished and sources of ignition removed or switched off.

If the leak is small, the valve should be covered with a plastic bag and taped or fastened with a rubber band, and the cylinder removed to the open air, where the valve may be tightened or the gas allowed to disperse.

If the leak appears to be serious, the building should be evacuated pending the removal of the cylinder by trained persons.

9. Radiation safety

Biological effects of radiation

Radiological protection is concerned with protecting humans against the harmful effects of ionizing radiation. Such radiation can cause harmful effects which are: (i) *somatic*—clinically observable in irradiated individuals; or (ii) *hereditary*—observable in the descendants of irradiated individuals.

Somatic effects are classified as stochastic or deterministic. A *stochastic* effect is one in which the probability of occurrence is proportional to, and severity independent of the dose of radiation; there is no threshold below which harmful effects do not occur; even the smallest dose carries some risk. A *deterministic* effect is one in which the severity of the harm rather than its probability depends on the dose; there is a threshold below which the effects do not occur. Stochastic effects include radiation-induced cancers, e.g. leukaemia, bone, lung and skin cancers, the onset of which may occur many years after irradiation. The deterministic, non-stochastic effects include minor skin damage, hair loss, blood deficiencies, gastro-intestinal damage and cataract formation.

The hereditary effects of radiation exposure to the gonads include chromosome damage or gene mutation which are expressed in the progeny, either as well-defined genetic disorders, or as reduced resistance to infectious diseases. Irradiation of the germ cells in the gonads in high doses can also cause cell death, resulting in temporary or permanent impairment of sterility in both sexes; in females it may affect menstruation. Exposure of the developing fetus, particularly between weeks 8–15, increases the risk of congenital malformations, mental impairment, or radiation-induced cancers in later life.

Radiation quantities and units

Radionuclides are unstable isotopes of elements whose nuclei undergo spontaneous transformation to produce more stable atoms. Such nuclides are said to be *radioactive* and the transformation process is one of *radioactive decay* or *disintegration*. It is usually accompanied by the emission of ionizing radiation in the form of atomic or subatomic particles (alpha, beta or neutron particles) or electromagnetic radiation (gamma or X-rays). In the health-care laboratory the most commonly used radioactive sources are those that emit beta and gamma radiation.

The activity of a radioactive substance is defined by the number of atoms disintegrating per second. In 1975, the *Conférence générale des poids et mesures* adopted new units of measurement in the field of ionizing radiation as a part of the SI system of units. The new SI unit for the activity of a radioactive substance is the “becquerel” (Bq) which represents one disintegration per second.

The commonly used multiples of the becquerel include:

$$\begin{aligned}\text{kilobecquerel (KBq)} &= 10^3 \text{ Bq} \\ \text{megabecquerel (MBq)} &= 10^6 \text{ Bq}\end{aligned}$$

gigabecquerel (GBq) = 10^9 Bq

The older unit of activity was the curie (Ci), which is that amount of radioactive material which undergoes 3.7×10^{10} nuclear disintegrations per second. Submultiples of the curie include:

millicurie (mCi) = 10^{-3} Ci

microcurie (μ Ci) = 10^{-6} Ci

The numerical factors for conversion are:

1 Bq = 2.7×10^{-11} Ci and 1 Ci = 3.7×10^{10} Bq

and the corresponding relationships between the older units and SI units are:

1 Ci = 37 GBq

1 mCi = 37 MBq

1 μ Ci = 37 KBq

The harmful effects arising from the interaction of ionizing radiation and a biological system depend on the total amount of energy absorbed by that system, the rate at which it is received and the nature of the absorbing body tissue. The amount of energy which is absorbed per unit mass of tissue is called the "absorbed dose" (D). In the SI system the absorbed dose is expressed in joule per kilogram, for which the special name "gray" (Gy) is used.

1 Gy = 1 JKg^{-1}

The older unit of absorbed dose was the rad, which is equal to 100 ergs per gram.

The absorbed dose represents the energy absorbed per unit mass of the medium; it does not reflect the degree of damage caused by different types of radiation and so cannot be used to predict the severity or probability of the radiation-induced damage to the biological system. For the same absorbed dose, neutrons and alpha particles are biologically more effective than X-rays, gamma-rays or beta particles.

In radiological protection this is taken into account by weighting the absorbed dose by a factor related to the quality of the radiation (58). This factor is called the radiation weighting factor, W_R , and is selected for the type and energy of the radiation incident on the body or, in case of a source within the body, emitted by the source. The radiation weighting factor for X-rays and gamma and beta radiation is one.

The weighted absorbed dose is called equivalent dose, H_T .

The equivalent dose in tissue T is given by the expression:

$$H_T = \sum_R W_R \cdot D_{TR}$$

where, D_{TR} is the absorbed dose averaged over the tissue or organ T, due to radiation R.

The unit of equivalent dose is the joule per kilogram called sievert, Sv. (The older unit of equivalent dose was the rem, roentgen equivalent man.) The SI units and the older units of dose are related as shown below:

1 Gy = 100 rad

1 Sv = 100 rem

1 mGy = 100 mrad 1 mSv = 100 mrem

$$1 \text{ uGy} = 0.1 \text{ mrad} \quad 1 \text{ }\mu\text{Sv} = 0.1 \text{ mrem}$$

The relationship between the probability of stochastic effects and equivalent dose is found also to depend on the organ or tissue irradiated (58). For this reason a quantity called effective dose is used for indicating the combination of different equivalent doses to different tissues or organs. The factor by which the equivalent dose in a tissue or organ T is weighted is called the tissue weighting factor, W_T , which represents the relative contribution of that organ or tissue to the total detriment due to the effects resulting from uniform irradiation of the whole body.

The effective dose is the sum of the weighted equivalent doses in all the tissues and organs of the body:

$$E = \sum_T W_T \cdot H_T$$

where H_T is the equivalent dose in tissue or organ T and W_T is the weighting factor for tissue T. For example, the International Commission on Radiological Protection (ICRP) (59) recommends the following weighting factors for different tissues or organs:

Gonads	0.20
Bone marrow (red), colon, lung, stomach	0.12
Bladder, breast, liver, oesophagus, thyroid	0.05
Skin, bone surface	0.01
Remainder	0.05

The simplifications involved in the derivation of the equivalent dose and the effective dose are useful approximations to the true biological situation, depending on the current understanding of radiobiology. They allow an assessment of risk in general terms and provide a usable basis for radiological protection.

Principles and organization of radiation protection

The use of radionuclides in the health-care laboratory implies the potential irradiation of personnel and of members of the public. Therefore, any plan for radiation protection should concentrate on these two categories of potentially exposed persons.

The hazard from the use of unsealed sources of radiation may arise from external radiation or from radioactive material taken into the body.

For many laboratory activities the relative importance of these two hazards depends on the particular radionuclide, the labelled radiochemicals and the operational procedures.

External radiation

The type and energy of the radiation largely determines its ability to penetrate the outer layers of the skin. Gamma radiation presents the greatest risk because of its ability to penetrate the outer skin layers and irradiate sensitive tissues and organs. Alpha particles have little or no penetrating power and so present no external hazard. Beta particles have intermediate penetrating power, depending on their energy. The control of external radiation is based on four principles—time, distance, shielding and substitution.

Time

Radiation dose is the product of the dose per unit time and the time of exposure. The dose received decreases in direct proportion to the reduction in exposure time. The time of exposure during manipulations may be reduced by:

- practising unfamiliar techniques without using the radionuclide;
- ensuring that all radioactive sources are returned to storage immediately after use;
- removing radioactive waste from the laboratory at frequent intervals;
- spending as little time as possible in the radiation area or laboratory;
- effective time management or planning of laboratory manipulations.

Distance

Increasing the distance from the radiation source effectively reduces the exposure, as the radiation dose is inversely proportional to the square of the distance from the source (inverse square law). Doubling the distance therefore reduces the dose four times. Various devices and mechanical aids are used to increase the distance between the operator and source, e.g. long-handled tongs, clamps, remote pipettors.

Shielding

Radiation energy-absorbing or attenuating materials placed between the source and the operator or other occupants of the laboratory limit exposure. The choice and thickness of any shielding material depends on the penetrating ability (type and energy) of the radiation. For low energy beta emitters (^3H) shielding may be unnecessary but for other beta emitters a 1 cm thick Perspex or Plexiglass is required. The absorption of high energy beta radiation, such as the beta-rays from ^{32}P , by high density materials such as lead produces high energy X-radiation such as "Bremsstrahlung". This is why lead is not used as a shield for high energy beta-rays. For gamma emitters, lead is the shielding of choice. Gamma radiation is attenuated exponentially although in theory not totally absorbed by the shield.

Substitution

Radionuclide-based methods must not be used when other techniques are available. If substitution is not possible then the radionuclide with the least penetrating power or energy should be used.

Internal radiation

Internal radiation hazards arise from sources within the body, following exposure by inhalation, ingestion, absorption through the intact skin, or injection. The potential for damage from internal sources is greater than that from equivalent sources outside the body because the internal source is in contact with body tissue; there is virtually total transfer of the radiation energy to the body. The internal hazard of a radionuclide is expressed as *radiotoxicity* and depends on:

- the type and energy of the radiation;
- the radioactive half-life;
- the biological half-life;
- the characteristic properties of the radiochemical;
- the distribution and localization of the radiochemical within the body.

The internal radiation hazard will diminish as the radionuclide decays according to

its characteristic half-life. Some loss of radioactivity will also occur as a result of excretion of the radionuclide in the faeces, urine, sweat and expired air. The *biological half-life* is defined as the time taken for a 50% reduction, by normal excretion processes, of the amount of a given radionuclide in the body.

The principle of dose limitation is extended to normal internal radiation hazard by the use of *annual limits of intake (ALI)*. The ALI is the amount of a specified radionuclide which, if ingested, inhaled or penetrated through the skin in a year by reference man would result in a committed dose equal to the relevant annual dose limit (59). The radiation dose limits are given in Table 9.1 and the data for radionuclides is presented in Table 9.2.

Table 9.1. Radiation dose limits

Person	Site	Effective dose (mSv)	Period
Employee >18 years	Whole body	20	1 year
	Skin	500	1 year
	Lens of the eye	150	1 year
Trainee >18 years	Whole body	6	1 year
	Extremities or the skin	150	1 year
	Lens of the eye	50	1 year
The public	Whole body	1	1 year
	Skin	50	1 year
	Lens of the eye	15	1 year
Pregnant workers*			Until the end of pregnancy

* The embryo or fetus should be afforded the same broad level of protection as for members of the public. International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (59).

Table 9.2. Data for selected radionuclides

	³ H	¹⁴ C	³² P	³⁵ S	⁴⁵ Ca	⁵¹ Cr	¹²⁵ I
Principal emission	beta	beta	beta	beta	beta	gamma	gamma
Maximum energy (Mev)	0.02	0.16	1.71	0.71	0.25	0.32	0.035
Half-life	12.4 y	5730 y	14.4 d	87.4 d	163 d	27.8 d	59.6 d
Range in air	6 mm	24 cm	790 cm	26 cm	52 cm	—	—
ALI (MBq)	1000	40	8	30	20	200	1
Shielding	—	P*	P*	P*	P*	Lead	Lead
Monitor	GM	GM thin end window	GM	GM thin end window	GM end window	Scintillation counter	Scintillation counter or GM
Biological monitoring	Urine	Urine	Urine	Urine	Urine	Whole body	Thyroid scans

d days y years

GM Geiger-Muller counter

P* Perspex or Plexiglass

The control of the internal hazard is based on the following:

Containment

Laboratory facilities and equipment are designed to contain the radiochemical and so prevent or limit exposure. Many of these are similar to those used for the prevention of exposure to chemicals and microorganisms, and based on primary, secondary and tertiary barriers.

Selection of the radionuclide

The radionuclide with the least toxicity, i.e. least energy, shortest radioactive and biological half-lives should be selected, and the smallest amount consistent with the requirements for the procedure should be used.

Selection of radiochemicals

The labelled radiochemical should be in a physical form which is easily contained, e.g. as a solution in water or a non-volatile solvent, rather than as a dusty solid, volatile liquid or gas.

Safe working system

This includes safe methods, and adherence to standard operating systems, including good personal hygiene.

Contamination monitoring

Working areas, surfaces, equipment and containers require regular monitoring for contaminants. If there is an excess over the prescribed *derived limits*, appropriate decontamination procedures must be initiated.

The system of radiation protection recommended by the ICRP (58) is based on three general principles:

1. Justification of the practice
2. Optimization of protection
3. Dose limits.

One of the basic principles of radiation protection is that the radiation exposure of the patient, the staff, and the members of the public should be as low as reasonably achievable (the "ALARA" principle).

Good radiation protection in any laboratory or department where radioactive materials are used depends on an organizational structure.

The IAEA's Safety Guide (currently under revision) suggests the following key elements in the organizational structure of radiation protection.

- The Radiation Protection Adviser (RPA). This is a person with appropriate experience and technical qualifications to advise on radiation protection practice and legislative requirements. An organization should appoint as many RPAs as are necessary to provide the needed expertise. For large organizations this expertise may be found within the organization while small organizations may need to appoint outside consultants.
- The Radiation Protection Officer (RPO). This person should be a member of the local staff with operational radiation protection experience, appropriate technical

qualification and knowledge of legislative requirements. The principal duties of the RPO include the design of the operational radiation protection programme and its implementation and maintenance.

The appointment of an RPO is optional and would only be expected to be found within an organization with significant or widespread use of ionizing radiations.

- The Radiation Protection Supervisor (RPS). The appointment of an RPS is mandatory for all users of ionizing radiations. The main duties of the RPS are to supervise the day-to-day work with ionizing radiation to ensure the use of good radiation protection practice in accordance with the organization's radiation protection instructions.
- The Safety Committee. An important function of the radiation safety committee is to provide a direct link with the organization's management. In small organizations the main Safety Committee should regularly review, at least every 12 months, a formal report on radiation protection prepared by the above mentioned RPS, RPO and RPA.

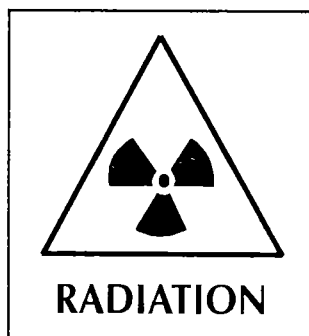
In an organization (e.g. hospital) where more than one department uses radiation sources, a more formal radiation safety committee should be established.

Written radiation protection instructions should be available in each laboratory or department where radiation sources are used.

Design and categorization of radiation areas

Laboratories where radionuclides are used must be designed to simplify containment, cleaning and decontamination. In general the radionuclide work area should be located in a small room adjoining the main laboratory, or in a dedicated area with the laboratory away from other activities. The entrance to the radiation area must be signalled with the international radiation hazard symbol (Fig. 9.1).

Fig. 9.1. International radiation symbol



The RPA must be involved in the planning and design or renovation of the radiation area or laboratory. The degree of radiation risk in the radionuclide laboratory will depend on the amount of radioactivity used, the radionuclides to be used and the type of operation.

To determine the requirements for planning any particular radionuclide department or laboratory the ICRP (60) has recommended the use of the concept of weighted activity. According to this recommendation, to determine the weighted activity, first assess the largest activity to be encountered at any time in the area to be planned.

This figure is multiplied by a modifying factor according to the radionuclide being used (Table 9.3).

The figure obtained is now multiplied by a second modifying factor (Table 9.4) determined by the type of operation. This takes into account the higher hazards involved in complex radiopharmaceutical preparations, and the lower hazards of storage areas and the patient's bed area after diagnostic injection.

The final figure obtained after the above two steps gives the weighted activity. The category of hazard can then be determined from Table 9.5.

Once the category of hazard has been determined, the broad requirements of planning can then be determined from Table 9.6.

