

6 LABORATORY FURNITURE

6.1 Introduction

Laboratory furniture is the interface between the user and the building.

When planning laboratory layouts it is important to keep the future in mind. The laboratory must be capable of responding to continual changes in user requirements in terms of the building, the laboratory space and, (arguably) most importantly, the laboratory furniture itself. The furniture must satisfy both the present user needs and meet future (often unknown and ever-changing) user requirements through adaptability.

'Laboratory furniture' can be defined to include: worksurfaces (*ie* benching), storage (*ie* shelves, cupboards, *etc*), specialist furniture systems (incorporating benching, storage, bench services), seating, boards (*ie* markerboards), balance tables *etc*.

In terms of capital expenditure, the laboratory furniture 'fit-out' (*ie* the supply, installation and commissioning of laboratory furniture and integrated services) can easily account for 10-15% of the total cost of a new laboratory. Therefore it is imperative that the selection of laboratory furniture, and its incorporation into the 'new' laboratory, are given the consideration they deserve. The intention of this chapter is to provide a preliminary guide to the laboratory designer; it is not the intention to provide a definitive guide to available laboratory furniture systems on the market.

It is (comparatively) recently that laboratory furniture has moved away from the once familiar, one-off solid teak installations. Laboratory furniture design has now evolved into fully integrated total 'Laboratory Furniture Systems' which can provide not only benching, but co-ordinated fume cupboards, storage, internal room dividers or screens and fully integrated partitioning.

Based on *modular construction principles*, these furniture 'systems' based originally on the evolving requirements of research and development offer a vast selection of standard components and fittings that can be combined to produce 'tailor-made' packages (including those with fully integrated services distribution). These packages are specifically designed to meet the needs of individual clients, and because, they are based on multicomponent or modular construction principles, future changes to benches can be undertaken at minimal inconvenience (and cost) to the user, often being carried out by the laboratory staff themselves.

Today's trend towards single, large, multi-use laboratories usually embraces areas or individual benches that are now normally classified as *wet*, *dry* or *instrument*. These classifications refer to the types of service provision to be provided to the laboratory space or bench. The level of servicing depends upon the level of work or studies to be undertaken, (*eg* routine, teaching, research *etc*). A strong emphasis is also placed on the standard of cleanliness required (*materials and construction detailing*). These requirements have now generally replaced the earlier concept of separate *chemical*, *biological* and *physical laboratories*.

Laboratory furniture layouts are governed not only by the proposed activities which are to be undertaken within the laboratory but also by the space (rooms) into which they are to be installed, and by the locations of incoming 'feeder' services which service the individual benches.

The design of the laboratory layouts within existing buildings (*ie* refurbishment) is often restricted by existing laboratory spaces and the location and number of incoming service feeder connections, particularly in older laboratory buildings. In any refurbishment exercise it would be prudent to reassess the existing service distribution and, if need be, re-position or add additional feeder service connections in order to maximise benching flexibility and adaptability in a 'fixed' laboratory space.

When designing laboratory layouts for new buildings, however, there should be no such limitations, provided that the laboratory layout requirements are addressed at a very early stage in the building design. If this is successfully achieved, the building can (and should) be designed around the needs of the laboratory layout and the associated service requirements.

In determining the final and most suitable laboratory furniture system and layout, to satisfy fully the user's present (and future) requirements, the following key decisions have to be taken by the Client and Design Team:

- (a) bench layouts;
- (b) bench services distribution;
- (c) under-bench storage and structure;
- (d) benchtop.

The design of laboratory furniture is governed by the size and proportion of the human body. Section 6.8, Ergonomics, at the end of this chapter looks at the basic ergonomic requirements of modern laboratory furniture.

6.2 Bench layouts

The basic requirement for any laboratory furniture layout is to satisfy the needs of the user. It must be carefully considered and agreed by the Client and the Design Team at an early stage in the evolution of any new laboratory (whether new-build or refurbishment).

The arrangement of furniture within the laboratory is related closely to issues of safety, and in part to human physique (Section 6.8). It is essential to provide adequate access to and separation between benches, equipment, and other furniture and apparatus. Work places and circulation areas in large laboratories should be separated to reduce risk of accidents and allow staff unobstructed, emergency egress. Because of the close relationship between benches and feeder services connected to those benches, it is essential that layouts and, in particular, spaces between individual benches are carefully considered. Every laboratory layout must maintain the requirements of published guidelines and safety standards.¹

The placing of individual benches within the 'global' laboratory layout gives rise to 3 generic styles of benching (Fig.6.1):

- (a) wall-related;
- (b) peninsular;
- (c) island.

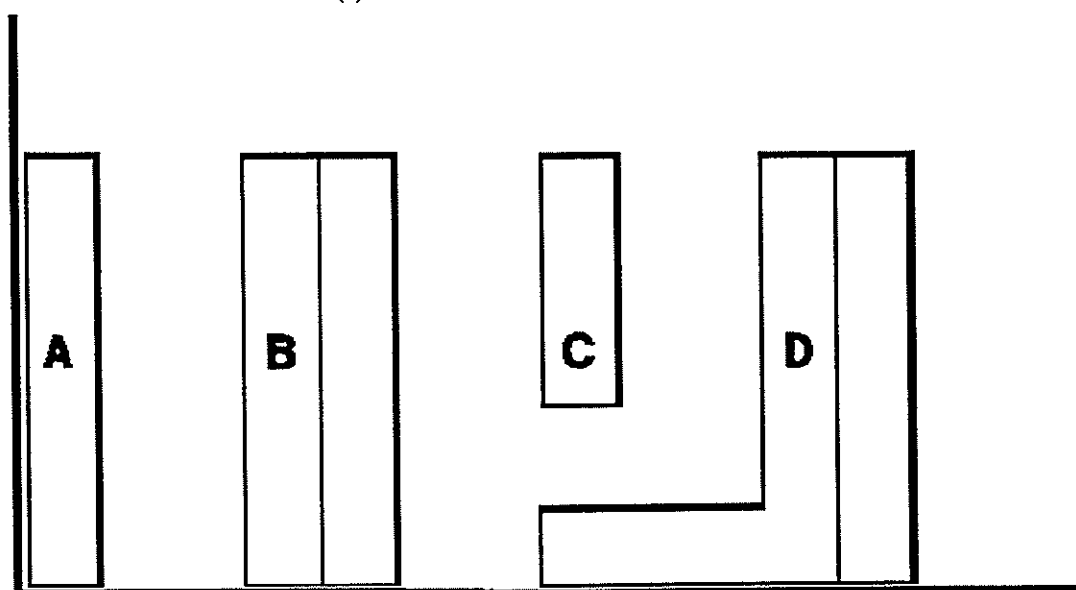


Fig.6.1: Laboratory bench configurations
A = wall-related; B = peninsular;
C = island; D = combined wall and peninsular.

Depending on the individual bench configuration adopted, specific decisions relating directly to these generic forms have to be considered.

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6.2.1 Wall-related

These are the simplest of all bench arrangements. If suitable, the wall can be used to support the bench, high- and low-level service runs, shelving and cupboards above the worktop. Whilst this reduces the amount of bench structure (and potentially overall bench cost) it limits the extent to which the bench can be modified or adapted in the future (see Fig.6.4). For example, if shelving is fixed directly to the wall, its relocation due to the requirements of a 'new' user would require repositioning fixings to walls, (and possible noise and dust) resulting in disruption to the work of the laboratory. Similarly, if the bench was required to be relocated away from the wall in any future remodelling of the laboratory, the support for the rear of the bench and any above worktop fixtures, could be lost.

These potential problems and restrictions on future laboratory flexibility and adaptability are overcome if a self-supporting bench system is used, which includes an integrated structure for over-bench shelving and fixtures.

One particular advantage of locating a bench against a parallel wall face is the potential for incoming and outgoing feeder services to the bench to be located at any point along the length of that bench. The wall which the bench abuts should ideally be flat with no projections. With some buildings, however, columns may project either on one, or both faces of the wall. This requires special consideration to avoid over-complicated bench and service arrangements around the columns: the bench should run past the front face of the columns. Depending upon the use of the laboratory, the void behind the bench (between columns) may need to be 'closed off', although this may increase costs. This void could be used to advantage, especially if feeder services are dropping to the bench from ceiling level. By positioning the service within the void behind the bench, the need to pass services through the bench worktop is avoided (Fig.6.2).

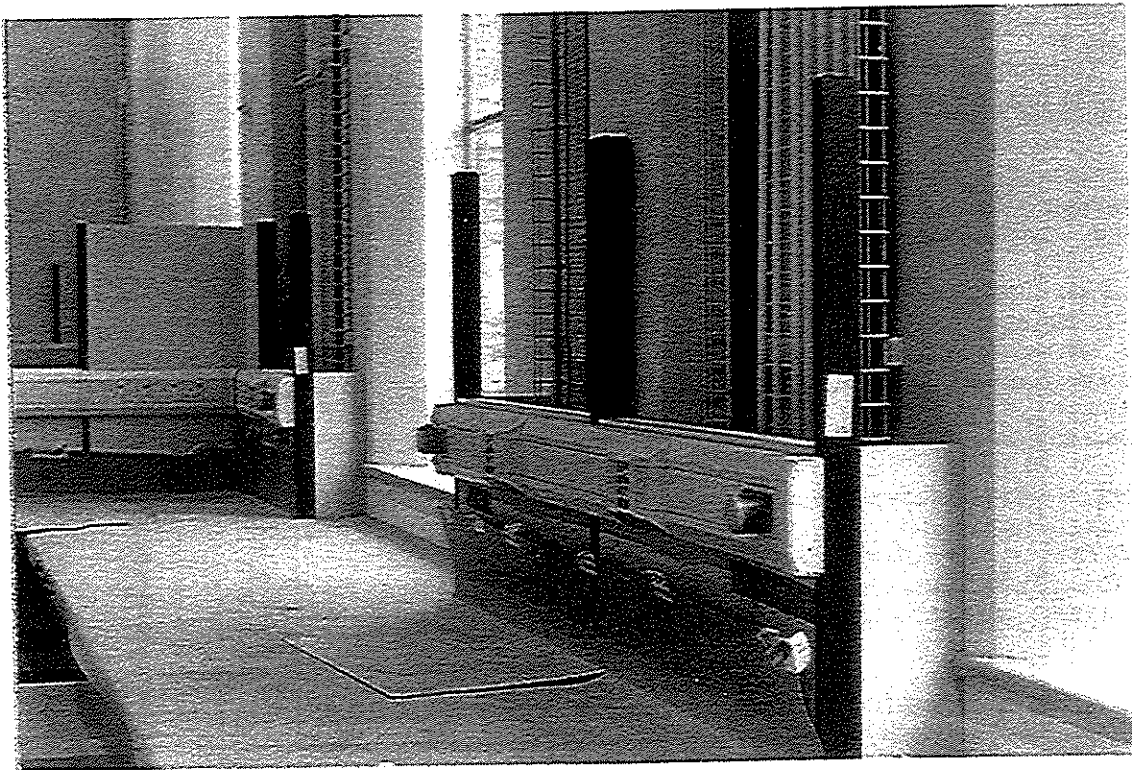


Fig.6.2: Bench feeder services 'dropping down' within void, between columns at rear of wall bench.
(*Photograph of bench installation in progress at new laboratories for the Health and Safety Executive at Sheffield. Designed by PSA Projects.*)

6.2.2 Peninsular

This configuration lends itself to running two benches back-to-back, utilising a single, central bench service spine to feed both worktops, thus reducing service runs and floor areas (Section 6.3). If

used in conjunction with a below worktop bench service distribution system, a clear, double width worktop can be provided. However, the extent to which the bench is in contact with the wall may limit the point of incoming service connections to feed the bench and outgoing waste runs to one location.

Depending upon the bench system chosen, central support uprights to the bench could also be used in combination with solid or translucent panels to provide screens to subdivide work areas within a single large laboratory area (see Fig.6.12).

6.2.3 Island

With the advent of large open-plan laboratory spaces, island benches are becoming commonplace in order to optimise the use of available space. Island benches can be arranged singly or back-to-back. As their name suggests, island benches are divorced from surrounding walls. Incoming feeder services generally enter the bench via overhead distribution, with vertical (flexible) droppers to the bench itself (see Fig.6.5). To avoid unnecessarily long flexible connections, which could present an untidy and unsatisfactory appearance and a potential hazard, incoming feeder service connections to island benches need careful consideration.

Based on modular construction principles, modern laboratory furniture offers a vast selection of standard components and fittings which can be combined to produce benches tailor-made to meet virtually any requirements. In planning a new laboratory it is beneficial to coordinate the furniture it contains with the enclosing structure. Many of the modular bench systems on the market are based on a module dimension size of 300 mm, ie underbench units or bench support structure are provided in increments of 300 mm, ie 600 mm, 900 mm, 1200 mm, 1500 mm etc. For convenience and cost, it is prudent to have overall bench lengths as multiples of these dimensions.

The laboratory building itself will have a similar preferred dimension planning grid and, particularly if a framed building, will also have a preferred structural grid, which is usually deemed to be 3600 mm. It is convenient to match the module of the furniture and that of the building together, particularly when planning bench layouts and bench service feeder locations (Fig.6.3). A 3600 mm module of the building structure not only meets the requirement of adjacent bench separation,¹ but also relates to the recommendations governing the shape and dimensions of area-based modular laboratories (Chapter 4).

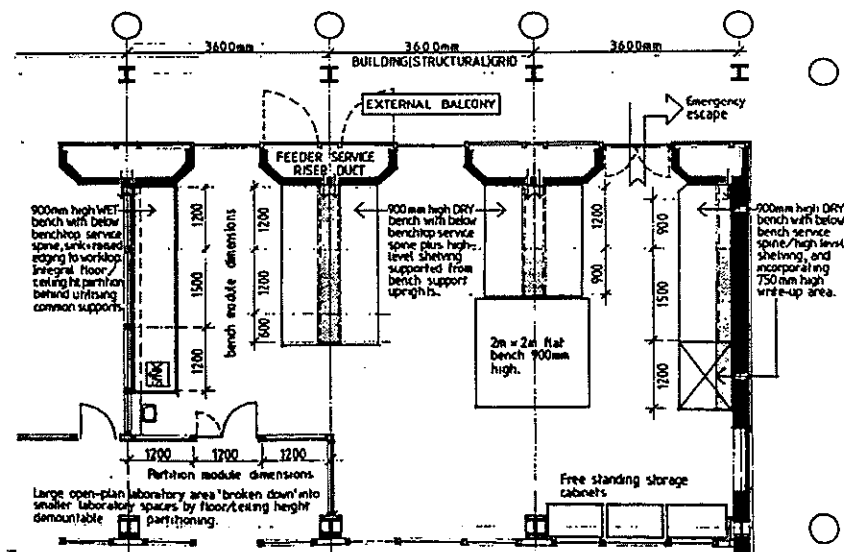


Fig.6.3: Relationship of bench layouts to building structure.
(Part Laboratory floor plan for the new laboratories
for the Health and Safety Executive at Sheffield.
Designed by PSA Projects).

Some bench systems have taken the principles of modular construction a stage further. By utilising and modifying their standard bench structural components, they are able to offer a complete package of fully integrated screens and full height partitions. Because they are formed using coordinated modular

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components, they are fully demountable and capable of being relocated elsewhere within the laboratory. The use of this facility can range from screens to demarcate a specific working area within an open plan laboratory, (*ie* translucent panels placed between vertical bench structures above the worktop), to a fully sealed, floor-to-ceiling partition enclosing specific specialist environments (*eg* for microbiology and for carcinogen-handling areas).

The final arrangement of any furniture layout within any laboratory is therefore governed by the following factors:

- (a) the work that is to be carried out within that laboratory;
- (b) the way in which the furniture and laboratory environment are to be used by the laboratory staff (ergonomics);
- (c) the requirements of (future) flexibility and adaptability;
- (d) the distribution of incoming and outgoing feeder services to and from the benches and equipment that require servicing;
- (e) the use of a preferred modular grid (for both furniture and building);
- (f) The requirement for the subdivision of single much larger laboratory spaces;
- (g) The requirements for fast and safe emergency egress.

6.3 Bench service distribution

A major factor in the success of any laboratory building is the distribution of services around the building and especially within the laboratory, *ie* the locations of service 'feeder' connections to which the laboratory benching and equipment are connected.

There are various forms that such service distribution around the laboratory can take; these are discussed more fully in Chapter 5, Building Services, but they can be defined briefly as:

- (a) within vertical service risers located either within or around laboratory spaces (permitting also service distribution between different floor levels);
- (b) at high level within ceiling voids or below ceiling in 'service booms', both of which require vertical service 'droppers' to feed services directly to the bench and equipment;
- (c) below floor level, with outlets located at pre-determined positions within the floor;
- (d) around the perimeter of laboratories, as horizontal service runs fixed to the perimeter walls.

The method of service distribution around the building is another issue which should be resolved early on in the development of any 'new' laboratory by the Design Team and Client as it clearly affects the layout and structure of the building. Equally, it is important to determine the location, distribution and number of bench and equipment service feeder outlets within the 'new' laboratory.

The latter requirement depends on a clear, early understanding of the required laboratory layouts and of the type of furniture 'system' to be employed. At this stage, it is prudent to consider providing 'additional' service feeder outlets which, although they may not be required initially, would provide options for future laboratory layouts.

Once a bench is connected to the service 'feeder' outlet, the incoming (and outgoing) services have to be distributed locally along the length (or part length) of that bench.² The majority of bench systems on the market treat bench service distribution as an integral part of their overall concept.

The most commonly used formats for integral bench service distribution are:

- (a) wall-mounted services;
- (b) table-top services;
- (c) service pedestals or media modules;
- (d) service spines (either above and/or below the worktop).

6.3.1 Wall-mounted services

Wall-mounted services are run around the laboratory utilising the perimeter walls for support (Fig.6.4). The service runs can be located either above or below worktop height and the number and position of outlets can be varied, being located either directly on the wall or the bench worktop.

This system is probably the most cost-effective, although it only allows servicing of a bench or a piece of equipment that is located adjacent to the wall on which the services run. Whilst this arrange-

ment allows flexibility in the number of service outlets provided, it does rely on the wall for support, and therefore suffers from restrictions in terms of furniture layout flexibility (Section 6.2).

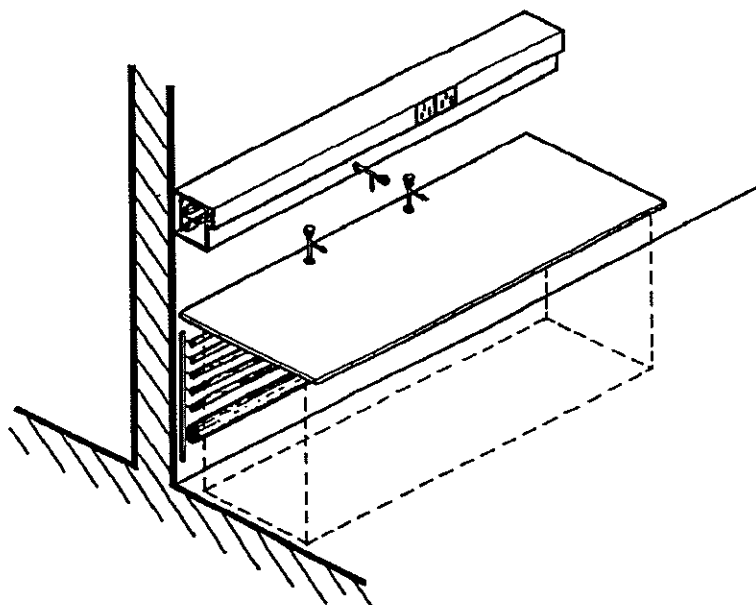


Fig.6.4: Wall-mounted services.

6.3.2 Table-top services

These service outlets are either located on the bench worktop or on a vertical service column (Fig.6.5). The services are supplied to the bench *via* a series of flexible pipes and hoses which, whilst giving a degree of flexibility in the positioning of the benches and equipment being served, result in an untidy and 'cluttered' appearance to the laboratory.

If service booms were used as the only method of servicing the benches, it would be necessary to install a large number in order to provide the greatest potential for future laboratory layout flexibility. Access to the booms is required if there is to be any future alterations to the service being provided and because they are located at or just below ceiling level, could prove a hindrance to maintaining the usability of the laboratory whilst such work is in progress.

6.3.3 Service pedestal or media module

Service pedestals or media modules provide a concentration of services at a defined location (usually island position) within the laboratory and are usually fed by services from either above or below (Fig.6.6).

The main advantage of these 'service stations' is that they can be used in conjunction with movable benching and tables or equipment which can be easily rearranged depending upon the requirements of the laboratory at that time. However, because these 'service stations' are relatively compact in nature, the number of different services or amount of individual service outlets they provide can be strictly limited.

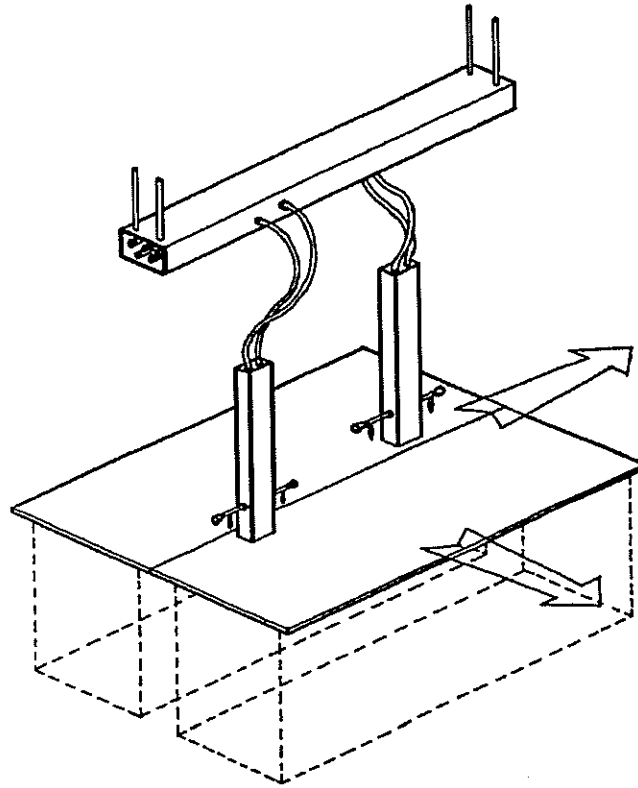


Fig.6.5: Table-top and service column services.

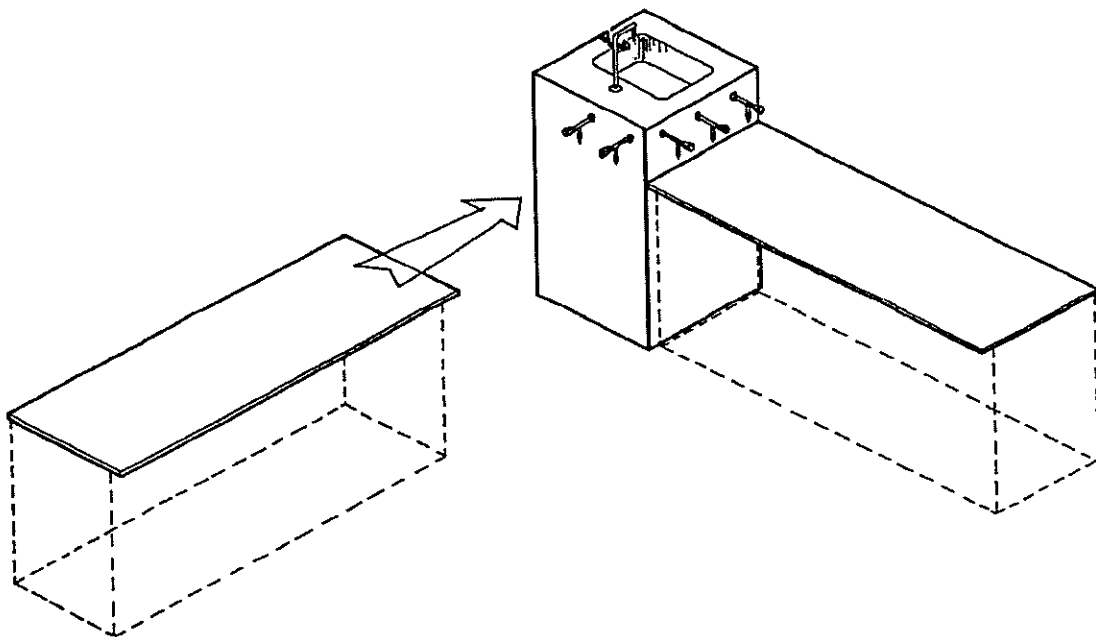


Fig.6.6: Service pedestal.

6.3.4 Service spines

There are two commonly used formats, either above bench worktop level or below. Some systems can offer a combination of above and below benchtop services, particularly to separate wet services and electrical services. The advantage of service spines when used either singly, or linked to form a continuous linear service run, is that they provide a high degree of flexibility and adaptability in the numbers and locations of services (and associated outlets), and that all services are easily accessible for future maintenance and/or adaptability.

