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SAFETY SERIES No. 30

MANUAL ON SAFETY ASPECTS
OF THE DESIGN AND EQUIPMENT
OF HOT LABORATORIES

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1969
ABSTRACT. A manual prepared by the IAEA with the help of three consultants from three countries. The purpose of this manual is to help those persons, particularly in the developing countries, who plan to design and construct a new hot laboratory or modify an existing one.

Contents: Introduction; Purpose; Scope; 1. Arrangement of working areas inside the building; 2. Enclosures; 3. Handling and viewing systems; 4. Transfer and transport systems; 5. Ventilation system; 6. Radioactive waste disposal systems; 7. Personnel protection; References.

Separately available in English and French.

(102 pp., 14.8 x 21 cm, paper-bound, 70 figures; 1969) Price: US $3.00; £1.5.0

THIS REPORT IS ALSO PUBLISHED IN FRENCH
FOREWORD

With the development of atomic energy application and research, hot laboratories are now being constructed in a number of countries. The present publication describes and discusses experience in several countries in designing equipment for these laboratories.

The safe handling of highly radioactive substances is the main purpose of hot laboratory design and equipment. The manual aims at helping those persons, particularly in the developing countries, who plan to design and construct a new hot laboratory or modify an existing one. It does not deal in great detail with the engineering design of protective and handling equipment; these matters can be found in the comprehensive list of references. The manual itself covers only basic ideas and different approaches in the design of laboratory building, hot cells, shielded and glove boxes, fume cupboards, and handling and viewing equipment. Systems for transferring materials and main services are also discussed.

The material has been prepared by three consultants appointed by the IAEA:

J.C. Campbell  United Kingdom Atomic Energy Authority, Risley, Warrington, Lancs, United Kingdom

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In the first stage of the compilation Mr. Kosyakov, then an IAEA staff member, co-ordinated the work. The task was completed under Mr. G.A. Dorofeev, who succeeded him as Project Officer.
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INTRODUCTION

With the advent of the atomic energy industry laboratories were called upon to handle ever increasing amounts of radioactive materials, so that it became a matter of prime importance that methods for the safe handling of these materials be devised [1-28].

The main object of these methods is the safety of the operators, the provision of conditions under which work is carried out on radioactive materials to enable reproducible and reliable results to be obtained, the maximum operating efficiency of the laboratories and the safe discharge of effluents and wastes from the laboratories.

Apart from the normal hazards in laboratories, e.g. chemical, equipment, fire, etc., radioactive laboratories have to be designed to safeguard the operators against external and internal radiation, and exposure to uncontrolled nuclear fission that can occur when fissile materials are brought together in excess of a particular critical quantity.

Protection against external radiation is given by installing the appropriate biological shield between the radiation source and the operator. The amount of shielding required for the operator's safety depends on the type, quantity and energy of the radiation. In dealing with alpha- and beta-emitters relatively thin biological shielding is required whereas special biological shielding is essential when protecting against gamma- and neutron-radiation. The provision of these special shields for the operator's protection must of necessity involve the use of remotely operated equipment for operations to be carried out behind these shields, so that elaborate viewing equipment and intricate manipulators have been evolved.

The internal radiation hazard is produced by radioactive material being taken into the human body; protection against this hazard can best be effected by isolating the material from the operator's environment. This isolation is achieved by containing the radioactive materials in an enclosure which can take the form of a fume cupboard, glove box, shielded box or hot cell. The integrity of the enclosure and standard of the ventilation required for the safety of the operator mainly depend on the following factors: toxicity of the material, quantity, specific activity, physical and chemical form, type of operation.

The radioactive materials, however, must be passed into and out of the enclosure, therefore safe methods for the storage and transport of the radioactive materials must be investigated, and the opera-
ting environment must be monitored to detect the presence of any contamination.

The hazard from uncontrolled nuclear fission can best be avoided by exercising strict control over the storage, movement and quantity of fissile materials in the laboratories.

The provision of an isolating enclosure or containment enables processes to be carried out under the best possible controlled conditions to suit the individual process and radioactive material.

Because of the various degrees of radioactive hazard in the laboratories it has been found beneficial for the operating efficiency of the laboratory to gather together in distinct and separate areas those sections or operations that give rise to the same or similar degree of radioactive hazard. Operators can move between these separate areas by passing through changing rooms where a change of clothes or protective clothing is provided for the operator's safety and to prevent the spread of contamination between areas. An integrated ventilation system for these areas must be carefully engineered to prevent the spread of airborne contamination between the areas.

PURPOSE

The primary purpose of this document is to serve as a guide for those persons or authorities (particularly in developing countries) who are responsible for the design and construction of new hot laboratories. It is intended to generalize concerning existing experience in different countries in the design and operation of hot laboratories, pointing out basic ideas and different approaches in the design of laboratory buildings, equipment and main services. Practical examples of the applications of these approaches have been discussed, and this discussion could prove helpful in the training of the operators for hot laboratories.

SCOPE

Section I describes the general principles of the arrangement and architectural disposition of areas inside laboratories according to the varying potential radiation and contamination hazards. Section 2 discusses enclosures for radioactive material containment. In
Section 3 viewing and lighting systems and various types of manipulators are presented. Transfer and transport of radioactive materials within the laboratories are discussed in Section 4. Ventilation of laboratories is discussed in Section 5, with particular reference to IAEA Safety Series No. 17, Techniques for Controlling Air Pollution from the Operation of Nuclear Facilities. Section 6 deals with various radioactive waste disposal systems. Personnel monitoring including changing room monitoring and protective clothing is described in Section 7.

1. ARRANGEMENT OF WORKING AREAS INSIDE THE BUILDING

1.1. Principles of classification of areas according to varying radiation and contamination hazards

A successfully designed laboratory must provide the facilities for the performance of the functions for which it was constructed, and must always be readily available for the performance of these functions whenever they arise [29-53].

In the case of radioactive laboratories the functions they are generally expected to undertake are the acceptance of radioactive material, the exposing and processing of this material, the dispatch of the product, and the safe discharge of any gaseous, liquid and solid wastes from this processing. Of these functions, those which give rise to the greatest hazard are the exposing and processing of the radioactive material. In the early days the separation of the operator and the hazard was attempted by enclosing the operator in protective clothing; this procedure had many obvious disadvantages and was soon superseded by placing the radioactive material in an enclosure.

To carry out the functions necessitates the breaching of the enclosure. The radioactive material has to be passed into the enclosure, and the operation of exposing and processing the material can be accomplished either by direct or remote manipulation through the enclosure. The product, solid and liquid wastes have to be passed out of the enclosure, and the gaseous effluent should not be allowed to leak into the operator's environment.

It is therefore evident that the performance of these functions can be associated with varying degrees of hazard, and it is possible to divide the laboratory into areas in which functions with the same

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degree of hazard are carried out. It is generally accepted that these areas fall into four categories. Each category is given different names in different countries in accordance with local practice. It is intended in this manual to designate these categories Zones I, II, III and IV.

Zone I. In this area no radiation or contamination hazard exists. Entry to this area is unrestricted.

Zone II. In this area no radiation and contamination hazard would normally be expected in excess of the local safety regulations for the operational staff. Entry to this area would require a minimum change of clothing. Minor surveys for the presence of radioactive materials are recommended for this area.

Zone III. In this area the probability of contamination and radiation hazard is greater than in Zone II because of the physical disposition of radioactive materials and the operations undertaken here. Radiation and contamination monitoring is required for this zone. Particular attention should be paid to air monitoring. Personnel movement between Zone III and Zone II usually requires a change of clothing and monitoring.

Zone IV. This area is designed as an enclosure, and in it radioactive materials are held, exposed and processed, and the probability of hazard from radiation and contamination is greatest. Access to this area is controlled, and is usually allowed only after the removal of radiation sources and any necessary decontamination. Special protective clothing and breathing equipment is worn, as specified by the health physicist in control.

Zone II is a general operating area in the laboratory. Zone III is usually an area where maintenance, decontamination, radioactive material transfers and other operations which may lead to some radioactive contamination are carried out. In hot laboratories, Zone III and Zone IV are clearly defined areas. However, in some laboratories because of the quantity and nature of the radioactive materials and with some special precautions being undertaken Zone III can be merged with Zone II for normal operation. In the event of expected or actual release of activity a part of Zone II can temporarily become Zone III.
The chance of contamination of Zone II from Zone III and Zone III from Zone IV by transfer of particulate matter is minimized by clothing and footwear changes, and the possibility of airborne contamination is lessened by ensuring that air always flows from Zone II to Zone III to Zone IV.

1.2. Architectural disposition of zones

Depending on the amount and type of radioactive material to be handled in the laboratory, Zone IV may be one of the following types of containment: fume cupboard, glove box, shielded box and hot cell. It is convenient to examine the disposition of zones in relation to the type of containment required in the laboratory.

1.2.1. Fume cupboards

Fume cupboards are chosen to provide containment in active laboratories whenever the probability and level of hazard from their use is low; as a consequence they are normally located within a Zone II area.

1.2.2. Glove boxes

Numerous arrangements of the zones are available when glove boxes are used as the enclosure. Two layouts commonly used in active laboratories are the "in-line" (between zones) arrangement and the "free-standing" arrangement. The "in-line" arrangement as illustrated in Fig.1a shows the glove boxes positioned between Zones II and III. Operation of the boxes is carried out in Zone II, while maintenance and decontamination of the individual boxes can be carried out in Zone III. Access between Zones II and III is via a changing room.

Where large numbers of boxes are required in a laboratory it is usual in the interests of economy to provide a common Zone III for lines of glove boxes as shown in Fig.1a.

The main advantages of the "in-line" arrangement are the relatively easy and quick access to a glove box to carry out maintenance or minor modification without disrupting operations at adjacent boxes, and the straightforward arrangement of services and communication between boxes.

1 All the figures are at the end of the Manual.
The disadvantages of this system are its inflexibility with regard to major modifications concerning the boxes themselves, and the somewhat uneconomic use of expensive building space.

In the "free-standing" arrangement glove boxes are positioned as required in a Zone II area where normal operation is carried out together with a limited amount of maintenance and minor modifications. Major maintenance and modifications are carried out in a special area to which the glove box can be moved. This layout is shown in Fig. 1b.

The advantages of this arrangement are its flexibility in the ease of replacing glove boxes, its economy of space and operational access to the four sides of the box. The main disadvantage is the greater down time needed for major maintenance on a box. This disadvantage can be minimized by providing a temporary Zone III at the box.

1.2.3. Shielded boxes

The disposition of zones for shielded boxes are similar to those described in Section 1.2.2. It should be noted that with "free-standing" shielded boxes, it is usual for provision to be made to remove only the containment box to the decontamination and maintenance area, after making the radiation sources safe.