Table 9.3. Modifying factors according to radionuclide

Class	Radionuclide	Modifying factor 1
A	^{75}Se , ^{89}Sr , ^{125}I , ^{131}I	100
B	^{11}C , ^{13}N , ^{15}O , ^{18}F , ^{51}Cr , ^{67}Ga , $^{99\text{m}}\text{Tc}$, ^{111}In , ^{123}I , ^{201}Tl	1.0
C	^3H , ^{14}C , $^{81\text{m}}\text{Kr}$, ^{127}Xe , ^{133}Xe	0.01

Table 9.4. Modifying factors according to type of operation

Type of operation or area	Modifying factor 2
Storage	0.01
Waste handling	0.1
Scintigraphic counting/imaging when administration is made elsewhere	
Patient waiting area	
Patient bed area (diagnostic)	
Local dispensing	1.0
Radionuclide administration	
Scintigraphic counting/imaging when administration is done in the same room	
Radiopharmaceutical preparation, simple	
Patient bed area (therapeutic)	
Radiopharmaceutical preparation, complex	10

Table 9.5. Categorization of hazard

Weighted average	Category
Less than 50 MBq	Low-hazard
50–50,000 MBq	Medium-hazard
Greater than 50,000 MBq	High-hazard

Table 9.6. Facilities required for radiation protection in relation to category of hazard

Category of hazard	Floor	Surfaces	Fume cupboard*	Room ventilation	Plumbing	First-aid
Low	Clean	Cleanable	No	Normal facilities	Standard	Washing
Medium	Non-permeable, easily cleanable	Cleanable	Yes	Good	Standard	Washing and decontamination facilities
High	Continuous sheet welded to walls	Cleanable	Yes	Extractor fan	May require special plumbing	Washing and decontamination facilities

*Laboratories only

Note: For low- and medium-hazard laboratories structural shielding is not required for the walls, however, it may be required for high-hazard laboratories, and the radiation protection adviser or radiation protection officer should make this determination.

Considering these broad requirements, the design requirements for a low hazard laboratory should include:

- non-porous crack-free walls and ceiling, preferably covered with good quality gloss paint, epoxy-resin or chlorinated rubber-based paint, to achieve a “hospital finish”;
- a non-absorbent and washable floor, e.g. sheet polyvinyl chloride (PVC) with welded joints, or polished linoleum. Wood or concrete should be covered with rubber-based paint to render them waterproof;
- bench-tops and other work surfaces should be of hard, non-porous materials, e.g. polished hardwood covered with disposable non-absorbent material, laminated plastic or solid resin;
- separate hand-wash basins containing wrist-, hand- or knee-operated faucets should be dedicated for work with radioactive materials;
- there should be a laboratory sink with an integral draining board for the disposal of aqueous radioactive waste and for washing or decontaminating equipment. The sink and its catchpool should be labelled with the radiation hazard symbol;
- there should be a chemical fume cupboard if radioactive gas or vapour is likely to be generated. This should discharge to a safe place. Otherwise a simple wall- or window-mounted extractor will suffice.
- a lockable cupboard or refrigerator should be provided for the storage of radiochemicals. If necessary this should be shielded to limit the external radiation.

Safe systems of work

Safe systems of work put into practice the principles of protection from external and internal radiation hazards. The systems must be described in writing, and be enforced at all times by senior staff. The rules for work with radioactive substances should include:

- work must be done only in an area or laboratory designed and dedicated for that purpose;
- only essential staff should be present;
- overalls, safety spectacles, disposable gloves and appropriate personal dosimeters should be worn;

- the smallest practical amount of radionuclide should be used;
- containers should be clearly labelled with the identity, activity and assay date of the radionuclide;
- radiation sources should be shielded before they are delivered, and unused material returned immediately to a shielded container or store;
- lead shielded carts or lead shielded containers should be used for transportation of radioactive materials within the hospital premises;
- radioactive waste should be removed at frequent intervals;
- radioactive materials should be handled on/over spill trays lined with disposable absorbent material. Separate trays are necessary for work with radioactive and non-radioactive materials.
- work other than with non-volatile radiochemicals in solution should be done in a fume cupboard or under a hood;
- smoking, eating, drinking and the application of cosmetics are prohibited in the radiation area;
- pipetting or aspiration by mouth is prohibited;
- contaminated gloves must be washed before removal and the hands washed again before vacating the laboratory;
- telephones, computer keyboards, light switches, door handles, etc. must not be touched with gloved hands;
- remote handling tools and devices should be used whenever possible;
- the working area, protective clothing and the hands should be monitored after completion of work;
- any contamination should be treated or removed immediately after completion of work;
- only trained staff should be permitted to handle radiochemicals; inexperienced staff who intend to use new processes or materials should practise with dry runs without the radionuclide, or be under immediate personal supervision of a trained worker;
- accurate records should be kept of the use and disposal of radionuclides.

Personal radiation monitoring

National regulatory bodies specify policies for monitoring occupational radiation to detect any exposure that is accidental or unplanned in the event of emergencies. This is to ensure that any dose limit is not exceeded. The appropriate regulations should be consulted for details. A permanent record of radiation doses should be kept, whether or not the doses are within the protection limits. Monthly or three-monthly dosimetry reports are useful in assessing the adequacy of radiation protection measures.

External dose monitoring

Persons who work with radiation sources may be monitored by a personal dosimeter which measures the accumulated dose. There are three types of dosimeters:

The film badge is a piece of photographic film in a special holder. The radiation exposure is related to the degree of blackening of the developed film. Filters of different materials are placed over segments of the film to enable identification and dose measurement of different kinds of radiation. Film badges are not expensive and the developed film may be stored to provide a permanent record.

The thermoluminescent dosimeter (TLD) consists of a small solid rod or wafer or a capsule containing crystalline powder, often lithium fluoride, which undergoes electronic excitation when irradiated. This excitation energy is released as light when the crystal is heated and the light output is a direct measure of the radiation dose. TLDs

are re-usable and the accuracy of measurement is higher although they do not provide a permanent record and are more expensive than film badges.

The pocket dosimeter is a pen-sized device which detects gamma or X-radiation as a minute current produced by the ionization of air inside a small chamber. These do not provide a permanent record and are more expensive than film badges, but do provide an immediate and continuous indication of dose.

Film badges and TLD dosimeters are widely used in health-care laboratory monitoring, although both are limited in their sensitivity to low-energy radiation, such as that from ^3H , ^{14}C and ^{35}S . They may be fixed to the lapel, or at level of the chest or waist when used as whole-body dosimeters. Exposure of the hands or fingers, as occurs while handling high-energy beta emitters such as ^{32}P , may be monitored with TLDs or film badges in special holders fixed to the wrist or worn on the finger as a stall or ring. Whatever type is used it should be:

- stored when not in use in a cool, dry place away from radiation sources;
- worn with the measuring window pointing away from the body;
- worn in the appropriate position to monitor the whole body, finger or hand doses;
- worn only by the person to whom it is issued;
- replaced immediately if it is damaged.

Internal dose monitoring

The internal absorption of radionuclides by body tissues is usually measured only after an accident that has contaminated the worker, or if the radionuclide is difficult to detect in other ways.

The available methods include:

- monitoring or analysis of urine, faeces or exhaled air;
- direct counting by a suitable monitoring device placed over a particular organ, e.g. for ^{125}I by a gamma probe placed over the thyroid;
- whole-body scanning of gamma radiation.

Monitoring for contamination and decontamination procedures

Monitoring surfaces enables the detection and removal of radioactive contamination. Such contamination may arise from the contact of equipment and work surfaces, instruments, protective clothing and persons with radiochemicals during normal operations, or from accidental spillage. Contamination may create conditions leading to an increased risk of exposure, or may invalidate analytical or diagnostic measurements. Routine or operation monitoring should be carried out during and at the end of every laboratory process or manipulation in which radionuclides are used. Special monitoring is necessary after spillage or suspected spillage of a radiochemical.

Monitoring

A contamination monitor which will respond to the radionuclide in use should be used to monitor radioactive contamination of work or body surfaces. Fixed or portable monitors should be used throughout radiochemical manipulations and afterwards to check for residual contamination.

When to monitor

- before opening a radiochemical vial or container;
- on the completion of a procedure;
- on leaving the radiation area for any reason;
- after a spillage.

What to monitor

- the external surfaces of vials and containers;
- all equipment and instruments used during the process;
- work surfaces, including bench-tops and edges, shelving, sinks, floors and the internal surfaces of cupboards, drawers, fume cupboards or other ventilated enclosures;
- personnel protective clothing, especially the front, sleeves, cuffs and overall pockets;
- soles of shoes;
- gloves before removal and then hands, including the finger tips and nails;
- the thyroid if ^{125}I is used.

How to monitor

- use a suitable instrument after checking power supply to batteries;
- record the background radiation away from the radiation area;
- hold the probe or detecting head close to the suspected surface (but not so close that the probe becomes contaminated) and move it slowly and methodically over the whole surface.

Action

- keep a record of any non-trivial contamination readings;
- mark off any contaminated area with chalk or adhesive tape;
- remove any contaminated clothing;
- if readings are in excess of the derived limits for surface contamination report to the RPS or RPA and initiate decontamination procedures.

Contamination surveys

If left untreated, spillages of radioactive materials offer a potential external radiation hazard. Spills may also contaminate the work and present an indirect radiation hazard risk by transfer to the hand, mouth and clothing. Spilt material may also become suspended as dry particles or vapour and may be inhaled. Hand monitoring and routine surveys of radiation areas, especially work surfaces, containers, equipment and instruments, are essential for contamination control. There are several methods.

Direct surface monitoring

Radioactive spillages and contaminated surfaces may be detected by hand-held instruments which respond to the emissions unless the energies are extremely low (e.g. ^3H), or the amount spilled is extremely small. Monitoring instruments should be regularly calibrated against a test source of the radiation under survey so that the contamination level may be assessed quantitatively, for example Bq m^{-2} , and the results compared with derived limits for surface contamination.

Geiger–Muller (GM) instruments are generally used to detect and measure medium- to high-energy beta emitters. They will also detect medium- and high-energy gamma radiation.

Scintillation monitors are more sensitive than GM counters to gamma radiation and those that use sodium iodide thin windows will detect low-energy gamma emitters such as ^{125}I and X-radiation.

Wipe and smear tests

This method is used to detect very low levels of contamination by low-energy beta emitters or to measure contamination arising from a particular radionuclide where several are in use. A wet or dry filter paper is wiped over a measured surface area and any radioactive contamination counted in a liquid scintillation instrument to give an approximate contamination level for the whole area.

Air monitoring

Airborne contamination in the form of particulate matter may be detected and measured by drawing a known volume of air through a filter paper which is then counted with a liquid scintillation instrument. Gaseous or vapour phase radioactive contamination may be counted after pumping a sample of air through filter paper or a particulate filter into a collecting chamber of known volume. Alternatively, a known volume of air may be liquefied and collected in a cold trap. Airborne contamination is expressed as Bq m^{-3} and the measured levels compared with the derived air concentration for the various radionuclides.

Decontamination procedures

When radioactive contamination is found, the first actions are to warn other staff (e.g. by warning signs or tape), contain the spillage, and then decontaminate the whole area. Detailed decontamination procedures should be included in the local rules and appropriate instruction and training given to all radiation workers.

Decontamination of the body surface

If the contaminated person has suffered a life-threatening injury appropriate first-aid or medical attention should take priority over decontamination. Otherwise, the affected parts should be washed thoroughly for at least 5 min with soap and water, if necessary under running water. Care is needed to prevent spreading of the contamination to other parts of the body, especially the eyes. Harsh detergents and abrasives should not be used as they may damage the skin and promote absorption of the radiochemical.

After washing, the affected area should be monitored with residual contamination. If the activity exceeds the level established by the radiation safety committee (usually this would be at a level of about 5 or 6 Bq cm^{-2}), washing should be continued until readings are below this level. If the level cannot be so reduced medical attention is necessary.

Contamination of eyes, cuts or puncture wounds

Immediate action must be taken to prevent the uptake of the radiochemical. The eye

should be washed with running water for at least 10 min, taking care not to spread the contaminated wash water to other parts of the body. Cuts and other skin wounds should be allowed to bleed for several minutes before they are washed with large amounts of water. Medical attention should then be obtained.

Ingestion or inhalation

Ingestion or inhalation of radiochemicals poses a serious risk and immediate medical attention is required. Arrangements should be made with the nearest hospital so that such casualties are treated by blocking (e.g. the uptake by the thyroid of ^{125}I can be blocked by giving tablets of potassium iodide), using ion-exchange agents or by inducing vomiting.

Clothing

Contaminated garments must be removed immediately and placed in a suitable container (e.g. a plastic bag or bucket) to prevent further contamination of the area. The affected worker should then be monitored for personal contamination and appropriate action taken.

Work surfaces and equipment

Liquids and loose powders should be contained and then mopped up with absorbent paper or tissues which are then placed in suitable containers. The area should then be washed down with detergent and water to remove any residual contamination and monitored. Washing and monitoring should continue until the contamination limit is achieved. Contaminated equipment and containers, etc. may be immersed and left overnight in a suitable detergent solution and then rinsed thoroughly before monitoring. Contamination that is resistant to detergent treatment may be treated by:

- chromic acid for glassware;
- dilute nitric acid for plastics;
- dilute sulphuric or metal polish acid for stainless steel;
- 6% nitric acid + 1% sodium fluoride, or rust remover, for ferrous metals;
- paint removers or solvent strippers for painted surfaces;
- wax solvents for linoleum;
- metal polish for non-ferrous metals.

Some of these agents are corrosive and may be toxic. They should be used only by trained staff wearing appropriate protective clothing.

Spills of radioactive halogens should NOT be treated with oxidizing agents as there will be vaporization of the free radiohalide.

Decontamination kits

A decontamination kit should be assembled and kept close to the radiation area or near the RPS. The composition of the kit will depend on the scale and nature of the work, however, a comprehensive kit for a health-care laboratory should include:

- simple first-aid kit (see Chapter 12);
- rubber or vinyl disposable gloves;
- heavy duty rubber gloves;

- plastic disposable aprons;
- disposable overshoes;
- absorbent paper towels or tissues;
- decontamination detergent in easy-use container;
- soap;
- soft nail brush;
- eye-wash kit, containing saline;
- rubber tubing with tap/faucet connector;
- long-handled tongs or forceps;
- plastic waste bags;
- scissors;
- chalk or pencil;
- radioactive hazard warning tape;
- plastic dustpan and brush;
- potassium iodide tablets with dosage instructions;
- sodium thiosulphate solution, 25 g L⁻¹ containing 2 g potassium iodide for treating ¹²⁵I spills.

A suitable calibrated monitor should be included or available.

Storage of radiochemicals

Labelled radiochemicals decompose as a result of self-irradiation and the energy liberated by radioactive decay. It is therefore important that the manufacturers' recommended conditions for storage are applied to ensure maximum stability. The following general storage requirements may need to be supplemented for particular radiochemicals:

- storage out of direct sunlight;
- storage of solutions in the dark;
- storage at the lowest specific activity consistent with use;
- no dissolved oxygen in organic solvents used for radiochemical stock;
- addition of 2–10% ethanol to aqueous stock solutions to act as a free-radical scavenger;
- storage at lowest temperature consistent with the suppliers' recommendation, but in general not frozen.

Radiation emergencies and accidents

The most common types of accidents which may occur in any radionuclide laboratory involve fire, explosions, spillage of a significant amount of radioactive solution and misplacing or losing of radioactive sources.

Despite the fact that these events are usually unpredictable, it is advisable that adequate plans and written instructions are prepared in advance to deal with accidents which may occur in the laboratory. The staff must be trained to implement the plan and strictly follow the instructions in the event of an accident.

When an accident occurs, the hospital administrative authorities, the department head and the radiation protection officer must be informed immediately and necessary remedial measures must be taken.

In case of a serious accident, involving bodily injury, the first priority is to give first-aid to the persons affected by the accident. Then, assisted by suitable monitoring instruments, radioactive substances should be removed from the skin, hair and other

parts of the body by using physical methods. Contaminated, small wounds can be washed, preferably with a product that makes the radionuclide insoluble, e.g. magnesium sulphate for the alkaline earth elements or chelating agents which form complexes with high valence elements.

In case of contamination through the gastro-intestinal or respiratory tract, the decontamination measures should be carried out under the supervision of a trained physician.