(a) Above bench worktop

With this arrangement, the services are located within a casing above the bench worktop. The service outlets (taps, sockets *etc*) can be positioned either on the front or the underside of the service casing (Fig.6.7). Additional service runs may be required below bench level to either 'feed in' incoming services or to run wastes from sinks, drip cups *etc* incorporated into the bench.

The above-bench service casing provides a 'ready-made' shelf unit although at a fixed height for storage. However, the service casing can restrict the use of the bench by reducing the clear, usable depth of the actual worktop itself.

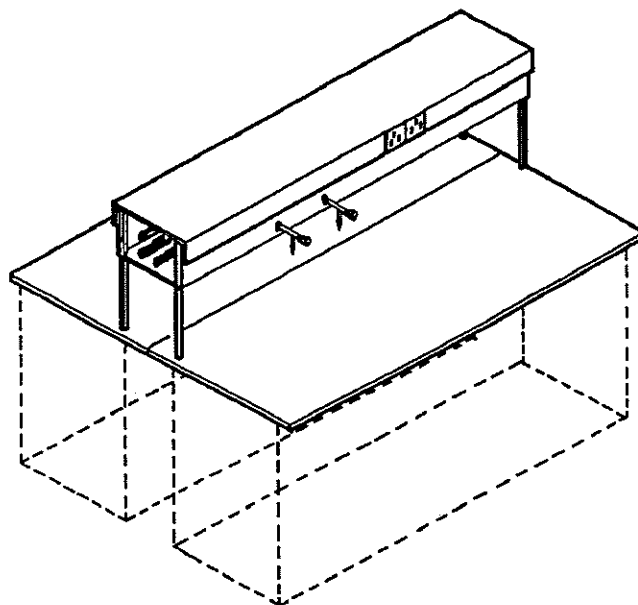


Fig.6.7: Above-bench service spine.

(b) Below bench worktop

All services and wastes are distributed along the bench below the worktop in a 'service zone' either at the rear of the bench or immediately under the worktop (Fig.6.8).

Service outlets to the bench can be located either directly on to the bench worktop, or *via* extended pipework to outlets mounted on a vertical fascia behind the worktop (see also Fig.6.12). Service distribution below bench worktop allows for the full depth of the worktop to be used without restriction, and overcomes potential problems with above bench service runs passing in front of windows when the bench is positioned adjacent to a laboratory perimeter wall.

With the many and varied servicing requirements of the modern laboratory, it is not uncommon for differing bench service distribution systems to be used within the same laboratory environment.

Depending upon the service distribution chosen, the form of under-bench structure also requires consideration, particularly in relation to the requirements for the use of the potentially large volume of space that exists below the bench worktop.

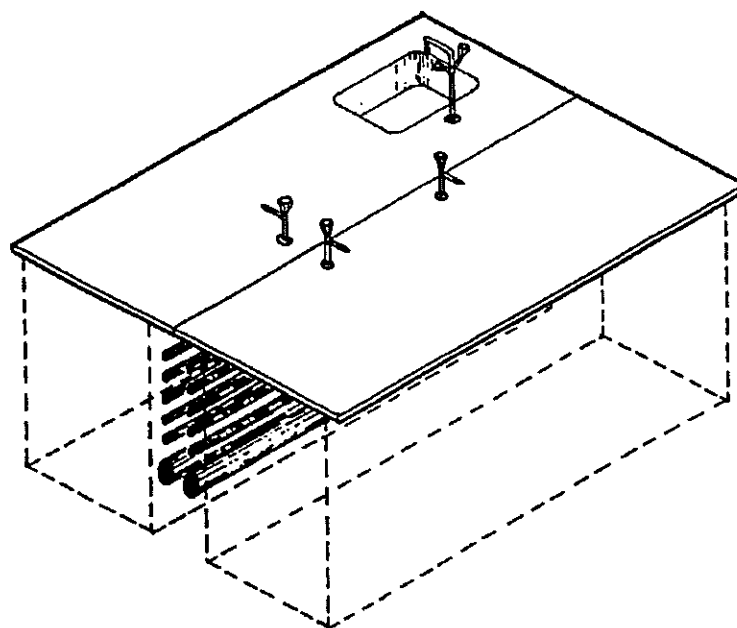


Fig.6.8: Below-bench service spine.

6.4 Under-bench storage and structure

In any laboratory, there is a vast amount of potentially usable space below the benchtops which is traditionally given over to storage in the form of cupboards or drawers between the required knee hole positions. Closely related to this is the bench support structure, the main task of which is to provide a rigid, stable support for the chosen worktop, at the required height.

In general, there are 3 main forms this storage and bench support requirement can take:

- (a) *pedestal units*: (fixed) supporting the worktop directly;
- (b) *suspended units*: (relocatable) hung off the worktop support structure;
- (c) *roller-mounted units*: (fully movable) floor-mounted and therefore independent from the worktop support structure.

6.4.1 Pedestal units

The floor-mounted pedestal storage units are used directly to support the chosen worktop, thus eliminating the need for a separate support system (Fig.6.9).

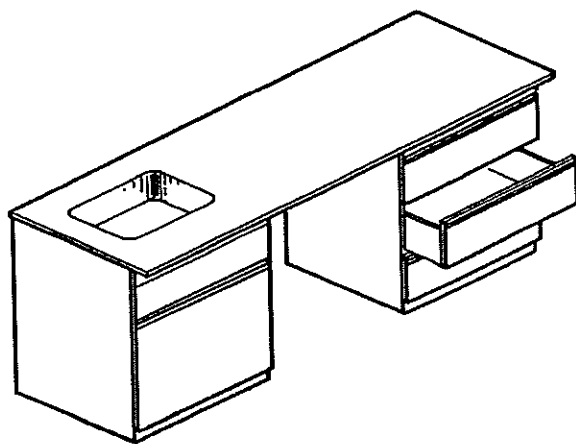


Fig.6.9: Pedestal units.

The use of pedestal units does not easily allow future changing or repositioning of the underbench units relative to the worktop, and can restrict access to any underbench service runs.

As a direct result of the problems encountered with the traditional arrangement of fixed pedestal units, various systems of laboratory benching are now available that have addressed these issues. Manufacturers now offer ranges of furniture which not only provide easily movable or interchangeable underbench storage units, but also separate the underbench units from the floor, thus assisting cleaning and making more accessible underbench service runs.

6.4.2 Suspended units

This arrangement requires a support frame work for the worktop, which also supports the suspended underbench storage units (Fig.6.10). The units can be relocated under a bench or changed for different types. Because the units are raised above the floor, and are movable, usually laterally along the length of the bench, a certain amount of access can be gained for cleaning and service maintenance.

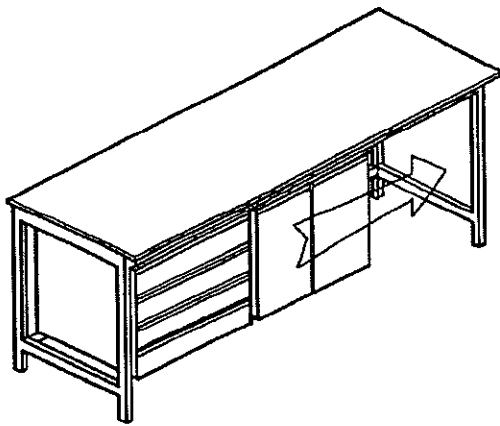


Fig.6.10: Suspended units with 'table' support framework.

6.4.3 Roller-mounted units

Again a separate support frame work for the worktop is required. The storage units are mounted on rollers or casters which, because they are totally independent of the bench, provide true flexibility in terms of repositioning, interchangeability and gaining access to under-bench services and for cleaning (Fig.6.11). In the interests of safety, all units should be fitted with lockable rollers or casters to prevent the units being moved accidentally.

These roller-mounted units can, if fitted with a suitable top, be used as additional work surfaces. The user can pull these units out from under the bench adjacent to a work station, and use them to provide additional support for equipment and books.

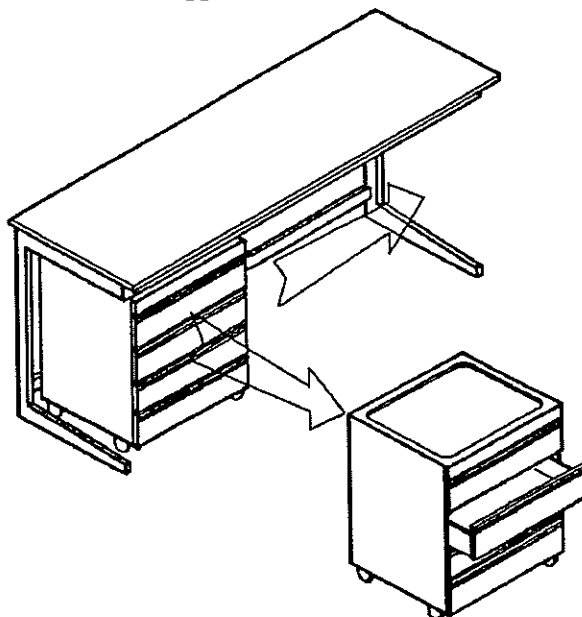


Fig.6.11: Roller-mounted units with 'C'-frame supports.

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The modern 'flexible' underbench storage systems offered by many of today's furniture manufacturers are only made possible by the types of benchtop support structures now being used on many of the bench systems.

Traditionally, the pedestal unit supported the worktop, and many of the more flexible systems now available still offer this option, particularly at sink locations, where the sink bowl projects below the underside of the worktop.

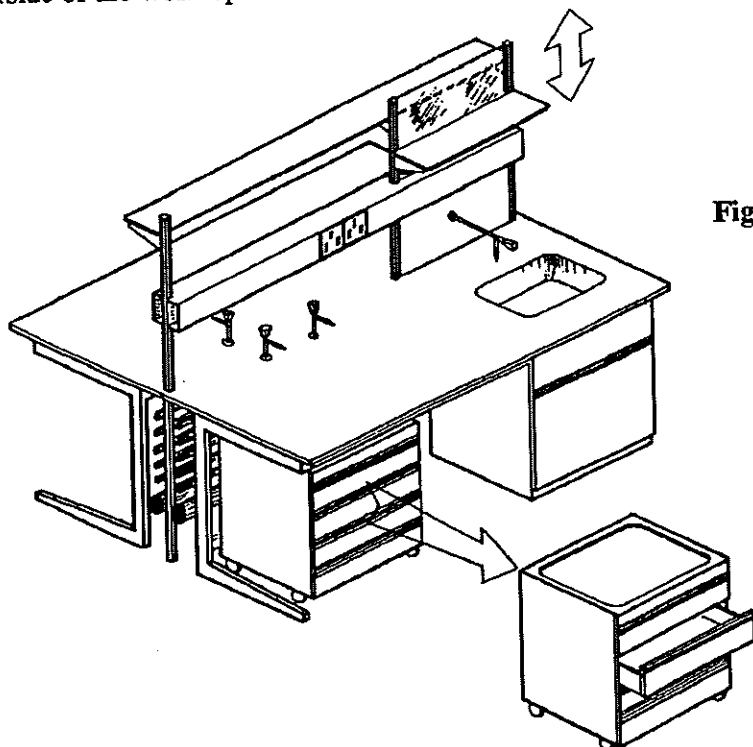


Fig.6.12: Combined above- and below-bench service spines, 'C'-frame bench support structure, pedestal and roller-mounted underbench units.

Many of the modern furniture systems provide benchtops supported on legs at regular intervals, both at the front and back of the bench, or by a cantilevered 'C' frame system (both of which should have height-adjustable feet to allow levelling of the bench during installation). Whilst both systems in conjunction with movable storage units allow greater use of the available volume below the bench, the 'C' frame system in combination with the roller or caster-mounted underbench units provides perhaps the greater flexibility (Fig.6.12). With the 'C' frame, underbench units can be positioned anywhere below the bench and, because there are no front legs, the position of knee holes is unrestricted.

The growing complexity of experimental work has made storage within the laboratory a major problem (see also Chapter 8). A great variety of equipment, apparatus and chemicals must have adequate and appropriate storage facilities provided, and to a large extent, underbench storage fulfils this task.

Many manufacturers offer modular storage systems, whereby drawers, containers, racks and other storage facilities are readily interchangeable between the various storage units, be they under-bench units, floor-mounted free standing cabinets or units hung off walls.

Safety and cleanability are important factors when considering storage provisions. For example, on drawers and cupboards below the bench, the use and type of handles should be carefully considered. Any handles that project are vulnerable to damage and may also be a danger to the legs of the users of the bench. There are many recessed types of handle or finger pull available, but consideration to the cleaning of these items (usually in the form of a rebate) is required.

The cleanability of the inside of drawers and cupboards may also be of importance to the user. Some manufacturers offer rounded internal corners to cupboards and drawers thus eliminating the square corners considered by many to be dirt traps.

Materials used to construct storage units should be carefully considered. Some specific storage requirements dictate specific materials (eg acids and solvents) but generally a strong, damage-resistant

material, capable of being washed down should be used for bench and unit carcassing, particularly as underbench units are vulnerable to kicking and damage by trolleys.³ Plastic laminate faced chipboard, for example, is particularly good for this purpose, being both cost-effective and aesthetically pleasing.

The main function of the structure below the bench, be it pedestal units, legs or 'C' frames is to give adequate support to the worktop. (Any unusual loading requirements for the bench should be identified early). Traditionally the worktop is the place where the majority of laboratory work is carried out; it is therefore the materials used in its construction that require the most consideration. It is the worktop that concludes this preliminary guide to some of the important decisions that have to be considered when determining the requirements for any 'new' laboratory furniture fit out.

6.5 Bench top

The choice of materials used for the construction of the laboratory bench worktop is arguably the most important decision when establishing laboratory furniture requirements.

The basic requirements for all materials used in the laboratory environment are 'cleanability', resistance to damage and aesthetics. For bench worktops, the requirements may be far more specific, depending upon the type of work to be undertaken on the bench. The material has to suit the conditions to which it will be exposed. Consideration has to be given to the properties of the material, in terms of chemical resistance, physical characteristics (thermal expansion, conductivity *etc*), light reflectance and mechanical properties (impact strength, surface hardness *etc*).

In determining the users requirements, early consideration must be given to the worktop, as depending on the material to be used, it could account for the single most expensive item within the overall laboratory furniture budget. If an inappropriate material is chosen, the ultimate success of any new (or refurbished) laboratory could be jeopardised. Plastic laminate faced chipboard, for example, may be a cost-effective and a suitable material for the worktop of instrument benches, but it would not be suitable for areas where chemicals are to be used regularly.

Many laboratory furniture manufacturers offer a wide range of different benchtop materials to suit the different laboratory environments and (likely) bench requirements. What is of importance is for the requirements of the laboratory to be determined early so that the right material can be chosen and, if necessary, budgeted for, in the discussions between the Client and the Design Team. It is not the intention to discuss here the individual benchtop materials available and their specific properties and characteristics; for this expert advice should be sought. It is, however, necessary within the scope of this chapter to consider the benchtop with regards to safety, as it is on the bench worktop, that the majority of laboratory work is undertaken, which invariably involves the use of potentially dangerous chemicals, including solvents and acids.

Accidental spillage of chemicals, (acids *etc*) is probably the most likely form of accident to occur in the close environment of the laboratory worktop. It is therefore important that the materials chosen withstand the effects of regular contact with such substances. Equally important is the containment of any spillage at the point of accident, and not to allow the spilt material to spread to other areas such as floors or walls. (On wet benches, it is good practice to provide both 'jointless' worktops, and splash-backs to protect walls and partitions).

On benches where liquids are to be used, it is prudent to provide a raised edging around the perimeter to the worktop surface to contain any spillage. Many of the benchtop materials likely to be used in combination with liquids can be supplied with an appropriate form of raised perimeter edging.

The form of raised edging should be considered (Fig.6.13). In profile it should have rounded internal corners to aid cleaning, and it should be of such a height as to contain any spilt liquid, but not obstruct the use of the bench. In practice, an upstand height of between 5 and 10 mm is usually considered appropriate.

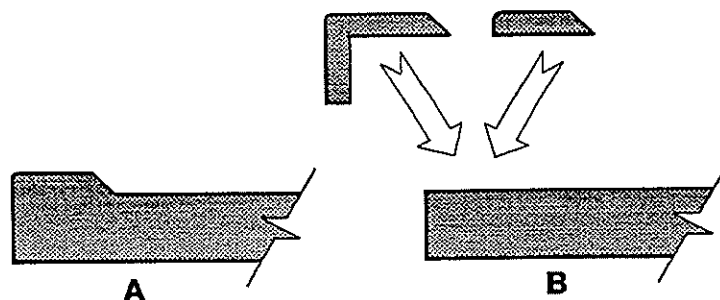


Fig.6.13: Benchtop raised edging: A=integral, B=applied.

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Some materials, such as cast epoxy resins, offer the choice of either an integral raised edge, (formed during casting of the sheet material), or a post-applied edging strip. The post-applied edge can be used to edge around cut-outs in the worktop, (eg around columns or service drops) thus avoiding fabrication of costly and complicated moulds. The post-applied raised edging can also be applied to existing flat (or dry) worktops where a 'change in use' (ie to wet) or a general safety update is required.

It is also important to consider carefully the colour of the chosen worktop material. Many of the materials used for bench worktops can be supplied in a range of colours which can be used to complement, and enhance, the overall aesthetics of the final laboratory design. Colour, however, is not only about aesthetics; the colour or colours chosen should be considered in relation to the materials used and the laboratory work to be undertaken. For plastic laminates, for example, minor scratching of the material's surface is not so noticeable when light colours are used but, with dark colours, scratching becomes more apparent.

The careful use of colours can also enhance laboratory safety. If particular chemicals or powders are known to be used on specific benches, the colour of the bench worktop can be chosen to enhance noticeability should any spillage occur. Similarly different bench types (eg wet or dry) can be broken down into different coloured worktops to demarcate specific activities, such as write-up areas.

Clearly the final form of the bench worktop and the whole furniture provision are the result of a long and often detailed analysis of the proposed laboratory and its specific requirements and environments. The above covers some of the major issues with regard to the bench worktop. Obviously, the costs associated with some of the more specialised materials and fabrication processes are considerable.

The choice of form and material of the bench worktop can make or break a project in terms of cost and performance. Because the bench is usually the focal point of much of the activity within the laboratory, the benchtop must be considered not only in relation to materials and cost, but also in respect to the safety of the user.

6.6 Seating

When determining laboratory furniture requirements, it is important to consider the type of seating required. Modern laboratory work can involve the laboratory user being seated for long periods (eg overseeing specific experiments, or writing-up notes at designated writing-up areas).

Depending upon the activity being undertaken, the requirements of the seating differ.

6.6.1 Bench experimental work

It is important that the height of the seat relates to the height of the worktop. Usually the seat is approximately 300 to 400 mm below the work surface. With high benches (900 mm) this means using a chair or stool with a seat height of approximately 600 mm. Chairs with adjustable height seats are available which can be used with adjustable height benchtops and can also be adjusted to suit the ergonomic requirements of individual users.

In the laboratory environment, chairs and stools made from easily cleaned, impervious materials should be considered to aid decontamination. Chairs with castors should be avoided if any adventitious movement of the chair could lead to accidents, eg during pouring of liquids (acids etc).

6.6.2 Writing-up areas

Again the seat height should relate to the height of the work surface.

Often long periods are spent at these work-stations and consequently long-term comfort should be considered, eg by providing chairs with an adjustable back support. Again, if the writing-up area is within the general laboratory environment, easily cleaned, impervious materials should be used. In this instance, chairs with castors can be beneficial as they aid movement around the work-station, ie to adjacent drawers.

6.6.3 Other considerations

For safety reasons, when chairs or stools are not in use, they should be placed under the desk or worktop (in the knee-hole space) to avoid obstruction to general circulation (particularly in emergencies). Chairs and stools should not be used to stand on to gain access to high-level shelving or tops of cupboards etc. This is particularly important if castors are fitted to the chair or stool.

The selection of laboratory seating should ultimately depend upon the type of work to be undertaken, height of the work surface and the degree of manoeuvrability and stability required of the seat.

Some laboratory furniture manufacturers market their own range of seats which not only meet constructional standards, but also compliment the design and style of their specific laboratory furniture range.

6.7 Summary

The intention of this chapter has been to act as a preliminary guide to the laboratory designer. In so doing it has identified key decisions that have to be taken by the Client and Design Team with respect to determining the final and most suitable laboratory furniture system and layout to satisfy the user's present and future requirements. The list of topics covered is not exhaustive, and the degree of importance of any one issue will vary from project to project depending upon the identified requirements.

For the laboratory designer to understand fully and respond to the needs and requirements of the Client, and in particular the end user, it is essential to maintain a thorough understanding of laboratory design, and an up-to-date awareness of what the laboratory furniture market can offer. Also, the issues of safety within the potentially dangerous environment of the modern laboratory should be fully explored via a close working relationship with the Design Team. The laboratory at all times must be a safe place in which to work, and the careful consideration of the furniture it contains should be paramount in achieving this requirement.

The laboratory bench was traditionally, and still is, the focal point of the laboratory, and a clear understanding of laboratory furniture design is essential to making any 'new' laboratory a success.

Laboratory furniture is the true interface between the user and the building.

6.8 Appendix A: Ergonomics

Scientists and artists alike throughout history have been preoccupied with the proportions and dimensions of the human body. This preoccupation has played a fundamental rôle in the history and development of architectural design. The relatively new science of Ergonomics,⁴ 'the study of man in his environment', has to a great extent conditioned the way in which environments such as laboratories are perceived. Conditioned by critical anthropometric dimensions, buildings and furniture are designed and sized to be used by the human body, and laboratories, along with the furniture they contain, are no exception.¹

Although each individual person is unique in terms of both size and build, it is necessary to establish average human parameters in order to establish standards for the design and construction of laboratory furniture. It is important that the requirements of the user are fully appreciated and consideration should always be given to the needs of non-standard groups of users. School children and school laboratory furniture are one such group that has very specific needs and requirements.⁵

Within the scope of general laboratory furniture design, it is perhaps the laboratory bench, and specifically the worktop, that warrants most attention. Traditionally it is on the worktop that the majority of laboratory work is carried out. To understand the anthropometric requirements of the worktop, the critical dimensions of height and depth require careful consideration.

6.8.1 Worktop height

The worktop height should be governed by its relationship to the posture of the person working at that bench, usually either standing or seated on a chair or stool, and not necessarily directly related to its height above the floor. (The usually accepted provision is 750 mm high where being seated is a requirement, and 900 mm for standing). It should also be remembered that bench work does not only occupy the horizontal plane of the worktop, but also the volume of space directly above, and the way in which the use of this vertical space is perceived can also set the fundamental criteria for determining specific worktop heights. For example, the use of tall apparatus may warrant a relatively low bench height to enable access to the full height of the apparatus to be maintained without resorting to the (potentially) dangerous use of steps and ladders. Some laboratory furniture manufacturers offer benches with easily adjustable worktop height, through either manual or automatic operation, although it should be borne in mind that adjustable height worktops will probably compromise the important storage potential below that bench (Section 6.4).

Laboratory furniture

6.8.2 Worktop depth

Depth, the second of the critical dimensions, is governed by the maximum convenient reach of those using the bench. It is common practice to place gas outlets and other service fittings towards the rear of the bench to overcome potential nuisance and safety problems caused by projecting fittings situated on the front of the worktop. The required ease of access to the rear of the bench therefore dictates the overall depth (usually accepted depth being within the range 600 mm to 850 mm). It is however possible to have a requirement for deeper worktops, to meet the requirements of specific pieces of apparatus, and where access to the back of the worktop, from the front, is not normally required.

The principal concern governing the use of any piece of laboratory equipment or item of furniture is safety. Already discussed is the relationship of worktop height and depth to the human body, and this in essence is the principal criterion governing the safe use of any laboratory. Furniture, and particularly laboratory furniture, must be designed so as not to compromise the safety of the user.⁶

Shelving is another item that requires particularly careful consideration, especially if it is to be placed directly above bench worktops. It must be located so that the user does not have to overstretch (and maybe over-balance), which is potentially dangerous especially if chemicals are located either on the shelf or the worktop below. Many furniture manufacturers offer adjustable height shelving that can be altered by individual users to suit their physical requirements in terms of reach.

As with shelving, free-standing storage cabinets can also present their own potential dangers. It is common practice these days to use extensive vertical storage in order to make use of the volume of the laboratory rather than just the (expensive) floor area. To do so presents the problem of access. Some manufacturers offer integrated ladder and support rail systems to their tall cabinets, which are safer than using conventional step ladders or stools. However, it should be remembered that such cabinets *must* be adequately restrained to prevent them tipping over. Usually this is achieved by fixing the cabinet back to a rear wall.

The provision of underbench storage also needs careful consideration (Section 6.4). Much research has been carried out regarding the organisation and management of storage⁷ and tests have resulted in acceptable limits for reaching storage which are influenced by body size, forces to be exerted and frequency of access required.⁸

The above covers briefly the basic issues of safety with respect to ergonomics within the environment of a modern laboratory. There are many other aspects of safety that are equally important, but if the laboratory and in particular the furniture (and furniture layouts) it contains are designed specifically in relationship to the human physique, then the potential risks involved with compromising user safety, are greatly reduced.