1.2.4. Hot cells

Generally with very few exceptions hot cell laboratories conform to the in-line arrangement as described in Section 1.2.2. The geographical position of the maintenance area varies considerably, typical arrangements being shown in Figs 2-4. Figures 2 and 3 show arrangements of single and double lines of hot cells with the maintenance area (Zone III), the cells (Zone IV) and the operation area (Zone II) on the same level. The advantages of this type of arrangement are the containment of contamination by the rigid enforcement of controls between Zones II, III and IV, and the economic layout because of the arrangement of the building on one floor.

Figure 4 illustrates a single line of hot cells with separate maintenance areas on the roof and at the rear of the cell. The advantage of this layout is that associated with vertical access to the hot cell, but this advantage is only gained by the additional building cost caused by the increase in building height.

Many versions of the in-line arrangement are described in the literature of hot cells, the variations being caused by a combination
of many factors, e.g. available space, existing facilities, and transport problems.

1.2.5. Special areas

Any laboratory consists of a complex variety of the containments mentioned above, and their arrangement either as units or as combined groups are mainly dictated by the nature of radioactive material being handled and the type of work being carried out in the laboratory.

Because Zones II, III and IV are controlled zones it is essential that special areas are established at the entrances to the zones. Here personnel can be given the appropriate change of clothing and be monitored as they pass from zone to zone.

2. ENCLOSURES

The principal purposes of enclosures are preventing the spread of radioactive contamination, protecting the operators from external radiation exposure and, if required, providing a controlled atmosphere for processing and/or safety reasons.

Enclosures are therefore designed to meet the varying combination of these hazards. Fume cupboards are used when the contamination and external exposure hazard is low; when the external exposure hazard increases the fume cupboard is replaced by a simple shielded cell which can be constructed in various materials, the most common being cast iron, mild steel, lead and concrete.

When the contamination hazard is increased but the external exposure remains low glove boxes are introduced. The required leak tightness of the glove box depends on the degree of the contamination hazard. With an increase in both the contamination and external exposure hazard the glove box must be placed within a biological shield and thus have been developed the shielded box, where the glove box is surrounded by a shield of cast iron, mild steel, lead or a combination of these, and the more elaborate hot cells with concrete shields, the containment being provided by either special linings of the cell or special independent boxes placed in the cell.

The glove boxes, shielded boxes and elaborate hot cells may also provide a controlled atmosphere.
In practice there is no distinct limit of hazards to separate these types of enclosures.

2.1. Fume cupboards

A fume cupboard is an enclosure in which material is handled in isolation from the operator's environment. Handling the material is effected through an opening in the fume cupboard, and the isolation is achieved by directional air movement through the opening into the fume cupboard. These cupboards are used when the level of radioactivity of the material being handled is in the micromilli-curie range.

Some factors that have a bearing on the design of the fume cupboard are toxicity of the chemicals used and the physical form of the materials being handled, wet or dry operations, corrosion problems associated with the processes and the requirement for structural strength of the cupboard if some lead shielding is occasionally required for personnel protection.

Fume cupboards can be constructed in mild steel, stainless steel, polyvinyl chloride and reinforced resin-bonded laminates (e.g. fibreglass with polyester or epoxide). The front sliding panel can be manufactured from transparent plastic, or toughened or laminated glass. When mild steel is used the interior of the cupboard must be painted to achieve a suitable finish, to provide resistance to corrosion and ease of decontamination. Stainless steel, because of its cost, should be confined to those cases where its use is essential for corrosion and temperature conditions. The use of plastics for cupboards is becoming more popular because of their cheapness, resistance to corrosion and ease of decontamination. Care however should be used, when using plastics, to exclude the use of certain solvents and to limit the temperature of operations.

Services used in fume cupboards are usually water, gas, vacuum and electricity, and it is good practice to ensure that the controls for the services are situated outside the fume cupboard to minimize the number of movements through the front opening (Fig. 5).

Ventilation of the fume cupboards is of the once-through type, a detailed description of which will be found in Section 5 (see Figs 5 and 64).

Fume cupboards are usually situated within Zone II areas because of their low potential hazard. The hazards of radioactive contamination can be reduced by ensuring that the openings of the fronts
of the fume cupboards are normally the minimum required, and if possible they should be closed. When closed, access to the cupboard can be gained by means of rubber gloves fixed to ports in the front panel. This improves the containment and so further reduces the chance of contamination.

2.2. Glove boxes

A glove box is a leak-tight enclosure in which material may be manipulated in isolation from the operator's environment. This manipulation is effected through gauntlet gloves fixed to ports in the walls of the box [54-70].

Glove boxes are used to provide containment for hazardous materials. The hazards may be toxic, radioactive and pyrophoric, or any combination of these. Usually glove boxes have no shielding protection against penetrating radiation so that they are used, in hot laboratories, to deal with alpha- and beta-activity. The levels of this activity may vary from minute to large amounts. One further use of the glove box is the maintenance of the purity level of the material being handled.

Some typical factors affecting the design of a glove box are its use for production or research, the processes to be carried out, the hazards associated with these processes, and whether it is to be an in-line or free-standing box.

If the box is to be used for research work then the main feature in its design should be its versatility; for production use a specialized design is required.

The installation of mechanical and electrical equipment in the boxes must be examined to ensure that the glove box maintains its integrity. For example, a piece of vibrating machinery should be installed so that no vibration is transmitted to the box or to other equipment in the box.

The hazards associated with the processes must be carefully analysed so that the necessary features can be incorporated to combat these hazards. For example, if a highly toxic pyrophoric powder is being exposed in the box then the design should ensure a high standard of box integrity together with a minimum movement of a special inert atmosphere within the box.

If the box is to be installed in an in-line arrangement, then the operating and maintenance faces must be clearly defined. If it is to be free standing, then any face can be used for operating or maintenance.
Materials that can be used in the construction of glove boxes are mild steel, stainless steel, polyvinyl chloride and reinforced resin-bonded laminates. Viewing panels are usually manufactured from transparent plastic, or toughened or laminated glass.

The choice of construction materials must be dependent on a number of factors such as chemical compatibility, fire resistance, structural strength to withstand heavy or shock loads, and ease of decontamination.

Gloves are manufactured from materials combining the following characteristics: flexibility, leak tightness, resistance to abrasion and aggressive media. Typical materials possessing these characteristics to varying degrees are natural latex rubber, neoprene rubber and butyl rubber.

Natural latex rubber is cheap, has good flexibility, reasonable resistance to acid conditions and adequate leak tightness but has low resistance to solvents. Neoprene latex rubber gives better resistance to solvents and ultraviolet light, and has better leak tightness. Milled neoprene has increased mechanical strength and leak tightness. Butyl rubber has good leak tightness and is used with dry boxes and controlled atmospheres. Some special materials are used for particular conditions. In boxes where there is a handling hazard with beta-activity, lead rubber is often used for the gloves. Thickness of material used for gloves should be decided by the conditions and operations in each box. Figures 6 and 9 show different types of gloves, and Fig. 7 a typical arrangement of gloves.

Glove ports are generally located in the viewing panels, some of their methods of attachment being illustrated in Fig. 8. Figures 9 and 10 show two types of glove-changing procedures; the French system shown in Fig. 10 is used mainly with shielded boxes. A typical bag transfer system is shown in Fig. 11, and special transfer ports are illustrated in Fig. 12.

Various methods of fitting viewing panels are shown in Fig. 13, the choice being determined by the leak tightness required. Fig. 13a shows an economic seal with a reasonable standard of leak tightness, Fig. 13b a system that is decreasingly used although the standard of leak tightness is higher - the clamping angle should be installed in short sections to ensure uniform clamping pressure. Figure 13c indicates a French joint developed for joining two half boxes together, and Fig. 13d shows the French joint used where each side of the box is a removable panel. Systems (c) and (d) are more expensive than (a) and (b).
Some typical gasket sections are illustrated in Fig. 14. If gaskets are not manufactured in one piece then it is important that the joints in the gaskets themselves are not made at the corners. Soft rubber seals in one piece can ensure a high grade of leak tightness.

The construction of the glove box should ensure that the interior is smooth and free from any pockets where dust or gas can be trapped. Support of vibrating equipment and furnaces within the boxes should be carefully assessed to eliminate any problems with associated equipment.

The ideas concerning maintenance in the laboratory in which the box is to be used have an effect on the structure of the box. If the box is to be used in an in-line system then the maintenance will probably be carried out from one face, and the depth of the box should be governed by the ability of the maintenance staff to reach all sections. If the box is to be used in a free-standing arrangement then it may be desirable to have secondary flanges on the box so that it can be attached to a decontamination or maintenance centre or have a PVC tent attached in situ for maintenance purposes.

Services for glove boxes generally comprise compressed air, vacuum, liquid feeds, electricity, instrumentation and effluent drainage. Segregation of electrical and mechanical supplies should be enforced, and the control of all services should be positioned outside the box either on attached or separate panels. Controls for the processing equipment should also be established outside the box on separate panels.

Typical details of penetration of glove boxes for piped services and electrical cables are shown in Fig. 15. In certain cases where the leakage rate is to be minimized it is necessary to seal the leak path through the cables themselves, or to use sealed bulkheads.

Lighting of glove boxes is described in Section 3.

The ventilation of glove boxes is dependent on the material being handled and the processes being used. It is described in Section 5 (see Figs 7 and 65).

Glove boxes are suitable for in-line or free-standing arrangements. The layout determines the procedure for decontamination and maintenance. With the in-line arrangement direct access to the boxes is provided in Zone III, whereas with the free-standing arrangement the glove box can be taken to a special area or a tent can be erected at the box.
2.3. Shielded boxes

A shielded box is an enclosure whose containment is provided by an air-tight box and whose biological shield is constructed from a high density material, e.g. lead, steel. The containment can also be provided by the biological shield itself [36, 51, 52, 54, 58, 60, 71-74]. Figure 16 illustrates these two types of shielded boxes, (a) French type, (b) Russian type.

Shielded boxes are used in hot laboratories when the alpha-beta-gamma-activity of the material being handled is of millicurie to thousand curies level, depending very much on the energy of gamma-rays. The alpha-beta-gamma-activity may also be associated with neutrons.

The factors that have a bearing on the design of shielded boxes are concerned with containment and shielding. Those affecting containment have been enumerated in Section 2.2; in addition the effects of the higher level of radiation must be taken into account.

Determination of the shielding thickness can be carried out after estimating the quantity, nature, location and concentration of the radiation in the box together with an appreciation of the normal and exceptional positions and duties of the operators and maintenance staff on the various sides of the shielded box.

Materials used in constructing the containment box have already been described in Section 2.2. These materials must be closely examined for their resistance to the radiation produced by the radioactive material being handled; for example, transparent plastic windows may be used up to a certain level of radiation, above which glass, which may be stabilized, must be used. Materials for gaskets must be carefully chosen and the use of plastics, which break down under high irradiation releasing corrosive products, should be avoided.

Common materials for the biological shield are lead, cast iron and steel; where neutrons are present special plastics can be used.

Panel-type construction is used with cast iron and mild steel. Lead can be used in the form of bricks, blocks or as a filling for a mild-steel fabricated casing.