Within the area affected by the accident, action must be taken to prevent further spread of contamination or the intake of radioactive materials.

The borders of the contaminated area must be clearly marked and the decontamination of the working surfaces should be carried out by using physical methods (absorbent materials, washing with detergent and water) and then using recommended chemical compounds. A recommended list of chemicals for use in such circumstances should be available in the health laboratory.

Radionuclide checklist

The following checklist is provided as a source of self-examination for those responsible for conducting work in health-care laboratories in a safe manner. In addition, all responsible persons should keep in mind any special local circumstances that may require additional attention.

1. Is work with radionuclides essential or justifiable?
2. Does the laboratory conform to appropriate design standards?
3. Are written standard operating procedures and local rules adequate for the work?
4. Are the radiochemicals safely and securely stored?
5. Do laboratory staff know how, what and when to refer to the RPA and RPS?
6. Are written instructions pasted in the laboratory for dealing with radiation accidents and spills?
7. Are adequate records kept to account for radionuclide acquisitions, use and disposals?
9. Are radioactive waste disposals consistent with the national requirements and licence conditions?
10. Are staff instructed and trained in radiation-based techniques and in radiation protection?

10. Transport and receipt of clinical material

As the principal hazard of transporting and receiving clinical material is infection this subject is covered in detail in the *WHO Laboratory Biosafety Manual (2)* and only an outline is given here.

Specimen containers

Specimen containers should be leak proof and made of break-resistant plastic or glass. Screw-capped containers are preferable for liquid specimens. Open containers should be prohibited even for direct transfer from the wards to the laboratory.

Re-usable containers should be carefully inspected before re-issue. Disposable containers conforming to relevant national standards or specifications should be purchased only from reliable suppliers after approval by the Laboratory Director or the Safety Officer. After the container is filled and closed, no visible blood or other material should remain on the outside. If this does occur the container should be wiped with a suitable disinfectant (e.g. a 1/50 dilution of household bleach; see Chapter 7) and dried.

Specimen containers should be clearly identified by self-adhesive labels. Some institutions use special warning labels for specimens from patients known or suspected to have viral hepatitis, HIV or Risk Group 3 infections (see page 54). As it should be assumed that all patient specimens are potentially infectious, the same universal precautions (see page 60) should apply to all specimens. Request forms should accompany all specimens. They should not be wrapped around containers but kept separate or protected in a plastic pocket.

Internal transport of specimens

Specimens carried by hand from clinical areas to the laboratory or between laboratories should be placed upright in appropriate tube racks or trays placed in a leak proof metal or plastic container. The racks and boxes should be easy to clean and should be disinfected at least once a week or immediately if a specimen has leaked. The request forms should be kept apart from the specimens during transport. Porters and messengers who handle the specimens should not pass through or visit canteens and rest rooms while they are carrying specimens. They should be instructed to wash their hands often, especially before meal breaks and before returning home. They should be instructed in the procedures to be followed in the event of a spillage.

Reception in the laboratory

Laboratories should have easily accessible specimen reception rooms that should be separate from the offices. Handwashing facilities and a disinfectant solution should be available. In small laboratories a special reception table with an impervious and easily cleaned surface should be available. The reception staff should be instructed on

the potential hazards of manipulating patient specimens. They should wear protective coats and gloves and take the same universal precautions (see page 60) as laboratory staff, especially when handling leaking or broken specimen containers. Liberal use should be made of the disinfectant to clean up spilled fluid and to decontaminate the table surface at the end of each working shift. If a specimen container has leaked or is damaged a member of the laboratory staff should be consulted and should decide how to deal with it. Specimens that arrive in sealed plastic bags should be delivered unopened directly to the relevant laboratory bench. Packages containing specimens or cultures received by mail or other public carrier should not be opened in the office but in the reception room. If the package shows signs of damage or leakage, extreme precautions should be taken for opening and this should preferably be done in a biological safety cabinet.

Transport of specimens by mail, air, etc.

There are strict national and international regulations about packaging and shipment of patient specimens by mail, air freight and other carriers. Common definitions of packaging and labelling have been agreed by the various organizations involved (47-50) and these are set out in detail in the WHO *Laboratory Biosafety Manual* (2), in which the necessary documentation is also described.

Three-layer packaging (Fig. 10.1) should be used for the shipment of all infectious substances, specimens and cultures (1,10,16,47):

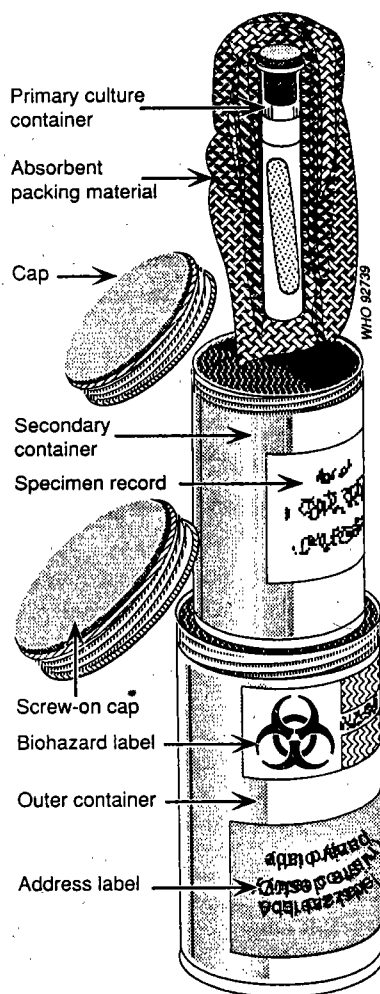


Fig. 10.1. Packing infectious material for the post

1. The specimen should be placed in a leakproof, tightly-closed receptacle (the primary container), made of break-resistant glass or plastic.
2. The primary container should be wrapped in enough absorbent material (e.g. paper towels, tissue, cotton wool) to absorb all the fluid in case of leakage.
3. The wrapped specimen container should be placed in a strong watertight secondary container.
4. The secondary container should be placed in an outer package strong enough to protect the contents from physical damage and humidity during transit. The outer container should be clearly labelled "Urgent Biological Specimen for Analysis".

Special warning labels, and shipment documents, obtainable from local postal and air line services should be used for international shipment of infectious substances.

11. Disposal of waste and recycling of materials

Health laboratory wastes and contaminated materials can present a hazard both to laboratory workers and to the community. The uncontrolled dumping of solid and liquid, chemical and biological laboratory wastes can also threaten the environment. The presence of contaminated items in public sites, such as used syringes and hypodermic needles may pose an infection risk if bloodborne microorganisms remain viable. Such waste can cause public alarm through fear of infection. Similar fears may arise if wastes bearing the radioactive label are found on public access sites.

The safe disposal of laboratory waste is therefore of prime importance (1,10,61-63).

Recycling re-usable items and recovery of salvage from waste can represent a valuable resource.

Waste control

The principles of effective and safe waste control are:

- minimizing the amount of waste produced, either by reducing the scale of the activity or by recycling waste products so that they may be re-used after appropriate treatment;
- selection and use of materials so that the waste produced is not hazardous or is only minimally hazardous;
- conversion of hazardous substances to less hazardous ones by chemical reaction or dilution in a non-hazardous medium;
- segregation of wastes according to the method of treatment or disposal to ensure that highly reactive chemicals are not accidentally mixed in the waste stream;
- correct labelling;
- use of robust, leak proof containers in a safe and secure storage area or compound preferably outside the main laboratory area in conditions that deter human and animal scavengers;
- selection of disposal methods according to the chemical and physical characteristics of waste materials, after evaluation of the health and safety risks and environmental consequences of all available methods.

The labelling, storage, transportation and disposal of hazardous wastes is usually subject to national regulations and codes of practice. Laboratory staff should be conversant with any relevant local requirements and restrictions. Hazardous wastes transported across national boundaries may also be subject to international controls.

Types of waste

A number of waste classification systems have been proposed. The following categories are proposed for health-care laboratory waste. For convenience, here the term "waste" is used to include material that can be re-used or disposed, for example:

- sharps
- chemicals (other than radioactive substances)
- radioactive substances
- infectious materials
- pressurized containers
- general, non-hazardous waste (“municipal solid waste”)
- equipment effluents.

Sharps

These are items that can cause a cut or puncture, such as needles, syringes, scalpels, saws, blades and broken glass. Contaminated sharps offer the greatest infection hazard.

Disposable items

These should be placed in sharps containers at the work station. To avoid needlestick injury, needles should not be removed from syringes or resheathed; the complete syringe and needle assembly should be placed in the sharps container. Sharps containers should be incinerated (see below).

Re-usable items

These should be placed in a puncture-resistant metal or plastic container at the work station. The contents should be chemically disinfected or autoclaved before cleaning and further processing.

Management of sharps containers

Sharps containers should not be overfilled (not more than two-thirds of their capacity). There should be a readily available supply of empty containers for use at work benches. Filled containers should not be placed in plastic disposal bags. They should be transported with care; staff should wear stout leather gloves when handling them in case sharps penetrate the container wall. Filled sharps containers may be autoclaved within the laboratory site before final disposal, ideally by incineration. They should not be placed in the colour-coded plastic bags used for other waste. If autoclaving is not possible before incineration, sharps containers should be taken to the incinerator by a trained and responsible member of the laboratory staff who should supervise the incineration.

Chemical waste

Chemical waste and redundant chemicals and residues have the same hazardous properties as that of pure substances. In order to reduce risks to laboratory staff, the community and the environmental procedures necessary for their disposal should be an integral part of laboratory planning and management. Although information about the disposal of specific chemicals is usually given in the suppliers' safety data sheets a waste control strategy should be established. Disposal methods should be agreed upon before chemicals are purchased or used.

Chemical waste includes chemicals, e.g. from diagnostic and experimental work and cleaning, housekeeping and disinfection procedures. Some of these may be hazardous like:

- toxic or highly toxic (including carcinogens and teratogens)

- corrosive
- flammable
- reactive (explosive, water reactive).

Storage

It is usually necessary to store chemicals for some time before disposal. Choice of containers is therefore important. Some chemicals, when stored in metal containers for long periods, can cause corrosion. For example, in the presence of water, chlorinated solvents hydrolyse to generate hydrochloric acid, or leach out the plasticizer from polyethylene or other plastic containers, rendering them susceptible to breakage.

Disposal methods

Apart from the employment of specialist contractors several disposal methods are available to health-care laboratories:

Disposal to the public sewer

Dilution with water and dispersal into the sewerage system is often convenient for small amounts, up to 100 g of water soluble solids or 100 mL of water-miscible liquids. Strong acids and bases should first be diluted to near-neutral pH and not poured into sewers with mineral salts, such as azides, cyanides, hypochlorites and sulphides, which will generate highly toxic gases if acidified. Disposal to the sewer is not suitable for highly toxic, malodorous or water-non-immiscible chemicals, nor for chemicals that can react with metal drainage piping to produce dangerously reactive substances; for example, solutions of sodium azide and picric acid react with copper and lead piping to form explosive metal azides and picrates.

Disposal to the atmosphere

Dilution by air and disposal to the atmosphere may be acceptable for small volumes of gases and volatile liquids provided that the dilution is such that the final concentration is no greater than 10% of any occupational exposure limit, threshold limit or lower flammable limit. The gas or vapour should be released in such a way that it cannot re-enter the laboratory or affect adjacent buildings and nearby public areas.

Disposal to landfill sites

Subject to local and national regulations or codes many non- or low-hazardous chemicals may be dispersed in small amounts (up to a few kilograms) with other wastes in landfills, provided there is little risk that they will be leached out into ground water, streams or rivers.

Toxic wastes, such as the salts of arsenic, antimony, barium, cadmium and mercury, may be buried in deep landfill sites approved for the disposal of hazardous waste.

Chemical treatment prior to disposal

Dangerous chemical wastes and residues are best treated chemically before disposal with the object of producing a non-hazardous or less hazardous waste which is suitable for disposal by one of the dilution or dispersal methods. The precise method will depend on the nature of the waste material. The risk evaluation for each process should identify the appropriate option. Typical examples of chemical reactions com-

monly used for waste treatment include hydrolysis, complexation, oxidation and reduction with suitable reagents, with control of the reaction conditions.

Thermal treatment

Chemical wastes may be destroyed by oxidative combustion, incineration or pyrolysis. Most organic solvents are converted to CO_2 , H_2O , and/or NO_x and other gases when they are burned with a plentiful supply of air or oxygen. Chemicals containing halogens will produce hydrogen chloride and other halides. These highly corrosive combustion products will attack the incinerator lining and smoke stack unless they are removed by passing through a water scrubbing or spray unit. Chemical incinerators should be allowed to reach a combustion temperature (in the primary chamber) sufficient for complete oxidation, usually about 1000°C , before the waste is added, but some chlorinated hydrocarbons require 1400°C .

Solid wastes may be added directly or placed in combustible (paper, card) containers. Liquid wastes may be absorbed on to combustible material, such as vermiculite or fed into the chamber through an atomizer nozzle.

In areas where incinerators are not available, the amounts of chemical waste are small, and other disposal methods are not possible, it may be acceptable to burn such wastes in shallow, open trays or pits in open country. These should be well away from occupied buildings or residential areas. The disposal should be done by experienced staff.

Radioactive waste

For practical reasons, all radioactive wastes can be classified as liquid, solid or gaseous wastes. All actions related to disposal of radioactive wastes to the environment must be carried out in full compliance with national regulations on radiation protection.

Liquid wastes include the remains of unused radioactive suspensions and solutions, rinsing water that had been used for cleaning contaminated equipment, water from contaminated laundry and excreta from patients.

The excreta from patients who have received relatively low amount of radioactivity for diagnostic purposes can usually be released to the sewage system.

The disposal of liquid radioactive wastes into the normal sewage system should strictly follow the recommendations of national regulations. General principles and detailed recommendations on waste disposal are given in the internationally accepted code of practice of the IAEA (64) which is, at present, under revision.

Solid radioactive wastes include contaminated equipment (e.g. vials, syringes, drinking glasses, etc.), laundry, dressings, disposable paper, cotton, etc.

All used linen should be checked for contamination and sent to a specialized laundry or washed in a room specially designed and designated for this purpose. Other solid radioactive waste should be kept in a properly ventilated room until it can be disposed as low-level radioactive waste or the radioactivity decays sufficiently, so that it can be disposed of as non-radioactive waste.

The radioactive wastes containing long-lived carbon-14 and tritium should be kept in special containers and sent to industrial waste depositories.

Infectious waste

Infectious waste includes any material, other than sharps, which may contain sufficient potential pathogens to cause disease.

In view of the potential risks to health it is essential that no infected or potentially infected material, for disposal as waste, recycling or salvage recovery shall leave the laboratory unless it has been sterilized (e.g. autoclaved) or disinfected by a proven effective process.

Segregation

Infectious waste should be carefully segregated from other kinds of waste by placing it in colour-coded bags which should be sealed when three-parts filled. These bags should be supported in metal or autoclavable plastic boxes to minimize damage and retain spillages.

Bulk (24 h) urine specimens are a special case. They may be safely disposed of by emptying directly into a sink connected to the sewer.

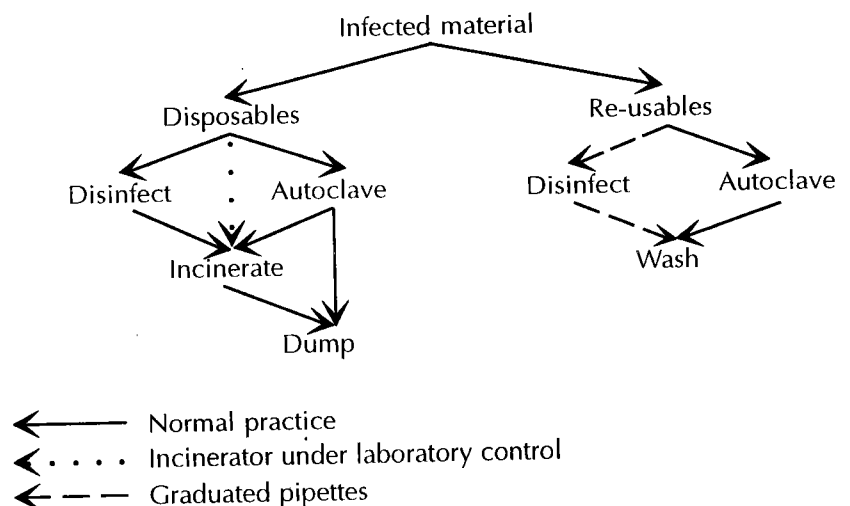
Treatment

The flow chart (Fig. 11.1) shows the options for the treatment and disposal of infectious waste (10).