6.9 References

1. BS3202 Part 3: 1991, *Laboratory furniture and fittings: Recommendations for design*, British Standards Institution.
2. Brassington, P.W. (1983), 'Laboratories - traditional or flexible?', *Laboratory Technology*, March - April, Uplands Press.
3. BS3202 Part 2: 1991, *Laboratory furniture and fittings: Specification for performance*, British Standards Institution.
4. Neufert, E. (1980), *Architects Data*, (second international English edition), Granada, pp 9-15.
5. *School furniture, standing - sitting position*, Building Bulletin 52 (1976), Department of Education and Science, HMSO.
6. BS3202 Part 1: 1991, *Laboratory furniture and fittings: Introduction*, British Standards Institution.
7. Branton, A.J. and Drake, F.P.F.J. (1972), 'Adaptable furniture and services for education and science', *Architects Journal*, 16 August, pp 377-387. (Later reprinted as *Laboratories Investigation Unit Paper No.6: Adaptable furniture and services for education and science*, 1976.
8. Jones, J.C. (1968), *Ergonomics for Industry 11: Layout of work spaces*, Ministry of Technology, HMSO.

7 VENTILATED ENCLOSURES and FUME DISCHARGE

7.1 Local exhaust ventilation

Local exhaust ventilation is one of the most effective means of limiting the release of hazardous substances into the workplace atmosphere, provided it is properly designed, installed and used.^{1,2,3} The basic elements of such an exhaust system are:

- (a) an inlet terminal which may be a hood, enclosure, or other collecting or containing device;
- (b) suitably constructed and routed ductwork to an appropriate discharge point;
- (c) sometimes a filter, scrubber, steriliser or other air-cleaning device to reduce the concentration of the contaminant in the airstream;
- (d) a fan or inductor to provide an appropriate airflow;
- (e) a discharge system to disperse the effluent safely.

Simple inlet terminals, such as a rectangular slot, are effective only when the contaminant is released close to the inlet and there is no interfering air movement due to the velocity of emission of the contaminant, thermal rises or draughts including those induced by movements of the operator.^{3,4} Due consideration has to be given to the rate of release of the contaminant and to the adequacy of the volume rate of extraction through the hood as well as the capture velocity at the point of release.

Various improvements can be effected by introducing flanges around the entrance of the terminal or by constructing a box-like enclosure to form a 'receptor' hood which partially surrounds the process.^{5,6,7} If further improvement is called for, a device of partial containment, *eg* a fume cupboard (Section 7.4) or of total containment, *eg* a glovebox, would be needed.

In the laboratory, local exhaust terminations may be categorised loosely by use as:

- (a) *for chemical operations*
hoods (canopies),
chemical work stations,
fume cupboards (fume hoods in American parlance),
gloveboxes.
- (b) *for radiochemical operations*
fume cupboards,
gloveboxes.
- (c) *for microbiological operations*
safety cabinets,
flexible film isolators.
- (d) *for pathological operations*
histology dissecting benches.

In addition, there may be items which are not required to protect the *operator* but which may form part of the ventilation system:

- (e) *for product protection only*
laminar flow clean-air rooms and work stations.

Ventilated enclosures and fume discharge

The Control of Substances Hazardous to Health Regulations 1988^{8,9} require the thorough examination and testing of all local exhaust ventilation systems at least once every 14 months (and more frequently for certain specified systems).

7.2 Clean-air rooms and work stations

A 'clean-air room' or 'clean-air work station' is a space in which the airborne particulate contamination is maintained at a far lower level than in conventionally air-conditioned spaces.¹⁰ Such rooms and work stations also have the advantage of very low levels of bacterial contamination and are therefore of use in situations where a sterile environment is required.

Clean rooms and work stations find application in, for example:^{10,11}

- (a) manufacture and processing of pharmaceutical products,¹²
- (b) control of microbiological contamination in the food industry,
- (c) sterile handling of biological material (often with the added need of operator protection against any toxic or biological hazards present),^{13,14}
- (d) various 'high-tech' industries related to aerospace, semi-conductors, optical components, audio components including compact disks, film stock and medical devices.
- (e) surgery and nursing, in particular when the immunological resistance of the patient to disease has been reduced by chemotherapy.

It must be stressed that these are all applications in which the product or patient has to be kept clean or sterile; in some applications the facility must also protect the operator from toxic or microbiological hazards associated with the work as in (c) above.

In a laminar or *uni-directional* airflow clean room or work station, the whole body of air moves through the space either vertically or horizontally with uniform velocity (Fig.7.1). Thus, any contaminant found at a point in the space will not move perpendicularly to the direction of flow but will be swept directly to the extract grilles with less opportunity to contaminate adjacent workpieces than there would be in a conventionally ventilated space where there is a degree of turbulence. All fittings should therefore be designed to minimise turbulent airflow, including, for example, the need to ensure that any suspended light fittings are aerodynamically shaped.

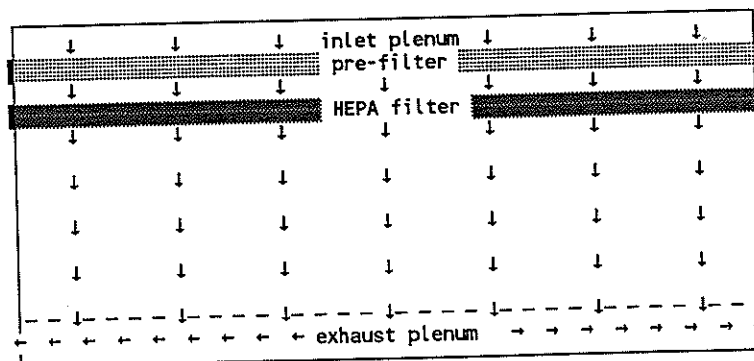


Fig.7.1: Laminar or uni-directional downflow clean room or work station.

The relevant Standards for clean air are BS 5295: 1989¹⁵, US Federal Standard 209D¹⁶, German Standard VDI 2083¹⁷, French Standard AFNOR X4410¹⁸ and Australian Standard AS 1386.¹⁹

BS 5295: Part 2¹⁵ gives guidance on the design and construction of clean rooms and clean air devices, including guidance on layout, ancillary rooms, access, airlocks, emergency exits, changing rooms, methods and materials of construction, environmental control, lighting, noise and vibration. Installations are described in terms of the maximum permissible number of particles per m³ (class C to class M, using successive letters of the alphabet except I) and in terms of their occupancy state (eg as built, unmanned, manned). The maximum particle counts permitted in each class are given in Table 7.1. The table in BS 5295 also specifies the minimum pressure difference between clean rooms

or totally enclosed devices and unclassified areas (15 Pa for classes C to K; 10 Pa for classes L and M) and that between the classified area and adjacent areas of lower classification (10 Pa for all classes except class M for which no limit is specified).

Table 7.1

Maximum permitted particle counts in controlled environment installations
(BS 5295¹⁵ and US Fed. Std 209D¹⁶)

Class of environmental cleanliness		Maximum permitted number of particles/m ³ (equal to, or greater than, stated size)				
BS	US 209D	0.3 µm	0.5 µm	5 µm	10 µm	25 µm
C	1	100	35	0	NS*	NS
D	10	1 000	350	0	NS	NS
E	100	10 000	3 500	0	NS	NS
F	100	NS	3 500	0	NS	NS
G	1 000	100 000	35 000	200	0	NS
H	1 000	NS	35 000	200	0	NS
J	10 000	NS	350 000	2 000	450	0
K	100 000	NS	3 500 000	20 000	4 500	500
L	-	NS	NS	200 000	45 000	5 000
M	-	NS	NS	NS	450 000	50 000

* NS: no specified limit.

7.3 Fume hoods (canopies)

Fume hoods or canopies, for the removal of contaminants, are usually either *receptor* hoods where the contaminant moves naturally into the exhaust inlet (eg by thermal rise or velocity of emission) or *captor* hoods where the contaminant has to be pulled into the exhaust inlet.^{1,3}

The design of captor hoods, including the effect of flanges, and the choice of capture velocity (usually at least 0.5 m/s to overcome air movements in the workplace) are considered in the literature.^{2,3,4,5,6,20}

7.4 Aerodynamic fume cupboards

The description, 'aerodynamic', is applied to fume cupboards (Fig.7.2) which are so styled that the airflow patterns, especially at the edges of the working aperture, are streamlined; this is in contrast to the turbulent flow through the aperture of older designs with 'square-fronted' side fascias and sills.

The current specification for general purpose fume cupboards is given in the three Parts of British Standard BS 7258: 1990,²¹ supplemented by a Draft for Development DD 191: 1990 on a method for determination of the containment value of a laboratory fume cupboard.^{22,23,69}

Fume cupboards are mentioned briefly in an introductory text by the Health and Safety Executive¹ and the practical experience of many years and an extensive bibliography is collated in various Monographs and Handbooks.^{24,25,26} Advice has been given by the Department of Health and Social Security²⁷ and guidance was published in a booklet by the Royal Society of Chemistry in 1990²⁸ with particular regard to obligations under the Control of Substances Hazardous to Health Regulations 1988.⁸ Manufacturers' literature on various designs of fume cupboard is available; not all designs comply with the current British Standard.

Ventilated enclosures and fume discharge

In addition to the examination and testing which must be carried out on a fume cupboard system at least every 14 months under the Control of Substances Hazardous to Health Regulations 1988,^{8,9} BS 7258 Part 3²¹ lists the items which must be maintained every 6 months and every 12 months.

The requirements for an aerodynamic fume cupboard and its associated extract and air supply systems can be specified under the following headings:²⁹

1. *The fume cupboard itself*
 - (a) aerodynamic features and containment,
 - (b) other safety features including controls and alarms,
 - (c) chemical resistance, ease of decontamination, working temperature of the working and lining surfaces,
 - (d) siting in the laboratory.
2. *The extract system*
 - (a) volume rate of extraction and velocity in ducts,
 - (b) duct materials, construction, route through building,
 - (c) fan selection - access for servicing, chemical resistance, spark-proof fan impeller (non-metallic, or metallic with brass inserts or 'rubbings' which would be the first points of contact with the casing if the fan ran out of true),
 - (d) noise characteristics,
 - (e) discharge arrangements,
 - (f) energy conservation measures.
3. *The air-supply system*
 - (a) adequacy and interlinking with extract requirements,
 - (b) siting of supply grilles within laboratory,
 - (c) degree of air-conditioning required,
 - (d) noise characteristics,
 - (e) location of entry points for air taken into the supply system,
 - (f) energy conservation measures.

7.4.1 The aerodynamic fume cupboard

The following features are expected in an efficient aerodynamic fume cupboard (Fig.7.2):

- (a) shaped side-fascias and front sill (airfoil) to encourage non-turbulent flow through the working aperture into the fume cupboard otherwise airborne contaminants may be carried towards the operator by turbulent eddy currents,
- (b) a readily demountable (for cleaning) rear baffle with extract slots to improve the degree of uniformity of the air velocity over the area of the working aperture and to purge the entire volume of the working chamber including that immediately above the working surface (BS 7268: Part 1²¹ recommends that the extract slot are not adjustable or that the manufacturer's instructions are carefully adhered to),
- (c) an air by-pass or other compensating device to prevent excessive velocities for the air entering through the working aperture as the (vertically sliding) sash is lowered,
- (d) a drained working surface, dished or otherwise designed to deal with spilt liquids, with the dishing starting or a raised edge some 150 mm into the fume cupboard from the plane of the sash (to ensure that users place their apparatus at least 150 mm into the fume cupboard to reduce the chances of poor containment),
- (e) a good seal between the working surface and the interior walls to prevent ingress of chemicals into the supporting structure of the fume cupboard or onto services or storage cupboards below (the best seal is provided by a welded construction - if the working surface and walls are of compatible materials - but this makes much more difficult the replacement in service of the working surface if it becomes damaged),
- (f) an adequate air velocity into the fume cupboard, with reasonable uniformity over the whole area, when the sash is raised to the working height (at least 450 mm) with a mechanical stop if the working height is less than the maximum height to which the sash can be raised. The velocity specified is usually in the range 0.5 to 1 m/s,²⁴

although some fume cupboards contain fumes well at, say, 0.3 m/s under 'ideal' as opposed to working conditions where there is a moving operator and other sources of air disturbance in the room. Some designs perform poorly at high velocities, in particular because the incoming air bounces forward from the rear baffle.

The British Standard²¹ specifies performance type testing (in a prescribed test room) and commissioning tests on site for the air velocity entering the fume cupboard measured at points on a reference grid in the plane of the sash.

Unfortunately it is not possible to specify the desirable features of a fume cupboard with sufficient precision to guarantee the production of a unit that will perform well. For example,²⁵ slight differences in the airfoil section of the sill result in undesirable eddy-formations in some models, and poorly designed by-passes permit the escape of fumes especially if there are strong thermal rises within the fume cupboard. It is therefore important to obtain information on the performance of a model of fume cupboard, when installed in a realistic situation, by a containment test^{22,69} preferably supported by a smoke test.³⁰⁻³³

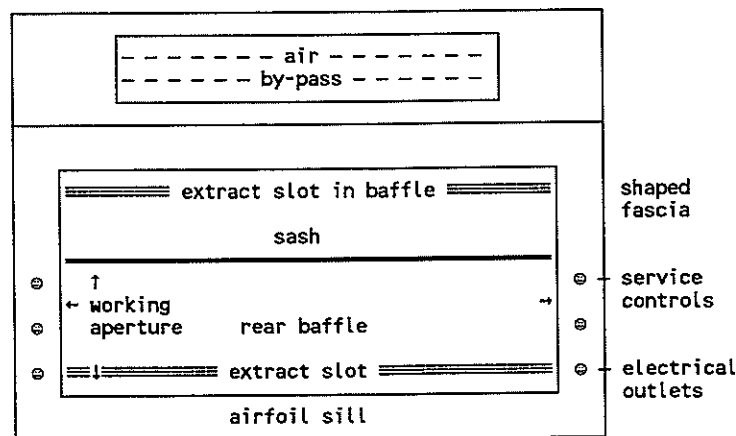


Fig.7.2: The aerodynamic fume cupboard.

7.4.2 Other safety features

Other safety features expected in a fume cupboard are:

- fail-to-safe mechanisms to prevent sashes falling if the sash-supporting device fails,
- water faucets and gas connectors positioned in the side walls so that they can be reached without the necessity of placing head and shoulders inside the working chamber; electric light luminaire sealed from the working chamber and maintained from outside,
- control taps and electrical socket outlets on side fascias (BS 7258: Part 1 requires the electrical sockets to be so placed that it shall not be possible for liquids or flammable vapours to flow over the front edge of the fume cupboard onto the outlets),
- absence of maintenance service panels inside the working chamber,
- fail-safe airflow indicator, and visual and audible alarms. BS 7258: Part 1 requires the indicator to show that the *airflow* is satisfactory (not just that power is supplied to the fan motor), *ie* within 10% of the specified volume extract rate, *or* when the extract rate falls to less than 80% of the specified rate. A two-state indicator is preferred, showing normal and alarm conditions.
- an indication that there is satisfactory interlinking/interlocking with the inlet air supply, as required by BS 7258: Part 1, 3.6 Note 2.
- precautions against explosions are not normally required beyond the selection of a suitable glazing material (see below) for the sash to deal with minor over-vigorous reactions. Some work has been reported on testing a fume cupboard in which various sizes of explosive charge were detonated up to 7.32 gram of a material equivalent to dynamite (at which level the cupboard was destroyed!).³⁴

Ventilated enclosures and fume discharge

7.4.3 Materials of construction

The materials of construction for the surfaces which come into contact with fumes should be selected with regard to the following:

- (a) chemical resistance,
- (b) solvent attack,
- (c) absorption and ease of decontamination,
- (d) working temperature,
- (e) fire risk,
- (f) thermal stress,
- (g) surface abrasion and mechanical stress,
- (h) explosions.

The properties of various materials are reviewed in the British Standard²¹ and elsewhere.^{25,35} For the *working surface*, the material chosen is usually selected from:

- (a) stainless steel (acid resisting grades),
- (b) vitrified ceramic slab,
- (c) plastics materials,
- (d) solid epoxy resin,
- (e) lithium aluminium silicate glass ceramic,
- (f) melamine-formaldehyde laminates,
- (g) lead,
- (h) slate or man-made stone.

For the *linings and rear baffle*, the list is extended to:

- (i) epoxy-coated mild steel,
- (j) toughened glass,
- (k) polycarbonate sheet.

The sash in most fume cupboards is glazed in toughened glass. BS 7258 states that laminated glass may be used for the sash, but its limitations should be appreciated: it has lower resistance to thermal shock and thermal gradients and a lower maximum working temperature than toughened glass. Also, if laminated glass separates when broken, the pieces are likely to be more hazardous than the small pieces produced when toughened glass shatters.

Special considerations apply in certain cases: perchloric acid digestions could lead to a conflagration or explosion if any organic material or certain metals are used in the construction; hydrofluoric acid attacks glass; radioactive materials may require heavy shielding if they emit gamma radiation; flammable solvents require sufficient flow of air to keep the concentration of the vapour below 10% of the lower explosion limit (BS 7258: Part 3, 3.2.5).

The materials of construction for the surfaces which do not come into contact with fumes are not judged by the same criteria. The BS 7258 makes the point that, if the space beneath the fume cupboard is used to store flammable materials, then the framework shall be non-combustible; however, flammable solvents must be kept in properly designed cupboards or stores.

7.4.4 Siting in the laboratory

Siting of the fume cupboard within the laboratory, with minimum clearances for avoiding disturbances,²¹ is of considerable importance. Among the points to consider are:

- (a) not to obstruct an escape route (an uncontrolled reaction in the fume cupboard might impinge upon the route),
- (b) away from doors and circulation paths (air movements caused by doors or people can affect containment adversely),
- (c) away from structural obstructions such as pillars and side walls (disturbance of smooth airflow patterns just outside the working aperture can affect containment adversely),
- (d) away from air supply grilles (jets of air passing near the working aperture can affect containment adversely).

7.4.5 The extract system

The extraction system has many items which have to be carefully designed including:

- (a) rate of extraction air *velocity* through the working aperture is usually specified as not less than 0.5 m/s;²⁴ velocities lower than this are unlikely to overcome the disturbances caused by movements of the operator. The UK Department of Health has recommended a velocity of 0.9 m/s for spraying chromatograms.³⁶ The *volume* rate has to be sufficient to scavenge the interior thoroughly; in the case of work with flammable material, the concentration in the fume cupboard and duct should not exceed 10% of the lower explosion limit.²¹
- (b) air velocities within ducts,²¹
- (c) negative pressure in ducts within the building,
- (d) noise levels at fume cupboard and in occupied spaces through which the duct runs,
- (e) route of duct with respect to fire compartments,
- (f) fall to drain on near-horizontal duct runs,
- (g) drainage connection to the waste system (not discharged on to roof),
- (h) materials of construction (see below),
- (i) inspection covers (not in *bottom* surface of duct to prevent condensate falling on maintenance fitter when removing cover),
- (j) labelling of duct for identification and hazard warning purposes,
- (k) fan type (usually centrifugal) and material of construction with the motor outside the duct,
- (l) lockable setting-up dampers and possibly fire dampers (in horizontal duct runs),
- (m) filtration (safe-change) if appropriate,
- (n) washdown.

The material of construction for the extract ducts is usually selected from:^{26,24,21}

- (a) **Rigid pvc** which is widely used because of its chemical resistance (with notable exception to organic solvents) and ease of fabrication. It has the disadvantages of a low service temperature of only 60°C, possible embrittlement through ageing if exposed to ultraviolet radiation in the environment (unless encased for protection) and the production of smoke and corrosive products in a fire. The pvc may be reinforced externally by wrapping with glass-fibre/resin laminate (GRP).
- (b) **Polypropylene** has a higher service temperature of up to 90°C and may be used with organic solvents. It burns when ignited by flame and drips as it burns but is available with a glass fabric backing that allows external wrapping with glass-fibre/resin laminate (GRP) to improve the fire retardation.
- (c) **Coated mild steel** has an even higher service temperature. Electrostatically applied, heat-cured epoxy coatings have to be carefully applied to prefabricated, flanged sections of ductwork which must not be damaged during erection. The coating can be checked for flaws using an electrical conductivity test. Failure of the coating could lead to insidious corrosion of the metal.
- (d) **Stainless steel** has particular application where a high service temperature and resistance to attack by certain specific chemicals (eg perchloric acid) are required. It is however susceptible to attack by halogens and certain commonly used acids (eg hydrochloric acid).

Multiple extract systems with collection ducts, as opposed to individual systems, and fume dispersal are considered in Section 7.8 below.

7.5 Vortex fume cupboards

Variations have been introduced to increase the containment efficiency by creating an air vortex within the fume cupboard by injecting air directly into the interior of the working chamber. The vortex entrains the contaminant and has an accumulation facility which absorbs 'puffs'. The air velocity through the working aperture may be greater near the sides of the fume cupboard than in the middle thereby reducing the aerodynamic wake caused by an operator standing in front of the fume cupboard.

Designs have a horizontal vortex, spiralling to extract points at each side,^{37,38} or a vertical vortex.³⁹

7.6 Recirculating fume cupboards

For some specified applications, *recirculating* fume cupboards have been advocated. These are self-contained units requiring no ductwork to atmosphere. The fumes are extracted through filters appropriately selected for the chemicals to be removed and then discharged back into the laboratory.^{40,41,42} Specific provision is made to monitor the state of the chemical filters so that they are replaced before significant breakthrough occurs.

7.7 Microbiological safety cabinets

Microbiological safety cabinets are the principal items of equipment for providing physical containment in microbiological laboratories. Most microbiological procedures are known to produce inadvertent aerosols containing microorganisms. The cabinets are used as secondary barriers to minimise the hazard of air-borne infections by preventing the escape of these aerosols into the laboratory environment and their inhalation by the workers.⁴³ They do not prevent spillage; they are not effective against chemical hazards.

Certain types of cabinet also protect the experiment from airborne contamination.

The selection of a microbiological safety cabinet is based on the hazard offered by the microorganisms used, *ie* the Hazard Group in which those organisms have been placed by the Advisory Committee on Dangerous Pathogens⁴⁴ (see also Appendix II), the potential of the technique to produce aerosols and the need to protect the work from airborne contamination.

The type and siting of microbiological safety cabinets should be settled at the design stage as trunking and exhaust systems are required. Siting is critical (see below).

There should be separate exhaust systems for each cabinet with no cross-connections and no linkage with the exhaust systems of fume cupboards.

7.7.1 Types of microbiological safety cabinet

There are three types of microbiological safety cabinet: Classes I, II and III.^{44,45,46,47} These are described below. Their effectiveness depends on airflow, containment capability, integrity of the High Efficiency Particulate Air (HEPA) filters, and in the case of Class I and Class II cabinets, their position in the room in relation to ventilation currents and the movements of staff. Fig.7.3 shows good and bad sites for these cabinets.

Tests for effectiveness should include: airflow rate and direction, determined with anemometers and smoke generators; ability to retain particles released into the working space (containment factor); and the penetration factor (*ie* efficiency) of the HEPA filters. These tests are described in BS 5726.⁴⁷

The cabinets should be tested at the factory, on initial installation in the laboratory, on relocation, and annually.

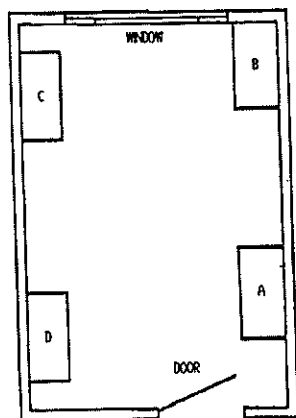


Fig.7.3: Sites for safety cabinets in relation to cross draughts from door and window and movement of staff.
A is bad;
B is poor;
C is better;
D is best.

(a) Class I microbiological safety cabinet

A Class I microbiological safety cabinet (Fig.7.4) is an open-fronted, ventilated cabinet for personnel protection with an unrecirculated inward airflow away from the operator. It is fitted with a HEPA filter (Section 7.7.2) to protect the environment from discharged microorganisms. A primary filter is also fitted to reduce the load on the HEPA filter.

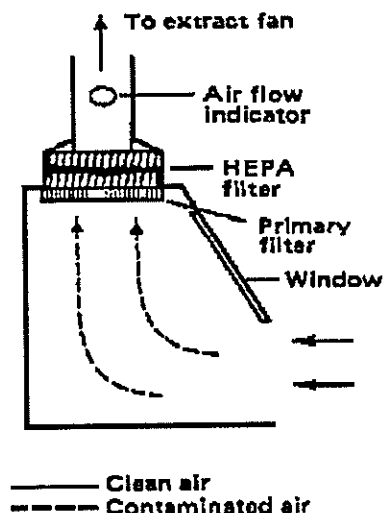


Fig.7.4: The Class I microbiological safety cabinet.

Class I cabinets may be used with low or moderate hazard microorganisms (Hazard Groups 2 and 3). They provide operator protection but do not protect the material (product) within the cabinet from contamination.

(b) Class II microbiological safety cabinet

A Class II microbiological safety cabinet (Fig.7.5) is an open-fronted, ventilated cabinet for personal, product and environmental protection which provides an inward airflow and HEPA-filtered supply and exhaust air. There are two main variations of Class II cabinet: Class IIA recirculates 70% of the air; Class IIB recirculates 30% of the air.