The joints in the biological shield should be carefully designed and positioned to minimize radiation leakage. Typical joints are presented in Fig. 17. Straight joints in the shield can be filled with lead in the form of wool, powder or shot.
Lead walls are normally constructed with bricks having chevron or curved joints. A brick-built lead wall is illustrated in Fig. 18 and indicates the variety in the French standard type of bricks that are required. Figure 19 shows the British standard features in the design of lead brick penetrations for tongs, windows, services, etc., which are essential for the protection of the operators against radiation leaks. If the walls are constructed with large cast lead panels the same standard components for windows, etc., should be fitted.

Figures 20 and 21 show the use and method of changing flexible bootings at the various penetrations. It should be noted that if the containment box is to remain independent of the shield then the booting must be attached to the penetration on the box. Handling, viewing and lighting equipment is discussed in Section 3.

When shielded boxes are constructed with panels, one side of the shield should be installed as a moveable unit. This gives the added advantage of easy replacement of the containment box (if it has been installed as an independent unit) and easy access for maintenance or modification to the equipment in the box after the removal of the radiation sources.

The services required for shielded boxes are similar to those already described for glove boxes. Their method of installation is different because of the radiation hazard; wherever they penetrate the biological shielding special plugs must be used which prevent a direct shine of radiation from inside the box.

When a variety of services are required at one point it is usual to design remotely operated connectors.

The ventilation of shielded boxes is similar to that of glove boxes, and is described in Section 5.

The layout of shielded boxes follows the in-line or free-standing arrangement.

2.4. Hot cells

A hot cell is an enclosure in which highly radioactive material is handled in isolation from the operator's environment. This enclosure is a permanent feature of the laboratory [36, 50, 61, 74-100].

Hot cells are used in laboratories when the activity level of the material being handled is of the hundred to hundreds of thousands curie range, and when it is certain there will be a continuing demand for the use of such cells over a number of years.
The main operations carried out in the cells are examination of irradiated fuel and canning materials, the experimental chemical reprocessing of spent fuel and irradiated targets, metallurgical research, radioisotope production and other high-level radiation research work.

Design of hot cells should only be attempted after a detailed specification has been drawn up. Typical questions that help to establish the specification are: What are the quantities, sizes and shapes of the radioactive materials to be examined and/or processed? What type and energy of activity is expected? Is the cell for production or research use? What types of operations are to be performed? Wet? Dry? What type of material-handling flasks are to be used? Are they top, bottom or side loading? What services are required? What type of viewing system is to be used? Are there any special lighting requirements? What type of manipulators are required? What philosophy of maintenance is to be adopted? What other hazards apart from radiation are present? Is there a requirement for an inert atmosphere? Are there special requirements for radioactive wastes disposal?

The main construction material for hot cells is concrete, which is relatively cheap and its density can be varied to suit requirements of space, viewing system, availability of raw materials, etc.

Common types of concrete for use in hot cells are:

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<tr>
<th>Type</th>
<th>Mass density (gm/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland cement</td>
<td>2.4</td>
</tr>
<tr>
<td>Barytes concrete</td>
<td>3.5</td>
</tr>
<tr>
<td>Steel shot concrete</td>
<td>5.6</td>
</tr>
</tbody>
</table>

Hot cells that deal with quantities of isotopes with high alpha and neutron hazards are constructed in concrete having a high hydrogen content, typical concretes being:

<table>
<thead>
<tr>
<th>Type</th>
<th>Mass density gm/cm²</th>
<th>Water content wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrophosphorus-serpentine</td>
<td>3.4</td>
<td>6</td>
</tr>
<tr>
<td>Magnetite-limonite</td>
<td>3.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>
Other mixtures of materials utilize the neutron-absorbing qualities of individual elements. An example of this is "Chemtree 13", which is a leaded concrete containing boron and with a specific gravity of approximately 4. Another method of providing shielding against beta, gamma and neutron radiation is to build the cell wall in the form of a tank filled with water.

When designing and constructing concrete shield walls for hot cells, two important points should be noted. There should be sufficient steel reinforcement to cater for shrinkage, cracking and impact loads; and where there are any penetrations of the wall such as windows, service sleeves, manipulator or periscope tubes, etc., careful attention must be paid to the pouring of the concrete to eliminate any cavities in the wall around these penetrations.

With beta-gamma concrete cells it is usual to line the base with stainless-steel sheet or to have a complete stainless-steel bench just below window level. This gives a reasonable decontaminable surface on an area where abrasion can occur because of the movement of materials and equipment. The internal walls and roof of the cell should be given a good paint finish\textsuperscript{2}. A strippable plastic covering over the walls and roof can also be used to help the decontamination problems.

Alpha-beta-gamma hot cells have two types of containment. One type with the containment integral with the shield is usually constructed in two ways. The containment can be built as a box by welding stainless-steel sheets to a steel frame. The welding of the box can be tested and a pressure or vacuum test applied to the complete unit. This box can then be used as the internal shuttering for the concrete shield, or concrete blocks can be placed around it as in the plutonium facility at Marcoule. The second method of construction is to build the concrete shield and to have cast into the walls, roof and floor a steel framework to which stainless-steel sheets can be welded, and again the welds and complete structure can be tested.

The second type of containment has the box entirely separate from the concrete biological shield. The internal walls, roof and floor should be given the normal finish, and the containment box should be of the glove-box type suitable for operation with master-slave manipulators as shown in Fig. 22.

To leave the operating area free of equipment which is not required for operational control at the cell face it is good practice

\textsuperscript{2} Special paints with a base of polymerizing resins are applied for the finishing.
to provide services and equipment either immediately above or below the operating face. Figure 23 shows how the operating area can be left free of equipment, which has been installed instead on the floor above, thus allowing the operator adequate space for easy manipulator removal, lighting replacement, insertion and withdrawal of periscope and installation of additional services. Controls for in-cell equipment should be arranged round the window so that where possible visual checks can be obtained that the equipment responds to the controls. Grouping of the controls should be carefully examined in conjunction with operational procedure to ensure that the operator needs a minimum of movement.

Transfers of radioactive materials into and out of hot cells can be made via transfer ports in the roof, wall or floor of the cells by means of shielded transfer flasks. The transfer ports must be fitted with compensating shielding to ensure that the operational staff is shielded against penetrating radiation as the material is being passed through the biological shield. A shielded valve at each transfer port allows easy posting procedure. Transfer of material is described in Section 4.

Doors are provided for easy access to cells or for quick intercommunication between adjacent cells. Of the various types of doors the cheapest form is where a part of the biological shield is constructed in large removable blocks, which when removed from the wall give access to the cell. The next most economical form is the rollout concrete door, and the most common of the other types are the metal sliding door and the metal hinged door. Figure 24 shows a plan view of an alpha-beta-gamma facility at Dounreay in Scotland in which three of the above mentioned types are used. The rollout concrete doors are used in the metallurgical and analytical cells, where space permits their economical use. In the case of the chemical reprocessing cells the metal sliding doors are used to divide the three cells in the most economical use of building space, and the metal hinged door gives access to the cells.

Difficulties can be experienced when attempting to make a seal with these large doors. Typical solutions to this problem are the use of inflatable seals or the provision of a lightweight independent panel which gives a good seal. An example of the latter is shown in Fig.25.

In hot cell facilities, monitoring of the air in Zones II and III is carried out, and at the transfer ports provision is made both for installation of gamma alarm monitors and intercommunication with
the operating face. Particular attention should be paid to the building finishes and floor coverings in the Zone III area so that in the event of an accidental spillage of radioactivity the problem of decontamination is made easier.

Careful consideration should be given to the positioning of the extract filters for cell ventilation as the cost of floor or bench space in cells is extremely high and the filters should not occupy potential operational space in the cell. It should be remembered, however, that they must be accessible for remote replacement.

In some installations, special shielded areas are provided at the rear of hot cells for maintenance and decontamination purposes. One example of this is the Atomics International Hot Cell Facility at Santa Susana in the United States of America, a plan view of which is shown in Fig. 26. The decontamination areas in this facility are fitted with viewing windows and manipulator positions so that decontamination of equipment and its subsequent removal or maintenance can be carried out under controlled conditions in a space especially designed for this purpose.

Various services are required in hot cells. Viewing equipment must be provided, which may be either large viewing windows backed up by monocular and periscope, or a television viewing system.

Manipulation can be done with master-slave manipulators, a remotely controlled crane or remotely operated power manipulators. Special arrangements for the provision of water, steam, gas, vacuum, chemical reagents and electrical power inside the cell must be made. Typical arrangements of service sleeves for gas and liquor pipes are shown in Fig. 27a; electrical supplies can be provided as shown in Fig. 27b. Electrical plugs and sockets for use inside the cell should be chosen with great care, and they should be designed for easy and safe manipulation. Illumination of hot cells is usually provided by lamps – tungsten, quartz iodine, mercury vapour, sodium, etc. – placed inside the cell, replacement of the lamps being either direct or remote.

The ventilation of hot cells is discussed in Section 5.

As previously stated, the layout of hot cells generally follows the in-line arrangement with clear distinctions between Zones II, III and IV. Changing rooms are established at the entrance to Zones II and III, and provision is usually made for a temporary changing room to be established wherever the containment of Zone IV is breached for personnel access. Typical layouts of hot cell laboratories are shown in Figs 2-4 and in Figs 22-24, and Fig. 26.
3. HANDLING AND VIEWING

To ensure the successful performance of work in any enclosure viewing, lighting and handling equipment are necessary. These three types of equipment are interdependent, the light transmission factor of the window determining the required level of illumination within the enclosure, and the type and coverage of the manipulator determining the position and size of the viewing window in the wall.

3.1. Viewing systems

Common viewing systems in use in hot laboratories are windows, periscopes and television [12-15, 35, 36, 41, 50, 101-130].

3.1.1. Mirrors

Mirrors were originally used to view over walls as shown in Fig. 28. However, with increasing thicknesses of the shielding wall this system of viewing is impracticable because of radiation leakage. Mirrors are still used inside enclosures to enable operators to view those areas not visible through the normal window.

3.1.2. Windows

Various types of windows are used with each type of containment. Fume cupboards and glove boxes generally have viewing panels made from either transparent plastic, or laminated or toughened glass, depending on the work being carried out. Shielded boxes are usually provided with lead glass windows. A typical arrangement of this type of window is shown in Fig. 29. The lead glass block is fitted in the steel cylindrical holder with lead powder and polyester resin cement. The most suitable type of lead glass for 50 mm of lead shielding is a 5.2 g/cm² density type as a 110-mm thick block. Two blocks are assembled for 100 mm of lead. For more than 100 mm of lead cerium-stabilized glass at the hot side is required, and a special radiation-resistant window should be installed in the containment box. Allymer CR39 is an example of high-radiation and chemical-resistant plastic glass.