Autoclaving

Autoclaving is the safest and most satisfactory method of treating infectious waste. The bags containing waste should be left in their plastic or metal containers but opened to allow penetration of steam. The autoclave cycle should be 15–20 min at 121 °C HTAT (holding time at temperature), 10 min at 126 °C HTAT or 3 min at 134 °C HTAT. Though after autoclaving the waste is no longer hazardous it should preferably be incinerated.

Fig. 11.1. Flow chart for the treatment of infected material
(Source: reference 10. Reproduced by kind permission of the publisher)



Disinfection

Treatment with chemical disinfectants (see pages 60–61) is not suitable for all kinds of infectious waste and should be restricted to re-usable pipettes (Fig. 11.1). Disinfectants are used in bench discard jars as an immediate “make safe” procedure but the contents should be autoclaved before disposal or recycling (2,10).

Incineration

If, exceptionally, the infectious waste cannot be autoclaved it should be incinerated.

Properly-designed institutional incinerators that subject waste to not less than 1000 °C should be used. There are specifications for waste incinerators (62).

Waste which is awaiting incineration should be securely stored under cover and steps should be taken to prevent access by people, animals and birds.

Landfill

Burial of decontaminated waste in a special landfill site is an acceptable option only when incineration is technically impossible or is not permitted for practical or legal reasons. Waste disposed of in this manner should first have been autoclaved. Syringes and needles should first be removed and destroyed mechanically. The waste should be deposited in trenches, covered with earth, and compacted daily. The controlled fill should be fenced and scavenging strictly prohibited (63).

Pressurized containers

Aerosol cans and other vessels containing residual gas under pressure may explode if incinerated, or present a fire risk if accidentally punctured.

They should never be placed in containers with other waste but carefully punctured in the open air and left there for sufficient time to allow any residual gas to escape. They may then be placed in non-hazardous waste containers.

General, non-hazardous waste

General non-hazardous waste includes domestic, packaging and other substances that do not pose a special handling problem or hazard to human health or the environment. This is known as municipal solid waste. It is usually collected by the local authority and either incinerated or landfilled. Where this service is not available it may be burned on site or buried.

Effluents

Effluents from analysers that do not contain chemicals which might react with the metal waste piping (see page 26) may be discharged directly into the laboratory waste plumbing system. Reactive wastes should be collected in appropriate vessels and treated as described under Chemical Waste above.

Potentially infected liquid waste from certain kinds of microbiology laboratories should be ducted to holding tanks where they are steam- or chemically treated before final discharge to the sewerage system.

Recycling

Chemical wastes

The cost and inconvenience of disposal, including the storage, treatment, transportation and ultimate destruction of chemical wastes, and the availability and cost of new reagents and solvents lead to considerations of recovery and re-use of chemicals.

Organic solvents

If not too heavily contaminated these may be purified by fractional distillation or evaporation, or by chemical treatment, but it is rarely possible to separate mixed solvents into their components, especially if they have similar boiling points. Small amounts of solutes may be removed from solution by adsorbents, such as activated charcoal or ion-exchange resins, by precipitation or liquid extraction, enabling the original solvent to be re-used.

Precious metals

Metals such as mercury may be extracted from laboratory wastes but the cost of extraction is relatively high. It involves the concentration of very dilute solutions and precipitation of the metal as an insoluble compound, followed by chemical conversion to a re-usable form. Alternatively, some materials may be recovered directly from aqueous solution by treatment with a reducing agent such as sodium borohydride or by electrolysis.

Laboratories which undertake the recovery of solvents or chemical reagents will need storage facilities consistent with the hazardous nature of the wastes. They will also need appropriate containers so that wastes are separated according to method of treatment and chemical incompatibility.

Recycling of equipment

Certain small items of equipment may be recycled if they are so designed and are sterilized or disinfected beforehand. Some items, however, termed "disposable" are intended by the manufacturers to be used only once and then disposed of. To prevent transmission of bloodborne microorganisms, such as HBV, HIV and malarial parasites, disposable items used in blood and other specimen collection, e.g. plastic syringes, hypodermic needles and lancets, should not be re-used.

Plastic disposable items, such as pipettes and inoculation loops, should not be re-used unless they can withstand steam sterilization or effective chemical decontamination.

Gloves

Surgical and examination gloves are intended for single use only. Nevertheless in some situations these gloves may be re-used. General-purpose utility gloves may be re-used but should be discarded if they are peeling, cracked, discoloured or have punctures, tears or other evidence of deterioration.

The procedure for recycling gloves recommended by the WHO (46) is as follows:

- rinse gloved hands thoroughly in a hypochlorite solution containing 0.1% available chlorine;

- rinse gloved hands in clear water to remove the disinfectant (disinfectants may cause deterioration of gloves);
- wash gloved hands with soap and water and rinse thoroughly (detergents may cause enhanced penetration of liquids through undetected holes in the gloves);
- remove gloves and hang them up by the cuffs to dry;
- wash hands;
- test the gloves for holes before re-using by filling each glove with about 350 mL of water at room temperature, twisting the cuff through 360°. Place them in a rack for 2 min; look and feel for leaks. Turn gloves inside out, allow to dry and dust with French chalk or talcum powder before re-using.

Syringes and needles

While disposable items are generally preferred in the interests of safety, it may be necessary, for economic reasons to re-use syringes and needles. It is imperative that needles and syringes be decontaminated as early as possible in the recycling process. The following outlines the procedure for re-cycling re-usable glass or plastic syringes and needles:

- wear gloves and take great care to prevent needlestick injuries and cuts;
- leave the needles attached to the syringe;
- aspirate hypochlorite solution, or another suitable disinfectant containing 0.1% available chlorine, into the syringe;
- immerse the syringe and the attached needle in the disinfectant solution, horizontally in a flat tray;
- leave them immersed in the disinfectant solution for 20 min;
- discharge the disinfectant solution from the syringe and needle;
- rinse the syringe and needle with water, filling and emptying several times;
- examine needles and syringes for needle barbs, integrity of syringe seal (rubber ring), the fit of the needle hub to the syringe, whether syringe markings are readable, etc.; discard as sharps waste if considered unfit for re-use;
- sterilize the syringe and needle by autoclaving or disinfecting by boiling for 20 min in water prior to re-use.

Glassware

- leave glass pipettes in a suitable disinfectant overnight. Ensure that they are completely submerged and that there are no air bubbles; wash with very hot water.
- place slides, syringes, etc. immediately after use in an appropriate disinfectant; ensure that they are completely immersed;
- autoclave the jar and its contents;
- autoclave used glass petri dishes;
- wash and reprocess.

Protective clothing

- place contaminated laboratory gowns, coats and other protective clothing in dedicated containers, located within the laboratory;
- autoclave or disinfect;
- wash and process.

Salvage

The economic value of salvage recovered from health-care laboratory waste will depend upon the local conditions and factors such as labour costs against the cost and availability of new items should be taken into account.

No attempt should be made to recover salvage from any material that has not been effectively decontaminated or which falls within the general waste category.

Good examples of salvage are the re-use of metal sharps containers and plastics containers used initially for packaging solids and liquids.

For further information about laboratory waste management see references (6,10, 61-64).

12. First-aid in the laboratory

First-aid is the skilled application of accepted principles of medical treatment at the time and place of an accident. It is the approved method of treating a casualty until he is placed in the care of a doctor for definitive treatment of his injury.

The primary purposes of first-aid are three-fold:

- to sustain life:
 - resuscitation procedures;
 - control of bleeding.
- to prevent a patient's condition from worsening:
 - cover wounds;
 - immobilize fractures and large wounds;
 - place the patient in the correct position.
- to promote recovery:
 - reassure the patient;
 - relieve pain;
 - handle gently;
 - protect from cold.

The term first-aid describes any person trained in the principles and practice of first-aid and who possesses a Certificate of Competence from a recognized first-aid training authority. This Certificate of Competence usually has limited validity (3–4 years), following which a refresher course and re-certification are necessary.

The well-recognized priorities in first-aid treatment are:

- act quickly, quietly and methodically;
- reassure the casualty;
- if breathing has stopped start resuscitation;
- control bleeding;
- guard against the onset of shock;
- do not remove clothes unnecessarily;
- do not attempt to do too much;
- do not allow people to crowd around;
- arrange for appropriate medical care.

In health-care premises there is usually a requirement that trained first-aiders are available on site. A list of individuals so trained should be prominently displayed within the laboratory together with telephone numbers of the emergency services. First-aid rooms or areas, suitably equipped and readily accessible should be available to all health-care laboratories.

Minimum first-aid facilities

The minimum first-aid facilities consist of:

- a first-aid box;
- first-aid equipment;
- eye irrigation equipment;
- antidotes to poisonous chemicals used in the laboratory and instructions for their use;
- protective clothing and safety equipment for the person rendering first-aid.

The first-aid box

The first-aid box should be constructed from materials which will keep the contents dust and damp-free. It should be kept in a prominent position and be easily recognized. By international convention the first-aid box is identified by a white cross on a green background.

The contents of the first-aid box should be restricted to the following:

- instruction sheet giving general guidance;
- individually-wrapped sterile adhesive dressings in a variety of sizes;
- sterile eye-pads with attachment bandages;
- triangular bandages;
- sterile coverings for serious wounds;
- safety pins;
- a selection of sterile but unmedicated wound dressings.
- mouthpiece for mouth-to-mouth resuscitation in cases of suspected infection;
- resuscitation face mask with one-way valve for use in cases of say cyanide poisoning or facial damage;
- A first-aid manual, e.g. of the Red Cross, Red Crescent or St. John's Ambulance.

The contents of the first-aid box should be inspected regularly to ensure that they remain in satisfactory condition and should be replenished immediately after use.

Eye irrigation

Eye irrigation equipment should also be readily available and staff trained in its correct use. Single-use packages, containing sterile water or saline, are preferred because they offer the least risk of infection (see page 49). If these are not available and the wash-bottle types are provided, their contents should be changed regularly and checked to ensure that they remain in satisfactory condition. Irrigation systems that are connected to the mains water supply are satisfactory only where the supply is of a high bacteriological standard.

First-aid training

While any accident or incident requiring first-aid treatment can occur in the health-care laboratory, special training should be given in the management of accidents most likely to occur in these circumstances. These include:

- cuts and abrasions, needlestick injuries;
- burns, scalds, corrosive injuries;
- electrical injuries and shock;
- asphyxia;
- poisoning.

Needlestick injuries, cuts and abrasions

The individual should remove protective clothing, encourage free bleeding followed by liberal washing of the affected part and hands in soap and water; wounds should not be sucked.

A skin disinfectant, if appropriate, should be applied and a protective first-aid dressing done. The accident should be recorded. The injured worker should then go immediately to the first-aid room and inform staff of the cause of the injury and the agent involved. If considered necessary a physician should be consulted and his advice followed.

Burns, scalds and corrosive injuries

Burns are caused by dry heat which may arise from:

- fire, flame, contact with hot objects;
- friction;
- electrical current.

Scalds arise from moist heat and are produced by:

- hot water;
- steam;
- hot oil.

The potential for accidents involving acids, alkalis and other corrosive chemicals is high in the health-care laboratory where such substances are in common use.

Examples include:

- hydrochloric acid;
- nitric acid;
- sulphuric acid;
- glacial acetic acid;
- trichloroacetic acid;
- chromic acid;
- sodium hydroxide;
- potassium hydroxide.

Regardless of the cause of the burn injury, the skin lesion is the same, i.e. tissue destruction.

Immediate treatment

The immediate need is to reduce the heat. Quench flames and cool tissues with cold water or any other non-flammable fluid in hand. Remove smouldering clothes by seizing them in a non-burning area. Otherwise smother the flames by whatever means possible.

Burns frequently occur in frightening circumstances and reassurance of the casualty is of the greatest importance.

The casualty may suffer from shock, related to the extent of the burned area and this is exacerbated by loss of fluid into the tissues and by oozing from the wound. The injured area rapidly becomes red, swollen and blistered.

The aims of the first-aid treatment of burns are:

- to reduce the effects of heat and alleviate pain;
- to lessen contamination and the risk of infection;
- to reduce discomfort and swelling;
- to ensure an adequate fluid intake;
- to get the severely burned or scalded casualty to medical attention as quickly as possible.

Immersion of the burned part in cold water, if possible, will reduce the spread of heat in the tissues and reduce the pain. The part should be gently cleaned and dried. Lotions, ointments and oil-based dressings should not be applied. Blisters should not be pricked. To avoid the risk of interference to the local blood supply, anything of a constricting nature should be removed or loosened, e.g. rings, bracelets, belts, etc., before the part starts to swell. The casualty should be given small and frequent cold drinks and protected from draughts and cold. In casualties seen some time after the injury it is unnecessary to remove burned clothing since it has already been rendered sterile by the heat. Wet clothing, however, should be removed.

If the burned area is liable to become dirty, e.g. hand or foot, it should be lightly covered by a sterile or clean dressing.

Burns from corrosive chemicals

It is important to flush the area with copious amounts of running water. Contaminated clothing should be removed but the first-aider should take care not to contaminate himself during the process. To prevent the accumulation of the corrosive substance underneath the affected part (sumping), free drainage should be ensured. After this decontamination procedure, the burned area is treated as a wound.

Phenol derivatives (carbolic acid compounds) are commonly used in health-care laboratories. These substances penetrate rapidly and deeply into tissues. Unless quickly removed their penetrative and corrosive action continues. Systemic absorption can result in serious renal damage. After their immediate treatment, casualties with phenol burns should be seen urgently by a doctor. Immediate surgery may be necessary to limit further damage.

Additional hazards

Asphyxia (see page 108) is a common complication in burns caused by major fires; the oxygen having been consumed by the fire. This is aggravated by smoke which irritates the respiratory tract and lungs.

Fumes from strong acids or alkalis, especially when heated are respiratory irritants and can produce pulmonary oedema. Fumes from burning petrol have a very high carbon monoxide content.

The management of such casualties is:

- remove patient from the danger area;
- treat for asphyxia (see page 109);
- transfer the patient urgently for medical attention.

Injuries due to electrical current

Injury produced by electric current results from the passage of the current through the body. Several types of injury may occur.

Contact burns

These are usually found at the points of the body where the current has entered and left. Firm contact with moist skin is more damaging than contact with dry skin. It should be appreciated that tissues deep to the skin may also be affected and that the actual depth of the injury may not be apparent for some days. If the casualty is not thrown clear, he may be fixed to the point of contact and receive very severe local burns. The first-aider should switch off the current and pull out the plug. If this is not possible the victim should be physically removed from danger. There is the added danger to the first-aider attempting to isolate the casualty from the electrical source. The first-aider should devise an impromptu system for separating the victim from live contact without touching him with bare hands. As moisture is a conductor the first-aider should ensure that he is standing on dry non-conducting material before attempting to remove the casualty from danger. This can then be attempted with a length of dry cloth, rubber sheet, non-metallic rope or electricians' rubber gloves. Contact with the casualty's arm pits should be avoided as these may be moist from perspiration. First-aid treatment of burns (see above) may then be started.

Flash burns

If high voltage current jumps a gap, causing an arc, the flash so produced may burn exposed parts of the skin or damage the eyes. While the injury is usually superficial it may look very alarming as a wide area will be blackened by the volatilized metal; when cleaned, however, much of the skin will be found to be intact. A flash burn will usually affect both eyes; if only one eye is giving trouble the cause is probably a foreign body. If the eyes are affected the casualty should receive immediate medical attention.