Class IIA cabinets may be used with low or moderate hazard microorganisms (Hazard Groups 2 and 3), minute quantities of toxic chemicals, and trace amounts of radionuclides. Class IIB is suitable for larger amounts of toxic, volatile or radioactive substances. Care must be taken in selecting the appropriate Class II cabinet for these purposes.

(c) Class III microbiological safety cabinet

A Class III microbiological safety cabinet (Fig.7.6) is a totally enclosed, ventilated cabinet which is gas-tight and is maintained under negative air pressure (125 pascal [0.5 inch water gauge]). The supply air is HEPA-filtered and the exhaust air is passed through two HEPA filters in series. Work is performed with attached long-sleeved rubber gloves.

Class III cabinets are used for high hazard microorganisms (Hazard Group 4) and provide a total barrier between the operator and the work. Flammable gases should not be used in Class III cabinets.

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

7.7.2 High Efficiency Particulate Air (HEPA) filters

Filters suitable for microbiological safety cabinets (and other microbiological operations) should conform to BS 5726.^{47,70} Ideally not more than 3 particles should be recovered when the filter is challenged by a dose of 100,000 particles.

Ventilated enclosures and fume discharge

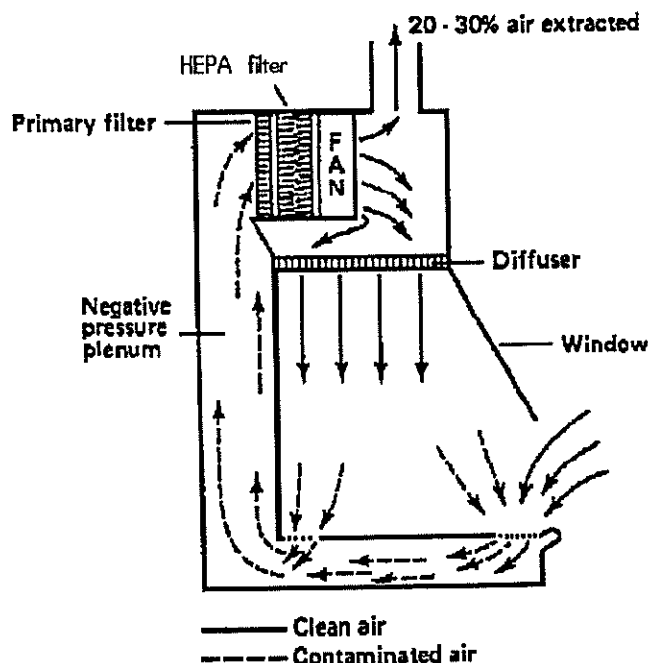


Fig.7.5: The Class II microbiological safety-cabinet.

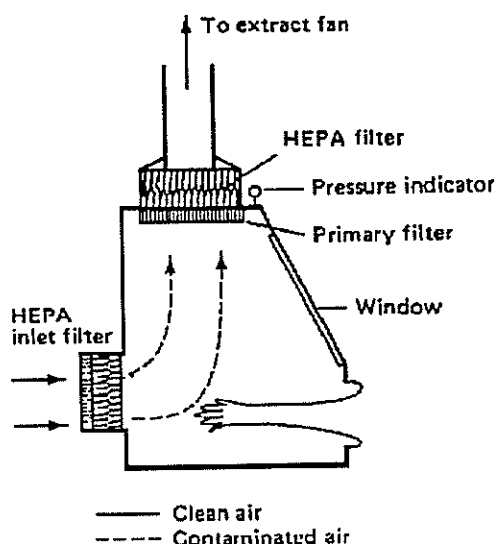


Fig.7.6: The Class III microbiological safety cabinet.

7.7.3 Service connections to microbiological safety cabinets

Gas and electricity cut-offs should be adjacent, but external to microbiological safety cabinets. Gas burners disturb airflows in cabinets and their use should be discouraged. If bunsen burners are absolutely necessary they should be 'micro-bunsens' of the Kampff type.

7.7.4 Selection and installation

Class I cabinets are suitable for most microbiological work but where protection of the workpiece is necessary, *eg* in tissue culture techniques, a Class II is better. Class III cabinets are essential for work with Hazard Group 4 pathogens and are unnecessary for other microbiological activities.

Only those cabinets that meet the requirements of British Standard 5726⁴⁷ should be purchased. Installation should be done by the cabinet manufacturer after consultation at the design stage. Poorly installed cabinets offer hazards to workers.

7.7.5 Performance tests

Full tests of the efficiency of microbiological safety cabinets should be done only by experienced operators, usually the staff of specialist companies. Local staff should restrict themselves to testing airflows, and only then where practicable, as with Class I cabinets. Only an outline of these tests is given here.

To satisfy the requirements of BS 5726 these tests should include:

- (1) airflow measurements,
- (2) operator protection (containment) test (Classes I and II cabinets),
- (3) external contamination test (Class II cabinets),
- (4) cross-contamination test (Class II cabinets).

(a) Airflows

Class I cabinets: The airflow through the working aperture, measured with a suitable vane or hot wire anemometer at the geometrical centre and at all four corners, should be between 0.7 and 1 m/s. This should agree with the airflow meter incorporated into the cabinet controls.

Class II cabinets: The mean downflow, measured at several points on a horizontal plane 100 mm above the top edge of the working aperture should be between 0.23 and 0.5 m/s. The mean airflow into the working space should be not less than 0.4 m/s.

Class III cabinets: The airflow through the glove ports when the gloves are detached should be not less than 3 m/s.

(b) Operator protection test

In principle this involves releasing into the cabinet a known volume of an aerosol containing a known number of particles of suitable size during operation and counting the numbers in air sampled immediately outside the working face of the cabinet. The protection factor is calculated from these figures and is broadly speaking the ratio of the number of particles released (the challenge dose) and the number that escape. BS 5726 required that this figure is not less than 10^5 . Standards for this test, including equipment and procedures are given in BS 5726.

(c) External contamination test

This tests the efficiency of the air curtain that descends at the working face of a Class II cabinet to prevent organisms entering the cabinet. An aerosol of known composition is released outside the working face of the cabinet during operation and 12 petri dishes of culture media are placed on the working surface. After 4 minutes these are closed, removed and incubated. Not more than 5 colonies should develop compared with 300 when the fan is not operating.

(d) Cross contamination test

The aerosol is released at one end of the cabinet working space and dishes of culture media are placed at the other end. Again, there should be no more than 5 colonies after incubation, compared with the control of 300.

7.8 Fume extraction and discharge

7.8.1 General considerations

The dispersion of effluent from the laboratory is concerned with processes operating at short distances from short stacks emitting relatively small quantities of obnoxious or toxic materials. Problems that arise relate to the immediate vicinity of the discharge point and may involve re-entry of fumes through nearby windows or air intakes. At greater distances dilution in the atmosphere almost invariably provides adequate protection.

Dispersal from a stack is a complex subject with many variables to be considered if a comprehensive analysis is attempted. At the laboratory scale,²⁶ factors usually taken into account include height of building from which the effluent is discharged, height and proximity of adjacent buildings, height of discharge stack, design of discharge termination, efflux velocity, location of neighbouring air intakes and of walkways (including those used by maintenance personnel). Meteorological factors obviously affect the dispersal but, in practice, they do not usually feature largely in the development of a *laboratory* design, at least in part because of the paucity of information available on problems of this scale. Discharge stacks and the discharges therefrom may be subject to various statutory controls.

7.8.2 Filtration, scrubbers etc

For the majority of chemical and radiochemical applications in the laboratory, filtration before discharge is not required. Small releases are better discharged as they arise and not accumulated in a filter with the subsequent problem of disposal of a discrete, contaminated object. When filters⁷⁰ are fitted, they may be to trap particles (eg 'HEPA' units⁴⁷) or chemicals (eg activated charcoal⁴⁸ - which also desorbs⁴⁹). They should be near the source, have an appropriate means of monitoring the residual capacity (eg manometers for particulate filters, gas samplers for chemical filters), a 'safe-change' housing and an identified disposal route. Occasionally wet scrubbers, using water or an appropriate chemical solution, are advocated, in particular for acid vapours (eg perchloric acid vapour).^{26,50,51} Although not always very effective, fume cupboards used for acid digestions and their associated ductwork are sometimes fitted with water washdown systems.²⁵ There is some pressure to monitor discharges at the laboratory scale, eg the discharge of radioactive iodine.^{52,53}

7.8.3 Single/multiple extract systems

In a simple extract system with one fume cupboard served by one extract fan, the design can incorporate a prescribed efflux velocity. Some installations demand a multiple system with several fume cupboards served by a common extract system, or perhaps by individual *extract* fans but a common collection/dilution duct and *dispersal* fan (Fig.7.7).

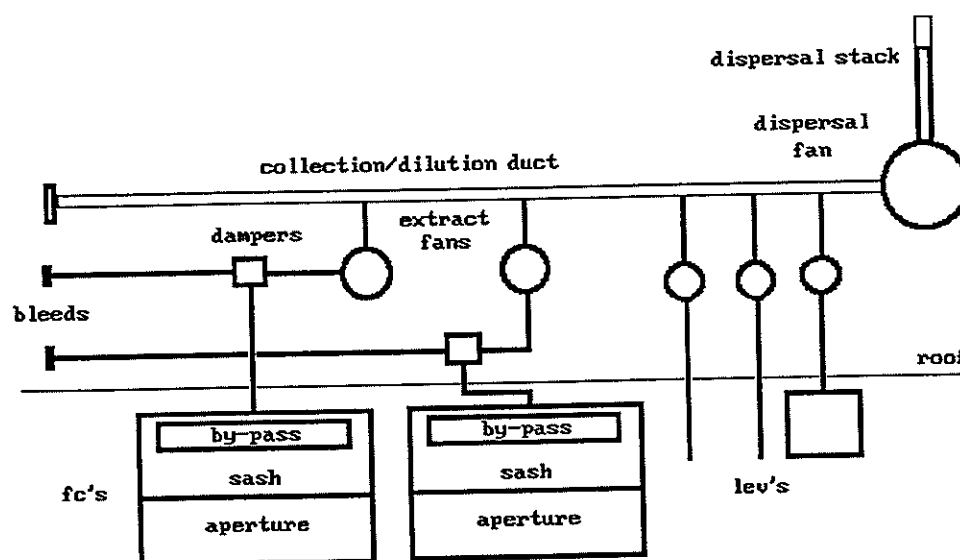


Fig.7.7: Multiple extract system with collection/dilution duct.

There are disadvantages as well as advantages to the installation of a collection and dilution duct.

Among the advantages are:

- (a) reduced levels of contaminant on the roof immediately adjacent (within, say, 25 metres)²⁴ to the discharge stack;
- (b) reduced effect of fluctuations in wind pressure on the extract rate;
- (c) more than one fan can serve one room without reverse flow through passive fans serving the same room;
- (d) one duct can be taken to the highest and therefore most favourable roof location on which to mount the discharge stack;
- (e) the aesthetic value of a single discharge stack rather than a series of individual stacks (which could, of course, be grouped together and surrounded by a cosmetic feature to give the appearance of a single stack).

Among the disadvantages are:

- (f) failure of the dispersal fan rendering all the fume cupboards in the system inoperative. (Redundancy can always be built into the system if desired: a standby duplicate motor and perhaps fan can be incorporated if the consequences of inoperation of the whole system justified the additional capital cost.);
- (g) the capital costs of the extra ductwork (of large cross-section) and of the dispersal fan and motor in addition to the costs of the extract fan and motor for each fume cupboard;
- (h) the additional running and maintenance costs of the dispersal fan and motor;
- (i) the need to ensure an adequate discharge velocity when only one fume cupboard is operating;
- (j) presence of incompatible substances (usually not a major issue because of the large dilution factors in the system).

Multiple systems and the need to conserve energy lead to the requirement to control volume rates under varying operating conditions, *eg* varying sash heights on fume cupboards and the ability to switch fume cupboards on and off at will. This can now be done by the elegant application of fluid dynamics in the *venturi valve*²³ which maintains a selectable volume flow rate over a wide range of pressure drop (150 to 750 Pa) across the valve (Fig.7.8).

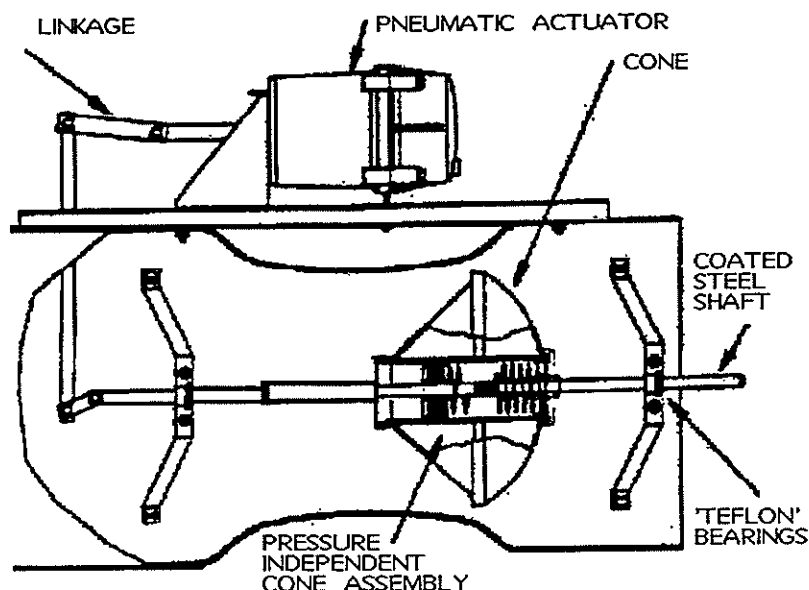


Fig.7.8: The venturi valve for the control of airflow in variable and fixed volume applications.²³

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7.8.4 Discharge terminals and velocity

The terminal or cowl at the top of the stack must be designed so that it assists dispersal, minimises the effect of wind pressure and provides some protection against ingress of rainwater, preferably by a drain connection to the stack or to the fan casing (Fig.7.9). Inverted-cone weather caps have been implicated in 'downwash' problems for years^{20,54} and examples abound of terminations based on poor design principles and of stacks located at unsuitable positions.^{24,55} Preferred terminals are designed to throw the effluent vertically upwards at high velocity (Fig.7.10), in order to clear the aerodynamic wake of the stack and that of the building, although high wind and other meteorological factors can limit the efficiency of the arrangement. BS 7258²¹: Part 2, suggests a velocity normally not less than 7 m/s and a preferred design figure of 10 m/s although values in the range 15 - 20 m/s have been used in some locations.^{20,24,56}

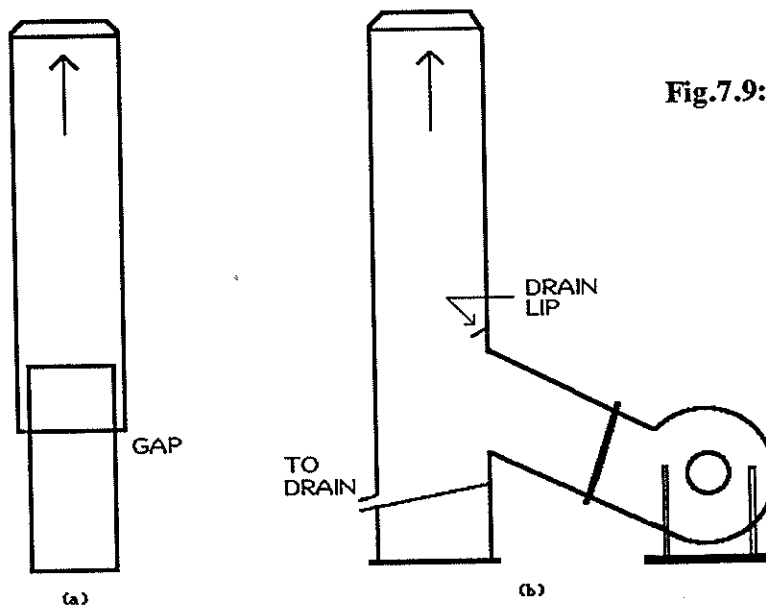


Fig.7.9: Methods of protecting extract system against rainwater;
(a) rainwater not collected,
(b) rainwater piped to drainage system.

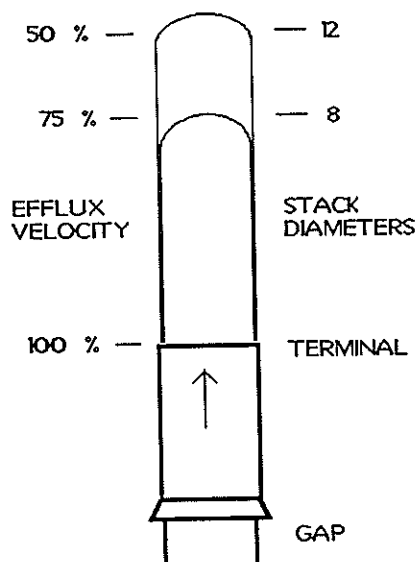


Fig.7.10: Velocity contours for a vertically discharging termination in still air.²⁰

7.8.5 Stack height

The airflows (Fig.7.11) and velocity contours around a cubical building give rise to 3 zones of aerodynamic distortion:

- the displacement zone upwind of the building,
- the wake downwind of the building, and
- the cavity immediately adjacent to the building.²⁶

The first aim is to discharge the effluent at a height greater than the cavity boundary which may be 125% of the building height.²¹ Dispersion factors are affected considerably by actual building shape, orientation to the wind direction, adjacent buildings, topographical features, meteorological factors (eg wind speed and temperature inversions). The British Standard²¹ suggests, for an isolated rectangular building of low plan ratio in flat open country, a height of discharge above ground of 1.25 multiplied by the highest point of the building, or 3 m above the highest point, whichever is the greater, for an isolated vertical flue with plain opening.

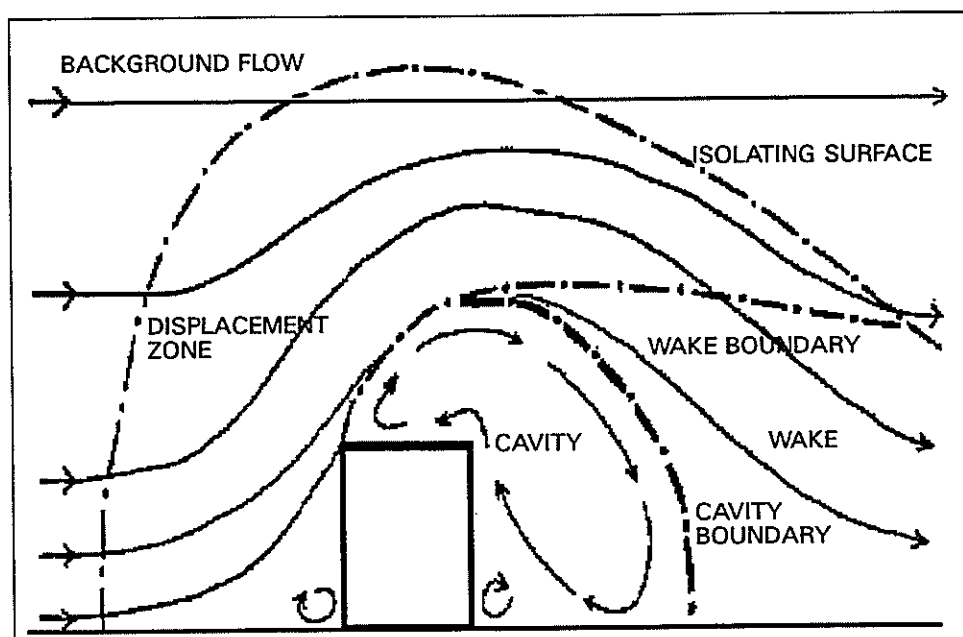


Fig.7.11: Schematic airflows passing an isolated cubical building on flat ground.²⁶

Various studies on the significance of stack height have been published.^{26,57,58,59} Hall,⁶⁰ in a Symposium arranged by the Laboratory of the Government Chemist, considered the increase in acceptable effluent discharge rates as a function of the ratio of stack height to building height (Table 7.2).

Table 7.2

Effect of stack height relative to building height on acceptable discharge rate⁶⁰

<u>stack height</u> building height	acceptable increase in discharge rate of contaminant
1.0	x 1.0
1.25	x 2.5
1.5	x 6.0
2.0	x 17.0
2.5	x 25.0

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7.8.6 Dilution and dispersal formulae

A few formulae and rules-of-thumb have been published to estimate the likely concentrations around a *laboratory-scale* building, in addition to the more extensive work on larger scale discharges from, say, power stations. Several of these formulae, some of the more useful dating from the 1960s, have been summarised in the literature²⁴ and it does appear that little new work has been published since the early 1980s.^{61,62} One particularly relevant study made in the 1960s^{24,63,64} on a model of the National Institutes of Health, Bethesda, gives estimates for the dilution factors between a discharge aperture at roof level and air intakes (a) on the same wing of the building, (b) on a different wing separated from the first by an air space, and (c) at ground level:

$$\text{dilution factor} = 2.22 M \left[3.16 + 0.1 \frac{S}{(A_d)^{1/2}} \right]^2 \frac{U}{U_d}$$

where S = the shortest arc between discharge and intake points (m),
 A_d = area of discharge aperture (m^2),
 U_d = wind speed (m/s),
 U = (vertical) discharge velocity,
 M = configuration factor with the following values for the 3 configurations

- (a) $M = 1.5$
- (b) $M = 2.0$
- (c) $M = 4.0$

Applying this formula to a building 10 m high, 15 m wide, 25 m long, with a discharge aperture (0.025 m^2) on the centre line of the roof and an air intake at ground level adjacent to the building ($M = 4$), the dilution factor is 180.

Another formula given by ASHRAE,^{24,65} developed from wind-tunnel data, gives a dilution factor of 44 for the same building configuration.

7.9 Air supply systems

The air extracted from a laboratory has to be replaced in an appropriate manner (See also Section 5.4.2). 'Natural ventilation', that is the introduction of air through open windows, has many drawbacks: the windows may not always be open, the air is not conditioned or filtered, the rate of supply varies with wind conditions and is consequently erratic, the windows may not be suitably placed to purge the whole volume of the laboratory or to prevent draughts near fume cupboards or other local exhaust ventilation terminals.

Some designs rely on air taken from an internal corridor *via* a transfer grille in the wall or door. This is inexpensive and the air taken from the corridor may well be warm. However, normal use of the corridor may make the air dirty and there is no longer a fire and *smoke* barrier between the laboratory and the corridor. An intumescent honeycomb cell⁶⁶ may be inserted in the grille to maintain the integrity of the *fire* barrier but it does not provide a *smoke* barrier at low temperatures.

A preferred air supply system will be fan-assisted, with filtering⁷⁰ and other conditioning of the air to a degree appropriate to the nature of the laboratory. It will be interlocked with the extract system, often with a time delay to ensure that the extract or the supply airflow is established first depending on the application, and fitted with warning signals to indicate failure. For 'clean' laboratories, the air supply rate usually exceeds the extract rate by some 10% so that a positive pressure is maintained in the room; in laboratories for work with toxic substances, the supply rate is usually some 10% *below* the extract rate to create a slight negative pressure in the room.

High volume flowrates are likely to be encountered. It is important to avoid draughts which may adversely affect staff or the efficiency of the fume cupboards or local exhaust ventilation terminals. The siting of air supply grilles and the velocity of discharge are therefore important.

It may be necessary to switch the ventilation system on or off following an accident or during a fire; clearly labelled start and stop switches are often placed near the exit from the laboratory or in an anteroom in addition to any switches mounted near the fume cupboard or local exhaust ventilation terminal.

Energy conservation must be considered (Section 5.4.2). This will involve regard for the managerial controls applied to working practices in the laboratory. For example, the ventilation may be re-

quired to run 24 hours a day or only infrequently, variable extract rate fume cupboards may be installed, heat recovery may be investigated (but is usually not practicable in small installations). The debate must cover the need to provide adequate general ventilation and to prevent reverse airflow out of fume cupboards and other enclosure when they are not in use.

The use of interconnected venturi control valves²³ (Fig.7.8) provides a convenient means of interlocking variable supply rates to variable extract rates⁶⁷ and to Building Energy Management Systems (BEMS).⁶⁸

The hygiene of air conditioning and ventilation systems affects indoor air quality. Both designers and building operators need to consider procedures which mitigate any adverse effects on the occupants.⁷²

7.9.1 Variable air supply for switched fume cupboards

The simplest ventilation system for a fume cupboard installation, at least in principle, arises when the airflow requirements are constant, *ie* when all of the fume cupboards run all of the time at the same extract rate. Difficulties can manifest themselves when the system has to be balanced especially if it is complex in terms of the number of fume cupboards and disparity in duct-runs. Such a mode of operation is not always acceptable to the user because of the pattern of work may not require continuous use of all fume cupboards or there may be constraints on the total capacity of the air-handling units or a desire to introduce some energy conservation by extracting less air.

(a) Several fume cupboards in one room.