Hot cells are provided with large viewing windows of various types. A common type of window in hot cells is shown in Fig. 30a, consisting of a series of lead glass blocks fitted into a mild steel framework cast into the biological shielding. The space between
the glass and the framework is filled with lead-wool. The space between glass blocks is often filled with oil to avoid reflections and increase transmission. In many cases dry-type windows are used where the surfaces of each glass block are specially treated. Lead glass windows are used to advantage with dense biological shielding because in this case the window thickness is reduced and a better view is obtained. Care has to be taken with the spacing of the glass to prevent Newton's rings. Such windows are made with different types of glass with density between 2.3 and 3.6. The thickness of the stabilized glass on the hot side should be sufficient to prevent the browning of the first block of unstabilized glass as a result of radiation. Figure 31 gives spectral transmission of several types of glass. Common 1% cerium-stabilized lead glass becomes brown by $10^5$ R. For very high activity cells, more stabilized lead glasses have been made, but in these cases a lead cover is required to protect the hot face of the window when not working.

For work with mixed neutrons and gamma-radiation a window as shown in Fig. 30b can be used. This consists of a stepped mild-steel case filled with Magnetite concrete fitted with alternate lead glass blocks and oil tanks. At the end sections of the window both on the hot side and operating side are oil tanks faced with 2.5-mm thick plate glass. Sectioning of the oil tanks between the lead glass blocks prevents the loss of all the oil at the same time.

The simplest kind of liquid-filled window uses water. This is applied for work with mixed neutron and gamma-radiations. The disadvantage of such windows is the poor shielding efficiency to gamma-radiations which leads to disproportion between the thicknesses of the window and the dense shielding materials used for the walls. To increase the density zinc bromide solution is commonly used. Figure 30c shows a typical zinc bromide window, consisting of an epoxy-lined opening in the concrete with twin plates of silicate glass fitted at the hot side and twin plates of lime glass fitted at the operating side. The interspace between the inner glasses is filled with zinc bromide solution. Alternatively, the window tank may be an epoxy-lined concrete or mild-steel tank inserted in a hole left in the biological shielding. A further modification is when a lead glass block is fitted between the two silicate glasses on the hot side of the window. This type of window minimizes the gamma-dose received by the zinc bromide when viewing highly active objects.

With a large window it is possible for more than one person to view at the same time, and stereoscopic vision is still retained.
This type of window is the most economical type to use when viewing objects in hot cells, particularly if the shielding is made of ordinary concrete. Another advantage of the zinc bromide windows is their high transmission and colourlessness. Care has to be taken to ensure that the zinc bromide solution does not make contact with ferrous materials, otherwise it will become clouded. Exposure to radiation may also liberate free bromine from the solution. This can be prevented by the addition of hydrazine hydrobromide or hydroxylamine hydrochloride, which act as stabilizing agents.

The main disadvantages for all windows are chromatic and spherical aberration and localized optical imperfections which reduce resolution. Loss of colour discrimination also occurs from the lighting and the intrinsic colour of the viewing media.

3.1.3. Periscopes

Periscopes are used for viewing objects in hot cells, a typical arrangement being shown in Fig. 32. It consists of a tubular body inserted through the biological shielding as a lens system that permits the viewing eye-piece to be in such a position that protection from gamma-radiation is achieved. A turret lens may be incorporated so that magnification can be varied, and a scanning device may also be fitted. The main advantage of this type of viewing is the close examination of detail, sharp image and true colour being obtained even through thick shielding. The periscope may also be used in conjunction with a microscope or camera. Use of an eye-piece for viewing tends to be tiring, and only one person at a time can use the instrument. Also if no scanning device is fitted the field of view is limited. The in-cell part of the periscope is usually protected against contamination by using a booting or a permanent gas-tight cover.

3.1.4. Television

Highly active objects may be viewed by means of television cameras. The main advantage over the other methods described is where the object being viewed is in a hazardous or inaccessible position. It is possible for more than one operator to view objects at the same time, or view widely separated points simultaneously. The television cameras may be mounted to view from any vantage point, but it is convenient to have the camera set along the operator's
line of sight to the object being viewed, so that the operator does not have to re-orientate himself. Normal television systems do not provide stereoscopic viewing. To assist this, lighting may be arranged to produce shadows to show depth perception. Alternatively two cameras may be used, connected to two receivers set at 90° fitted with polaroids and a half-silvered mirror. Impressions of depth are then obtained by viewing with polaroid glasses. The reliability of electronic systems when subjected to high radiation doses cannot be guaranteed and stand-by equipment is desirable. In any case the lenses must be stabilized, and for irradiation up to $10^4 \text{R/h}$ "nuvistor" irradiation-proof electronic tubes must be used. Plastic insulated wires should be avoided. The main applications of television systems are for back cell areas, transportation corridors and vehicle-mounted manipulators.

3.2. Lighting systems

The types of lighting provided for fume cupboards and glove boxes are either tungsten or fluorescent lamps. The required level of illumination in the boxes is 150 to 300 lx, and the light fitting is usually suspended above or on the side of the box, where a suitable transparent panel is mounted. The type of lighting depends on the quantity of light required, size of the box and whether rotating machinery is present (stroboscopic effect). Care must be taken to counteract the action of ultraviolet light on rubber and plastic by the use of filters. The heating effect of the lighting inside the boxes should be minimized.

Tungsten, fluorescent and sodium are the types of lighting used in shielded boxes where the level of illumination required is 1000-1500 lx. Higher illumination is necessary because of the lower optical transmission of the shielding windows. Figure 33a shows a typical installation of a light fitting, where the containment is an independent box. The fitting can be removable for bulb replacement without risk of contamination.

The choice of the type of lighting depends on the nature of the operations being undertaken. Are sharply defined images required or is colour definition necessary?

Lighting in hot cells is usually provided by normal tungsten, quartz iodine, sodium or mercury vapour lamps. The level of illumination required is 1500-3000 lx. Figure 33b shows a typical arrangement of a removable lighting system for direct bulb replace-
ment; alternatively the fitting may be mounted directly in the cell and should be remotely changed and posted out of the cell. By casting cooling tubes in the shield plugs gas cooling can help to eliminate the heating effect of the bulb. Reasons for choice of lighting are similar to those stated in the previous paragraph.

Lead glass and zinc bromide solution are dispersive media, and when an object illuminated by light of different colours is viewed through these media the images produced by the different colours do not coincide because of the different refractive indices of the media produced by the various colours. This blurring of the image is not acceptable in certain cases, and it is essential that when a sharp image is required a monochromatic light is used. Sodium lamps can be used successfully for this purpose, and if colour definition is required a spot lamp of either tungsten or tungsten iodine can be used.

The danger of damaging the plastic bootings of manipulators by ultra-violet rays must be avoided: a few weeks' exposure in front of a mercury vapour lamp causes more damage than a radiation dose of $10^8$ R.

3.3. Remote manipulation and handling equipment

The development of handling equipment and manipulators has progressed with the increasing level of radioactive material being handled and with the evolution of the various types of enclosures. With low-level activity the simplest form of protection is to put distance between the source and the operator. Simple tongs were therefore introduced, and as the level of radioactivity (radiation and contamination) increased the tongs and accessories were designed to permit operation through thin and thick shield walls. Manipulators were developed to operate over shield walls, and as the radiation hazard further increased through-the-wall manipulators were evolved. With a further increase in the contamination hazard, the need for a highly controlled atmosphere in hot cells was established and the sealed through-the-wall manipulators were produced.

The need to handle heavy material and equipment within hot cells led to the development of power manipulators and remotely operated cranes.

Simple tongs with special accessories are used in glove boxes and shielded boxes. Figure 34a shows a typical tongs arrangement in which the tongs can be replaced by withdrawing them through the ball leaving the grip inside the box. Articulated tongs are used to
give increased coverage. One French type is shown in Fig. 34b, and a Russian type in Fig. 34c. The wrist can be swung up to 90° by turning a muff at the handle. A very sophisticated American type of articulated tongs (the Minimanip) is shown in Fig. 34d. The elbow and the wrist are articulated, and the ball and joint are located in the vertical wall and rotate about a horizontal axis thus giving a reversed up-and-down motion. When the shield wall is thin the ball is tight and friction is not a problem. However, with a thick lead wall the lead ball can be mounted in a gas roller or ball bearing to eliminate friction.

The manipulator is a machine with six degrees of motion. Right to left (X motion), backwards and forwards (Y motion), and up and down (Z motion); the wrist has azimuth and elevation, and the tongs have rotation.

Figure 35 shows an articulated French master-slave manipulator, with a load capacity of 3 kg, which can be mounted either through the ceiling or the wall. The through-the-wall version has the advantage of being safer when the radiation level is high.

Figure 36 shows two versions of articulated master-slave manipulators with an upper arm section; (a) French; (b) German type. These types of manipulators, because of the disposition of the upper arm, allow objects on the bench to be cleared with greater ease.

Two types of telescopic master-slave manipulators, with a load capacity of 5 kg, are shown in Fig. 37. These manipulators operate through the ceiling.

The French manipulator shown in Fig. 37b allows the slave arm to have a greater Y motion than the master arm; this is achieved by the replacement of the upper horizontal tube in Fig. 37a by the telescopic assembly (a) shown in Fig. 37b.

Figure 38 shows through-the-wall telescopic US manipulators. The manipulator shown in Fig. 38a has a load capacity of 5 kg and can be fitted with two additional features on the standard motions; these are displacement motions in the X and Y places giving the operator better visibility and covering a greater depth of cell.

Figure 38b shows a Soviet-type M-22 which has a load capacity up to 15 kg. It is a through-the-wall type and is designated for operating cells of up to 2.5-m width, 1.8-m depth and front wall thickness up to 1.5 m. Operator’s movements are accomplished by means of steel cables. Design of the slave wrist provides remote replacement of the tongs instruments. The manipulator is able to carry out movements in seven degrees of freedom; motions in X, Y
and Z directions, wrist rotation around vertical and horizontal axis, instrument rotation (540°) and tongs claw. To enlarge the service area and for removal of the manipulators the slave arm can be manually straightened to a horizontal position. Any intermediate position of the slave arm may be fixed. Model M-33 is another master-slave manipulator of the same handling capacity and similar design, made of titanium alloys for work in large radiochemical cells with very aggressive media. For motion transmission steel bands in combination with chains are used. Straightening of the slave arm up to horizontal position is accomplished by means of an electrical motor and may be fixed in any position. The wrist design enables rotation of the tongs up to 2.5 revolutions. For the operation of small cells with a front wall thickness less than 350 mm, a small master-slave manipulator of type M-31 with a handling capacity of 3 kg is used. Compared with M-22, apart from its size, it also has some improvements: bands instead of cables are used for motion transmission; manual straightening of the slave arm is simplified; rotation of the tongs is extended up to 2.5 revolutions. There are two modifications of M-31: of steel, for regular operations, and of titanium alloys, for operation of chemical cells.

Figure 39a shows the standard version of the telescopic master-slave manipulator. This type can have load capacities of 10, 15 and 25 kg. It is normally fitted with electrical indexing on the X and Y motions.