Ventricular fibrillation and shock

Although ventricular fibrillation is considered to be the main cause of death by electrical shock, there is also some evidence that death may be due either to asphyxia or cardiac arrest. Breathing may cease and the carotid pulse may be impalpable. Under these circumstances the resuscitative procedure should commence as a matter of urgency. There are three main steps:

- ensure patent airways;
- give mouth-to-mouth resuscitation;
- apply external chest compression.

In an unconscious subject lying on his back the tongue will fall back and block the airway. To ensure an open airway:

- support the nape of the neck and press the top of the head backwards (Fig. 12.1),
- press the angles of the jaw forward from behind (Fig. 12.2).

These manoeuvres extend the head on the neck and lift the tongue clear of the airway (Figs. 12.2 and 12.3).

Fig. 12.1. Opening the airway 1

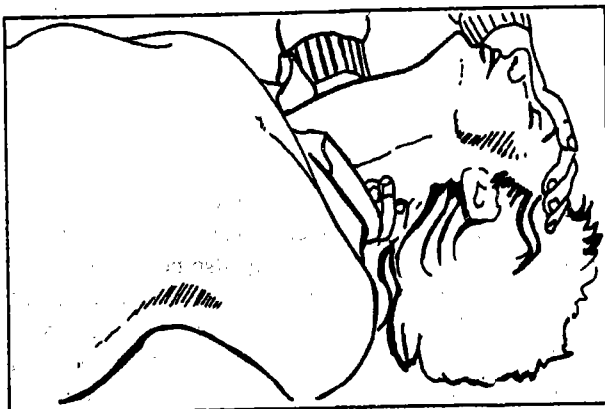
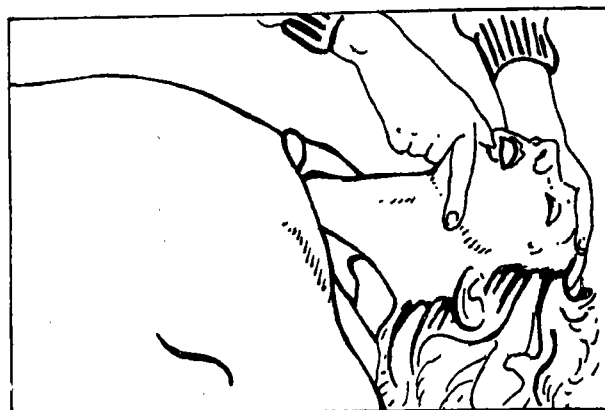


Fig. 12.2. Opening the airway 2



If the breathing centre is capable of initiating breathing, as soon as the airway is opened the casualty will gasp several times and then start to breathe.

If the casualty does not start to breathe spontaneously then mouth-to-mouth resuscitation should be attempted.

Mouth-to-mouth resuscitation

For mouth-to-mouth resuscitation the casualty should remain in the "open-airway" position (Figs. 12.1–12.3). If there is any doubt that the casualty may be infectious use the resuscitation mouthpiece. In cases of cyanide or similar poisoning, where the casualty's expired air may be toxic to the first-aider, use the one-way valve face mask.

The following steps should then be taken in the order given:

- extend the casualty's neck and tilt the head backwards;
- open your mouth wide and take a deep breath;
- pinch the victim's nostrils together between your index finger and thumb (Fig. 12.4);
- seal your lips around the victim's mouth: if this is not possible use the mouth-to-nose technique.

In this method close the patient's mouth during inflation with the thumb holding the lower jaw;

- blow into the victim's lungs until they are filled (Fig. 12.5);
- when you see the victim's chest rise remove your mouth to allow the air to escape from his lungs, and turn your head to one side;
- give the victim four inflations to saturate the blood with oxygen;
- check the carotid pulse (Fig. 12.6).

If the carotid pulse is present, continue to inflate at the normal breathing rate of 12–18 breaths per minute; if the stomach contents are regurgitated turn the victim's head to one side and clean out his mouth. When there are signs of natural respiration adjust your breathing to coincide with that of the victim; Signs of recovery include



Fig. 12.3. Clearing the airway



Fig. 12.4. Mouth-to-mouth resuscitation



Fig. 12.5. Mouth-to-mouth resuscitation

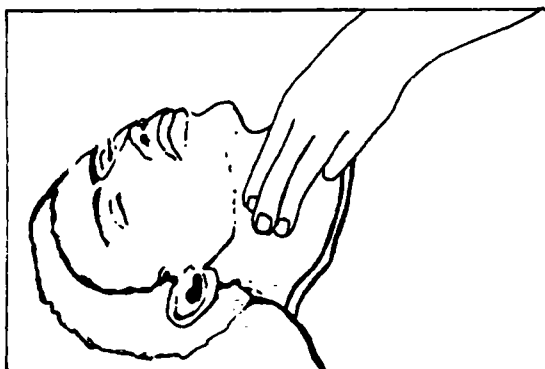


Fig. 12.6. Finding the carotid pulse

return of natural colour, quivering or slight movement of the body and gasping. When breathing is restored place the victim in the recovery position (see below).

If the carotid pulse is absent, the victim's pupils are widely dilated and body colour remains blue-grey; external cardiac compression should be started while continuing to ventilate the lungs in the ratio of one inflation of the lungs to six or eight depressions of the sternum.

When the patient begins breathing unaided and no further first-aid is required place him/her in the Recovery Position (see below).

Recovery position

For placing the victim in the recovery position follow the steps given below:

- kneel at the side of the casualty;
- turn the head towards you (Fig. 12.7);
- push the casualty's nearest arm under his/her back (Fig. 12.8);
- pull the other arm over the chest (Fig. 12.9);
- cross the far leg over the nearest leg;
- with one hand grasp the casualty's leg by the clothing on the far hip (Fig. 12.10);
- pull the casualty over on your knees, while protecting the head with your other hand (Fig. 12.11);
- bend the upper leg forward;
- free the lower arm and extend it backwards;
- place the upper arm in a bent position forwards;
- tilt the casualty's head back to ensure a clear airway (Fig. 12.12);
- check the breathing.

External cardiac compression

The method for external cardiac compression is as follows:

- place the victim on his back on a firm surface, usually the floor;
- strike the chest over the area of the heart; this may start the heart beating spontaneously;
- if there is no response, commence external cardiac compression;
- kneel at the side of the patient;
- define the lower half of the sternum;
- place the heel of your hand on this part of the bone keeping the palm and fingers off the chest (Fig. 12.13);
- cover this hand with your other hand;
- with arms straight rock forward and press down on the lower half of the sternum (Fig. 12.14); the pressure should be firm and controlled: erratic or violent action is dangerous. In an unconscious adult the sternum can be pressed towards the spine for 3.5–4.0 cm;
- repeat the pressure once per second;
- check the effectiveness of the compression of the heart by:
 - observing the size of the pupils;
 - feeling for the carotid pulse;
 - watching for improvement in the victim's colour.

The lung–heart resuscitation may have to be continued until the victim reaches definitive medical aid. If there are two first-aiders, one should undertake inflation of the lungs, note the size of the pupils and feel for carotid pulsation while the other undertakes cardiac compression.

Fig. 12.7. Recovery position 1



Fig. 12.8. Recovery position 2



Fig. 12.9. Recovery position 3

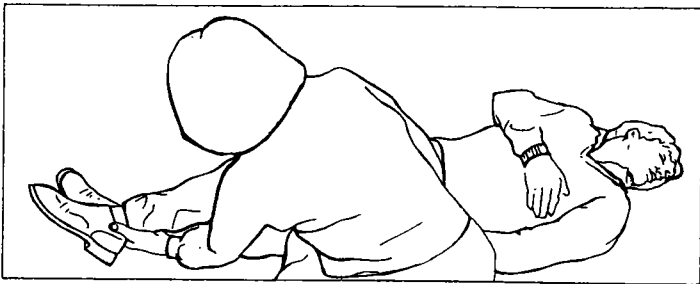


Fig. 12.10. Recovery position 4

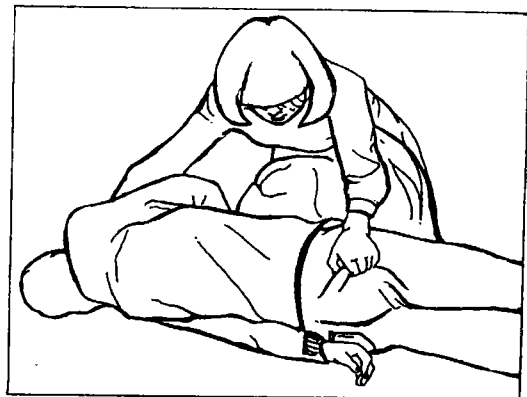


Fig. 12.11. Recovery position 5

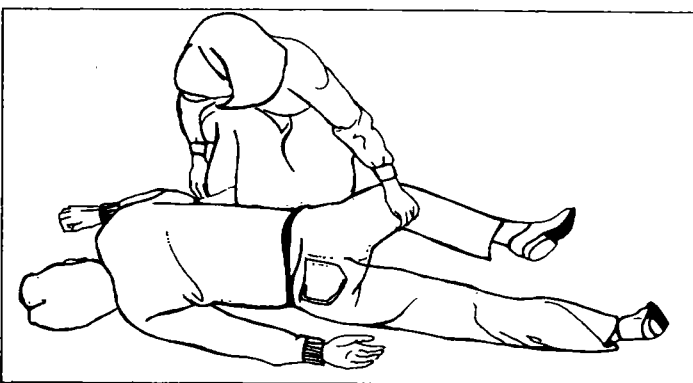


Fig. 12.12 Recovery position 6; readjusting the airway

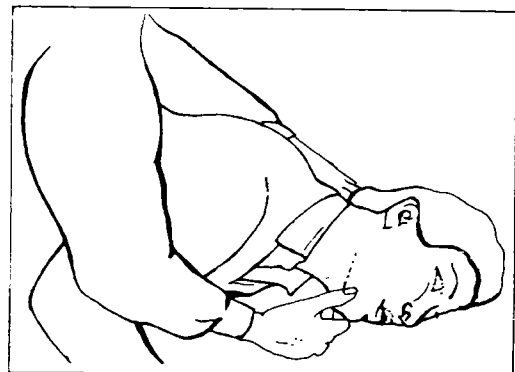
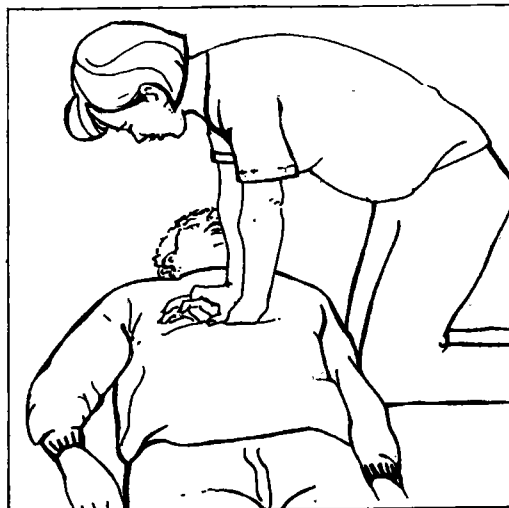


Fig. 12.13. Cardiac compression 1



Fig. 12.14. Cardiac compression 2



Asphyxia

Asphyxia is produced by general lack of oxygen in the blood or by failure of its delivery to the tissues: if untreated, breathing and heart action will stop.

Clinically the following features are noted:

- breathing rate and depth increase;
- congestion of the head and neck occurs;
- face, lips, conjunctivae and nail beds of the fingers turn blue (cyanosis);
- noisy breathing with frothing may occur;
- consciousness is lost;
- fits may occur.

In the health-care laboratory asphyxia can occur under a number of circumstances:

Conditions affecting the utilization of oxygen:

- by the blood — carbon monoxide poisoning;
- by the tissues — cyanide poisoning.

Local conditions affecting the airways:

- spasm — irritant gases;
- obstruction — tongue falling back in the unconscious casualty;
— swelling of tissues in scalding;
- compression — swelling due to injury.

Conditions affecting the respiratory centre:

- poisoning

Conditions affecting the mechanism of respiration:

- central origin — epilepsy, rabies, encephalitis;
- regional origin — injury to upper part of the spinal cord.

Compression of the chest:

- crush injuries.

Treatment is aimed at:

- ensuring an open airway so that air can reach the lungs;
- ensuring an adequate circulation so that oxygen can reach the tissues.

If this is not achieved then damage to the brain and other vital organs will occur. To attain these treatment objectives both mouth-to-mouth respiration and external cardiac compression will often be required. Success depends on immediate recognition and swift action.

Carbon monoxide poisoning

With the introduction of non-toxic domestic gases this should become much less prominent. In the workplace it usually arises through defective appliances, cracked pipes or flues in an enclosed, poorly ventilated space.

The inhalation of fumes from partial combustion of fuel and from internal combustion exhausts will still remain a danger.

Clinically there is:

- pink coloration of lips and skin;
- confusion, stupor;
- a state resembling alcoholic intoxication.

If prolonged exposure has occurred the victim may be in coma.

The first-aid actions are:

- if the victim is in a room or an enclosed space, before entering, ventilate your lungs then hold your breath;
- go in and get the victim out;
- if you cannot do so at once cut off the source of the gas;
- obtain a full supply of fresh air by opening doors and windows;
- if a smouldering hazard exists be very careful not to increase the fire-risk by creating a draught.

Accidents involving chemicals

In these events prompt action is essential and medical assistance often necessary but first-aid should not be delayed until medical aid arrives.

Areas that have special or unusual chemical hazards should be posted with appropriate warning signs and signs that show the location of safety showers and eye-wash stations.

Eyes

If chemicals get into the eyes they should be washed thoroughly with clean water for at least 15 min. Such treatment, given promptly, will probably minimize damage to the eye but no attempt should be made to touch the eye or to remove particulate matter: this is part of medical treatment.

Gassing

Casualties often arise after failure of a vessel or connection resulting in the liberation of gas. The gas may be recognized by smell, by the colour coding on a cylinder or by a notice displayed indicating the nature of the hazard. Generally, the affected person should be taken into the fresh air, clothing around the neck and waist loosened and the victim kept warm. If breathing is shallow or weak, oxygen will have to be given, by a qualified person. If breathing has ceased, artificial respiration should be commenced immediately. Anyone exposed to toxic gases should be kept under observation, however trivial the exposure may have been.

Chemical contamination of clothing

Clothing may by accident become saturated with solvents or other chemical solutions. The clothing should be removed immediately and decontamination procedures instituted. The victim should be kept warm.

Accidents involving specific chemicals

The remainder of this section is devoted to examples of first-aid actions appropriate to individual hazardous chemicals. Foresight is important in dealing with these hazards, and it is necessary for the laboratory and each individual in it to be aware of the emergency procedures appropriate to each situation. Where specific antidotes exist, these should be posted together with instructions for their use. Accidents arise from inhalation, infection or exposure to skin (see Annex 3).

Acids: e.g. acetic, sulphuric, hydrochloric, nitric and phosphoric acids.

Lungs: remove from exposure; rest and keep warm; in severe cases or if exposure has been great, obtain medical attention.

Skin: drench the skin copiously with water; remove contaminated clothing and wash before re-use; in severe cases obtain medical attention; blisters or burns should receive medical attention.

Mouth: wash out the mouth thoroughly with water and give water to drink together with milk of magnesia or milk. Keep patient warm and quiet.

Alkalis: e.g. sodium, potassium ammonium or calcium hydroxides.

Lungs: remove from exposure, rest and keep warm; in severe cases or if exposure has been great, obtain medical attention.

Skin: drench the skin with plenty of water; remove contaminated clothing and wash before re-use; in severe cases, obtain medical attention.

Mouth: wash out the mouth thoroughly with water; give copious water followed by vinegar or 1% acetic acid to drink or give copious amounts of lemon juice; obtain medical attention.

Narcotics: e.g. carbon tetrachloride, chloroform, tetrachloroethane, anaesthetic gases.

Lungs: remove from exposure, rest and keep warm; in severe cases obtain medical attention and apply artificial respiration if breathing has stopped.