Consider several fume cupboards installed in one room, each requiring a constant air supply when operating (*ie* not variable extract fume cupboards in which the extract rate varies with sash height), but which can be operated independently by switching individual extract fans on or off. A control unit can easily sense the number of fume cupboards in use and adjust the air supply system according, perhaps by utilising a pole-changing motor or a speed controller or a pre-settable venturi control valve (Fig.7.8). If a fume cupboard is switched off by stopping its individual extract fan, the possibility of reverse airflow out of the fume cupboard and into the room must be considered as the room is likely to be operated at a slightly negative pressure in a hazards laboratory. Dampers in the extract duct or attempts to balance the air pressures may not provide a satisfactory solution and the extract system may have to incorporate a reduced pressure collection/dilution duct (Fig.7.7).

(b) Several fume cupboards but in different rooms

If the fume cupboards are in different rooms in a building and are isolated from one another in terms of the air demands, the potential for reverse flow may be present. However, remote users may not be aware of each other's work programme and it would be particularly serious if there was local switch control of the extract fans²⁶ such that the fume cupboards in one room could be turned off without warning by a person in another room. The latter problem can be overcome by mounting a switch and illuminated sign at each fume cupboard with the sign indicating both that the airflow is satisfactory *and* that the extract fan is being held on by the switch at that particular fume cupboard.

(c) Several fume cupboards, each with a variable extract rate

If fume cupboards in a system can not only be switched on and off by the users but also have variable extract rates which depend on the sash height, a full variable air volume (Section 5.4.2) system would be required involving a sophisticated control system⁷¹ and possibly venturi control valves (Fig.7.8).⁶⁷

7.10 References

1. *An introduction to local exhaust ventilation*, HS/G 37, Health and Safety Executive (1987), HMSO, ISBN 0 11 883954 3.
2. Stewart, L.J. (1985), *Design guidelines for exhaust hoods*, TN 3/85, Building Services Research and Information Association (BSRIA), Bracknell, ISBN 0 86022 142 3.
3. British Occupational Hygiene Society Technical Guide No.7, *Controlling Airborne Contaminants in the Workplace*, (1988), H and H Scientific Consultants Ltd, ISBN 0 905927 42 7.

Ventilated enclosures and fume discharge

4. Fletcher, B. and Johnson, A.E. (1986), 'The capture efficiency of local exhaust ventilation hoods and the role of capture velocity', In Goodfellow, H.D., Ed., *Ventilation '85: Proceedings of the 1st International Symposium on Ventilation for Contaminant Control*, October 1985, Toronto, pp 369-91; Chemical Engineering Monographs 24, Elsevier Science Publishers, ISBN 0 444 42622 1.
5. Fletcher, B. (1978), 'Effect of flanges on the velocity in front of exhaust ventilation hoods', *Ann. Occup. Hyg.*, 21, 265-9.
6. Garrison, R.P. (1983), 'Velocity calculation for local exhaust inlets - graphical design concepts', *American Industrial Hygiene Association Journal* 44(12), 941-7.
7. *Dust extraction systems in the ceramics industry*, Health and Safety Executive (1975), HMSO.
8. *The Control of Substances Hazardous to Health Regulations 1988*, SI 1988 No.1657, HMSO.
9. *The maintenance, examination and testing of local exhaust ventilation*, HS(G)54, Health and Safety Executive (1990), HMSO, ISBN 0 11 885438 0.
10. Whyte, W. (1991), *Cleanroom Design*, Wiley, ISBN 0471 92814 3.
11. Farquharson, G.J. (1989), 'Building and facility design for clean and sterile pharmaceutical product manufacture'. In Vincent, J.H. (1989), Ed., *Ventilation '88: Proceedings of the Second International Symposium on Ventilation for Contaminant Control*, September 1988, London, pp 231-6, Pergamon, ISBN 0 08 036148 X.
12. *Guide to Good Manufacturing Practice for Medicinal Products*, (1989), Commission of the European Communities, Office of Official Publications, 2 rue Mercier, L2985, Luxembourg.
13. *Laboratory Containment Facilities for Genetic Manipulation (Note 8)* (1988), Advisory Committee on Genetic Manipulation, Health and Safety Executive, 1 Chepstow Place, London W2 4TF.
14. *Protection of Laboratory Workers from Infectious Diseases Transmitted by Blood and Tissue* (1989), National Committee for Clinical Laboratory Standards, 771 East Lancaster Avenue, Villanova, PA 19085, USA.
15. BS5295: 1989, *Environmental cleanliness in enclosed spaces*; Part 0, *General introduction, terms and definitions for clean rooms and clean air devices*; Part 1, *Specification for clean rooms and clean air devices*; Part 2, *Method for specifying the design, construction and commissioning of clean rooms and clean air devices*; Part 3, *Guide to operational procedures and disciplines applicable to clean rooms and clean air devices*; Part 4, *Specification for monitoring clean rooms and clean air devices to prove continued compliance with BS5295: Part 1*, British Standards Institution, London.
16. US Federal Standard 209D: 1989, *Clean room and work station requirements, controlled environment*, Office of Technical Services, Department of Commerce, Washington, D.C.
17. VDI 2083: 1990, 3 Parts, *Cleanroom Engineering Classes*, Vereinigte Deutsche Ingenieure, VDI-Gesellschaft Technische Gebäude Ausrüstung, Graf-Recke Strasse 84, D-4000 Düsseldorf, Germany.
18. AFNOR X44101: 1972, *Définition et Classification de la Propreté Particulière de l'Air et d'autres Gaz*, Association française de normalisation, Tour Europe, Cédex 7 - 92080 Paris La Défense, France.
19. AS1386: 1989, 7 Parts, *Cleanrooms and Work Stations*, Standards Association of Australia, 80 Arthur Street, North Sydney, New South Wales, Australia.
20. ACGIH, *Industrial Ventilation: A Manual of Recommended Practice*, American Conference of Governmental Industrial Hygienists, (Distributors H & H Scientific Consultants Ltd, Leeds, UK).
21. BS 7258: 1990: *Laboratory fume cupboards*, Part 1: *Specification for safety and performance*; Part 2: *Recommendations for the exchange of information and recommendations for installation*; Part 3: *Recommendations for selection and use*, British Standards Institution, London. (Revised)
22. DD 191: 1990: Draft for Development, *Method for determination of the containment value of a laboratory fume cupboard*, British Standards Institution, London. (Now Part 4 of revised BS 7258)
23. *Information from*: H and H Scientific Consultants Ltd, PO Box MT27, Leeds LS17 8QP.
24. Hughes, D. (1987), *A literature survey and design study of fumecupboards and fume-dispersal systems*, Science Reviews Occupational Hygiene Monograph No.4, H and H Scientific Consultants Ltd, ISBN 0 905927 50 8. (out of print)
25. Cook, J.D. and Hughes, D. (1989), *Fumecupboards revisited*, HHSC Handbook No.2, H and H Scientific Consultants Ltd, ISBN 0 948237 01 5.
26. Hughes, D. (1989), *Discharging to atmosphere from laboratory-scale processes*, HHSC Handbook No.4, H and H Scientific Consultants Ltd, ISBN 0 948237 03 1.
27. *Health Equipment Information* (1980), 69/80 and 70/80, *Microbiological Safety Cabinets and Laboratory Fume Cupboards: Recommendations concerning their choice, installation, routine maintenance and use*, Department of Health and Social Security 14 Russell Square, London WC1B 5EP.

28. *Guidance on laboratory fume cupboards* (1990), The Royal Society of Chemistry, ISBN 0 85186 329 9.
29. Hughes, D. (1986) 'Laboratory fume cupboards and fume-dispersal systems'. In Goodfellow, *loc. cit.* reference 4, pp 53-63.
30. Smoke pellets: P.H. Smoke Products Ltd, Farfield Works, Glen View Road, Eldwick, New Bingley BD16 3EF, W. Yorkshire.
31. Brock's Fireworks Ltd, Industrial Division, Sanquhar, Dumfriesshire DG4 6JP, Scotland.
32. Smoke generators: Concept Engineering Ltd, 30 White Waltham Airfield Estate, Near Maidenhead, Berks SL6 3QQ.
33. Smoke generators: T.E.M. Engineering Ltd, Gatwick Road, Crawley, Sussex RH10 2RQ.
34. Koenigsberg, J. (1986) 'The explosion-resistant fumehood', *American Laboratory*, 12(2), February, 89-96.
35. Everett, K.E. and Hughes, D. (1981), *A Guide to Laboratory Design*, Butterworths, ISBN 0 408 70935 9.
36. *Health Notice HN(76)36* (1978), 'Health service management: possible risk to health from the spraying of chemicals in the laboratory', Department of Health and Social Security, London, 16 August.
37. Ljungqvist, B. and Waering, C. (1989), 'Some observations on "modern" design of fume cupboards'. In Vincent, J.H. (1989), Ed., *Ventilation '88: Proceedings of the Second International Symposium on Ventilation for Contaminant Control, September 1988, London*, pp 83-8, Pergamon; ISBN 0 08 036148 X.
38. *ASSAB BAHCO Tornado Extractor Cupboards*, KEBO Lab International, K & K-Greef Ltd, Suffolk House, George Street, Croydon, CR9 3QL.
39. Waldner-MSA Ltd, Ratcliffe House, Leacroft, Kingston Road, Staines, Middx TW18 4NN.
40. *Astecair Fume Cupboards*, ASTEC Environmental Systems, 30-31 Lynx Crescent, Weston-super-Mare, Avon BS24 9BP.
41. *Toxicap Ductless Fume Cabinets*, Bigneat Ltd, 64 Solent Road, Havant, Hants PO9 1JH.
42. *Non-ducted Filtraton Fume-Hoods*, Safelab Systems Ltd, 62 Prince Street, Bristol BS1 4QD.
43. *Class II Bio-Safety Cabinet Series*, set of 4 video training programs made by Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO), available from H and H Scientific Consultants Ltd, PO Box MT27, Leeds LS17 8QP, UK.
44. *Categorisation of Pathogens and Categories of Containment* (1990), Advisory Committee on Dangerous Pathogens, HMSO.
45. *Laboratory Biosafety Manual* (1983), (new edition in press 1992), World Health Organization, Geneva.
46. *Biosafety in Microbiological and Biomedical Laboratories*, 2nd edition (1988), Centers for Disease Control, National Institutes of Health, US Government Printing Office, Washington DC.
47. BS 5726: 1992, *Specification for Microbiological (Biological) Safety Cabinets*, (four Parts), British Standards Institution, London.
48. *For example*, Penair Filtration Ltd, Watson Mill Lane, Sowerby Bridge, W. Yorks. HX6 3BW.
49. Keimig, S.D., Esmen, N.A., Erdal, S. and Sansone, E.B. (1991), 'Solvent desorption from carbon beds in ducted and non-ducted laboratory fume hoods', *Applied Occupational and Environmental Hygiene* 6(7), 592-7.
50. Alliger, H. (1976), 'The birth of a scrubber', *American Laboratory*, December.
51. Renton, L.A. and Duffield, G.A. (1986), 'Preliminary evaluation of an integral scrubber/fume hood design for control of noxious vapours'. In Goodfellow, H.D., *loc. cit.* reference 4, pp 677-686.
52. Stevens, D.C. (1985), *Sampling of Gaseous Wastes Discharged to the Atmosphere*, Report No.R11567, AERE, Harwell.
53. Radman Associates, Harvey House, Bollington, Macclesfield SK10 5JR; tel. 01625 576000, fax 01625 576001.
54. Clarke, J.H. (1965), 'The design and location of building inlets and outlets to minimise wind effect and building re-entry of exhaust fumes', *American Industrial Hygiene Association Journal* 26, 242-8, May-June.
55. Drivas, P.J., Simmonds, P.G. and Shair, F.H. (1972), 'Experimental characterisation of ventilation systems in buildings', *Environmental Science and Technology* 6(7), 609-14.
56. *A User Guide to Dust and Fume Control*, The Institution of Chemical Engineers, Rugby CV21 3HQ.
57. Snyder, W.H. and Lawson, R.E. (1976), 'Determination of a necessary height for a stack close to a building: a wind-tunnel study', *Atmospheric Environment* 10, 683-91.

Ventilated enclosures and fume discharge

58. Lamb, B.K. and Cronn, D.R. (1986), 'Fume hood exhaust re-entry into a chemistry building', *American Industrial Hygiene Association Journal* 47(2), 115-23.
59. Wilson, D.J. (1977), 'Effect of stack height and exit velocity on exhaust gas dilution', *Trans American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE)* 83, No.2439, RP136, 157-67.
60. Hall, D.J. (1980), 'The discharge of fume cupboard effluents into the atmosphere', in *The Development and Use of Fume Cupboards, Fume Hoods and Ventilated Safety Enclosures for Laboratories*, Proceedings of the Symposium, March 1979, London, Laboratory of the Government Chemist, June 1980, pp 106-28.
61. Wilson, D.J. (1983), 'A design procedure for estimating air intake contamination from nearby exhaust vents', *Trans American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE)* 89, Part 2A, No.2769 (RP-204), pp 136-52.
62. Wilson, D.J. and Chui, E.H. (1987), 'Effect of turbulence from upwind buildings on dilution of exhaust gases', *Trans American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE)* 93, Part 2, NT-87-25-3, pp 2186-95.
63. Halitsky, J. (1968), 'Gas diffusion near buildings'. In Slade, D.H. 1968, *Meteorology and Atomic Energy*, Report No.TID-24190, July, US Atomic Energy Commission.
64. Halitsky, J. (1968), 'Diffusion of vented gas around buildings', *Journal of the Air Pollution Control Association* 12(2), 74-80.
65. Wilson, D.J. (1976), 'Contamination of air intakes from roof exhaust ducts', *Trans American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE)* 82, 1024-38.
66. *Honeycomb Fire Dampers*, Building Research Establishment Digest 158 (1975), HMSO.
67. McGregor, A. (1991), 'Variable air volume systems for laboratories with fume hoods', *Proceedings of the CIBSE National Conference 1991*, Canterbury, April 1991, pp 352 - 63, Chartered Institution of Building Services Engineers, London.
68. Shaw, M. and Willis, S. (1991), 'Intelligent building services control and management systems', *loc. cit.* Ref. 67, pp 536 - 47.
69. Fletcher, B. and Johnson, A.E. (1992), 'Containment testing of fume cupboards: I, Methods', *Annals of Occupational Hygiene*, 36, 3, pp 239-52.
70. Bennett, K. (1991), *Air Filters: a selection guide*, Building Services Research and Information Association, (available from H and H Scientific Consultants Ltd, Leeds).
71. Parsloe, C.J. (1991), *The Commissioning of VAV Systems in Buildings*, Building Services Research and Information Association, (available from H and H Scientific Consultants Ltd, Leeds).
72. Loyd, S. (1992), *Ventilation System Hygiene: A Review*, Building Services Research and Information Association, (available from H and H Scientific Consultants Ltd, Leeds).

8 STORAGE FACILITIES

8.1 Functions of stores

The essential function of storage facilities is often assumed to be no more than the keeping of goods and materials in a secure fashion under conditions which prevent or reduce deterioration. However, such a picture overlooks the dynamic nature of storage: the receipt and unpacking of goods, the allocation and movement of goods to appropriate storage areas, the distribution of goods to laboratories and other areas and often the return of unwanted goods including hazardous wastes and empty containers from the laboratory. Design of storage facilities must cater for all of these transitory activities and not simply for the keeping of goods in the storeroom itself.

Although a single store may be adequate to meet the needs of a small laboratory it is more common for a number of stores to be provided each serving a particular function. Goods are often received and distributed through a stores hierarchy: a central receiving store with facilities for the handling of bulky containers and subsequent dispensing and distribution to other stores or direct to laboratories, the subsidiary stores including those for the keeping of specific types of goods and finally the departmental store or stock-room serving one or more laboratories. With the exception of storage within the laboratory itself (see Chapter 4), a number of common design requirements apply to all storage facilities.

8.2 Basic design requirements

The receipt, keeping and distribution of goods form the main elements of the storage process and irrespective of the type of goods a number of design elements are relevant:¹

- (a) the location of the stores is of fundamental importance. There should be good access for vehicles with sufficient space for parking and manoeuvring and for the off-loading of goods quickly and safely preferably at a covered loading bay. The goods delivery area should be away from pedestrian routes to avoid traffic accidents. A central store should be conveniently positioned in relation to its customers: departmental or subsidiary stores and laboratories;
- (b) storage areas must have good physical security, perhaps supplemented by automatic closed circuit television scanning (CCTV) or other intruder alarm systems, in high-risk or sensitive areas to prevent intrusion or unauthorised access whether from outside or inside the laboratory building;
- (c) the provision of flooring and furniture of adequate strength and stability for the weight and size of goods to be accommodated;
- (d) there must be adequate clearance between adjacent rows of shelving, racks or cupboards to allow for safe access by staff, mechanical handling equipment and trolleys. Furniture must be located in such a way as to ensure ease of escape from the storeroom to a safe area;
- (e) lighting should be sufficient to enable labels and other documents to be clearly read;
- (f) the health and comfort of stores staff must be considered by the provision of adequate heating and ventilation, welfare and rest period facilities. Separate office facilities may be provided within the storeroom itself or in an adjoining area where transaction records can be securely kept;
- (g) emergency equipment must be provided to deal with small fires, spillage and first aid; bulk storage of hazardous goods may entail automatic fire detection and extinguishing systems.

The main storage facility will be a general-purpose storeroom for the accommodation of laboratory

Storage facilities

consumables, small items of equipment, non-hazardous chemicals and those chemicals and solvents provided on a daily basis to individual workers or departments. Within this storeroom will be areas set aside for the hazardous chemicals or other materials requiring special environments including flammable liquid cabinets, ventilated storage cupboards and refrigerated storage. Stocks of hazardous or highly flammable materials kept within the main stockroom should be strictly limited to provide for the normal daily requirements. Alternatively, such goods may be delivered to laboratory users directly from purpose-built storerooms.

8.3 Chemical storage

The safe storage of chemicals² requires consideration of their intrinsic hazardous nature, chemical and physical properties and the size and weight of containers. Certain chemicals may be controlled by legislation and in these cases the mandatory legal requirements may specify the manner of storage.^{3,6} For hazardous chemicals generally the storage facilities must allow for the segregation of certain hazard types and the prevention of contact, accidental or otherwise, of incompatible chemicals which together undergo violent reaction. Separation may be achieved within the stockroom by distance, physical containment barriers, or alternatively by the provision of separate buildings. A dry, secure and ventilated storeroom with chemical-resistant furniture is required. Temperature control must be such that chemicals are neither exposed to excessive heat which may increase volatility or overpressurise containers nor exposed to cold causing liquids to solidify, rupturing their containers. Additional requirements may apply to specific chemical types.

It is an essential component of stores policy and management that all areas, cupboards and containers are inspected at least once a year for signs of deterioration of the stock and to identify chemicals that are surplus to requirements or in a dangerous condition.

8.3.1 Corrosive and irritating chemicals

These chemicals require a separate area set aside within the main storeroom or suitable cupboards which should be ventilated if the substances are volatile. Containers should be stood on corrosion resistant trays or banded shelves to contain spillage or the container kept in an outer receptacle. Shelving should be non-absorbing and lipped and should not be higher than head height. Water should be available both for emergency drench showers and eye baths and for spillage treatment.

8.3.2 Toxic chemicals

Highly toxic chemicals, including controlled drugs, pesticides and those which are widely recognised as being 'poisonous', must be kept in secure storage with strictly limited access.^{5,7}

8.3.3 Reactive chemicals

Highly reactive chemicals may be hazardous because of the violence of their reactions with other incompatible substances or because they undergo reaction or rapid deterioration when exposed to air or water. The separation of mutually incompatible chemicals^{2,8} is particularly important in bulk stores where large containers are housed. Oxidising agents^{9,10} should be kept separate from incompatible materials such as flammable liquids, oils and greases, and ordinary combustibles; wooden shelving should be avoided unless chemical resistant trays or double-layer receptacles are used. However, there is no generally recognised classification scheme for the separation of incompatible chemicals² and further expert advice may be necessary according to the range and quantities of chemicals to be accommodated.

Safe storage of air- and water-sensitive chemicals relies largely on maintaining the integrity of the immediate container but it is necessary to keep such containers away from all contact with moisture.

8.3.4 Flammable solvents

The design and construction of stores for highly flammable liquids and petroleum spirit is controlled by statutory regulations^{3,4} with the objective of preventing fires within the store and protecting the contents against fires in an adjoining area or building. Such a store will generally be licensed and regularly inspected by the Local Authorities' Petroleum Inspectors.

Typically,^{1,11-13} a solvent store will be a separate structure of non-combustible and fire-resisting construction. Ventilation will be provided naturally by means of low- and high-level air bricks or mechanically using a flame-proof or intrinsically safe electrical system driving a fan with a non-sparking impeller. If artificial lighting is needed, this must also be provided by flame-proof fittings and switches. A door sill with a solid sealed floor must give a banded volume capacity sufficient to contain the contents of the store and an automatic carbon dioxide or dry powder fire extinguishing system must

be provided in large solvent stores. A lightweight roof or wall panel may also be provided for explosion venting.

The solvent store may be divided into several compartments for excise solvents, waste or used solvents and for liquids that are both highly flammable and toxic.

8.3.5 Compressed gases

Separate storage facilities will be required for compressed gases in cylinders whether full or empty. Cylinders may be stored in an external compound away from the building, in a store adjoining the building or kept within the laboratory building itself. While the optimum arrangement is influenced by the number of cylinders and the types of gas, all cylinder stores must have adequate fire resistance or separation, be well ventilated at both high- and low-level and enable gases to be segregated according to hazard type. The general requirements¹⁴ for an external gas cylinder store are:

- (a) a location that is readily accessible to, but protected from, vehicles both for normal deliveries and for emergency purposes, is away from drains, basements and ventilation intakes and at the recommended safe distances from other buildings, storage facilities, site boundaries, roadways or sources of ignition;
- (b) a lightweight roof to give protection against the weather with at least two sides constructed largely of open wire mesh or steel louver panels. The two remaining sides should have ventilation openings at high- and low-level unless they are required to be of fire-resisting construction or form part of an adjoining building;
- (c) a non-combustible and non-porous floor, preferably of concrete or similar material laid to allow water to flow away from the store;
- (d) dimensions and means of escape so that the travel distance from any point within the store to a final exit is not greater than 6 metres. The exit doors must be readily opened from the inside and be wide enough to enable trolleys or other devices for transporting cylinders to pass through;
- (e) electrical equipment in a store containing highly flammable or oxidising gases or within a 3 - metre distance of the store boundary should be flame-proofed or of equivalent design and construction;
- (f) cylinders should be separated in the store according to their hazard groups: highly flammable, oxidising, corrosive, toxic, or simple asphyxiants. Fire-resisting barriers or partitions together with safe distances should be used to isolate incompatible types from each other and all cylinders must be secured in an upright position.

External housing of cylinders may also be required when the gases are supplied to the laboratory user by means of fixed pipes and associated valves and fittings. A limited number of cylinders may be accommodated in an external gas supply point, being a suitably ventilated, secure compound or gas cabinet, located against an outside fire-resisting wall and away from windows, drains and air intakes.

Cylinders may be kept within buildings to provide a piped gas supply to several laboratories. Such internal gas supply rooms should be provided with extraction ventilation giving at least 10 air changes per hour with high- and low-level air supply and exhaust grilles. The exhaust ventilation system should be continuously monitored with a visual or audible alarm system giving warning of failure. All ignition sources must be removed from supply rooms containing flammable gases; electrical lighting or other systems must be flame-proofed or of an equivalent standard. A clearly labelled emergency isolation valve capable of being operated from outside the room should be provided for each supply cylinder or manifold.

8.4 Laboratory consumables and apparatus

Laboratory consumables, disposable products, glassware and small items of equipment and components will be stored in the main stock-room together with chemical reagents and solvents issued on a daily basis. Although such items do not warrant special storage conditions a clean, dry environment should be provided to prevent deterioration. Adequate space should be available for unopened cartons to be kept and plastic items isolated from accidental contact with or contamination by solvents and their vapours.

Cryogenic liquids, liquefied gases¹⁵ and cardice¹⁶ kept in insulated tanks or other vessels should be located in well ventilated areas, preferably exposed to the open air, and away from air intakes. Radioactive substances¹ including waste must be kept in storage areas secured against intrusion, flooding and damage by fire and separate from flammable or explosive substances. Storage cabinets used for radioactive waste may need to be of substantial concrete or metal construction with banded or lipped shelving.

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A radiochemical store will need refrigerators or freezers for keeping biochemical or radiopharmaceutical products to prevent deterioration.

Stores usually represent the greatest concentration of hazardous substances within the laboratory building. They can pose a significant potential risk to the building, its occupants and to the general environment in the event of an accident. The provision of sufficient and safe storage facilities should anticipate and prevent these hazards and at the same time eliminate or lessen the need for laboratory workers to hoard hazardous substances in inadequate conditions.

8.5 Security

As a general principle all storage areas from large scale facilities to individual laboratory stores should be secure against access by unauthorised persons. Security is needed for a number of reasons but especially to prevent theft, pilfering and vandalism. Stores are particularly vulnerable because of the concentration of goods kept there, the high frequency of visits by delivery drivers and persons collecting goods and the almost universal custom of locating such facilities at the rear of buildings where intruders may be unobserved. Goods within the store which are most at risk from theft include personal computers and ancillary equipment, drugs and other medicinal products, poisons, precious metals and hypodermic syringes and needles. Lack of security is also inimitable to good stock control.