Figure 39b shows an adaptation of the standard manipulator for use in a hotcell with a low floor arrangement. This type of manipulator – the extended reach – has similar load capacity to the standard model. Manipulators in Fig. 39 are US and UK designs.

An essential accessory to the tongs and manipulators previously described is the protective booting. The use of this booting has a fourfold purpose: to prevent contamination of the slave arm, to resist corrosive media, to maintain containment of the enclosure and to provide a safe system for the removal and repair of the tongs and manipulators. The booting for these tongs is shown in Fig. 20, and the technique for changing this booting is also indicated.

Figure 40 illustrates the different types of booting for through-the-wall manipulators. The methods of changing the booting follows the types of glove changing procedure (see Figs 9 and 10). Double bootings are used for strong containment, as for controlled atmosphere. They may consist of a standard booting and an additional one placed outside the containment (see, e.g. Fig. 23).
The different types of attachment of booting at the wrist are illustrated in Fig. 41. This feature is essential to allow for the safe removal of manipulators for maintenance. PVC is the material normally used for booting, but special materials can be incorporated at the wrist ends because of the high irradiation level.

Where the need for a highly controlled atmosphere is predominant, sealed master-slave manipulators may be used. Figure 42 shows two such types.

The US manipulator shown in Fig. 42a has the seal at the "hot" end of the wall tube, and the slave arm is detachable in the cell by means of a crane. Figure 42b illustrates a German design with the seal at the "cold" end of the wall tube. Both models can be fitted with extended-reach slave arms. A recent sealed manipulator developed at Dounreay in Scotland is a power-assisted master-slave manipulator with hydraulic transmission which makes it possible to handle 25 kg without effort.

There are a number of designs of power manipulators for use in hot cells. The manipulator consists of a slave arm mounted on a carriage which gives the X-Y motions and a telescopic tube giving the Z motion. The arm can have from one to three articulated sections, and has tongs possessing swinging and rotating motions. The movements are produced by electric motors and the control is positioned outside the cell. The load capacity can vary from 25 to 100 kg, depending on the geometrical configuration of the articulated sections.

Maximum applied forces or torques are usually limited by friction or automatic cut-out; force of the grip is pre-set and adjustable, and tools can be incorporated at the wrist.

In some cases the manipulator can be mounted on a column that moves along the wall of a hot cell, and vertical motion up and down the column and horizontal telescopic motion can be included.

In designing hot cells careful attention should be paid to the provision of built-in facilities for maintenance and repair of power manipulators.

Provision of remotely operated cranes in hot cells is essential when dealing with heavy equipment, and a compact crane design will effect a considerable saving in cell space.

Water ponds are often associated with storage of radioactive materials before their acceptance in hot laboratories. Tongs are the usual handling equipment installed. The tongs tanks need not be sealed since the water provides the shielding. With hydraulic
tongs it is worth considering the use of water as the operating fluid since the pond cannot be fouled by any leakage from the cylinders.

The main advantage of a master-slave manipulator is its ability to reproduce faithfully at the slave end the motions and forces exerted at the master end, and to feed back any slight pressure differences from the slave to the master end; to achieve this it is essential that the design of the manipulators should ensure good balance, low friction, low inertia and minimum deflections, which require aircraft design techniques, and the materials of construction should be carefully chosen to achieve these ends.

Manipulators may be mounted on vehicles to permit remote recovery in emergency conditions. Figure 43 shows two typical vehicles.

3.4. Relative dimensions of cells, manipulators and windows

Carefull attention should be paid to the close connection between the dimensions of cells, manipulators and windows. The shielding thickness determines the type of manipulator to be selected, the depth of cell determines the length of the fully extended slave arm of the manipulator, and the length of slave arm determines the minimum cell height. The centre distance between a pair of manipulators is usually 70 to 80 cm, which then determines the width of the cell. The shielding thickness and width and height of the cell determines the size of the window, and the clearance required to remove the manipulator can now be determined. Figure 44 shows the general limits for using different types of manipulators depending on cell dimensions and shielding thicknesses. Figure 45 shows typical coverage diagrams for a pair of manipulators and the limit of viewing in the cell.

4. TRANSFER AND TRANSPORT SYSTEMS

The safe operation of enclosures is dependent on the introduction and discharge of radioactive materials to and from the enclosures [131-143]. The hazards involved in any transfer can be radiation, contamination or a combination of these, and the types of transfer can be direct or indirect. Direct transfer can be between an enclosure and its environment and between two enclosures with a permanent connection.
Indirect transfer is between two separate enclosures via an independent portable enclosure, i.e. a transport container. The transfer system can be one way only or reversible.

4.1. Shielded transfer systems

These systems are intended for use where there is only a radiation hazard.

4.1.1. Direct shielded transfer system

4.1.1.1. Between an enclosure and its environment

Figure 46 indicates the different types of locks used to give access to enclosures. This system is used for transfer of inactive material and radioactive material held in its own shielded container.

4.1.1.2. Between two enclosures with a permanent connection

Three types of transfer between connecting enclosures are illustrated in Fig. 47. The radiation lock shown in Fig. 47c can be used to give access between enclosures of different shielding thicknesses. When there is a line of shielded enclosures the most common method of transfer is by a shielded tunnel. Figure 48 shows alternative positions for such a tunnel, the choice of position being dependent on the laboratory layout.

A pneumatic rabbit system can be used to transfer samples. Low active samples are commonly sent through unshielded pipes. This system is often used between a reactor and a laboratory enclosure. Hydraulic rabbits can be used with pool reactors.

A pool is often connected to an enclosure by means of a water channel, the water performing three very useful functions, as shielding, as a means of isolating the enclosure and as an easy mode of access.

4.1.2. Indirect shielded transfer system

Transfers between widely separated enclosures are usually achieved by means of a shielded container, one exception being the rabbit system described above.
The two common methods of transfer are first to place the shielded container inside the enclosure for loading and unloading, and second to position the container outside the enclosure and to load or unload from the container through a hole in the biological shield.

4.1.2.1. Transfer with container inside enclosure

Small containers can be passed into the enclosure through a radiation lock, as shown in Fig. 46a. Heavy containers can be passed into the enclosure through a roof port or a door in the wall. This method should not be used when there is any possibility of a contamination risk. Transfers from pools can be made in a similar manner.

4.1.2.2. Transfer with the container outside the enclosure

The container is placed in position at the transfer port in the shield wall or ceiling. The transfer of material can be made by means of a winch or a push-pull device on the container or a pick-up device within the enclosure. Figures 49a and 50a show typical arrangements. The main advantage of this system compared with that in Section 4.1.2.1 is the saving of expensive enclosure space. Transfers from a pool can be carried out as shown in Fig. 50b.

4.1.3. Shielded containers

Containers described in this section are for use in transfers between enclosures inside a particular factory or research centre. If the container is required for external transport then it should be designed to meet the very stringent regulations as laid down in the IAEA Safety Series No. 6, Regulations for the Safe Transport of Radioactive Materials.

An important factor in the choice of material for containers is the density. The higher the density of the material used the greater is the saving in weight of the container.

4.1.3.1. Containers with covers or plugs

Figure 51 shows types of containers with covers and plugs. With covers and plugs, straight joints should be avoided to prevent a radiation hazard. Figure 51(1) and (2) shows different types of covers.
Figure 51(4) shows a container with a plug. The main advantage of this type is the large difference in weight of plugs and covers. With the smaller weight of the plug this type is much more flexible to operate.

4.1.3.2. Containers with sliding valve doors

Figure 49 shows containers with different types of sliding valves. This type of container is economical because of its simplicity, but care must be taken to ensure the mechanical safety of the valve.

4.1.3.3. Containers with rotating valve ports

This type of container is safer mechanically than the sliding valve container during transport, but its weight is considerably greater. Figure 50a shows a typical multichannel container with revolving interior. Also shown is a rotating wall valve that can be used instead of the straight wall plug. Figure 50b illustrates a rotating valve door container in position for transfer of material from a pool.

4.1.3.4. Special transfer system

A transfer system used at Windscale is shown in Fig. 52. Radioactive sources can be transferred between different enclosures that share a common maintenance area. A container with a sliding valve is mounted on a bogie that tracks over the length of the operating area. The bogie can be stopped at any enclosure, the container is then rotated and moved to make contact with the enclosure wall valve. The valves on the container and enclosure are opened remotely, and a tray from the container can be moved into the enclosure to deliver or remove sources.

4.2. Contained transfer systems

These systems involve the transfer of material that involves problems of contamination only.

4.2.1. Box system

This system allows passage of material into or out of a box and must achieve two objects: the atmosphere of the box should not be
disturbed, and contamination must not be passed out of the box. To achieve these objects various locks have been devised: air lock, vacuum lock and washable lock.

Air locks can be used in conjunction with the ventilation system to prevent the outflow of airborne contamination. Vacuum locks can be used to prevent loss of the special atmosphere in the box, and the washable lock can be used to prevent any surface contamination of the transferred material.

4.2.2. Bag posting system

In this system the containment of the enclosure is always maintained. Figure 11 illustrates the bagging technique. It should be noted that this bagging procedure ensures two-way operation.

4.2.3. Contained direct transfer system

Figure 53a and b shows a tunnel between two boxes. In Fig. 53a the tunnel is fixed and in Fig. 53b it is flexible to permit the removal of one or other of the boxes, as shown in Fig. 53c. The fixed tunnel arrangement is suitable for use when one box has a controlled atmosphere.

When there is a line of enclosures the tunnel system as described in Section 4.1.1.2 can be adopted if the tunnel is made a containment. The rabbit system can also be used.

4.2.4. Double door transfer systems

Figure 54 shows a US remotely operated transfer system developed to minimize the spread of contamination where the risk is high. Figure 55 shows a French hand-operated transfer system developed for conditions of high contamination risks.

4.3. Contained shielded transfer systems

These systems are used for transferring materials which combine the hazards of radiation and contamination and, as would be expected, are a combination of those systems described in Sections 4.1 and 4.2.
4.3.1. Contained shielded direct transfer system

These systems are used for two or more enclosures joined together.

Figure 56 shows the tunnel system for two adjacent enclosures and a line of enclosures. In Fig. 56b it is possible in many cases to omit the shielding door to the tunnel. The tunnel itself must be an enclosure to ensure containment.

4.3.2. Contained shielded indirect transfer systems

When the contamination hazard is not too great the containment can sometimes be achieved by controlled air flow. Such a system is illustrated in Fig. 57 using a container shown in Fig. 51.

The container is opened under an auxiliary shield with a small top bulge into which the plug is lifted. An off-set rod is used to remove the plug from the transfer port, and the container is then tilted on wheels so that its cavity is in position opposite the transfer port, which is lined with a flexible plastic tube fitted to a flange on the containment box. (Replacement of the plastic tube is as shown in Fig. 21.) The wall plug has a plastic cover (replaceable outside the shield) which can be used as a seal on the containment box whenever the box is to be removed. Whenever the containment is open air is drawn through the transfer port by the box ventilation system, the air velocity being maintained high enough to prevent contamination leaking from the box. Tongs operating from the other side of the cell are used to load or unload the container when it is in position. This system is used in France for containers with 5 to 15 cm of lead shielding.