Skin: for narcotics which are also corrosive, drench the skin with water and wash with soap and water; remove contaminated clothing and wash before re-use; unless contact has been slight, obtain medical attention.

Mouth: wash out the mouth thoroughly with water.

Cyanides: e.g. hydrogen cyanide, sodium or potassium cyanide, acetonitrile.

Lungs: obtain medical attention; wear breathing apparatus; remove casualty from exposure and remove all clothing, place in the open air; if casualty is breathing, break a capsule of amyl nitrite over a cloth and let the casualty inhale for 15–30 sec each minute until trained personnel can administer cobalt edetate injection; if breathing has stopped apply artificial respiration (use one-way valve mask) to aid inhalation of amyl nitrite.

Skin: obtain medical attention; administer amyl nitrite and proceed as above; if a cyanide antidote is preferred and the casualty is conscious, administer the antidote and when vomiting has ceased, continue as above.

Mouth: obtain medical attention; administer amyl nitrite and proceed as above; if a cyanide antidote is preferred and the casualty is conscious, administer the antidote and when vomiting has ceased, continue as above.

Phenols: e.g. phenol, cresol.

Lungs: remove from exposure, rest and keep warm; in severe cases or if exposure has been great, obtain medical attention.

Skin: remove contaminated clothing and swab contaminated skin with glycerol, liquid polyethylene glycol or a mixture of liquid polyethylene glycol (70 parts) and methylated spirit (30 parts) for at least 10 min; obtain medical attention; wash contaminated clothing before re-use.

Mouth: wash out the mouth thoroughly with water; give plenty of water or milk to drink; obtain medical attention.

Organophosphorus compounds:

Lungs: obtain medical attention; wear breathing apparatus; remove casualty from exposure and remove clothing, placing it in the open air; if breathing has stopped, apply artificial respiration, and persevere until medical aid arrives.

Mercury compounds:

Lungs: remove from exposure, rest and keep warm; obtain medical attention.

Skin: drench the skin with water and wash with soap and water; remove contaminated clothing and wash before re-use; unless contact has been slight, obtain medical attention.

Mouth: wash out the mouth thoroughly with water and give a large quantity of milk to drink; obtain medical attention.

Annex 1. Risk assessment

Some of the chemicals, equipment and procedures used in health-care laboratories are intrinsically hazardous. Protection of the worker must therefore be ensured by assessing the nature and extent of the risks involved so that effective steps may be taken to eliminate, reduce or control them.

A step-by-step assessment involves determining:

- the hazardous properties of substances used in the laboratory;
- the physical properties of those substances in relation to health hazards;
- the ways in which workers may become exposed to those substances and the routes of exposure;
- the procedures that may release hazardous substances.

The hazardous properties of substances

A list of all substances, chemical and biological, that are used or stored in the laboratory, should be prepared. Chemicals may mostly be identified by consulting the store and purchasing records, but a physical inspection may reveal old stocks of chemicals and stores of biological agents. The list of biological agents, i.e. microorganisms, is easily prepared from laboratory reports.

The next step is the ranking of the items listed in order of hazard. Annex 3 provides information on a number of hazardous chemicals commonly used in health-care laboratories. Further information may be found in manufacturers' data sheets, container labels and the books listed in the references in Chapter 8 and Annex 3.

The chemicals may then be ranked from "harmless" to "dangerous" and given arbitrary numbers from 1 to 10 on the basis of the hazard. Microorganisms may be ranked according to the Risk or Hazard Class or Group (1–4) in which they have been placed in national or supra-national lists.

Physical properties of hazardous substances in relation to health hazards

Chemicals and biological agents may be in the form of solids, liquids, vapours, gases and aerosols. Chemicals, in whatever form may be toxic, flammable and/or explosive. In this context, "toxic" means generally hazardous to health, i.e. as poisons, corrosives, carcinogens, radioactivity, asphyxiants. The ranking order will depend at least partly on the physical nature, i.e. the ease with which the agents may be contained, the ways in which they may contaminate the environment and the route by which they enter the human body (see below).

The forms in which hazardous substances may be present are:

Solid. The larger the particles the less the hazard of dispersion.

Dust. Chemicals may be supplied in a finely divided state, or may be pulverized in the laboratory, e.g. for ease of solution and in the preparation of mixtures. Dust particles so produced are easily dispersed, and, depending on their size, may become airborne, settling at some distance from the point of generation and meanwhile subject to inhalation.

Liquids and suspensions. These may leak from their containers, be spilled or splashed, contaminating the environment.

Aerosols. Liquids may become aerosolized. This occurs when they are subjected to a violent disturbance, as in squirting, production of jets, mixing, pouring and the breakage of liquid films, as in the bursting of bubbles. These result in the formation of minute droplets. If these droplets are larger than 0.4 µm in diameter they settle rapidly and contaminate surfaces. Smaller particles, especially those that are 0.2 µm in diameter, remain suspended in the air for long periods and are moved by local air currents and dry, leaving "droplet nuclei" which also eventually settle and contaminate surfaces. They may also, either as aerosols, or as droplet nuclei, be inhaled.

Gases and vapours. These may be dispersed by local air currents and may be inhaled.

Biological agents. Microorganisms may be present in clinical material, as colonies on solid culture media, and as suspension in liquid media.

Tables AN1.1 and AN1.2 suggest ranking orders of substances in relation to human health. These must be considered, however, in the light of the route of entry to the human body (see below).

Table AN1.1. Ranking order for chemical hazards, based on ease of containment

<i>Low</i>		<i>High</i>
Solid	Liquid	Gas or vapour
Non-flammable	Flammable	Flammable
	High flashpoint	Low flashpoint
Not explosive	Low explosive risk	High explosive risk

Table AN1.2. Ranking order of microbial hazards, within Risk Groups

<i>Low</i>			<i>High</i>
Clinical material	Cultures on solid media	Cultures in liquid media	Aerosols

Ways in which workers may become exposed: portals of entry

Workers may become exposed to hazardous substances if those substances "escape" from their containers and contaminate the laboratory environment as described above. Workers may become exposed in several ways:

- skin contact, directly or by manual transfer;
- absorption through the skin and mucous membranes;
- ingestion, directly or by manual contact ("hand-to-mouth" transfer);
- inhalation of airborne particles, aerosols or droplet nuclei.

Procedures that may release hazardous substances

Apart from accidents, many laboratory activities may result in the release or dispersion of hazardous substances. These include:

- grinding and pulverizing solids;
- mixing and pouring liquids;
- mechanically homogenizing liquids;
- centrifugation;
- pipetting;
- open bench microbiological techniques;
- poorly designed or improperly used equipment.

Quantification of risk

If numerical values are accorded to the hazardous substance or procedure, as described in Chapters 7 and 8 to the likelihood of an accident and release, then

$$\text{Risk level} = \text{Hazard value} \times \text{likelihood of occurrence}$$

The higher the risk level, the more important becomes the action to reduce exposure and the greater the necessity for monitoring.

Risk reduction

Risk reduction is achieved by:

- discarding high-risk chemicals and agents wherever possible by substitution with those that are less hazardous;
- where there are no alternatives to high-hazard agents, a reduction in scale of the procedures;
- use of containment such as ventilated enclosures, directional air flow, air filtration and equipment known not to generate or release aerosols;
- correct use of appropriate equipment.

Risks to the external environment

The above concerns risks to laboratory personnel. Laboratories may also generate materials that offer risks to humans, animals and plants in the general environment. Most of these stem from laboratory waste that has been improperly discarded, i.e. has not been made safe. If the procedures given in Chapter 11 are followed, there should be no risks external to the laboratory premises from such waste.

Another potential external risk is from laboratory specimens despatched to, and between laboratories. These risks are covered in Chapter 10, and in more detail for infectious materials, in the *WHO Laboratory Biosafety Manual (2)*.

For more information about risk assessment see references (65–67).

Annex 2. Model Standard Operating Procedure (SOP)

Definition and application

Comprehensive and unambiguous written operating procedures should be available covering all aspects of laboratory practice, both analytical and non-analytical. All staff must comply with these. Where analytical and microbiological procedures are described, relevant safety and decontamination protocols must be incorporated, including the actions to be taken after an accident. Alternatively, there must be clear cross-reference to Health and Safety Codes of Practice and Accident Procedures.

Standard Operating Procedures (SOPs) require regular review, at an interval of no more than 12 months, and should be altered if necessary. The introduction of a new, or alteration of an existing process must be recorded. The SOPs should be dated and signed by the Head of the Department. Expired SOPs must be removed.

Example of layout

Title

Standard Operational Procedure for . . .

Definition of topic

This SOP describes the method . . .

Area of application

This SOP is applicable (e.g.) to the determination/investigation of . . . to the procedure for . . . to the requirements of . . .

Where the SOP is applicable to the determination of a substance or substances the following must be stated in this section

- detection limits in matrix;
- minimum value to be reported;
- requirements of the geographical site;
- training requirements for the person performing the task.

Where the SOP is applicable to the performance of a procedure the following must be stated:

- purpose of the procedure;
- location of the procedure;
- limitations and exclusions applying to the procedure;
- training requirements of staff performing the procedure.

Definition and terminology

This refers to specific terminology only. General terminology need not be included in an SOP.

Premise

A premise is the theory of how the analysis/investigation works;

or a description of elementary working of an item of equipment;

or a summary description of a non-analytical or non-investigational procedure.

Health and safety

Dangers inherent in the process or procedure should be identified but with cross referencing to the Laboratory Safety Manual for detail to avoid duplication.

Some instruments may endanger the user if not used properly.
(*"Caution"—the user may be in danger!*)

Certain actions may result in damage to the equipment.
(*"Warning"—the equipment could be damaged!*)

Reagents and ancillary materials

This section refers to all substances, with the necessary degree of purity and possibly the brand name, required to achieve a correct result. Shelf-life should be specified here and also any storage requirements.

Equipment and accessories

In this section the equipment required and operational details necessary for successful execution are described.

Any associated computer hardware and software should be described.

Pre-analytical requirements

Description of specimen collection, transportation and reception. Only unique information need be given. Other details can be cross-referenced to the appropriate SOP. Specify laboratory storage criteria and maximum duration of possible storage.

Operating procedures

General: A short description of the technique, the method of calculation and any corrections to be applied.

Precautionary measures: Substances or instruments that may be hazardous. A list of measures which make it possible to work safely.

Safety measures which are generally applicable in the laboratory, such as wearing a laboratory coat and safety goggles, need not be included in specific SOPs as these will have been described in the Safety Manual. The use of a certain type of glove must be explicitly stated, however, as must the need to use protective breathing equipment.

Technical procedures

Detailed description of the conditions under which the equipment works, preferably in a clearly formulated table.

A separate statement of how equipment is calibrated and the necessary requirements for calibration and what measures are to be taken if and when problems occur.

Processing the results

Registration: Report which data are to be recorded in the logbook, or which form is to be used for registration of the data.

Calculation: State the formula for calculation; use short symbols. List the symbols and explain their meaning; state the unit of measurement in which they are expressed.

Report

State in the report:

- data required for identification of the specimen;
- the method used;
- the content, expressed in the applicable unit;
- any peculiarities which were observed during testing;
- whether or not any of the activities described in the SOP could have an effect on the results;
- the calculation method used.

Statement of precision and correctness

Repeatability: This is based on the analysis of a standard sample "n" times. Determine the average and the standard deviation.

Intra-laboratory precision: This is based on regularly including one or more control samples in a series of tests and performing within and between batch precision calculations.

Quality assurance

Internal quality control: Indicate first-line control, along with the use of a control card. State when action is to be taken and outline the plan of action.

Control of chemicals and glassware: State how the chemicals and the glassware are checked, for example, by a blank which is included in every series. If and when a sudden increase is discovered in a blank, the chemicals are to be checked individually and replaced where necessary. Repeat the check with specially-cleaned glassware.

External quality assessment: The procedure for external quality assessment must be defined.

Related documents

This section includes references to instruction manuals for equipment and software. The manuals should be securely stored and directly accessible to the SOP user.

Literature

Relevant literature references including evaluations in the field of analysis, safety and reporting must be available and accessible in the laboratory.

Annex 3. Chemicals: Hazards and precautions

This annex lists the basic health and safety information, data and appropriate safety precautions for a selected number of chemicals found commonly in the health-care laboratory. The list is not exhaustive and the absence of any particular chemical does not imply that it is non-hazardous. All laboratory chemicals should be treated with caution and in ways which will minimize exposure with good laboratory practice and good occupational hygiene practice. Further details may be found in hazard or safety data sheets, available from the manufacturers or suppliers and in the references cited in Chapter 8 and this annex. Safety data sheets give information for the pure chemical itself and may not address the actual risks associated with any particular chemical in all the applications and techniques in which it is used, especially if impurities are present.

Key to hazards and precautions

Physical properties

Solid/liquid/gas at normal temperature; melting point (m.p.) and boiling point (b.p.); water solubility (solids) or miscibility (liquids).

Health hazards

Health hazards are based on a European Community Directive (47), various regulations (48-51) for the classification and labelling of dangerous substances and typical suppliers' hazard data sheets.

Occupational exposure limits

Maximum exposure levels/occupational exposure standards (OES) for 8 h (long-term) and 10 min (short-term) in ppm or mg/m³ (68); or threshold limit values [(TLV); time weighted average (TWA) or ceiling value] (68).

Fire hazards (where applicable)

Flammability hazard based on flashpoint. Flammability range % in air at 20 °C.

Safety precautions

Includes guidance on glove materials and standard of eye protection according to the risk of minor liquid splashes (safety spectacles) or exposure to dust, gas, vapour or spray (chemical-grade goggles).

Incompatibility or reactivity hazards

Known violent or dangerous reactions with other chemical reagents.

Other special hazards and precautions

Chemical-specific non-standard storage, handling, disposal and spillage measures.

Hazardous chemicals**ACETIC ACID**

Physical properties	Colourless liquid with pungent odour; m.p. 17 °C, b.p. 118 °C; miscible with water.
Health hazards	Corrosive; causes severe burns; irritating vapour.
Exposure limits	OES (short-term) 15 ppm; OES (long-term) 10 ppm; TLV (TWA) 10 ppm.
Fire hazards	Flammable; flashpoint 40 °C; flammable range 4–16%.
Safety precautions	Do not breathe fumes; if contact with eyes rinse immediately with water and seek medical advice; wear nitrile gloves and eye protection.
Incompatible chemicals	Violent or explosive reaction with oxidizers and acetaldehyde.

ACETONE

Physical properties	Colourless volatile liquid with sweetish odour; m.p. -95 °C, b.p. 56 °C; miscible with water.
Health hazards	Irritates the eyes; inhalation may cause dizziness, narcosis and coma.
Exposure limits	OES (short-term) 1500 ppm; OES (long-term) 750 ppm; TLV (TWA) 750 ppm.
Fire hazards	Highly flammable; flashpoint -19 °C; flammable range 2.6–12.8%.
Safety precautions	Keep container in a well-ventilated area; keep away from sources of ignition; do not breathe vapour; wear eye protection.
Incompatible chemicals	Reacts violently with oxidizers (e.g. chromic and nitric acids) and chloroform in the presence of base.
Other hazards	Penetrates the intact skin; earth (ground) large containers and vessels to prevent static electricity discharges.

AMMONIA SOLUTIONS [35% in water or specific gravity (SG) 0.88]

Physical properties	Colourless liquid with pungent odour; miscible with water.
Health hazards	Corrosive; causes burns; irritating to the eyes, respiratory system and skin.
Exposure limits	As ammonia gas, OES (short-term) 35 ppm; OES (long-term) 25 ppm; TLV (TWA) 25 ppm.
Fire hazards	As ammonia gas, flammable range 16–25%.
Safety precautions	Keep container tightly closed and place a cloth over the closure before removing it; if contact with the eyes rinse immediately and seek medical advice; use in a fume cupboard or wear rubber or plastic gloves and chemical-grade goggles.
Incompatible chemicals	Reacts violently with mercury and halogens or forms explosive products.