8.5.1 Structural security measures

Structural measures may include high-level physical security barriers presented by safes and strong rooms kept in stores which are themselves protected against intrusion.¹⁷ External doors should be kept to a minimum number consistent with adequate means of escape and with the receipt and movement of goods; good quality locks and lockable surface or mortise bolts which are thief-resistant may be necessary. Other external openings, such as windows, fan lights and loading bays or wharfs, can be protected by shutters, expanded metal mesh grilles or bars which may be fixed or removable. The external area adjacent to the store may be fitted with security lighting which is permanently lit or activated by automatic sensors.

The store must also be secured against unauthorised entry from within the laboratory building. Internal doors and hatches must have strong doors, shutters and frames with security locks. Goods lifts which connect the store internally to other floors of the building can provide a weak point of entry unless the lift doors are kept locked or the lift mechanism is key-operated.

Whatever means of security are employed to protect the store it is essential that access is controlled by regulating the issue of keys. Mechanical keys, card keys, digital combinations and other entry devices must be available only to authorised persons. Entry may be further controlled by remote operated locks with telephone or television monitored entry points. High security storage areas may be fitted with positive individual recognition devices using voice or retinal identification.

8.5.2 Intruder alarm and surveillance systems

Alarm systems to detect and deter intruders can supplement the structural security measures, further protecting the most vulnerable areas of the store.¹⁸⁻²⁰ A basic system may incorporate magnetic reed switches at openable doors and windows, electrically energised metal foil or wire fitted to glazed panels and pressure pads or vibration sensors giving point-of-entry detection. Space sensors can be used to detect heat radiation, movement, noise or vibration within the area of the store itself or its approaches using infrared, microwave, ultrasonic, or acoustic devices which may be active (energy transmitting) or passive (energy receiving). Alternatively, close circuit television (CCTV) systems can be used with fixed or remotely controlled zoom lens cameras to monitor entry points and areas within the building. The alarm system may sound an audible siren or bell to deter the intruder or activate a muted signal in a building security post, local police station or remote security company station with the intention of apprehending the intruder.

The laboratory designer in seeking to prevent illegal entry, arson, theft, pilfering and vandalism is increasingly turning to a combination of good structural security supplemented by visible detection and alarm systems. Specialist advice may be necessary¹⁹ if effective and practical measures are to be provided and to ensure that the needs of safety and security are mutually compatible.

8.6 References

1. Everett, K. and Hughes, D. (1981), *A Guide to Laboratory Design*, Butterworths, ISBN 0 408 70935 9.
2. Pipitone, D.A., Ed. (1991), *Safe storage of laboratory chemicals*, Wiley, ISBN 0 471 51581 7.
3. *Highly Flammable Liquids and Liquefied Petroleum Gases Regulations 1972*, SI 1972 No.917, HMSO.
4. *Petroleum (Consolidation) Act 1928*, HMSO.
5. *Poisons Rules 1982*, SI 1982 No.218, HMSO.
6. *Ionising Radiations Regulations 1985*, SI 1985 No.1333, HMSO.
7. *Storage of approved pesticides: guidance for farmers and other professional users* (1988), Guidance Note CS 19, Health and Safety Executive, HMSO, ISBN 0 11 885406 2.
8. *Storage of packaged dangerous substances* (1986) Guidance Note CS 17, Health and Safety Executive, HMSO, ISBN 0 11 883526 2.
9. *Storage and use of sodium chlorate and other similar strong oxidising agents* (1985), Guidance Note CS 3, Health and Safety Executive, HMSO, ISBN 0 11 883523 8.
10. *The storage and handling of organic peroxides*, (1991) Guidance Note CS 21, Health and Safety Executive, HMSO, ISBN 0 11 885602 2.
11. *Storage of flammable liquids in containers* (1990), HS(G)51, Health and Safety Executive, HMSO, ISBN 0 11 885533 6.
12. *Storage and use of highly flammable liquids in educational establishments* (1986), IAC/L15, Health and Safety Executive, 1 Chepstow Place, London W2 4TF.
13. *Firecode Storage of Flammable Liquids* (1987), Fire Practice Note 2, Department of Health and Social Security, HMSO, ISBN 0 11 321111 2.
14. BCGA Guidance Note GN 2, *Safe practice for the storage of gases in transportable cylinders intended for industrial use*, (1988); BCGA CP 8, *The safe storage of gaseous hydrogen in seamless cylinder and similar containers*, (1983); BCGA CP 18, *The safe storage, handling and use of special gases in the micro-electronics industry*, (1988), British Compressed Gases Association, St Andrews House, 26 Brighton Road, Crawley, West Sussex, RH10 6AA.
15. BCGA CP 19, *Bulk liquid oxygen storage at users' premises*, (1990) British Compressed Gases Association, St Andrews House, 26 Brighton Road, Crawley, West Sussex RH10 6AA.
16. *Dry Ice: Solid CO₂*, Data and Safety Sheet, BOC Ltd, The Priestley Centre, 10 Priestley Road, The Surrey Research Park, Guildford, Surrey GU2 5XY.
17. Sinnott, R.(1985), *Safety and Security in Building Design*, Collins, ISBN 0 00 383021 7
18. BS 4737, *Intruder alarm systems in buildings*, Section 4.1: 1987, *Code of Practice for planning and installation*, British Standards Institution, London
19. *Security Engineering*, Applications Manual AM4:1991, The Chartered Institution of Building Services Engineers, Delta House, 222 Balham High Road, London SW12 9BS
20. Pike, P. and Pennycook, K. (1992), *Application Handbook: Installation, commissioning and maintenance of fire and security systems*, BSRIA AH3/92, Building Services Research and Information Association (available from H and H Scientific Consultants Ltd, PO Box MT27, Leeds LS17 8QP).

9 WASTE MANAGEMENT

9.1 Introduction

Waste from laboratories can take any form and can present any hazard. It can vary from a piece of damp tissue, to a flammable solvent, to a highly pathogenic organism. Each particular type of laboratory will have its own specialised wastes and their control and disposal needs to be carefully preplanned rather than be left as a haphazard operation.

Several books and papers have been published on the subject¹⁻⁷ but, because of new developments and regulations in the whole field of waste management, many of the options previously open to a laboratory manager have now been curtailed.

There are two parts to waste management in a laboratory: waste control and waste disposal.

9.2 Waste control

The principles of waste control are as follows:

- (a) Minimise the amount of waste produced.
- (b) Organise experiments so that the waste produced is non-hazardous or of minimum hazard.
- (c) Segregate the waste for
 - (i) safety reasons
 - (ii) disposal reasons.
- (d) Keep adequate records.
- (e) Use properly designed and maintained storage areas.
- (f) Use competent disposal contractors licensed to handle the waste.

9.2.1 Minimising waste

In laboratories, each experiment or process should be designed so that either minimum quantities of waste products result, or smaller amounts of material are used so that less waste is produced. A viable alternative is to be able to use the waste product as feedstock for a further experiment.

This option requires careful planning and complete knowledge of the physical and chemical principles involved in the experiment. Thus waste minimisation can be made to form part of a teaching exercise or, in commercial premises, to force the staff to think with more care of their proposed experiments.

9.2.2 Reduction of hazardous waste

This is really a continuation of the philosophy propounded in Section 9.2.1. Thus, if a proposed experiment will produce a waste with very dangerous toxicological properties which would be expensive to dispose of, then a different experiment or experimental route should, if possible, be conceived so as to produce less hazardous material.

9.2.3 Segregation of waste

Manuals on the handling of chemicals state which materials need to be separated from each other and which need special storage conditions. For instance oxidising agents need to be separated from organic materials and alkali metals need protection from water. Material does not change its properties because it becomes a waste, therefore the same principles have to apply. Waste storage areas must be designed to accommodate the need for segregation and appropriate storage rooms and banded areas provided.

Disposal of chemical waste is becoming more controlled and waste disposal contractors require accurate descriptions of the waste. In addition, even small quantities of a particularly hazardous substance in a large quantity of inert material will cause the large quantity itself to become a hazardous waste and subject to much higher disposal costs. Thus the careful segregation of particularly hazardous material makes both safety and commercial sense.

9.2.4 Record keeping

Waste material must be accurately and legibly labelled. Careful records must be kept of the quantity and location. This will enable up-to-date checks of stock to be made and will enable the paperwork required by legislation, such as waste consignment papers, to be filled in quickly and accurately.

9.2.5 Storage area

Any area used for the storage of laboratory waste must be properly designed and maintained. Any leakage must be promptly attended to and effective fire precautions taken.

Many stores are in old sheds which are left alone to make their own way. It is of the utmost importance that a senior person is given responsibility for waste storage and disposal. They must make sure that all lights, safety systems and the building integrity are regularly inspected and maintained. The inspections should be logged and repairs and suggestions must be followed up and their completion recorded. Waste disposal and storage must not be made the responsibility of the most junior and unsupervised storekeeper.

9.3 Waste collection

Prior to storage and disposal, the laboratory personnel need to put their waste in containers within the laboratory. The design and use of these containers is most important as this aspect of waste disposal can have the most potential for danger. Accidental mixing of unsuitable materials in a bin could have disastrous consequences. There must be firm written instructions over each waste container as to what material may be put in it. Especial care must be taken with flammable solvents, the bins must be approved by the Fire Authorities and the bin area bunded. The bins should be easy to access and empty. It may be decided to use the bins for storage so that no emptying is needed within the laboratory. The bins would be taken direct to the storage area and replaced by empties. If this system is used, then care must be taken to clean the bins thoroughly before replacement; the same precaution is necessary if they are emptied within the laboratory. Codes of practice for the use of each container must be written and displayed and methods devised so that the laboratory personnel adhere to them.

The potential for the release of material into the atmosphere is highest from the containers within the laboratory. It is therefore essential that careful use and control of these containers is made a first priority. Special precautions must be taken for particularly hazardous waste. These will probably be covered by the required COSHH assessment⁸ but codes of practice must be put in place for handling this type of material.

The number, type and construction of each bin or solvent container will depend on the size of the laboratory and the substances used. However the layout and the codes of practice must be agreed and implemented.

In a computer laboratory, all that may be needed would be a waste paper bin; a microbiological laboratory should have special sequences of practice for sterilisation and/or disinfection of pathological waste including the containers.

Once the agreed waste disposal practices are in place then they should become ingrained into the habits of the personnel so that they become 'standard practice' and the possibility of placing two mutually reacting waste chemicals together in the same bin should be reduced to a minimum.

9.4 Waste disposal

Laboratories once saw to their own waste disposal. Many substances were flushed down the drain, others were burnt in an open tray whilst some were buried in shallow holes. Most of these methods have become obsolete or are forbidden by law. The only one that is, or should be, still used is the flushing of certain substances to sewer. However, this has to be done using written codes of practice. For instance, acids have to be neutralised prior to disposal and only substances permitted by the Water Authorities can be disposed of in this fashion.

More usually a contractor licensed by the Local Authority to dispose of laboratory waste should be used. It is incumbent on the waste producer, the laboratory, to ensure that the waste will be disposed of in a competent and legal manner.

The methods used for the treatment and disposal of waste can be listed as follows:

- (a) *Physical treatments*: weirs, filters, centrifuges and adsorbents for particulate or oil removal; infrared, ultraviolet and microwave radiation for specialist treatments.
- (b) *Chemical treatments*: neutralisation, precipitation and chemical oxidation.
- (c) *Pyrolysis*: thermal treatment in the absence of oxygen.
- (d) *Incineration*: thermal oxidation.

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(e) *Dilution, delay and dispersion*: use of landfill, or the dilution facility of water or atmosphere either to hold waste or to dilute it to such an extent that the components are no longer harmful.

(f) *Storage*: either in disused mines or specially built silos or bunkers.

Each of these methods has been and is used depending on the type of hazard posed by the waste. In practice most chemical waste is incinerated or landfilled. Modern practice attempts to ensure that no hazardous materials escape from these methods. For instance, landfills are monitored for methane gas and leachate is collected and treated. Incinerators are fitted with high performance, gas-scrubbing systems to ensure that no hazardous material escapes.

With the correct disposal system matched to the waste and with modern monitoring controls, chemical waste can be safely treated and disposed of.

9.5 Infectious waste

9.5.1 Definitions

It is a cardinal rule that no infected material shall leave the laboratory.⁹

A considerable amount of the waste that is generated by microbiological, clinical and biomedical laboratories contains or has been in contact with pathogenic microorganisms. Table 9.1 lists the waste from such laboratories which should be treated as infectious.

9.5.2 Principles

The safe and correct methods of treating infected laboratory waste are given in three official documents^{10,11,12} and other publications.^{13,14} These stipulate that infectious waste should be rendered safe by steam sterilisation (autoclaving) before final disposal, or that it should be incinerated, and under the supervision of laboratory staff.^{11,12,13}

9.5.3 Design implication

(a) Autoclaving

There are several different kinds of autoclave but not all are suitable for the treatment of infected waste. A competent microbiologist should be asked for advice on the suitability of various models and their capacity before planning decisions are made.

Autoclaves are large 'pressure vessels' that may occupy up to 4 m² of floor space. They are heavy and attention must be given to floor loading. Dimensions and dead weight are provided by manufacturers. There is a relevant British Standard.¹⁵ Autoclaves require a steam supply (some smaller models generate their own steam), a water supply, electricity, and a drainage facility for removing effluent. Larger autoclaves require a hood and mechanical extract system to remove steam and vapours.

As most large autoclaves are loaded from purpose-made trolleys, space must be allowed for these to be manoeuvred.

After it has been made safe by autoclaving, the waste may be removed by the Local Authority or a contractor for final disposal according to local arrangement, usually by incineration, rarely by landfill.

(b) Incineration

Large laboratories should have incinerators on site. Models suitable for laboratory use are available. These should conform to the appropriate British Standard¹⁶ and to the requirements of the Department of the Environment,⁵ the Health and Safety Commission,¹⁷ and the local Environment Health Department arising from current legislation relating to environmental pollution. Only those incinerators that satisfy current legal standards should be considered.

Laboratory incinerators should preferably be placed outside the main building but there should be easy access. Space should be provided for temporary storage of waste pending treatment, and for ash pending removal.

As incinerators require smoke stacks the local authority must be consulted about the height and the siting.

If infected material is to be removed from laboratories and incinerated elsewhere, a site should be designated for bags and containers awaiting collection. This should have an impervious floor base and provided with a drain and a water supply for washing down after decontamination as and when necessary. The area should be secure if it is inside the building, or adequately fenced to deter vandals and vermin if it is outside.

As with chemical waste, with competent handling and control procedures and suitable equipment, infectious waste can be safely disposed of without danger to the operators or the general public.

Table 9.1

Microbiological, clinical and biomedical laboratory waste.

The following should be regarded as infectious:

a. Disposables other than sharps

1. Specimens or their remains, in their containers, submitted for tests: containing blood, faeces, sputum, urine, secretions, exudates, transudates, other normal or morbid fluids but not tissues.
2. All cultures made from these specimens, directly or indirectly.
3. All other stocks of microorganisms that are no longer required.
4. Used diagnostic kits.
5. Used disposable transfer loops, rods, plastic pasteur pipettes.
6. Disposable cuvettes and containers used in chemical analyses.
7. Biologicals, standards and quality control materials.
8. Food samples, submitted for examination in outbreaks of food poisoning.
9. Paper towels and tissues used to wipe benches and equipment and to dry hands.
10. Disposable gloves and gowns.

b. Sharps

1. Hypodermic needles (with syringes attached if custom so requires).
2. Disposable knives, scalpels, blades, scissors, forceps, probes.
3. Glass pasteur pipettes; slides and cover glasses.
4. Broken glass, ampoules and vials.

c. Human and animal tissues and animal carcasses**d. Bedding from animal cages.****9.6 References**

1. RSC Chemical Information Group (1983), *Proceedings of a meeting on the disposal of hazardous waste from laboratories*, Royal Society of Chemistry Publications, London.
2. Pitt, M.J. and Pitt, E. (1985), *Handbook of laboratory waste disposal*, Ellis Horwood.
3. Fischer, K.E. (1987), 'Self-audits of hazardous waste operations in laboratories', *J. Chem. Educ.*, Vol.64, No.9, A207, Sept.
4. Department of the Environment, *Special Wastes: a technical memorandum providing guidance on their definition*, Waste Management Paper No.23, HMSO 1981, revised 1987.
5. Department of the Environment (1983), *Clinical Waste*, Waste Management Paper No.25, (under revision), HMSO.
6. Cook, J.D. (1987), 'Disposal of wastes from laboratories handling chemical carcinogens', *Chem. and Ind.*, No.12, p 404, June.
7. Kaufman, James A. (1990), *Waste Disposal in Academic Institutions*, Lewis Publishers Inc.
8. *The Control of Substances Hazardous to Health Regulations 1988*, SI 1988, No.1657, HMSO.
9. Collins, C.H., Hartley, E.G. and Pilsworth, R. (1974) *The Prevention of Laboratory Acquired Infections*, Health Laboratory Service Monograph No.6, HMSO.
10. Department of Health etc (1978), *Code of Practice for the Prevention of Infection in Clinical Laboratories and Post-mortem Rooms*, HMSO.
11. Advisory Committee on Dangerous Pathogens (1990), *Categorisation of Pathogens according to Hazard and Categories of Containment*, 2nd Edition, HMSO.
12. Health Services Advisory Committee (1991), *Safe Working and the Prevention of Infection in Clinical Laboratories*, HMSO.
13. Collins, C.H. (1989), *Laboratory Acquired Infections*, 2nd Edition, Butterworths.
14. Collins, C.H. and Kennedy, D.A. (1992), *The Treatment and Disposal of Clinical Waste*, HHSC Handbook, H and H Scientific Consultants, Leeds (in press).
15. BS 2426: 1988 and 1990: *Autoclaves for sterilisation in laboratories*; and BS 3970: 1990: *Specification for steam sterilisers*, British Standards Institution.
16. BS 3316: 1987, *Code of practice for the design, specification, installation and commissioning of incinerators for the destruction of hospital waste*, British Standards Institution.
17. Health and Safety Commission (1982), *The Safe Disposal of Clinical Waste*, (under revision 1992), HMSO.

APPENDIX I: CLINICAL LABORATORIES

I.1 Introduction

Clinical laboratories include histopathology, clinical chemistry, haematology and microbiological laboratories. Any of these laboratories may investigate infectious material and generate infected waste (Chapter 9). The design of microbiological laboratories is considered in Appendix II. Some special considerations, apart from those discussed elsewhere in this book, are considered below.

I.2 Histopathology laboratories

Human and animal tissues are examined for the diagnosis of disease by microscopy. The processing involves treatment with formaldehyde, flammable solvents and waxes. Eventually, the remains of the tissues must be disposed of safely and in a way that causes no offence to the public. Much of the material must be stored for long periods after examination for future reference should the patient return for further treatment, as well as for forensic purposes.

Workers are seated for some operations, but stand for others. Benches of suitable heights for both should be provided. As operators handle sharp instruments and hazardous chemicals they should not be required to sit on high chairs or stools which predispose accidents during dismounting.

As much of the work involves detailed microscopy, there should be provision for vibration-free microscope benches.

The following considerations must therefore be given to the design of these laboratories.

I.2.1 Protective air enclosures

Most tissue and organs for examination are placed in formalin solutions to preserve them. During the initial processing, therefore, the operator must be protected from inhaling formaldehyde gas. During subsequent processing the tissues are treated with various solvents some of which are toxic. Spot ventilation hoods over benches are essential for the initial examination and selection. Fume cupboards, either the standard type that exhaust to atmosphere or those that recirculate air after chemical treatment (but *not* microbiological safety cabinets or clean air work stations!) should therefore be provided.

The work of some histopathology laboratories, however, does require microbiological safety cabinets. This should be ascertained at the design stage.

I.2.2 Floor loading; storage

The equipment used in histopathology is not particularly heavy but special storage facilities, involving heavy loads, are required.

The remaining parts of tissues, after samples have been removed for examination, are retained for months and as they are in glass or plastic containers their total weight is considerable.

Glass slides of histological preparations are retained for long periods and in large numbers they are also very heavy. The siting and floor loading of slide storage rooms and cabinets are particularly important at the design stage.

The prepared tissues, in flammable wax blocks, are also retained for many months and require fireproof storage.

I.2.3 Fire precautions

Large amounts of flammable solvents are used in histological processing. Some of this processing is automatic, in machines that work unattended during the night. Consideration should therefore be given to the use of nonflammable building materials, fireproof partitions and fire and smoke detectors.

I.2.4 Waste disposal

Tissue and organs that have been processed are usually sterile and do not need autoclaving. Provi-

sion should therefore be made for them to be incinerated. Alternatively, and with the approval of the Local and Water Authorities, the material may be macerated (in machines similar to those used for domestic garbage) and discharged into the sewer. Such machines require special plumbing and other services. Installation after building is complete may pose serious problems.

I.3 Clinical chemistry laboratories

Large numbers of specimens of blood and body fluids are analysed to aid the diagnosis of disease.

Some of the equipment used in these laboratories is free-standing, but benching is required for other apparatus. Workers sit for some activities but stand for others. Provision should be made for both.

I.3.1 Protective air enclosures

The numbers, types and sites of fume cupboards should be determined early in the design stage. Microbiological safety cabinets are rarely needed.

I.3.2 Floor loadings

Much of the equipment is heavy and bulky. Loading should be ascertained at the design stage.

I.3.3 Fire precautions; explosive substances

In general, fire precautions are the same as in other chemical laboratories but some equipment requires flammable gases. Where possible, these should be piped in from outside. Azide solutions are sometimes used in clinical chemistry. As azides form explosive compounds with copper, this metal must not be used for plumbing.

I.3.4 Waste disposal

Clinical chemistry laboratories differ from other chemical laboratories in that the material to be analysed is potentially infectious. Unless items of equipment have self-contained infected waste reservoirs, arrangements should be made for the effluents of analysers to be conducted at least 250 mm into a waste system. This may require special plumbing.

I.4 Haematology (and blood transfusion) laboratories

Blood specimens are examined for cell contents and behaviour, either microscopically or with automated equipment. As in histopathology and microbiology, much of the work is done with the operator sitting down and benches should therefore be the correct height (see above and Chapter 6). Vibration-free benches are necessary for microscopy.

I.4.1 Floor loadings

Cold rooms, large refrigerators and deep freezers may be required but most of the equipment is bench-mounted and not particularly heavy.

I.4.2 Protective air enclosures

Class I or Class II microbiological safety cabinets (Chapter 7) may be required. Some haematology work requires clean air work stations and/or fume cupboards.

I.4.3 Fire precautions

There are no abnormal fire risks in these laboratories.

I.4.4 Waste disposal

The material handled is potentially infectious and arrangements should be made, as in clinical chemistry laboratories, for the safe disposal of effluents.

APPENDIX II: MICROBIOLOGICAL LABORATORIES

II.1 Introduction

There is no such single entity as a 'microbiological laboratory'. While many microorganisms are harmless, even beneficial, others vary greatly in their potential to cause disease in man and animals and to damage the environment. A microbiological laboratory must therefore be designed accordingly, varying from a room or set of rooms for which there are no special requirements, to one in which security arrangements, intended to protect workers, the general public and the environment, are as strict as those necessary to protect bullion or state secrets!

II.2 Containment: prevention of infection

Many microbiological laboratories investigate and identify microorganisms that cause disease in man, animals and plants. Measures are therefore necessary to protect workers from infection and to prevent the 'escape' of infectious material into the community. These measures form the basis of good design of microbiological laboratories.

There is general agreement among microbiologists and public health officials that microorganisms, *ie* bacteria, viruses, rickettsias, microfungi and parasites, should be classified into *Hazard Groups* according to their pathogenicity, *ie* their ability to cause disease. These groups, numbered 1-4 in increasing order of hazard, are shown in Table II.1. Those in Group 1 are mostly harmless, but Groups 2, 3 and 4 contain pathogens. This is the current (1990) classification of the UK Advisory Committee on Dangerous Pathogens (ACDP).¹ There are other classifications, *eg* of the World Health Organization (WHO),² the United States Public Health Service (USPHS),³ the European Federation of Biotechnology (EFB)⁴ and the Organization for Economic Cooperation and Development (OECD)⁵ but the principles are the same: the wording differs slightly. Several countries and organisations have drawn up lists of microorganisms in Groups 2 - 4 (any not so listed are presumed to be in Group 1). Again, these vary slightly from state to state, for scientific, geographic and demographic reasons.² The EFB system is also concerned with microorganisms that are responsible for diseases of plants and crops of economic importance.

Table II.1

Definitions of Hazard Groups*

<i>Hazard Group 1</i>	An organism that is most unlikely to cause human disease.
<i>Hazard Group 2</i>	An organism that may cause human disease and which might be a hazard to laboratory workers but is unlikely to spread to the community. Laboratory exposure rarely produces infection and effective prophylaxis or effective treatment is usually available.
<i>Hazard Group 3</i>	An organism that may cause severe human disease and presents a serious hazard to laboratory workers. It may present a risk of spread to the community but there is usually effective prophylaxis or treatment available.
<i>Hazard Group 4</i>	An organism that causes severe human disease and is a serious hazard to laboratory workers. It may present a high risk of spread to the community and there is usually no effective prophylaxis or treatment.