Figure 58 illustrates the transfer of radioactive waste in French laboratories using the container shown in Fig. 49b. This system is a simplified adaptation of the double-door system. A lightweight drum with sealed lid is placed in the container, and its shielding cover is removed close to the cell wall. The container is moved under the port and the drum is sealed to the containment flange, and the containment plug is raised into the box taking with it the drum lid, held by means of an electromagnet. When the drum has been filled the operations are reversed, and the filled sealed drum can eventually be discharged to the waste storage system via the bottom valve in the container.

When the contamination risk is high then the containment must be maintained during transfer operations.
In Fig. 59 a US remote bagging technique is shown. It is used on a containment box inside a concrete cell. Figure 54 shows the US double-door system which can be operated remotely inside a concrete shield.

Figures 60 and 61 show the UK system of direct bagging adapted for use with a shielded container. Figure 60 illustrates the horizontal posting of material. When used to introduce material the bag is replaced without welding. Figure 61 shows a vertical-type container in position. This system has been used where controlled atmospheres are required. Figure 62 shows the application of the French double-door system to shielded containers. The main advantage of this system is that it eliminates the risk associated with plastic bags.

4.4. Transfer and transport of radioactive liquids

Radioactive liquids arise from the dissolution of radioactive materials and from the wet decontamination of plant and equipment in enclosures. The hazards of these liquids can be any combination of chemical, toxic, radiation and contamination.

4.4.1. Direct transfer system

The safest method of transfer is by the direct system, i.e. via a pipe which goes from the point of arising to the point of disposal. This system is not always possible for hot laboratories.

Transfer of liquors can be carried out by the usual means, i.e. pump ejectors, air lift, etc., the choice depending on the particular conditions.

The installation of pipework which carries active liquor outside the containment boxes should be remembered when the laboratory is being designed. If boxes are going to be made removable then the piping should be designed to permit modification and replacement with the minimum risk of contamination.

4.4.2. Indirect transfer system

The transfer of active liquid from the point of arising to a container can be carried out by means of pumps, ejectors, air lifts, etc. It is essential that overfilling of the container does not take
place, and that the transfer pipes are designed to eliminate any risk of contamination when the container is uncoupled for transport.

The transfer pipes must be shielded to protect the operating staff from radiation, and any leaks from these pipes outside the containment must be readily detectable.

4.4.3. Container

Depending on the nature of the chemical, the type and level of activity of the liquid containers range from simple unshielded plastic bottles to heavily shielded vessels constructed in various materials.

Figure 63 shows an elaborate French system for highly active liquid transfer. The quantity of liquid is measured by using a dynamometer to weigh the inner tank and contents. Couplings are fitted with wash connections to eliminate contamination when disconnected. Various methods of filling the container are possible depending upon the conditions. For example, if liquid is to be transferred from a large holding tank then the container should be positioned above the holding tank and, by evacuating the containers and then connecting them to the tank, liquid can be lifted into the container. By using a protective shell the container can be used for external transport under Type B container regulations.

5. VENTILATION SYSTEM

The principles involved in the design of safe ventilation systems for hot laboratories are fully described in IAEA Safety Series No. 17, Techniques for Controlling Air Pollution from the Operation of Nuclear Facilities.

The ventilation system, apart from providing suitable operating conditions, can be used as an aid to prevent the spread of contamination by directing the flow of air from Zone I through Zones II and III to Zone IV.

Some features of the ventilation of the various enclosures are worth noting [50, 51, 144-157].

5.1. Fume cupboards

The minimum velocity through the opening of the cupboard is 0.5 m/s. It is common practice that the fume cupboards exhaust
all the air that is delivered to the room in which they are situated. It is therefore important that a suitable bypass system be installed so that the balance is maintained whenever the fume cupboards are closed. One bypass system is illustrated in Fig. 64.

5.2. Glove boxes

The extract system should be designed so that the depression in the glove box will permit the necessary air flow into the box under certain accident conditions, e.g. loss of a glove. Figure 65 shows the installation of a French system to meet these conditions.

Two filters are usually placed on each circuit, and it is important that the sizes of the inside filters are suitable for posting out through the standard facility. The inlet outside filter is changed when dusty, but the inside one still operates during exchange. The outlet inside filter is changed when dusty, and the outside one is still in operation during exchange.

5.3. Shielded boxes

It should be remembered when positioning extract filters that they have to be changed remotely. The ventilation system for the containment box should be similar to that for glove boxes; in addition the space between the box and the shielding should be tied into an extract system so that the shielding becomes a secondary containment.

5.4. Hot cells

Filters must be remotely changed, and their position should be examined very closely because of the very high cost of the enclosure space.

Because of the large volumes of air used it is important to filter the air as it enters the cell to the same standard as the outlet filter to minimize the changing rate of the extract filter.

The use of special atmospheres in enclosures is increasing, and in general there are two systems. The first is a once-through system, which can be used where the purity level of the atmosphere is high and the volume of gas required is low. The second is a recirculating system to be used when the volumes are high. With glove boxes and shielded boxes the greatest leakages occur through gloves.
and bootings, and the materials for these should be examined closely. Plastic windows should be avoided when a high purity level in the enclosure atmosphere is required.

6. RADIOACTIVE WASTE DISPOSAL SYSTEMS

Radioactive wastes from hot laboratories, as wastes from any other nuclear facilities, are subdivided into three main groups: liquid, solid and gaseous. Gaseous waste management is an integral part of the general ventilation system discussed in the previous section.

Wastes which are either known or suspected to be radioactive must first be collected and monitored so that the extent of the necessary treatment can be determined and performed. The level of activity and the radiation characteristics of the radioisotope involved determine the nature of waste handling and the treatment. In hot laboratories separate collection systems are usually installed to handle wastes known to be non-radioactive or of such low activity that they may be released to the environment without further treatment or handling. Different systems may be provided to collect wastes of varying activity level and nature [32, 147, 158-173].

6.1. Liquid radioactive wastes

According to the level of activity, liquid radioactive wastes are generally subdivided into three categories: low-level, intermediate and highly radioactive. The activity limits determining the segregation vary in different countries. Laboratory effluents are in the main segregated into the following categories:

(a) Non-radioactive liquid wastes (process wastes from laboratories in which no radioactive materials are used, all sanitary wastes, boiler blowdown, cooling water from non-radioactive processes, etc.).

(b) Low-level radioactive wastes which can be discharged into the regular sewage system after (or without) corresponding dilution or relatively short time storage for decay of the short-lived radionuclides. These may be wastes from tracer laboratories and low-level decontamination processes, some process wastes
of radioisotope laboratories containing short-lived radionuclides, etc. Such wastes should be collected in a separate holding tank.

(c) Radioactive wastes requiring special treatment. They are collected in a tank (or tanks), and after monitoring and conditioning transferred to a treatment or storage facility (see Fig. 66).

6.1.1. Collecting systems and segregation

There are two main types of systems for collecting liquid radioactive wastes:

(a) Active waste solutions are poured into specially provided containers and transferred to the laboratory collecting tank or directly to a treatment facility.

(b) Radioactive effluents are discharged from the place of arising through specially constructed sinks and drain lines leading to the collecting tank for monitoring and conditioning.

Sometimes a combination of the two systems is used. The choice of the system depends on many factors such as volume, regularity, activity level and nature of wastes, and design of the laboratory.

One of the advantages of collecting wastes in special containers is that the volume of material handled at any one time is greatly reduced. However, because these containers must be accurately labelled as to content, this system requires the full co-operation of laboratory staffs. This type of system is especially applicable to limited laboratory operations involving tracer levels of radioactivity and small volumes of total solution. Special containers are useful in segregating long-lived or more hazardous radionuclides that require specialized handling, treatment (decontamination) or disposal.

The type of container used (size, material and shielding) will, of course, depend on the activity level, the chemical composition and the volume of the effluent. Containers for storage and transportation are shown in Fig. 63. The use of special sinks and separate drainage systems leading to hold-up tanks is common in many big laboratories. Such systems permit segregation of low-volume high-activity wastes from large-volume low-activity wastes.
The materials used for drain systems should ensure the construction of leak-tight joints and offer adequate corrosion resistance. In most cases the ease with which the construction material can be decontaminated is an important consideration. Stainless steel, polyethylene, PVC, glass tubing and ceramic pipes are examples of materials commonly used. Obviously each material has advantages and limitations. If the nature of the wastes to be collected is known, it may be possible to select cheaper materials that will perform adequately under the particular conditions that prevail. An important requirement of a liquid-waste collecting system is that any leaks which may occur are rapidly detected and the leakage contained. The methods used will vary according to circumstances, but in general the systems should be easy to inspect, not buried in walls or floors. A particularly important factor is the level of radioactivity of the wastes being collected. In some cases double-walled piping and efficient leak detectors are used. A more common method is to place the collecting pipes in waterproofed troughs which collect any leakage from the piping.

The number of separate drains provided for radioactive wastes varies with the nature of the operation. Sometimes the laboratory may be provided with two or three separate drains collecting radioactive wastes of different types.

The segregation of liquid wastes at source is usually well worthwhile as it is normally more economical and satisfactory to treat small volumes of highly active effluent than to treat large volumes of effluent having a low-activity level. Therefore enclosures for radioactive operations (fume hoods, boxes, hot cells) must be designed so that they enable an easy segregation of the radioactive effluents of different types. It is always important to avoid an accidental leak of costly material or highly radioactive wastes through a drain designed for low-level radioactive decontamination wastes. A special trap or small intermediate collection tank is often installed in cells or in boxes for such a purpose.

When the volume of wastes is small the wastes may be solidified directly in the cell or box for convenience of transport. In some specific cases the pre-treatment of certain radioactive wastes can be performed directly in the laboratory.

6.1.2. Collection tanks

Collection tanks are usually located on the underground floor of the laboratory building, as shown in Fig. 66, and are provided
with an adequate radiation shielding. Sometimes they can be situated outside the building and after being filled may serve as transport tanks.

Collection tanks are provided with monitoring, sampling and conditioning equipment. The instrument dials showing the volume and activity of the collected wastes are usually placed in a central panel to facilitate control.

The use of double-walled tanks (or a tank within a tank) may be advisable if leakage from a collection tank would not otherwise be contained.

### 6.2. Solid wastes

Solid wastes consist of a wide variety of material encountered in laboratory operations. They may range from pieces of contaminated paper and laboratory glassware to furniture, equipment and machinery. Solid wastes also include such items as contaminated filters, absorbers and spent ion-exchange columns. Radioactivity classification of solid wastes is difficult because of their non-homogeneity as regards contamination. They are segregated during collection with a view to subsequent treatment and handling processes. The segregation into two groups, combustible and non-combustible wastes, is common practice.