AURAMINE

Physical properties	Yellow flakes or powder; insoluble in water.
Health hazards	Harmful by ingestion, inhalation and skin contact; may cause eye or skin irritation; possible carcinogen.
Safety precautions	Avoid skin contact and inhalation of dust; wear rubber or plastic gloves and chemical-grade gloves; use in a fume cupboard or wear dust respirator.
Incompatible chemicals	Strong oxidizing agents.

BENZENE

Physical properties	Colourless volatile liquid with characteristic odour.
Health hazards	Inhalation of vapour causes vertigo and headache, at high concentrations unconsciousness and death; danger of irreversible blood disease by prolonged or chronic exposure; may be carcinogenic; toxic by inhalation or absorption through skin.
Exposure levels	OES (long-term) 5 ppm; TLV (TWA) 1 ppm.
Fire hazards	Highly flammable; flashpoint -11 °C; flammable range 1.3–7%; fires produce large volumes of black, sooty smoke.
Safety precautions	Keep container in well-ventilated area and away from sources of ignition; use in fume cupboard or hood with

adequate ventilation; wear eye protection and nitrile or PVC gloves.

Incompatible chemicals Can react violently with oxidizers including chromic acid, potassium permanganate and liquid oxygen.

BENZIDINE

Physical properties Light yellow powder; m.p. 124 °C, b.p. 402 °C; slightly soluble in water but very soluble in acids and organic solvents.

Health hazards May cause bladder cancer; possible teratogenic effects or reproductive disorders; any exposure is extremely dangerous.

Safety precautions Avoid all exposure; wear eye and skin protection; use in fume cupboard, hood or suitable mechanical exhaust ventilation.

Other hazards Use is prohibited or legally controlled in many countries.

CARBON DIOXIDE (solid; "dry ice")

Physical properties Translucent white solid at -79 °C; sublimates to gas at ambient temperatures.

Health hazards Risk of asphyxiation in confined or poorly ventilated areas; contact with solid or with materials at "dry ice" temperatures causes severe frostbite.

Exposure levels OES (short-term) 15 000 ppm; OES (long-term) 5000 (as gas); TLV (STEL) 30 000 ppm; TLV (TWA) 5000 (as gas).

Safety precautions Wear heavy textile, leather or insulated gloves; cover large blocks with cloth or place in canvas or similar container; store only in ventilated room or area in open container.

Incompatible chemicals Alkali metals.

Other hazards Low temperature embrittlement may occur in some metallic, rubber or plastic materials exposed to solid CO₂ temperatures.

CHLOROFORM

Physical properties Colourless volatile liquid with characteristic odour; m.p. -63 °C, b.p. 61 °C; slightly miscible with water.

Health hazards	Harmful by inhalation, ingestion and skin contact; irritating to the skin; possible risk of irreversible effects; danger of serious health damage by prolonged or chronic exposure; causes cancer in animal tests and is a suspected human carcinogen.
Exposure limits	OES (long-term) 2 ppm; TLV (TWA) 10 ppm.
Safety precautions	Wear protective clothing (laboratory coat or plastic apron), nitrile gloves and eye protection; use in a fume cupboard.
Incompatible chemicals	Can react violently with acetone in the presence of base with nitrogen dioxide and some metals including lithium.
Other hazards	The vapour is an anaesthetic, causing drowsiness and unconsciousness; forms highly toxic phosgene when heated to high temperatures.

CYTOCHALASIN (A-J)

Physical properties	White powder; m.p. varies.
Health hazards	Toxic by ingestion, inhalation or absorption through skin may cause congenital fetal malformation.
Safety precautions	Avoid contact with eyes, skin and clothing; wear chemical-grade goggles and rubber or plastic gloves.
Incompatible chemicals	Strong oxidizing agents.

DIMETHYLAMINE

Physical properties	Colourless volatile liquid with ammoniacal odour; m.p. -50 °C, b.p. 56 °C; miscible with water.
Health hazards	Irritating to the eyes and respiratory system.
Exposure limits	OES (short-term) 25 ppm; OES (long-term) 10 ppm; TLV (TWA) 10 ppm.
Fire hazards	Extremely flammable; flashpoint -26 °C; flammable limits 1.8-10%.
Safety precautions	Keep away from sources of ignition; if contact with the eyes rinse immediately and seek medical advice; use in a fume cupboard; wear nitrile gloves and chemical-grade goggles.
Incompatible chemicals	Can react with oxidizers.

DIETHYL ETHER

Physical properties	Colourless highly volatile liquid with sweet characteristic odour; m.p. 116 °C, b.p. 34 °C; slightly miscible with water.
Health hazards	Vapour is an anaesthetic causing drowsiness and unconsciousness; repeated inhalation may be habit-forming.
Exposure limits	OES (short-term) 500 ppm; OES (long-term) 400 ppm; TLV (TWA) 400 ppm.
Fire hazards	Extremely flammable; may form explosive peroxides; flashpoint -45 °C; flammable range 1.7-48%.
Safety precautions	Keep container in a well-ventilated area; keep away from sources of ignition; earth or ground containers to prevent static electrical discharges; use in a fume cupboard; wear nitrile gloves to prevent degreasing of the skin.
Incompatible chemicals	Exposure to air and light may result in the formation of explosive peroxides; can react violently with oxidizers and halogens.

2,4-DINITROPHENYLHYDRAZINE

Physical properties	Orange-red crystalline powder; m.p. 200 °C; slightly soluble in water.
Health hazards	Irritating to the skin and eyes; harmful by ingestion, inhalation and skin contact.
Safety precautions	Keep moist to reduce explosion risk; wear dust respirator, rubber or plastic gloves and chemical-grade goggles.
Incompatible chemicals	Can react vigorously with oxidizers and reducers.

ETHANOL

Physical properties	Colourless volatile liquid with slight, characteristic odour; m.p. -130 °C, b.p. -79 °C; miscible with water.
Health hazards	Harmful if ingested; irritating to the eyes.
Exposure limits	OES (long-term) 1000 ppm; TLV (TWA) 1000 ppm.
Fire hazards	Highly flammable; flashpoint 12 °C; flammable limits 3-19%.
Safety precautions	Keep container tightly closed; keep away from ignition sources.

Incompatible chemicals	Can react violently with oxidizers, potassium metal and silver nitrate.
Other hazards	The various additives in rectified, industrial and methylated spirit, and absolute grades of ethanol may substantially increase the toxicity hazard.

ETHANOLAMINE

Physical properties	Colourless, non-volatile viscous liquid with ammoniacal odour; m.p. 10 °C, b.p. 171 °C; miscible with water.
Health hazards	Harmful by inhalation; irritating to the eyes, respiratory system and skin.
Exposure limits	OES (short-term) 6 ppm; OES (long-term) 3 ppm; TLV (TWA) 3 ppm.
Fire hazards	Flashpoint 85 °C.
Safety precautions	Wear rubber or plastic gloves and eye protection.
Incompatible chemicals	Can react with oxidizers.

FORMALDEHYDE SOLUTION (37–41% formaldehyde with 11–14% methanol)

Physical properties	Colourless liquid with a pungent odour; b.p. 96 °C; miscible with water.
Health hazards	Toxic if inhaled, ingested or absorbed by the skin; causes burns or ulceration of the skin; prolonged exposure to the vapour may cause conjunctivitis, laryngitis, bronchitis or broncho-pneumonia; may cause sensitization by skin contact; possible risk of irreversible health effects; probably carcinogenic to humans.
Exposure limits	As formaldehyde, MEL (short-term) 2 ppm; MEL (long-term) 2 ppm; TLV (TWA) 1 ppm.
Fire hazards	Flashpoint 50 °C.
Safety precautions	Wear protective clothing such as plastic apron, rubber or plastic gloves and chemical-grade goggles; use in fume cupboard or well-ventilated area.
Incompatible chemicals	Can react vigorously with oxidizers; with nitromethane to produce explosive products and with hydrochloric acid to produce the potent carcinogen bis (chloromethyl) ether.
Other hazards	Concentrated formaldehyde solutions become cloudy if stored below 21 °C and should be kept between 21 and 25 °C; dilute solutions (1–5%) and medium strength

solutions (5–25%) retain many of the hazards of the concentrated form.

GLUTARALDEHYDE

Physical properties	Colourless or pale yellow solution with a characteristic odour; m.p. $-14\text{ }^{\circ}\text{C}$, b.p. $188\text{ }^{\circ}\text{C}$; miscible with water.
Health hazards	Severe irritant to the eyes and upper respiratory tract; prolonged skin contact can cause sensitization.
Exposure limits	OES (short-term) 0.2 ppm; TLV (ceiling value) 0.2 ppm.
Safety precautions	Use in fume cupboard or in well-ventilated area; wear rubber or plastic gloves and eye protection.
Incompatible chemicals	Can react vigorously with oxidizers.
Other hazards	Often supplied in aqueous solution at various concentrations with added stabilizer to enhance stability.

HYDROCHLORIC ACID (10–37%)

Physical properties	Colourless fuming liquid with a pungent odour; miscible with water.
Health hazards	Corrosive; causes burns; irritating to the eyes, respiratory system and skin.
Exposure limits	As hydrogen chloride, OES (short-term) 5 ppm; TLV (ceiling level) 5 ppm.
Safety precautions	Do not breathe fumes; if contact with the eyes rinse immediately with water and seek medical advice; if contact with the skin, wash immediately with plenty of water; use in fume cupboard; wear rubber or plastic gloves and eye protection (spectacles or goggles).
Incompatible chemicals	Reacts vigorously with bases (solids and concentrated solutions), sodium metal and explosively with solid potassium permanganate; evolves toxic or explosive gases in contact with many metals.
Other hazards	Releases highly toxic fumes in fires.

HYDROGEN PEROXIDE

Physical properties	Colourless liquid; m.p. $-0.4\text{ }^{\circ}\text{C}$, b.p. $152\text{ }^{\circ}\text{C}$; miscible with water; supplied in aqueous solution at various concentrations.
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Health hazards	Causes severe burns at high concentration (60%) and at low concentration (6%) if contact with the skin is prolonged; otherwise dilute solutions are irritating to the eyes, respiratory system and skin.
Exposure limits	OES (short-term) 2 ppm; OES (long-term) 1 ppm; TLV (TWA) 1 ppm.
Fire hazards	Oxidizing agent; contact of concentrated solutions with combustible material can cause fire.
Safety precautions	If contact with the skin, wash immediately with plenty of water; wear nitrile gloves and eye protection if concentration exceeds 20%.
Incompatible chemicals	Reacts vigorously with a variety of chemical reagents including flammable liquids and gases, oxidizers and bases; is decomposed with evolution of oxygen by many reagents and by dusts and metals.
Other hazards	Can decompose evolving oxygen causing pressurization of containers; store away from direct sunlight preferably in a cool place; do not use metallic containers or equipment, e.g. brass, copper, iron.

IODINE

Physical properties	Bluish-black crystalline scales with a characteristic odour; m.p. 114 °C, b.p. 154 °C; practically insoluble in water.
Health hazards	Harmful by ingestion and inhalation; irritating to the eyes, respiratory system and skin.
Exposure limits	OES (short-term) 0.1 ppm; TLV (TWA) 0.1 ppm.
Safety precautions	Do not breathe vapour; avoid contact with the eyes; wear nitrile gloves.
Incompatible chemicals	Reacts violently with metals including aluminium, potassium and sodium, and with ethanol/phosphorus mixtures; reacts with ammonia giving explosive products.

MERCURY

Physical properties	Heavy silvery liquid; m.p. -39 °C, b.p. 357 °C; insoluble in water.
Health hazards	Toxic by inhalation; danger of cumulative effects; continued skin contact may cause dermatitis.
Exposure limits	OES (short-term) 0.15 mg/m ³ ; OES (long-term) 0.05 mg/m ³ ; TLV (TWA) 0.05 mg/m ³ .

Safety precautions	Keep container tightly closed; use in fume cupboard or well-ventilated area; wear rubber or plastic gloves.
Incompatible chemicals	Can react with ammonia, azides and ethylene oxide to form explosive products; reacts violently with bromine; forms amalgams with many metals; evolves toxic fumes if heated in fires.
Other hazards	Store containers and use over catchment trays to contain spillage; suck up spilt droplets into a small aspirator bottle fitted with a capillary collecting tube and connected to a pump; treat spilt areas with zinc dust to form an amalgam.

METHANOL

Physical properties	Colourless volatile liquid with characteristic odour; m.p. $-98\text{ }^{\circ}\text{C}$, b.p. $65\text{ }^{\circ}\text{C}$; miscible with water.
Health hazards	Toxic by inhalation and on ingestion which may cause headache, nausea or dizziness or damage the central nervous system especially the optic nerve resulting in temporary or even permanent blindness; prolonged skin contact may cause dermatitis.
Exposure limits	OES (short-term) 250 ppm; OES (long-term) 200 ppm; TLV (TWA) 200 ppm.
Fire hazards	Highly flammable; flashpoint $-16\text{ }^{\circ}\text{C}$; flammable range 7–37%.
Safety precaution	Keep container tightly closed; keep away from ignition sources; avoid breathing vapour and contact with the skin; use in fume cupboard or well-ventilated area; wear rubber or plastic gloves and eye protection.
Incompatible chemicals	Can react vigorously with oxidizers; reactions with magnesium or bromine can be violent and those with sodium hypochlorite, nitric acid, hydrogen peroxide or chloroform with sodium can be explosive.

NAPHTHYLAMINE (alpha and beta)

Physical properties	White to pink crystals; alpha—m.p. $50\text{ }^{\circ}\text{C}$, b.p. $300\text{ }^{\circ}\text{C}$; beta—m.p. $112\text{ }^{\circ}\text{C}$, b.p. $306\text{ }^{\circ}\text{C}$; free base insoluble in water but hydrochloride is water-soluble; unpleasant odour.
Health hazards	Both very toxic by inhalation, ingestion and skin contact; human carcinogen causing bladder cancer; experimental mutagen and teratogen.

Fire hazards	Forms explosive or flammable vapour at elevated temperatures.
Safety precautions	Avoid all exposure; wear suitable protective clothing; use fume cupboard, hood or suitable mechanical exhaust ventilation.
Other hazards	Use is prohibited or legally controlled in many countries.

NINHYDRIN

Physical properties	Supplied in aerosol spray cans as 0.5% solution in butanol; soluble in water
Health hazards	Harmful by ingestion and inhalation; irritating to the eyes, respiratory system and skin.
Fire hazards	Flammable; flashpoint 29 °C.
Safety precautions	Avoid inhalation of the spray or vapour and contact with the eyes; wear rubber or plastic gloves and chemical-grade goggles (unless spraying into an exhaust ventilated cabinet).
Incompatible chemicals	May react with oxidizers.
Other hazards	Contact with the skin produces a persistent violet stain.

NITRIC ACID (50–70%)

Physical properties	Colourless or pale yellow fuming liquid; m.p. -42 °C, b.p. 86 °C; miscible with water.
Health hazards	Corrosive; causes severe burns to eyes and skin; severely irritating and harmful vapour.
Exposure limits	OES (short-term) 4 ppm; OES (long-term) 2 ppm; TLV (TWA) 2 ppm.
Fire hazards	Oxidizer; contact with combustible material may cause fire; evolves toxic fumes in fires.
Safety precautions	Do not breathe vapour; if contact with the eyes rinse immediately and seek medical attention; if contact with the skin wash off immediately; remove contaminated clothing; wear PVC gloves, plastic apron and chemical-grade goggles; use in fume cupboard.
Incompatible chemicals	Reacts violently with many organic compounds, with most metals evolving toxic products, reducing agents and bases.

Other hazards Concentrated nitric acid is involved in more dangerous reactions than any other chemical reagent.

OSMIUM TETROXIDE

Physical properties Pale yellow crystals with characteristic pungent odour; m.p. 40 °C, b.p. 130 °C; high vapour pressure; soluble in water.

Health hazards Very toxic by inhalation, ingestion and skin contact, causing severe burns and irritation; vapour, solid and solutions cause irritation and severe burns to eyes and visual disturbance.