*Reproduced by permission of the Advisory Committee on Dangerous Pathogens.¹

It follows that different levels of 'containment' - the total sum of precautions necessary for safe handling - will vary according to the Hazard Group of the organisms being handled and will also fall into four groups or *Containment Levels*. These Levels, 1 - 4, are shown in Table II.2, which again is that of the UK ACDP¹ and equates with the Hazard Groups (see below). A slight problem arises here because the EFB and the OECD do not regard Level 1 as 'containment' because microorganisms in Hazard Group 1 do not require containment. The OECD/EFB system is included in Table II.2. It is important, in the initial stages of laboratory design, to recognise that there are two current systems of containment levels as there will, inevitably, be a single system under the EC.

Table II.2

Relationship between hazard category or class of microorganism and the containment levels for laboratory work

Hazard Category or Class		Containment Level	
UK ^a	EFB ^b	UK	EFB/OECD ^b
1	Harmless	1	*
2	Low risk	2	1
3	Medium risk	3	2
4	High risk	4	3

a. Also US and WHO

b. European Federation of Biotechnology and Organization for Economic Cooperation and Development (apply mainly to industry)

* The EFB and OECD do not apply the word 'containment' to work with organisms in this category. In industrial work they require only Good Industrial Large Scale Practice.

A summary of ACDP requirements for the four Containment Levels is shown in Table II.3. Here it should be stated that Level 4 laboratories are few in number and cannot be designed or operated (in the UK) without consultation with the Health and Safety Executive and the ACDP. No further reference will be made to these laboratories in this appendix.

II.3 Preliminary design principles

It is appreciated that constraints will be imposed on the design. These may be financial, priorities of other departments, number of rooms available and their place within the building. A designer rarely has the advantage of starting with a blank sheet of paper and a green field.

II.3.1 Who should design?

It is an unfortunate fact of life that too often the eventual user - the microbiologist - is rarely consulted. The result is often a badly designed laboratory which may be unsafe for work with human, animal or plant pathogens or ergonomically unsound, eg a microbiological laboratory designed as a chemical or even teaching laboratory. On the other hand, some microbiologists have quite bizarre ideas. Ideally, therefore, there should be collaboration between an architect or experienced designer and the microbiologist who will work in the laboratory, with advice from an independent microbiologist.

II.3.2 The nature of the work

The designer must first be informed and advised about the nature of the work - what kinds of microorganisms will be handled and the Hazard Groups into which they have been placed - and of the necessity of conforming to ACDP and EC requirements.

Not infrequently, however, as in clinical laboratories, organisms in Groups 1, 2 and 3 may be investigated in the same building. While they could all be handled in a Level 3 laboratory, it would be wasteful to design the whole facility to that level. Microorganisms in Groups 1 and 2, however, may all be handled at Level 2. Therefore a clinical (or 'mixed') laboratory would require rooms designed at

Microbiological laboratories

both Level 2 and Level 3. In clinical and biomedical laboratories much more of the work is at Level 2 than at Level 3 and therefore economies in design are possible, with, perhaps, several Level 2 rooms but only one Level 3 laboratory which would require its own ventilation system.

Table II.3

Summary of containment level requirements*

Containment requirements	Containment levels			
	1	2	3	4
Laboratory site: isolation	No	No	Partial	Yes
Laboratory: sealable for fumigation	No	No	Yes	Yes
Ventilation: inward airflow/negative pressure through safety cabinet mechanical: direct mechanical: independent ducting	Optional	Optional	Yes	Yes
	No	Optional	Optional ^a	No
	No	Optional	Optional	No
	No	No	Optional	Yes
Airlock	No	No	Optional	Yes
Airlock: with shower	No	No	No	Yes
Wash basin	Yes	Yes	Yes	Yes
Effluent treatment	No	No	No	Yes
Autoclave site: on site in suite in lab - free standing in lab - double-ended	No	No	No	No
	No	Yes	Yes	No
	No	No	Optional	No
	No	No	No	Yes
Microbiological safety cabinet/enclosure	No	Optional ^b	Yes	Yes
Class of cabinet/enclosure ⁶	-	Class I	Class I/III	Class III

- a. If a Class III microbiological safety cabinet⁶ is chosen for use at Containment Level 3, it may be necessary to provide supplementary air extraction in the room in order to achieve an inward flow of air. A Class III cabinet used alone for this purpose may be insufficient.
- b. Required for clinical microbiological suites.

* Reproduced by permission of the *Advisory Committee on Dangerous Pathogens*.¹

II.4 Design practice

II.4.1 Position of laboratories in buildings

Although the fire risks in microbiological laboratories are not as great as those in *eg* chemical and histopathology laboratories, they are still considerable. In addition, as in chemical laboratories, it is often necessary to exhaust air to atmosphere. This may be difficult, expensive, or even place the community at risk if the laboratory is on the ground or lower floors. Ideally, unless they are self-contained and free-standing, microbiological laboratories should be placed on the top floors of buildings.

II.4.2 Allocation of space

Microbiological laboratories need ancillary service areas. These include service rooms, for sterilisation and preparation, built-in incubators and refrigerators, special instrument rooms, stores, offices, staff rest rooms, lavatories and street clothing accommodation. Circulation space, corridors, stairs and hallways must also be considered.

These should all be placed for the convenience and safety of the professional staff, *eg* to avoid the necessity of carrying or wheeling trollies loaded with infectious or hazardous materials any farther than is necessary. This should take priority over other considerations.

There is often the temptation to place laboratories in the cores of buildings where there are no windows. This should be avoided. Core rooms may be used for incubators, refrigerators, instrument rooms and stores but no-one should be expected to work in rooms without windows.

The work of a laboratory or group of laboratories is rarely static. Changes in use are inevitable and, whenever possible, should be anticipated. There are excellent modular systems on the market that allow the sizes of rooms to be changed without relocation of services (Chapter 6).

II.4.3 Services

Electricity, water and gas are necessary and the numbers of outlets will depend on the number of work stations and equipment in use. This information will be obtained from the room data sheets (see below). It is best to double the stated requirements as laboratory workers accumulate equipment that they did not know they needed at the outset!

It is good practice to have isolation switches and cocks in cupboards outside each room in case there is a fire or accident in that room.

If cylinders or bottles of flammable gases (hydrogen, propane) are to be used, consideration should be given to external storage and a piped supply (Chapters 4 and 5). The services for microbiological safety cabinets are considered in Chapter 7.

II.4.4 Handwashing basins

Staff who handle infectious material need to wash their hands frequently and whenever they leave the room. Handbasins should therefore be provided in all rooms where such work is done. They should be placed near to exits. Elbow-, wrist- or knee-operated faucets should be fitted. Laboratory sinks are *not* suitable for handwashing in microbiological laboratories.

II.5 Ventilation and heating

Conflicts of interest not infrequently arise in air-conditioned buildings and even sometimes in those with conventional heating. The problems occur because laboratory accidents do happen and microorganisms are released into the air as aerosols. Even with the best technique some aerosols may be generated. Infected air, carried around a recirculating ventilation system or through leakage, may place at risk people in other parts of the building. Table II.4 gives some examples of such disease transmissions.

Table II.4

**Examples of infections that have occurred among laboratory workers
as a result of dispersion of pathogenic microorganisms**

Brucellosis	Rocky Mountain Spotted fever
Tuberculosis	Venezuelan equine encephalitis
Tularaemia	Typhus fevers
Plague	Q fever
Anthrax	Smallpox
Meningitis	Psittacosis
Streptococcal disease	Influenza
Whooping cough	Histoplasmosis
	Coccidiomycosis

Source: Collins, C.H., *Laboratory Acquired Infections*.⁷

Although there seems to be no official requirement for air flows in Level 2 laboratories it is highly desirable that it should be from 'clean' to 'dirty' areas, *ie* from corridors and hallways to the laboratories and not in the reverse direction and that there should be at least six air changes per hour in the laboratories.

Similarly, there should be an inward flow of air into Level 3 laboratories, ensured by total exhaust to atmosphere through HEPA filters in extract fans on the wall or the ceiling, interlocked with the exhaust of microbiological safety cabinets (see below and Chapter 7) so that either, but not both, are operating at any one time (Fig.II.1).

There is probably no reason why air should not be recirculated from Level 1 laboratories, but air from Level 2 laboratories should not be recirculated unless it is first passed through properly maintained HEPA filters. It is unsafe to recirculate air from Level 3 laboratories under any circumstances.

Heating, and wherever reasonably practicable ventilation, should be under the control of those who occupy a room.

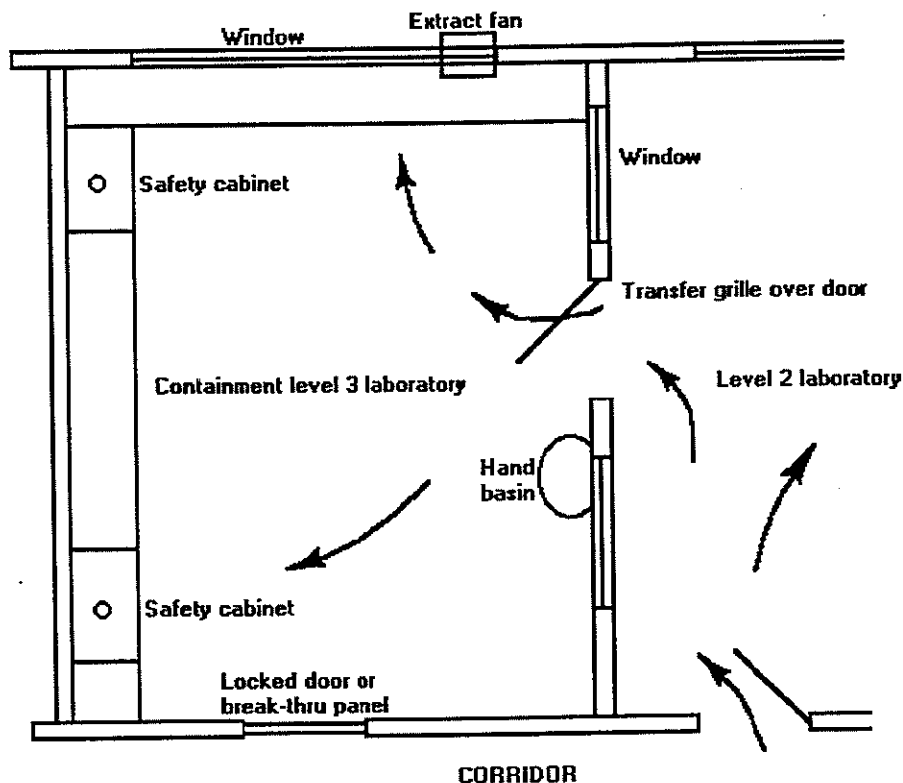


Fig.II.1: Suggested airflow patterns in microbiological laboratories designed to prevent the dispersion of air-borne pathogenic microorganisms.
(From Collins, C.H., *Laboratory Acquired Infections*, by permission of Butterworth-Heinemann.⁷)

II.6 Microbiological safety cabinets

Microbiological safety cabinets are the principal items of equipment for providing physical containment. Most laboratory techniques are known to produce inadvertent aerosols. The cabinets are used as barriers to minimise the hazard of air-borne infections by preventing the escape of these aerosols into the laboratory environment and their inhalation by the workers.

The importance of these cabinets to the safety of laboratory staff and other occupants of the building must be stressed. They are key features in the prevention of laboratory-associated infections. Many experienced microbiologists believe that microbiological laboratories should be designed *around* these cabinets.

The types and uses of microbiological cabinets are described in Section 7.7. They are the subject of a British Standard⁶ and specialist publications.^{1,2,7}

II.7 Surfaces and decoration

General advice on materials for walls, floors, ceilings and other surfaces is available.^{1,2,7} (See also Chapters 4 and 6). Floors and working surfaces should be impervious to acids and corrosive chemicals and easily cleaned. Painted, unrendered brick walls are not satisfactory. Flat surfaces, apart from benches and shelves, should be avoided as they gather dust and microorganisms. Floors and ceilings should be covered to the walls and, as laboratories have to be fumigated from time to time, all pipe and service communications between rooms should be sealed.

Floor covering should be heavy duty, non-slip vinyl, sealed at the seams and to the walls. Surface finishes (walls, ceilings, floors and benching) should be discreet, with no strong colours.

II.8 Fitting out rooms

Users should be asked to complete room data sheets. These will tell the designer the number of work stations or metre runs of benching that are required and the positions of electricity and gas service outlets. Microbiologists do not usually require water or sinks at every work station, nor do they require vacuum lines.

The number, measurements and brief description of each item of large equipment, and whether it is floor-standing or bench-mounted, should be supplied, together with its electrical rating and the proposed site.

Lighting is important and spot lighting (usually angle-poise lamps) are essential at every work station as much microbiological work needs close, well-lit attention.

The position and numbers of laboratory sinks, for staining purposes (and *not* for handwashing) should be noted and hand basins provided near to each door.

II.8.1 Benches and cupboards

Microbiologists sit to work and benchtops must therefore be at an ergonomically sensible height from the floor (usually about 0.7 m). High benches require high seats and predispose foot and ankle accidents. Benches are best cantilevered to allow freedom of leg movement. Depth of benches is also important: anthropomorphic studies have suggested that 0.6 m is convenient so that the worker does not have to rise from his/her seat to reach articles at the back of the bench. Bench surfaces should be impervious and easily cleaned.

Underbench cupboards should be easy to move but not so that they move when drawers or doors are opened. Overbench cupboards should be so placed that the sitter's head does not hit them when he/she rises. Nor should they be so high and so deep that workers have to over reach or stand on something to place or remove objects. Wall cupboards should not be too deep.

II.9 Service rooms

In general at least two service rooms are required, one for the treatment of infectious materials and waste and the other for the preparation of culture media and reagents.

II.9.1 Infectious materials and waste

One service room should be dedicated to the decontamination (sterilisation) of equipment for re-use and of infected waste before it is finally disposed of as required by the Department of the Environment (DoE)⁸ and the Health and Safety Commission (HSC).⁹ An autoclave of sufficient size is required and consultation is again required at the design stage in respect of the floor loading and plumbing. This room needs ergonomic attention to avoid cross-pathways of infected and sterilised materials with consequent risks of infection. A flow chart is shown in Fig.II.2 (See also Chapter 9).

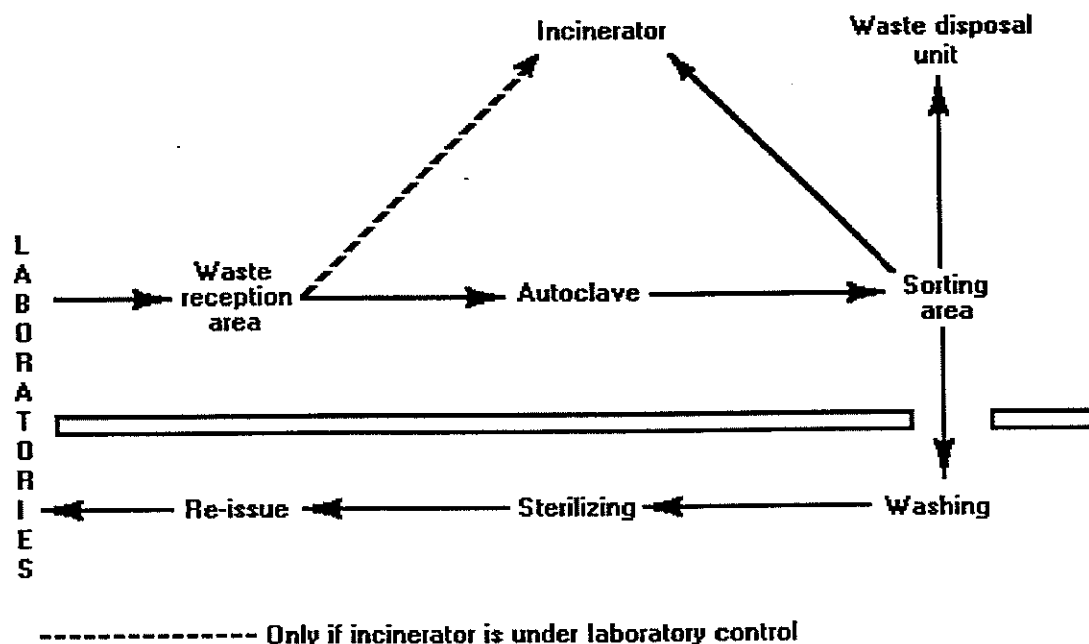


Fig.II.2: Flow chart for the decontamination of infected equipment and waste in microbiological laboratories. The pathways of infected and decontaminated materials must not cross.

(From Collins, C.H., *Laboratory Acquired Infections*, by permission of Butterworth-Heinemann.⁷)

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II.9.2 Preparation room

The other service room is required for the preparation of sterile materials for use in the laboratories. This may be fitted out much as a Level 1 or Level 2 laboratory although no infectious materials will be used. At least one bench should be high enough for workers to stand while they perform certain duties. This room will also require an autoclave - it is bad practice to use the same autoclave for infected and clean materials - and a clean air (laminar flow) work station which is *not* a microbiological safety cabinet.

II.10 Instrument rooms

Certain instruments, *eg* large centrifuges, electron microscopes, balances and analysers may need separate accommodation. Windows are not generally required but considerations should be given to floor loading and the provision of vibration-free bases, especially in electron microscopy rooms.

II.11 Offices

The only important design feature in which a microbiological laboratory office differs from any other office is when it used for the reception of pathological material which may be infectious. It should not be carpeted in case of spillages and should be provided with a laboratory-type bench for unpacking and sorting the specimens.

II.12 Stores

Microbiological laboratories use a great deal of disposable equipment and materials for which adequate storage facilities are necessary. Some of this material is flammable.

Chemical stores (which may be shared with other laboratories) should have external electrical switches and sealed lighting in case of spillage of flammable chemicals. They should be well ventilated and have impermeable floors and a sill to prevent spilled chemicals leaking out under the door.

II.13 References

1. *Categorisation of Pathogens According to Hazard and Categories of Containment* (1990), Advisory Committee on Dangerous Pathogens, HMSO.
2. *Laboratory Biosafety Manual* (1983), (2nd edition in press 1992), World Health Organization, Geneva.
3. *Biosafety in Microbiological and Biomedical Laboratories*, (2nd edn 1988), Centers for Disease Control and National Institutes of Health, US Government Printing Office.
4. Frommer, W. and a Working Party of the European Federation of Biotechnology (1989), 'Safe biotechnology III: Safety precautions for handling microorganisms of different risk classes', *Applied Microbiology and Biotechnology* **30**, 541-552.
5. *Recombinant DNA Safety Considerations* (1986), Organization for Economic Cooperation and Development, Paris.
6. BS 5726:1992, *Microbiological (Biological) Safety Cabinets*, British Standards Institution, London.
7. Collins, C.H. (1988), *Laboratory Acquired Infections*, 2nd edn, Butterworths.
8. *Clinical Wastes*, Waste Management Paper No. 25, (1987), Department of the Environment, HMSO (under revision 1992).
9. *The Safe Disposal of Clinical Waste* (1982), Health and Safety Commission, HMSO (under revision 1992).

APPENDIX III: RADIOACTIVE LABORATORIES

III.1 The nature of the hazard

Radioactive substances emit radiations which ionise the material through which they pass. The ionisation initiates chemical reactions in the material which may result in gross changes observed in the material.¹ The radioactive or radionuclide laboratory must therefore be designed to minimise the exposure of persons to ionising radiation and, as one means to this end, protect them from contamination by radioactive substances.

The hazards of ionising radiation and the principles of protection against the radiation are reviewed by the *International Commission on Radiological Protection (ICRP)* which publishes its recommendations in the *Annals of the ICRP*. The last major revision of the recommendations appeared in 1991 as *ICRP Publication 60*,² they are summarised in HHSC Handbook No.8.³

Radioactive sources are generally classified as 'closed' or 'sealed', or as 'open' or 'unsealed'. In the former class, the actual radioactive substance is either encapsulated in a high-integrity container, eg sealed inside a welded stainless steel cylinder, or bonded in a tough plastic sheet. The hazard then arises from exposure to the radiation field around the source; no contamination by radioactive material can occur (unless the sealed source leaks - hence the statutory requirement to perform periodic leak tests on sealed sources^{5,6}). Intact sealed sources therefore give rise to an *external* hazard only.

Unsealed sources, in addition to the possibility of giving rise to an external hazard (which depends on the type of radiation emitted), may cause contamination by dispersal of the actual radioactive substance. The radioactive substance could then be inhaled, ingested, or absorbed through the skin to become an *internal* hazard in the body.

The design of a laboratory for work with unsealed radioactive substances has, therefore, to provide appropriate protection against both the external hazard (principally by shielding) and against the internal hazard (by features for contaminant control). The prime concern is to safeguard the health and welfare of people in or otherwise affected by the laboratory. In addition, sensitive counting equipment requires protection against both forms of hazard at levels far below those relevant to safety.

III.2 Statutory requirements in the UK

Fig.III.1 represents schematically the ways in which regulatory control is exercised in England³ (a similar pattern obtains in the other constituent parts of the United Kingdom). European Directives,⁴ promulgated in the case of ionising radiation under the EURATOM Treaty, lay down the basic requirements for legislation in the Member States of the European Community. These requirements are then incorporated in Acts and Regulations formulated in Parliament at Westminster and enforced through the appropriate government agencies, viz the Ministry of Agriculture, Food and Fisheries (MAFF), the Department of Employment and the Health and Safety Commission (HSC) and Executive (HSE), the Department of the Environment and Her Majesty's Inspectorate of Pollution (HMIP), the Department of Health, and the Department of Transport. Advice and technical services are available from the National Radiological Protection Board (NRPB).

The Acts of Parliament and statutory Regulations relating to ionising radiation which have some bearing on laboratory design are:

- 1960 *The Radioactive Substances Act.*⁵
- 1985 *The Ionising Radiations Regulations, SI No. 1333.*⁶
- 1990 *The Environmental Protection Act.*⁷

Radioactive laboratories

The principal inspectorates in the UK are:

- (a) HM Inspectorate of Pollution (Department of the Environment) for The Radioactive Substances Act 1960 and The Environmental Protection Act 1990;
- (b) the Health and Safety Executive for The Ionising Radiations Regulations 1985.

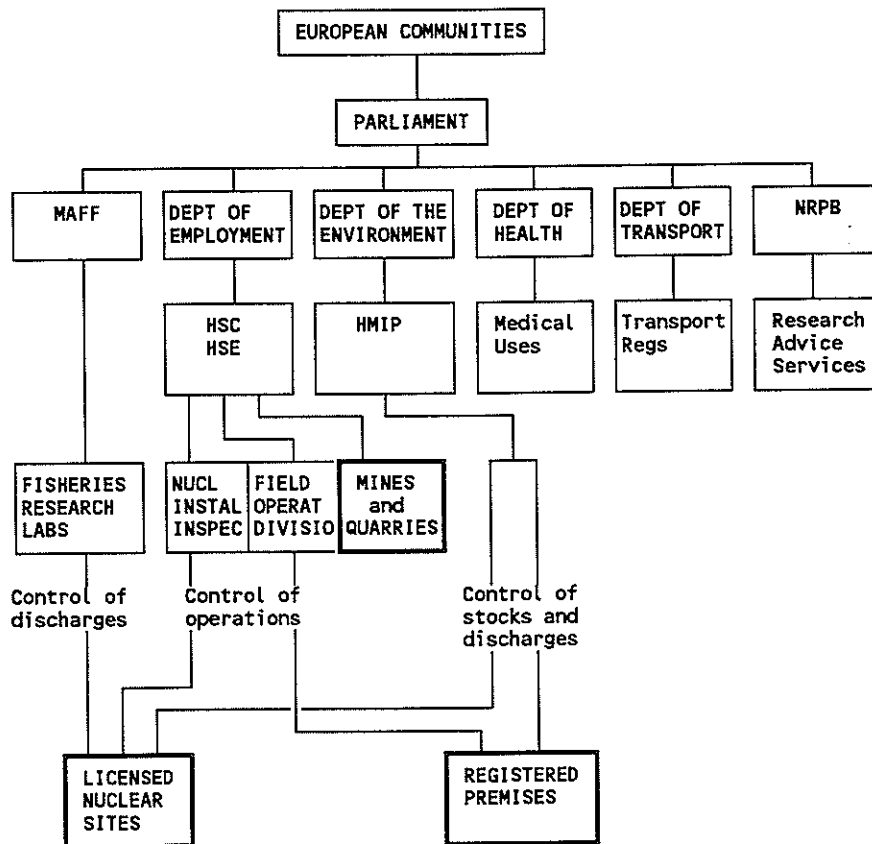


Fig.III.1: Regulatory and advisory bodies for radiation control in England.³

The Radioactive Substances Act 1960 (replaced 1993) and The Environmental Protection Act 1990
 These Acts apply to radioactive substances and do not apply to electrical machine sources such as X-ray sets.