The collection of solid wastes does not usually present a difficult problem. Frequently normal refuse containers, shielded if necessary, can be used for small contaminated objects. It is preferable for such containers to have an inner lining, for example, plastic sheeting. These liners are usually sealed by a plastic clip, adhesive tape or welding when full, a procedure which facilitates removal from, and prevents contamination of, the outer container. Containers are collected in a specially equipped room or chamber, and transported to a central treatment facility at appropriate intervals. In some laboratories solid wastes from cells and boxes are collected and conveyed to a holding room by special conveyor along the line of cells or boxes. Figure 58 illustrates the transfer of highly active solid wastes in sealed drums placed inside shielded containers to a central treatment facility.
7. PERSONNEL PROTECTION

7.1. Changing rooms

All movements of personnel and equipment between zones must be through changing rooms. The purpose of these rooms is three-fold: (1) as an air lock to prevent any spread of contamination between the zones; (2) to ensure personnel protection through additional protective clothing before entering a zone with higher contamination hazard; (3) to check contamination on personnel before returning to a "colder" zone, personnel decontamination can be carried out if required.

Changing rooms are usually permanent but in certain circumstances temporary facilities or tents may be used.

The design of changing rooms depends on their relative position in the zones.

7.1.1. Initial changing rooms between Zone I and Zone II

The main purpose of this changing room is for putting on laboratory coats and overshoes. Figure 67 shows a typical arrangement. The workers remove such clothes as required in a cold section, put on overshoes, and cross over the bench to take their working clothing from the "hot wardrobe". A special changing room is often provided for visitors, clean laboratory coats being taken from the cold side.

On their return the workers take off their laboratory coats and cross the bench; they then wash their hands and monitor their normal clothing.

7.1.2. Changing rooms between Zone II and Zone III

These are similar to initial changing rooms, except that the contamination hazard is higher. The operators take off their laboratory coats in a colder wardrobe, put on new overshoes, cross the bench and put on "hot" clothes from the hot wardrobe. When coming back into Zone II they are monitored before taking off the "hot" clothes, remove gloves and overshoes and drop them in a waste drum, then put on laboratory coats, etc.
7.1.3. Changing rooms between Zone III and Zone IV

This zone requires pressurized suits which provide protection for the whole body and cover the normal Zone III "hot" clothing. Such changing rooms, as shown in Fig. 68, are provided with the means, usually in the form of showers, of decontaminating the pressurized suit on return. For exceptional or short entries the suit is often used once and, instead of being decontaminated, it is dropped in a waste drum. It is useful to help the worker to undress with gloves through a containment panel from the cold side. Contaminated wastes can be transferred by bagging. There is always a risk of contaminating the "hot dress" when taking off the pressurized suit, so the worker often has a shower after removing it. Such changing rooms require space, several monitoring devices, lengthy decontamination operations, and involve long "dead" periods.

Two methods of entry to higher risk zones are illustrated in Figs 69 and 70, which show methods that eliminate the need for elaborate decontamination facilities. The newt suit, shown in Fig. 69, can be compared with bagging. The other system is an application of the double-door system (Fig. 70). Both enable Zone IV to be entered quickly without a special fixed changing room. Such suits, even though expensive, can effect considerable saving in the construction of the laboratory.

7.1.4. Temporary changing rooms — tents

If it is necessary to enter a free standard cell within Zone II a small temporary Zone III should be set up. This can be achieved by using plastic tents and/or mobile intervention boxes, as shown in Fig. 70.

7.1.5. Emergency changing rooms

Most centres possess emergency changing rooms, usually of the trailer type with suitable waste storage for clothing and liquid. It is important that an ample supply of clean clothing should be available.

7.2. Monitoring

To ensure the safety of laboratory personnel an adequate monitoring system must be provided. This system includes personnel
monitoring and area monitoring. The monitoring is carried out by specially trained personnel with the help of special radiation measurement equipment such as dosimeters, radiation indicators and radiation monitors that are capable of determining individual exposures and radiation fields in working areas, as well as surface and air contamination [174-186]. It is intended, in this section, to give only the main principles of the monitoring system. Detailed information may be found in other IAEA publications.

7.2.1. Personnel monitoring

The principal objects of a personnel monitoring system are to prevent over-exposure and avoid unnecessary exposure of personnel working with various sources of radiation. An adequate system of personnel monitoring in hot laboratories must provide for the measurement, evaluation and recording of significant doses accumulated by persons together with a recording of the conditions under which these doses were received. Personnel monitoring in hot laboratories usually includes monitoring of external exposure and of skin and clothing contamination.

The monitoring of external exposure is used to assess the whole-body doses and doses received by parts of the body if there is any likelihood of their being significantly in excess of the whole-body dose (for example, doses received by the fingers in case of working with soft gamma-radiation sources in a glove box). In case of accidental over-exposure, such information may be particularly useful in deciding on subsequent action. External exposure is usually monitored with physical indicators of small weight and size (film badges and rings, pocket chambers, activation detectors, etc.) which make it possible to estimate the dose equivalent for the region of the body where they are placed provided that the conversion factors required to calculate the dose equivalent from measured quantities can be determined.

A proper assessment of the individual, area and job radiation situations make it possible to select adequate personnel monitoring devices and methods, and the proper frequency of exposure assessments. In simple cases it is sufficient if the individual wears a single dosimeter on the trunk of the body and the readings provided by this dosimeter are accepted as representing the whole-body exposure to the external radiation. In situations where the radiation distribution is not uniform it may be necessary to wear dosimeters
in several places on the body. In complex radiation situations, i.e. several types of radiation, it is necessary to wear a dosimeter sensitive to all types of radiation likely to be encountered. In laboratory practice neutron monitoring is rare. However, it should be noted that provision of neutron monitoring may be necessary not only in work with neutron sources, but also in chemical work with intensive alpha-isotopes in the presence of light elements due to \((\alpha, n)\) reactions.

Monitoring of the clothing and skin is normally done to detect any potential risk of incorporating radioactive material. Such monitoring is particularly necessary when a person crosses the border between two zones with different levels of contamination hazards. Therefore all changing rooms should be equipped with special monitors. It is sufficient to employ a contamination detector that will indicate whether the contamination is below the acceptable limit. A contamination detector that gives a quantitative response is useful in indicating the level of contamination and the progress of decontamination. Special hand monitors or hand-foot monitors are convenient if frequent monitoring of hands or feet is required. The monitor should give a sound or light signal when the contamination exceeds the acceptable level.

### 7.2.2. Area monitoring

Some indications of the dose received by a person may be obtained by monitoring his environment. To apply the results of such monitoring to the person one must know how long he has been in the area, details of his movements therein, and changes in environmental conditions with time. Unless these additional factors are accurately known, complete reliance can be placed on area monitoring only where the hazard is trivial and where the monitoring devices give adequate warning of any deterioration in exposure conditions.

The object of area monitoring is to provide an adequate assessment of external radiation, concentrations of radioactive aerosols and gases in the air, and surface contamination.

When the purpose is to provide an assessment of individual exposure, area monitoring is carried out in the specific working area of the person concerned. It is aimed at determining the type, energy, level and uniformity of the radiation. Radiation levels are determined by instruments (fixed, portable or semi-portable) designed to indicate directly the rate of external radiation exposure.
In most of the hot laboratories radiation levels in working areas are measured continuously with fixed monitors located in the vicinity of the operator. Reading parts of the monitors are usually located at a control panel. Duplicated reading instruments may be located directly in the monitored area. The monitors must give an audio or light signal when the radiation level exceeds the acceptable level. In some cases monitors are also installed in cells with reading instruments located in the cell control area or at the central panel. Portable or semi-portable measuring equipment is used for periodical monitoring of working rooms, for assessment of contamination level of surfaces in the area, for indicating the progress of decontamination operations, as well as for evaluating the level of activity for determining the duration of working time in areas with higher radiation level (maintenance of cells, work in accident conditions, etc.).

Selection of an air monitoring system depends on many factors including type of operation, toxicity of the material to be handled, and safety standards of the protective installation and devices. There are two systems in practice. The more complicated one is a fixed centralized system with continuous or periodical sampling of the air at the working places and centralized measuring and reading equipment. Another system is based on periodical air sampling in working areas with portable or semi-portable samples.

Air sampling procedures should be based on the assumption that the activity of the sampled air is representative of the activity of the inhaled air. Since the radioactive contamination of the air inhaled by person may be substantially different from that in the working space as a whole, it is preferable to sample the air directly in his zone, using portable or semi-portable devices.

7.3. Protective clothing

When passing between zones it is imperative to change clothing. There is a variety of protective clothing in use in hot laboratories. A full description of this clothing can be found in the IAEA Safety Series No. 22, Respirators and Protective Clothing.

It must be certain that the two types of gas-tight pressurized suits, shown in Figs 69 and 70, have no air escape into the cell's atmosphere, so they can be used in zones with controlled atmosphere. In the case of a tritium hazard, these suits give the best protection for operators. Other pressurized suits allow tritium, in spite of high air velocity, to enter through the escape valve.
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FIGURES

FIG. 1. Arrangement of glove boxes
(a) In line
(b) Free standing.

FIG. 2. Single line arrangement of hot cells
1. Operating area
2. Hot cells
3. Decontamination room
4. Changing rooms
5. Offices and laboratory
6. Workshop
7. Cask storage.
FIG. 3. Double line arrangement of hot cells
1, 2. Operating area
3, 4. Concrete shielded cells
5. Transfer rooms

FIG. 4. Elevation showing arrangement of zones
1. Mechanical master-slave manipulator
2. Removable roof slab
3. Crane
4. Rectilinear electric manipulator
5. Barrier
6. Door
7. Access ports
8. Shielding window
FIG. 5. Fume cupboard
1. Front sliding panel
2. Inlet flow
3. Outlet ventilation
4. Control of services.

FIG. 6. "Telescopic" glove
1. Glove port: the tight part 2 fits round the forearm and wrist; the wider part 3 enables easier movements than gloves in Figs 9 and 10.
FIG. 7. Typical arrangement of gloves in boxes
1. Gloves  4. Inlet filters
2. Safety plug  5. Outlet filters

FIG. 8. Glove ports
(a) Plastic port welded or cemented;
(b) and (c) Detachable metal or plastic ports.
The glove bead can be fitted 1. In grooves
2. By recesses.
FIG. 9. Glove-changing procedure
1. Remove adhesive tape (a) or clamp (b)
2. Move glove bead from second to first groove
3. Place new glove on second groove and remove old glove

FIG. 10. Glove changing system by ejection
1. Remove lock ring
2. Fix ejection device to box flange and rotate screw to release glove
3. Replace lock ring.
FIG. 11. Bag transfer system
(a) Posting out - place object in bag,
weld and cut off
(see detail of welding)
(b) Posting in - (1) place object in bag
(2) weld outside the box
(3) cut off inside the box.

FIG. 12. Special transfer port (for posting in only)
(a) Seal made by container
(b) Seals fixed to port
1. Hot side
2. Container
3. Lip seals.
FIG. 13. Panel fixing
(a) Combined attachment and seal
(b) Old system with holes in the panel
(c) (d) (e) Clamping.