Exposure levels OES (short-term) 0.0006 ppm; OES (long-term) 0.0002 ppm; TLV (short-term) 0.0006 ppm; TLV (TWA) 0.0002 ppm.

Safety precautions Keep container tightly closed and in a well-ventilated place; use solid and solutions in fume cupboard or hood; wear chemical-grade goggles and protective gloves; make up solutions by adding the unopened ampoule to required volume of water, stopper and shake to break ampoule.

OXALIC ACID

Physical properties Colourless crystals; soluble in water; m.p. 186 °C.

Health hazards Harmful if in contact with skin or if ingested; dust irritates respiratory tract and eyes; solutions irritate eyes and may cause skin burns.

Exposure levels OES (short-term) 2 mg/m³; OES (long-term) 1 mg/m³.

Safety precautions Avoid contact with skin and eyes; use normal good laboratory and occupational hygiene practices and wear eye protection and gloves.

Incompatible chemicals Oxidizing agents

PERCHLORIC ACID (60–72%)

Physical properties Colourless liquid; miscible with water.

Health hazards Corrosive; causes severe burns to eyes and skin and if ingested; vapour is irritating and corrosive to eyes and respiratory system.

Fire hazards Powerful oxidizing agent may ignite combustible materials.

Safety precautions	Avoid breathing vapour and other exposure; wear protective clothing including nitrile gloves, eye and face protection; use hot solutions in fume cupboard or hood.
Incompatible chemicals	Combustible materials and reducing agents.
Other hazards	Powerful oxidizing agent; may form explosive products if in contact with many inorganic and organic materials; contaminated wooden floors, benches, etc. may explode on percussion.

PHENOL

Physical properties	Colourless or pale pink crystals with characteristic odour; m.p. 41 °C, b.p. 82 °C; soluble in water.
Health hazards	Toxic by ingestion, inhalation and skin contact; causes severe burns; vapour irritates the eyes and respiratory tract; rapidly absorbed through the skin; inhalation over a long period may cause digestive disturbances, skin eruptions and kidney and liver damage; prolonged contact with dilute solutions may cause dermatitis.
Exposure limits	OES (short-term) 10 ppm; OES (long-term) 5 ppm; TLV (TWA) 5 ppm.
Fire hazards	Flashpoint 80 °C; flammable range 1.7–6%.
Safety precautions	Do not breathe vapour; avoid eye and skin contact; use in fume cupboard; wear nitrile gloves and eye protection; if contact with the eyes rinse immediately with water and seek medical advice; if contact with the skin swab the contaminated area with glycerol, polyethylene glycol 300 or a mixture of liquid polyethylene glycol (70%) and methylated spirit (30%) and then flush with water; remove any contaminated clothing.
Incompatible chemicals	Can react vigorously with oxidizers.

PHOSPHORIC ACID

Physical properties	Colourless viscous liquid or moist white crystals; m.p. 42 °C, b.p. 130 °C; soluble in water.
Health hazards	Corrosive; causes burns to the skin and eyes.
Exposure limits	TLV (TWA) 1 mg/m ³ .
Fire hazards	Flammable gas evolved in contact with metals; evolves toxic fumes when heated in fires.
Safety precautions	If in contact with the eyes rinse with water and obtain medical advice; wear nitrile gloves and eye protection.

PICRIC ACID

Physical properties	Yellow crystals moistened with water or dissolved in alcohol; m.p. 122 °C; slightly soluble in water.
Health hazards	Toxic by ingestion; harmful by inhalation or skin contact which if prolonged may result in headache, nausea or skin eruptions; irritating to the eyes.
Exposure limits	OES (short-term) 0.3 mg/m ³ ; OES (long-term) 0.1 mg/m ³ ; TLV (TWA) 0.1 mg/m ³ .
Fire hazards	Explosive when dry.
Safety precautions	Keep moistened with water at all times or use only in alcoholic solution.
Incompatible chemicals	Forms salts with many metals which are more explosive than the acid itself; in contact with concrete may form calcium picrate which is a friction-sensitive explosive; it may react vigorously with reducing agents.

POTASSIUM HYDROXIDE

Physical properties	White flakes, powder, pellets or sticks; m.p. 360 °C, b.p. 1320 °C. Very soluble in water.
Health hazards	Corrosive; severe irritant and causes burns to eyes and skin; inhalation of dust causes extreme irritation to the respiratory system.
Exposure limits	OES (short-term) 2 mg/m ³ ; TLV (ceiling level) 2 mg/m ³ .
Safety precautions	If contact with the eyes immediately rinse with water and seek medical advice; if contact with the skin wash immediately; remove contaminated clothing; wear rubber or plastic gloves and eye protection even for dilute solutions.
Incompatible chemicals	Reacts violently with acids and with nitrobenzene and with many other reagents; evolves large quantity of heat when mixed with water; store in a well sealed container away from water and acids.

POTASSIUM PERMANGANATE

Physical properties	Purple crystals; m.p. 240 °C (decomposes); readily soluble in water.
Health hazards	Harmful if swallowed or if dust is inhaled; extremely irritating to eyes and respiratory tract.
Exposure levels	OES (long-term) 5 mg/m ³ (as Mn).

Fire hazards	Powerful oxidizing agent; may ignite combustible materials.
Safety precautions	Wear protective clothing, eye protection and particulate respirator if dust is produced.
Incompatible chemicals	Reacts violently or explosively if mixed with a wide variety of inorganic and organic compounds; avoid heating with organic material.

POTASSIUM TELLURITE

Physical properties	White deliquescent crystals; very soluble in water.
Health hazards	Toxic by ingestion and inhalation of dust; irritating to skin and eyes.
Exposure levels	OES (long-term) 0.1 mg/m ³ (as Te).
Safety precautions	Wear protective clothing.

PROPAN-2-OL

Physical properties	Colourless liquid with alcoholic odour; m.p. -89 °C, b.p. 82 °C; miscible with water.
Health hazard	Inhalation or ingestion may cause headache, dizziness, nausea, vomiting and coma; may cause severe damage if splashed in the eyes; can be absorbed through the skin.
Exposure limit	OES (short-term) 500 ppm; OES (long-term) 400 ppm.
Fire hazards	Highly flammable; flashpoint 12 °C; flammable range 2.3–12.7%.
Safety precautions	Keep container tightly closed; keep away from ignition sources; use in fume cupboard; wear nitrile gloves and eye protection.
Incompatible chemicals	Can react vigorously with oxidizers to form unstable peroxides on prolonged exposure to air and light.
Other hazards	70–85% propan-2-ol in water used as a disinfectant spray remains a flammable hazard and should not be used near ignition sources.

SILVER NITRATE

Physical properties	White crystals; m.p. 212 °C, b.p. 444 °C; soluble in water.
Health hazards	Severe irritant and may cause burns to the eyes and skin; harmful by ingestion; prolonged exposure may result in a bluish discolouration of the skin.
Exposure limits	OES (long-term) 0.01 mg/m ³ ; TLV (TWA) 0.01 mg/m ³ .
Fire hazards	May ignite combustible material.
Safety precautions	If contact with the eyes rinse with water and seek medical advice; wear rubber or plastic gloves.
Incompatible chemicals	Ammoniacal solutions can precipitate explosive silver nitride in the presence of base or glucose; can form explosive products with ethanol and may cause explosive polymerization with acrylonitrile; may cause ignition or explosion if mixed with charcoal, magnesium, phosphorus or sulphur.

SODIUM AZIDE

Physical properties	Colourless crystalline solid; m.p. 300 °C; soluble in water.
Health hazards	Very toxic by ingestion, inhalation and skin contact; may cause burns; dust and solution irritate the eyes and skin; mutagen.
Exposure limits	OES (short-term) 0.3 mg/m ³ ; TLV (ceiling value) 0.1 mg/m ³ .
Fire hazards	Decomposes explosively when heated above its melting point; evolves toxic fumes when heated; do not use water to extinguish fires.
Safety precautions	If contact with the skin wash immediately; do not inhale dust; wear rubber or plastic gloves and eye protection.
Incompatible chemicals	Explosive reactions with bromine, carbon disulphide or chromyl chloride; violent reaction if water is added to heated incompatible chemicals; solid reacts with heavy metals including copper, lead and mercury to form explosive metal azide salts; contact with acid evolves highly toxic gas.
Other hazards	Do not discharge into copper or lead pipe drainage systems.

SODIUM BIASELENITE

Physical properties	Colourless, white crystalline powder; soluble in water.
Health hazards	Toxic by ingestion and inhalation of dust; possible danger of cumulative effects; experimental teratogen; prolonged skin contact may cause dermatitis.
Exposure levels	OES (long-term) 0.1 mg/m ³ (as Se); TLV (TWA) 0.2 mg/m ³ (as Se).
Safety precautions	Wear protective clothing.
Incompatible chemicals	Oxidizing agents.

SODIUM CYANIDE

Physical properties	White crystalline powder with almond odour; m.p. 563 °C, b.p. 1496 °C; very soluble in water.
Health hazards	Extremely toxic by ingestion, inhalation and skin contact; irritating to the eyes.
Exposure limits	OES (long-term) 5 mg/m ³ ; TLV (TWA) 5 mg/m ³ .
Fire hazards	May evolve toxic fumes in fire.
Safety precautions	Do not inhale dust; avoid eye and skin contact; if contact with the skin wash immediately with water; remove contaminated clothing; wear chemical-grade goggles and rubber or plastic gloves; keep in a securely locked store.
Incompatible chemicals	Liberates extremely toxic hydrogen cyanide (HCN) gas in contact with acids or with water containing dissolved carbon dioxide; can form explosive mixtures with nitrites.
Other hazards	Treat spillage of solutions with bleaching powder (sodium hypochlorite) and leave for 24 hours; sweep up solid spills carefully and add to water containing bleaching powder; leave for 24 hours before discarding; keep cyanide antidote kit available in the laboratory; use amyl nitrite if the casualty is conscious and Kelocyanor injections if unconscious; if breathing has stopped apply artificial respiration (use one-way valve mask).

SODIUM HYDROXIDE

Physical properties	Colourless, flakes, powder, pellets or sticks; m.p. 318 °C, b.p. 1390 °C; soluble in water.
Health hazards	Solid and concentrated solutions (5%) are corrosive and

	cause burns or severe irritation to the eyes and skin; inhalation of dust causes damage or irritation to the respiratory tract; ingestion causes severe internal damage and irritation; dilute solutions (%) are irritating to the eyes or may cause severe damage if eye contact is prolonged.
Exposure levels	OES (short term) 2 mg/m ³ ; TLV (ceiling value) 2 mg/m ³ .
Safety precautions	If contact with the eyes rinse immediately and seek medical advice; if contact with the skin wash immediately with water; remove contaminated clothing; wear rubber or plastic gloves and eye protection even with diluted solutions.
Incompatible chemicals	Evolves large quantity of heat when mixed with water; reacts vigorously with chloroform-methanol mixtures and with strong acids.
Other hazards	Store in a well sealed container in a dry place.

SODIUM HYPOCHLORITE SOLUTION (10–14% available chlorine)

Physical properties	Colourless or pale yellow solution with chlorine odour; miscible with water.
Health hazards	Causes burns to eyes and skin; toxic by ingestion and inhalation.
Fire hazards	May evolve toxic fumes in fire.
Safety precautions	If contact with eyes rinse immediately with water and seek medical advice; if contact with the skin wash immediately do not inhale vapour; use in well-ventilated area; wear rubber or plastic gloves and chemical-grade eye protection.
Incompatible chemicals	Liberates highly toxic gas in contact with acids; can react vigorously with oxidizers; may react with nitrogen compounds to form explosive N-chloro-compounds; may react violently with methanol.
Other hazards	Gradually loses chlorine during storage; dilute solutions, used as disinfectant rapidly deteriorate; store away from acids in a cool well-ventilated area.

SULPHURIC ACID

Physical properties	Colourless, odourless viscous liquid; miscible with water.
Health hazards	Concentrated solution (15%) corrosive causes severe

	burns; mist and vapour highly toxic by inhalation; dilute solutions (%) irritating to eyes and skin; may cause burns and dermatitis.
Exposure limits	OES (long-term) 1 mg/m ³ ; TLV (TWA) 1 mg/m ³ .
Fire hazards	May evolve toxic fumes in fire.
Safety precautions	If in contact with eyes rinse immediately and seek medical advice; if in contact with the skin wash immediately; remove contaminated clothing; wear nitrile gloves and eye protection.
Incompatible chemicals	Is a powerful oxidizing desiccant and reacts vigorously with many reagents including organic nitro compounds, potassium permanganate, alkali metals and perchlorates.
Other hazards	Localized boiling may occur if concentrated acid is added to water.

THALLIUM ACETATE

Physical properties	White deliquescent crystals; m.p. 110 °C; very soluble in water.
Health hazards	Extremely toxic by ingestion with possible cumulative effects; affects nervous and cardiovascular systems; harmful through eye and skin contact.
Exposure levels	OES (long-term) 0.1 mg/m ³ (as Th); TLV (TWA) 0.1 mg/m ³ (as Th).
Safety precautions	Keep container tightly closed; use solid in fume cupboard, hood or mechanical exhaust ventilation system; wear protective clothing including dust respirator, chemical-grade goggles and rubber or plastic gloves; wear gloves and eye protection when handling solutions.

o-TOLIDINE

Physical properties	Colourless crystals; m.p. 186 °C; soluble in water
Health hazards	Harmful if in contact with skin or if ingested; dust irritates respiratory tract and eyes; solutions irritate eyes and may cause skin burns.
Exposure levels	OES (short-term) 2 mg/m ³ ; OES (long-term) 1 mg/m ³ .
Safety precautions	Avoid contact with skin and eyes; wear eye protection and gloves.
Incompatible chemicals	Oxidizing agents.

TOLUENE

Physical properties	Colourless liquid with characteristic odour; m.p. -95 °C, b.p. 111 °C; not miscible with water.
Health hazards	Harmful by ingestion, inhalation and skin contact; vapour and liquid irritate the eyes; prolonged skin contact may cause dermatitis.
Exposure limits	OES (short-term) 150 ppm; OES (long-term) 50 ppm; TLV (TWA) 100 ppm.
Fire hazards	Highly flammable; flashpoint 4 °C; flammable range 1.4-7%.
Safety precautions	Keep container tightly closed; keep away from ignition sources; earth (ground) containers to prevent static electrical discharge; do not inhale vapour; use in a fume cupboard or well-ventilated area; wear nitrile gloves.
Incompatible chemicals	Can react with oxidizers.
Other hazards	May contain benzene as impurity and prolonged inhalation of the vapour may cause blood disease.

TRICHLOROACETIC ACID

Physical properties	White hygroscopic crystals with pungent odour; m.p. 58 °C, b.p. 196 °C; very soluble in water.
Health hazards	Corrosive; causes severe burns to eyes and skin; inhalation is extremely destructive to respiratory tract and could be fatal.
Exposure levels	OES (long-term) 5 mg/m ³ ; TLV (TWA) 1 ppm.
Fire hazards	May evolve toxic fumes in fire.
Safety precautions	Avoid contact with the eyes and skin; wear rubber or plastic gloves and chemical-grade goggles; if contact with the eyes rinse immediately and seek medical advice.
Incompatible chemicals	Violent reaction with copper/dimethyl sulphoxide mixtures.
Other hazards	Store in a dry place; concentrated aqueous solutions may decompose violently.

XYLENE (mixed isomers)

Physical properties	Colourless liquid with aromatic odour; m.p. -30 °C, b.p. 140 °C; not miscible with water.
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Health hazards	Harmful by inhalation and skin contact; liquid and vapour irritate the eyes, mucous membranes and skin; prolonged skin contact may cause dermatitis.
Exposure levels	OES (short-term) 150 ppm; OES (long-term) 100 ppm; TLV (TWA) 100 ppm.
Fire hazards	Flammable; flashpoint 25 °C; flammable range 1–7%.
Safety precautions	Avoid contact with the eyes; wear nitrile gloves and eye protection; keep container tightly closed; keep away from ignition sources.
Other hazards	May contain benzene as impurity and prolonged inhalation of the vapour may cause blood disease.

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