The 1960 Act regulates (i) the keeping and use of radioactive substances and (ii) the accumulation and disposal of radioactive wastes. It requires, *inter alia*, the *registration* of the user and the premises for the keeping and use of radioactive substances, and the *authorisation* of the disposal of radioactive waste. Certain of the conditions have some relevance to laboratory design, *eg*:

- (a) reasonably practicable steps to prevent loss, escape or access by unauthorised persons;
- (b) reasonably practicable steps to ensure keeping sources in a suitable container in a suitable store constructed of non-combustible materials, not containing or near any explosive or flammable material, and clearly and legibly marked;
- (c) construction and maintenance of premises used for unsealed sources so that they can be easily cleaned;
- (d) sealed and labelled drainage system for the disposal of radioactive aqueous waste;
- (e) adequate discharge arrangements for the release of radioactive gases and vapours;

The 1960 Act is amended by Part V of *The Environmental Protection Act 1990* in relation to, among other things, the appointment and powers of inspectors (including to serve notices for failure to

comply with requirements), the charging of fees in connection with registration and authorisation,⁷ withdrawal of exemptions for the UK Atomic Energy Authority from certain requirements and the application to Crown establishments.

The Ionising Radiations Regulations 1985

*The Ionising Radiations Regulations 1985*⁶ control the use of radioactive substances and of electrical machine sources of ionising radiations (eg X-ray sets). They were made under The Health and Safety at Work etc Act 1974 and represent compliance in the United Kingdom with requirements in the EURATOM Directives of the European Community. The dose limits in the 1985 Regulations relate to the 1977 recommendations of the International Commission on Radiological Protection; it is anticipated that revised Regulations will be issued sometime in the future following a further European Directive based on the 1990 recommendations of the ICRP.²

The Regulations require an employer who uses significant amounts of radioactive substances to appoint a *Radiation Protection Adviser* who should be consulted by the employer about, *inter alia*, the prior examination of plans for new or modified premises.

III.3 Design features

Basic design features for an unsealed sources laboratory are described in several publications including ICRP Publication 25,⁹ the *Ionising Radiations Regulations 1985*⁶ together with the *Approved Code of Practice*¹⁰ and Chapter 10 of the *Guidance Notes for Medical and Dental Use*,¹¹ and *Report No.63* of The Institute of Physical Sciences in Medicine.¹² The extent of the facilities required depends on the hazard category of the radionuclides to be used, the nature of the proposed operations and the activity to be handled. The laboratories can be divided into three categories; *low*, *medium* and *high*.

The facilities required can be summarised as in Table III.1.

Table III.1

Summary of facilities required for radiation protection in the various categories of laboratory^{9,12}

Facilities	Category of laboratory		
	Low	Medium	High
Structural shielding	nil	nil	possibly.
Floor covering	cleanable	continuous	continuous, welded to coving at walls.
Bench surfaces	cleanable	cleanable	cleanable.
Room ventilation	normal	good	may require special features.
Fumecupboard*	no	yes	yes, perhaps with special features, eg shielded base.
Plumbing†	standard	standard	may require special features.
Washing‡ etc	washing	washing and decontamination	washing and decontamination.

* Room ventilation and fumecupboard extract/supply systems must be integrated (Chapter 7); warning labels on fume-extract ducts and fans. Filters are not normally required in the extracts from laboratory fumecupboards but sometimes monitoring of the effluent, eg radioactive iodine, is necessary.¹³

† Careful construction and routing in case of leaks; warning labels on pipes.

‡ Wrist- or knee-operated taps may be necessary.

Radioactive laboratories

The 1985 *Regulations* also require working areas to be designated as *controlled* if a person is likely to receive more than 3/10 of any prescribed dose limit and as *supervised* if a person is likely to receive between 1/10 and 3/10 of any dose limit. The full criteria for the designation of controlled areas is somewhat complex and is set out in Schedule 6 of the 1985 *Regulations*.

III.4 References

1. *IR1, 'Types and Effects', and IR2, 'Origins and Control'*, (1990), video training programs, University of Sheffield for Commission of the European Communities, H and H Scientific Consultants Ltd, Leeds, UK.
2. ICRP Publication 60, *Recommendations of the International Commission on Radiological Protection*, Annals of the ICRP, 21, Nos 1-3, 1991, Pergamon Press, ISBN 0 08 041144 4.
3. Hughes, D. (1991), *Notes on Ionising Radiation: Biological effects, quantities, dose limits and regulations*, HHSC Handbook No.8, H and H Scientific Consultants Ltd, Leeds, UK.
4. *Official Journal of the European Communities*, L246, 17 September 1980 and L265, 5 October 1984, HMSO (Revised Directive in preparation 1992).
5. The Radioactive Substances Act 1993, HMSO.
6. The Ionising Radiation Regulations 1985, SI No.1333, 1985, HMSO.
7. The Environmental Protection Act 1990, HMSO.
8. Memorandum *Pollution Control Charges for regulation under the Radioactive Substances Act 1960*, Her Majesty's Inspectorate of Pollution, Department of the Environment, March 1991.
9. ICRP Publication 25, *The Handling, Storage, Use and Disposal of Unsealed Radionuclides in Hospitals and Medical Research Establishments*, Annals of the ICRP, 1, No.2, 1977, Pergamon Press, ISBN 0 08 021510 6.
10. Approved Code of Practice: *The Protection of Persons Against Ionising Radiation arising from any Work Activity*, Health and Safety Commission, 1985, HMSO, ISBN 0 11 883838 5.
11. *Guidance Notes for the Protection of persons against ionising radiation arising from medical and dental use*, National Radiological Protection Board, Health and Safety Executive and Department of Health, 1988, HMSO, ISBN 0 85951 299 1.
12. Report No.63, *Radiation Protection in Nuclear Medicine and Pathology*, Institute of Physical Sciences in Medicine, York, UK, ISBN 0 904181 62 6.
13. *Private communication on monitoring for discharges of iodine-125*, Radman Associates, Lowerbrook, Rainow, Macclesfield SK10 5UP.

APPENDIX IV: ROOM DATA SHEETS

IV.1 Purpose

The information provided to the Design Team should be as detailed as possible to facilitate the detailed planning and design and to satisfy user requirements. *Room Data Sheets* provide the opportunity to establish precise plans and specifications for each discrete 'space' within the building and the interactions between different 'spaces' essential to the efficient operation of the laboratory as a whole. They should not be seen as a 'requisition' list of user demands. An illustrative data sheet is given below to indicate the type and detail of information required but variations on the form and content of the sheet may be necessary for each project. Completed sheets should be forwarded to the Project Team for consideration and agreement before the designers are instructed to proceed.

IV.2 ROOM DATA SHEET

Code	Item	Requirement
1.	Identification	
	Building Project Reference:	.....
	Room number or reference code	.....
	Faculty/Department/Section:	.....
2.	Functional use	
	Primary function code [Note 1]:	.....
	Specific function codes [Note 2]:	.....
		
		
3.	Size and occupancy	
	Number of occupants	.....
	Status of occupants:	.....
	Area (m ²):	.....
	Minimum width (m):	.....
	Maximum height (m):	.....

Room Data Sheets

4. Work surface and finishes

Internal surface finishes:

Work surface finishes:

5. Environment & Services

General lighting level:

Natural light (essential/desirable/undesirable):

Task/local/special lighting requirement:

Number of 13A power outlets:

Other supply voltages:

Maximum electrical loading (kW):

Data & communication (telephone/data outlets):

Ambient temperature control ($22 \pm 2^\circ\text{C}$ as standard):

General ventilation (volume air changes):

Air filtration:

Vibration sensitive equipment:

Automatic fire detection & extinction:

Water supply (hot/cold/deionised/potable) outlets:

Number of drainage outlets:

Fuel (natural) gas supply:

Special gases (piped/bottle supply):

Piped vacuum:

Compressed air/steam:

6. Security

Special/security locks:

Controlled/secure access system:

7. Equipment

List of large items of equipment/instruments:
(Dimensions/weight/clearances)

Equipment requiring non-standard services:

Estimated maximum electrical demand (kVA):

Estimated heat output from equipment (kW):

8. Storage units

General chemical (acids/bases) units:
Flammable liquid units:
Temperature controlled units:
Spark-free refrigerators:
Ventilated storage units:
Sterile or clean storage units:
Waste (chemical/solvent/biohazard/glass) units:
Secure units:
Equipment or consumables units:

9. Health & Safety

Fire extinguishers (AFFF/CO₂/powder/blanket):
.....
.....
.....
Automatic extinction (water/CO₂/halon):
Shower and eye-wash units:
Chemical fume cupboards (General purpose):
Chemical fume cupboards (Radionuclides/perchloric
acid/hydrofluoric acid/other special use):
.....
Microbiological safety cabinets (Class I/II/III):
.....
.....
Local exhaust ventilation (Hoods/benches/cupboards):
.....
.....

10. Adjoining rooms or facilities

If room is to be located adjacent to other room(s)
or share communal facilities list room numbers or
identification codes:
.....

11. Special requirements

List requirements or features not specified above:
.....
.....
.....
Other comments:

Room Data Sheets

12. Data sheet completed by:

..... (signature)

..... (print/type name)

Date

IV.3 Instructions for use

The data sheet is intended to provide information to the Design Team concerning the proposed activities and specific requirements in each laboratory. Some sections of the sheet may already have been completed to indicate the standard provision to be installed in line with Project and Design Team consultations. Please read the following Notes carefully before completing the sheet.

Note 1.

The primary functional use describes the main type of activity in the room or area according to the following codes:

Research laboratory	A1	Teaching laboratory	A2
Storeroom	A3	Preparation room	A4
Workshop	A5	Research office	B1
Admin office	B2	Other office	B3
Special environment	C1	Pilot plant	C2
Conference room	D1	Other	D2

Note 2.

The specific function code describes particular laboratory activities in rooms or areas with particular design codes or architectural or engineering services requirements:

Work involving -

Class 2 biohazards	P2	Class 3 biohazards	P3
Genetic modification	GM	Human/animal material	HM
Plant/animal pathogens	PP	Sterile environment	SR
Clean room environment	CR	Radionuclides (unsealed)	RU
Radionuclides (sealed)	RS	X-ray generators	RG
Lasers	RL	Chemicals (carcinogens)	CC
Chemical (explosives)	CX	Chemical (high toxicity)	CT
Chemical synthesis	CS	Analytical equipment	CA
High voltages	HV	High pressure gases	HP
High noise levels	HN	Pilot plant equipment	PS
Controlled temperatures	TR	Plant growth	PG
Cell culture	TC	Multi-purpose	XX

APPENDIX V: MINIMUM HEALTH AND SAFETY REQUIREMENTS IN THE WORKPLACE

V.1 Introduction

At the time of writing, proposals have been published by the Health and Safety Commission and the Home Office to implement in the UK the provisions of EC Directive 89/654/EEC¹ concerning the minimum safety and health requirements for the workplace, the '*Workplace Directive*'. The Workplace (Health, Safety and Welfare) Regulations 1992 and the Fire Precautions (Places of Work) Regulations 1992 are to be made under the Health and Safety at Work *etc* and the Fire Precautions Acts respectively. They become effective, in whole or in part, on 1 January 1993 applying to laboratories constructed, modified or used for the first time after 31 December 1992 from that date but applying to existing laboratories from 1 January 1996.

Many laboratories and premises containing laboratory accommodation have not previously been regulated by specific legislation, unlike factories and offices. General provisions imposed by the Building Act and Regulations, the Fire Precautions Act (as amended), the Education Acts and the Health and Safety at Work *etc* Act and Regulations have applied to certain laboratories and laboratory activities although many design issues and specifications have been based on accepted 'good practice' established by professional and other bodies such as the British Standards Institution, the Chartered Institution of Building Services Engineers, the Departments of Education and Health and the Health and Safety Executive.

The Workplace and Fire Precautions Regulations will replace a wide range of industry- or activity-specific regulations with a comprehensive set of requirements applying to all workplaces including laboratories in schools, colleges, universities, research institutes and hospitals. The new requirements are broadly consistent with existing ones so that laboratory designers and managers should not anticipate that wholesale changes to buildings will be necessary nor that building control officers and other enforcement agencies will impose new standards. However, an inevitable outcome of the new Regulations will be to raise the status of certain *recommended design objectives* to the level of *essential* or even *mandatory*, according to the criteria of Section 2.5, and for this reason brief summaries of some of the new requirements are given below to emphasise their relevance to laboratory design.

V.2 The Workplace (Health, Safety and Welfare) Regulations 1992²

An approved Code of Practice supports these Regulations which lays duties on employers and those who control workplaces in respect of their own employees, persons working at the workplace but employed by others, *eg* maintenance or service engineers, contract cleaners and security staff, or to all persons thus including students and members of the general public.

V.2.1 The working environment

The regulations require a reasonable temperature in the laboratory and ancillary areas to ensure thermal comfort. A minimum of 16 °C is necessary in all areas unless a lower temperature is necessary for process or environmental control, *eg* cold rooms or animal rooms. No maximum is set although persons should not be exposed to uncomfortably high temperatures caused by solar radiation, or by heat from laboratory processes or equipment which can be controlled by exhaust or general ventilation, insulation, or air conditioning.

The laboratory must have suitable and sufficient lighting, by natural means where possible, together with emergency lighting in laboratories where a failure of the normal artificial lighting would lead to

Minimum health and safety requirements

a dangerous situation. Lighting should provide a sufficient level of illumination consistent with the work activity, without being excessive, or causing glare or discomfort.

Fresh or purified air must be provided by natural or mechanical means to give effective and suitable ventilation according to the volume of the laboratory, the number of its occupants and their physical activities and the processes, materials and substances which may contaminate the air, create humidity or liberate heat.

Sufficient space must be available to laboratory and other workers so that they are not at risk by over-crowding. The minimum standard here is based on that applied previously in office premises, 11 m³ per person, where the ceiling height is 2 to 3.1 m, after allowing for the space occupied by the furniture, equipment, machinery and fittings. Such figures differ from current laboratory recommendations (see Section 4.10).

Floors should be properly constructed particularly in workplaces such as laboratories and store-rooms where toxic, corrosive or highly flammable liquids may be split. Materials and methods of construction should resist the corrosive properties of the spill, minimise the risk of slipping and prevent the contamination of drains and sewers or environmental release.

V.2.2 Safety provisions

Pedestrians and traffic must be able to circulate safely using routes which are sufficient in number and size to give effective separation of people and vehicles, ensuring unobstructed movement, safe access and egress. Safe refuges must be provided in loading bays or stairs to prevent people being trapped or crushed by a vehicle. Traffic routes should be clearly indicated by road markings and signs. This requirement will have particular importance where laboratory buildings, each with vehicular access and a delivery area, share sites with large numbers of pedestrians, *eg* hospitals, universities and colleges.

Where people may come into contact with doors, walls or partitions with transparent or translucent sections, the glass, plastic or other material used must be conspicuously marked so as to be clearly visible and be of such a composition as not to cause injury if it shatters. Glass or plastic with impact resistance Class A, B or C when tested according to BS 6206³ (toughened or laminated glass, acrylic, polycarbonate or pvc plastic) will satisfy this requirement although the impact resistance of plastic materials may deteriorate on exposure to UV radiation. Annealed and Georgian wired glass are unsafe in this context although the latter is often recommended to give an adequate fire resistance in doors and partitions. Alternatively, transparent or translucent areas in doors and partitions *etc* may be safe by position or by suitable protection. Openable windows and skylights should be capable of being opened safely and when fixed open they should not create danger to any person. The cleaning of windows and skylights must be able to be undertaken safely by the provision of external fixed or temporary platforms, cradles or ladders, or by having a sufficiently wide arc to opening or tilting windows so that they can be cleaned from inside the building.

Physical safeguards in the form of permanent barriers, guard rails or other fencing, must be provided to prevent falls from roofs or heights. This requirement is relevant to most laboratory premises because of the fume cupboards and other ventilation and air-conditioning plant, water tanks, *etc* which are frequently located at roof level together with satellite communication dishes and even storage areas for compressed gas bottles and highly flammable liquids.

V.2.3 Welfare facilities

Minimum provisions for sanitary conveniences and washing facilities are required to be readily accessible to all those in the workplace in keeping with the standards previously established for factories and offices. In view of the widespread use of toxic, corrosive, infectious or otherwise hazardous materials or substances, such a requirement may be interpreted to indicate the need for hand wash basins in all laboratories together with showers where there is likely to be exposure to offensive or corrosive substances and where work is undertaken in pathology or post-mortem laboratories.

Accommodation must be provided for clothing including special or protective clothing to be worn in the workplace. Separate accommodation for laboratory coats and overalls, *etc* and the staff's own outdoor clothing will be required since the latter may become contaminated by contact with the former.

Rest areas, rooms or other facilities for rest, including facilities for taking meals, must be provided with adequate seating and a table or tables. Since eating and drinking within laboratories is universally discouraged and usually strictly prohibited, most will have suitable facilities at the present time. However, in the case of new laboratory buildings completed, modified or occupied after 1 January 1993, pregnant women and nursing mothers are entitled to rest facilities enabling them to lie down and all persons in the workplace should be able to use rest areas or rooms where they will not experience

discomfort from tobacco smoke, *eg* by providing separate facilities for smokers and non-smokers or the prohibition of smoking in a single rest area.

V.3 The Fire Precautions (Places of Work) Regulations 1992⁴

These Regulations, made under the Fire Precautions Act 1971, implement the general fire safety provisions of the Workplace Directive. They are supported by non-statutory guidance issued by the Home Office and will be phased in over the period from 1 January 1993, for new, modified or converted premises from the date of completion of the building project, or premises first used after that date, to 1 January 1996 for existing workplaces. Although certain existing statutory requirements will be subsumed by these new Regulations, others will remain in force so that certain premises may be subject to several related requirements which may be enforced by separate authorities. Premises which are fire certificated by the Health and Safety Executive under the Health and Safety at Work *etc* Act 1972, the 'special premises' by virtue of significant process fire risks,⁵ are excluded from these Regulations. The Home Office guidance makes extensive reference to British Standards which effectively comprise the technical requirements necessary for compliance with the Regulations.

V.3.1 The assessment of fire risk

The fire precautions to be taken in any workplace are to be determined by an assessment of the risk to persons in case of fire based on the probability of fire occurring and the consequential effects should fire occur. Most laboratories and premises containing laboratory accommodation are likely to be assessed as being of *high fire risk* by virtue of the presence of easily ignited materials (highly flammable liquids and combustible gases), explosive materials and incompatible or reactive chemicals used in the laboratory itself or kept in storage areas.

The risk assessment should identify not only the level of risk to life as being high, normal or low in relation to the processes and activities undertaken but also the risks inherent in the size, layout and materials of construction of the building itself, and the number of occupants. The fire precautions necessary to minimise the occurrence and spread of fire and to enable occupants to escape to a place of safety are to be appropriate to the degree of risk. The assessment must be recorded in writing.

V.3.2 Means of escape

In a high risk laboratory there should be alternative exits sited so from any point in the room the angle of divergence measured from that point to the exits makes an angle of at least 45 ° and the distance of travel to either exit should not exceed 12 m. If only one exit from the laboratory is available or the angle of divergence is less than 45 °, then the distance of travel must be reduced to 6 m. These distances may be increased to 25 and 12 m respectively in laboratories of 'normal' fire risk. In addition, the total distance travelled from any point in the laboratory to a final exit from the building, a protected stairway or lobby or a separate fire compartment should not exceed 12 or 25 m according to whether escape is possible in one or more than one direction. Whatever the degree of risk, at least two exits will be required if more than 50 people occupy the laboratory. These requirements indicate that high fire risk laboratories will need at least two exits with a maximum distance of travel of 12 m from any point within to each exit. The laboratory exits should lead directly into a protected corridor or be within 13 m of a door leading to such a corridor or other protected area or to a building exit. In laboratory suites where access to an inner room is provided through the main laboratory, the distances of travel above apply when measured from any point in the inner room to the laboratory exits (see Section 4.5).

Exit doors should be at least 750 mm and escape routes at least 1.05 m wide. The latter must not contain any item which poses a fire risk, *eg* portable, gas or oiled fired heaters or those with unprotected flames or radiant bars, stored furniture, vending machines and electrical equipment other than normal and emergency lighting and fire alarm systems. Other than in basement areas, the construction of protected routes must provide for a minimum of 30 minutes fire resistance and have linings which have a surface spread of flame to Class 0.⁶ The occupant and exit capacities of each room, storey or building, based on floor areas, the number and width of escape routes, *etc* must be such as to enable the evacuation of high risk premises in 2 minutes.

Laboratory doors should not open across an escape route; outward opening doors will need to be recessed to avoid obstruction or the door hinged to open inwards provided the occupancy of the laboratory is less than 50 people. Doors forming part of a protected escape route must be fire-resisting, and fitted with a self-closure device and smoke seals. The Regulations will permit the use of automatic door release mechanisms linked to automatic or manual alarm systems provided that they fail to safety in the

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event of a power failure although most laboratory doors are required to be kept closed as part of the barrier or containment design. The escape routes should be clearly marked by exit and directional signs incorporating both words and pictographic symbols⁷ and suitably illuminated by normal and escape lighting powered by independent sources or electrical supply in basement areas, core or internal stairways and corridors, and other routes which may be used by persons working at night or other times when natural lighting may be insufficient (see BS 5266: Part 1).⁸

V.3.3 Means of fighting fire and giving warning

The laboratory must be provided with the means to extinguish fires according to the nature and quantity of flammable or combustible materials present, identified by the fire risk assessment. Portable fire fighting equipment should preferably be grouped together with hose reels at conspicuous fire points, normally located in escape routes and repeated at equivalent positions on each storey of the building. In high fire risk laboratories, additional suitable extinguishers should be located near the risk but not in a position where a user is placed in danger (see Section 4.14), or the means of escape should be protected by an automatic fire suppression system to BS 5306: Part 2.⁹

Alarm systems to give warning of fire must be provided to enable occupants of the building to have time to escape to a place of safety. In most laboratories this will require an electrical manual fire warning system to BS 5839¹⁰ Type M, although storage rooms and other areas which may be unoccupied for long periods may require automatic detection systems if a fire there could seriously affect any means of escape.

V.3.4 Storage of combustible refuse

Combustible refuse which is stored pending collection or disposal should be kept only in suitable fire-resistant containers or in a fire-resisting enclosure or compartment located away from public areas and kept locked except when access is required. Refuse storage areas should not contain sources of ignition, such as open element or naked flame heaters, heaters or lighting units with hot surfaces, or incompatible substances, *eg* strong oxidising agents. They should be ventilated to the open air. Containers provided for this purpose must be located in areas of low or negligible fire risk, *ie* outside the laboratory.

V.3.5 Management duties

The Regulations and Guidance also impose requirements on laboratory managers and supervisors in respect of:

- (a) the preparation of an emergency plan setting out the procedures and responsibilities in the event of a fire having regard to the assessment of fire risk;
- (b) the maintenance of the means of escape to ensure that it is kept free from obstruction;
- (c) the maintenance of the means of fighting, detecting and giving warning of fire including the examination and testing of relevant systems and devices;
- (d) the supervision of maintenance and construction work undertaken by persons who do not normally work in the workplace including an assessment of the additional risks created by such work and the provision of suitable precautions;
- (e) the provision of suitable instruction and training to staff so that they are familiar with the fire precautions to be taken and any special responsibilities that they may have in an emergency including the testing of procedures by means of fire drills to be held at least annually;
- (f) the keeping of records, for a period of at least 3 years, of maintenance work, instruction and training, fire drills, including deficiencies identified by the maintenance work, and any remedial work undertaken.

V.4 References

1. European Council, (1989), *Council Directive concerning the minimum safety and health requirements for the workplace*, Directive 89/391/EEC, OJ No.L393, 30.12.89, p1.
2. *The Workplace (Health, Safety and Welfare) Regulations 1992*, HMSO.
3. BS 6206: 1981, *Specification for impact performance: requirements for flat safety glass and safety plastics for use in buildings*, British Standards Institution, London.
4. *The Fire Precautions (Places of Work) Regulations 1992*, HMSO.
5. *The Fire Certificates (Special Premises) Regulations 1976*, S1 1976 No.2003, HMSO.
6. *The Building Regulations 1985, Approved Document B2/3/4, Fire Spread*, Department of the Environment and The Welsh Office, (1985), HMSO, ISBN 0 11 7518189 0.
7. BS 5499, *Fire safety signs, notices and graphic symbols; Part 1, Specification for internally-illuminated fire safety signs*; British Standards Institution, London.
8. BS 5266, *Emergency lighting Part 1, Code of Practice for the emergency lighting of premises other than cinemas and certain other specified premises used for entertainment*; British Standards Institution, London.
9. BS 5306, *Fire extinguishing installations and equipment on premises, Part 1, Hydrant systems, hose reels and foam inlets; Part 2, Sprinkler systems; Part 3, Code of Practice for selection, installation and maintenance of portable fire extinguishers*; British Standards Institution, London.
10. BS 5839, *Fire detection and alarm systems for buildings; Part 1, Code of Practice for systems design, installation and servicing; Part 2, Specification for manual call points; Part 3, Specification for automatic release mechanisms for certain fire protection equipment* British Standards Institution, London.



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