FIG. 14. Types of gaskets
(a) (b) (c) Standard extended strip
(d) Soft rubber one-piece seal.
FIG. 15. Glove box penetrations
1. Cold sides
   (a) Welded pipe fitting
   (b) Removable pipe fitting
   (c) Single-cable penetration
   (d) Multi-cable bulk-head seal.
FIG. 16. Typical shielded boxes
(a) Shielded box with independent containment box
(b) Shielded box with sealed shielding panels
1. Lead bricks
2. Lead glass window
3. Tongs on ball and joint
4. Containment box
5. Transfer door
6. Conveyor
7. Lighting
8. Services
9. Remote control of the door
10. Cast-iron shielding
11. Higher activity enclosure
12. Lower activity enclosure
13. Glove with shielded door.
FIG. 17. Construction joints in shield walls

(a) Pieces of the same material
1. A straight joint in front of a source can be compensated by a small block.
2. A straight joint which is never in front of a source can be accepted if scattered radiation is not too high.
3. Typical arrangement of joints of wall with roof (a) and bench (b).
4. Typical step joint - the radiation leakage through space (a) is compensated by step (b) and reverse; occasionally compensation by part (c) is necessary, when spaces (a) and (b) are large.
5. Chevron-type joint.
6. Curved joint, used for thick shield walls.
7. Shielding requirements at door openings - the shielding provided in line (a) must be the same as provided in line (c).

(b) Pieces of different material
1. Step joint - shielding presented by path (a) in steel and concrete must be the same as that presented by path (b) in concrete - if lead is steel - lined path (a) is smaller than path (b) and it must be compensated (see Fig. 17a(4)).
2. and (3) Typical lead glass window arrangements, shielding presented by paths (a), (b), (c), (d) must be the same.
FIG. 18. Typical chevron brick-built wall
1. Standard top brick
2. Standard ordinary brick
3. Standard base brick
4. Half top brick
5. Half ordinary brick
6. Half base brick
7. Corner top brick
8. Corner ordinary brick
9. Corner base brick
10. Corner pillar brick
11. T-junction pillar brick
12. Simple bricks on bench.

FIG. 19. Typical curved brick-built wall
1, 2, 3. Bricks
4, 8. Port bricks
5, 6. Inserts
7. Lead plugs
9. Frame for sphere
12. Depleted uranium sphere on gas bearing
13, 14, 15, 16. Reduction bricks.
FIG. 20. Booting change procedure (see also Fig. 9)
1. Remove grip tongs and sphere unit
2. Put bead of booting in first groove
3. Fit new booting in second groove using special device (a)
4. Release old booting.
FIG. 21. Ejectable ring system
1. Lead frame
2. Box flange
3. Ejection device
4. Elastic clamping ring in place
5. New clamping ring to be placed
6. Booting with lip seal in place
7. New booting to be placed.

FIG. 22. Alpha-Beta-Gamma facility with containment box separate from biological shield
1. Containment box
2. Master-slave manipulator
3. Window
4. Transfer system
5. Bench.
FIG. 23. Example of operating area free of equipment not required for operational control.

FIG. 24. Types of doors for hot cells
1. Roll-out door
2. Hinged door
3. Sliding door
4. Operating area Zone II
5. Maintenance area Zone III
6. Transfer room Zone IV
7. "Frogman" changing room
FIG. 25. Containment panel.

FIG. 26. Special shielded areas for maintenance and decontamination

1. Operating area (Zone II)
2, 3, 4, 5. Hot cells
6, 7, 8, 9. Corresponding back cells for maintenance or decontamination (Zone III or IV depending on the operations)
10. Storage of hot equipment
11. Air lock
12. Service and transfer area (Zone III)
FIG. 27. Hot-cell penetrations
(a) Hot-cell penetrations
1. Steel-lined hole
2. Concrete
(b) Sleeve for electric services
1. Steel-lined hole
2. Concrete
3. Metal tube with removable cable.

FIG. 28. Simple mirror viewing system.
FIG. 29. Lead glass windows for shielded boxes
1. Lead frames of different widths for chevron brick
2. Lead glass blocks.
FIG. 30. Windows for hot cells
(a) Lead glass window
(b) Lead glass and oil window for neutron and gamma
(c) Zinc bromide window
1. Safety stabilized glass  4. Oil
2. Lead glass block      5. Safety sealed glass
3. Cold side safety glass 6. Zinc bromide
                            solution.
FIG. 31. Lead glass properties.

FIG. 32. Periscope
1. Periscope
2. Lead plug for lamp change
3. Gas-tight transparent cover
4. Removable service plug with cooling tubes.
FIG. 33. Lighting systems
(a) Lighting system for shielded box
(b) Lighting system for hot cell
1. Bulb
2. Lead plug for lamp change
3. Gas-tight transparent cover
4. Removable service plug with cooling tubes.
FIG. 34. Tongs
(a) Tongs with ball and joint
(b) Articulated tongs
(c) Articulated tongs with adjustable angle
(d) Minimanip
1. Removable grip
2. Gas-tight intermediate piece
to which booting is fitted
3. Articulation control
4. Ball and joint.
FIG. 36. Improved articulated master-slave manipulators: (a) Upper arms with symmetrical movement and electric Y motion; (b) Slave arm with parallel and amplified movements.


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Please see http://www.ns-iaea.org/standards/
FIG. 39. Telescopic master-slave manipulator: (a) Standard type; (b) Extended-reach type;
e. Master fixed tube; 2. Window; 3. Penetration and shielding; 4. Booting; 5. Tongs; 6. Tongs
changing fixture.
FIG. 40. Booting for master-slave manipulator

(a) Old system: to fix the booting in the cell on the glove port (1) it is necessary to enter the cell

(b) British system: booting is fixed on the glove port (1) outside the cell. There is a risk of damaging the booting when inserting the manipulator

(c) US and French system with ejectable ring (2). This system can also be used with an independent containment box

(d) US system of independent box with flexible ceiling (3) and booting fixed on ring (4) hung on manipulator shoulder.
FIG. 41. Booting attachment at wrist
(a) Original gauntlet booting system
(b) Gauntlet with removable finger on intermediate sealed pieces
(c) Tongs with intermediate gas-tight piece - this disposition ensures lowest risk of damage to booting.

FIG. 42. Sealed master-slave manipulator
(a) Seal on hot side
(b) Seal on cold side
1. Slave assembly 3. Master assembly
FIG. 43. Manipulator vehicles
(a) PaR (USA)
(b) RIVET vehicle (UK)
1. Arm with three articulated sections
2. Television cameras and platform (not equipped in (a))
3. Telescopic column
4. Caterpillar vehicle
5. Control panel
6. Power unit
7. Cable drum.
FIG. 44. Diagram indicating typical correlation of cell parameters and manipulators.

FIG. 45. Typical coverage diagram for manipulators shown in Fig. 36
1. Wrist coverage
2. Tongs coverage
3. Absolute limit of viewing
4. Limit of viewing when handling.
FIG. 46. Radiation locks
(a) Two-door transfer port
(b) Rotating transfer port (small item access)
(c) Rotating transfer port (large item access)
(d) Drawer-type transfer port.

FIG. 47. Inter-cell transfer
(a) Simple shielding door
(b) Rotating valve door
(c) Shielded transfer lock.
FIG. 48. Tunnel transfer system: (a) Below bench system; (b) Behind cell system; 1. Shielding door; 2. Shielding tunnel; 3. Conveyor; 4. Tongs.
FIG. 49. Big shielded containers with valved doors
(a) Shielded container with sliding valve
(b) Shielded container with split bottom valve
(c) Shielded container with screwed plug valve
1. Container valve 4. Tray operating rod
3. Tray
FIG. 50. Shielded containers with rotating valves
(a) Container with rotating valve and magazine attached to concrete cell
(b) Container with rotating valve over pond
1. Rotating valve  5. Rotating door on the cell
2. Cell plug  6. Plug for top loading
3. Operating rod  7. Lock rod
FIG. 51. Small shielded containers
1. Container with heavy cover
2. Container with heavy pivoting cover
3. Handle with automatic lock to close container before lifting
4. Container with small plug
5. Cable for raising basket
6. Basket fixed to small plug.
FIG. 52. Special transfer system

(A) Bogie travelling down centre line of maintenance area
(B) Bogie rotated to present container to selected cell

1. Cell transfer port shielding door
2. Container shielding door
3. Transfer stillage
4. Turntable and slider assembly
FIG. 53. Tunnel transfer system (see also Fig. 7)
(a) Rigid tunnel
(b) Flexible tunnel assembly
(c) Disconnection of flexible tunnel
1. Rigid tunnel
2. Cell port plug
3. Flexible tube
4. Rigid tube to prevent tunnel deflating.

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FIG. 54.  Double-door transfer system
(a) General view showing all components
(b) Before connection
(c) Connected
(d) Opened for transfer
2. Cell door     6. Container door
3. Sealed container 7. Container gaskets,
4. Cylinders to seal cell door
   and container flanges to
   cell flange
FIG. 55. Double door with triple-effect joints
(a) General view with container in position and double door opened
(b) Detail showing port flanges gaskets and doors before connecting
(c) Detail when connected
(d) Detail when double door is open for transfer

When rotating the container into the cell flange, first the two flanges lock then the two doors interlock, and at the end of the rotation the connected double door unlocks from the container.

1. Cell flange with only one gasket to seal on the box
2. Cell door with triple-effect joint
3. Joint: first effect - between flange & door
   second effect - inside its groove
   third effect - between the two doors when connected
4. Rotating lock ring to fix the cell door
5. Bayonet connection to fix container to the cell flange
6. Container door
7. Container flange with triple-effect joint
8. Bayonet connection to fix the door to the container
9. Bayonet connection to fix the two doors together.
FIG. 56. Sealed shielded transfer system (see also Figs 47c and 48)
(a) Tunnel between two shielded cells
(b) Tunnel connecting a line of cells
1. Shielded enclosure 4. Containment box
2. Shielded door 5. Gastight door

FIG. 57. Indirect transfer system with low contamination risk
1. Container plug 4. Offset rod
2. Auxiliary shielding 5. Plastic lining for transfer hole
7. Intermediate piece for container (8)
Both (7) and (8) can be replaced by a bigger container on the same tilting platform (9).
FIG. 58. Solid waste transfer system
(a) General view
(b) The container is connected
(c) Double door is opened
1. Container 7. Gastight door
2. Shielding cover 8. Transfer chamber
3. Lightweight drum 9. Shielded gastight door
4. Split bottom door 10. Electromagnet
5. Auxiliary shielding 11. Drum cover
6. Containment box
FIG. 59. Remote bagging transfer system
1. Cell port with gasket
2. Bag fitted on support ring
3. Bag adapter ring
4. Lifting fork
5. Polythene bag
6. Transfer chamber
7. Jack for bag exchange
8. Remote bag welder and cutter
(a) Place material in bag from inside the box
(b) Weld, cut and place the material by manipulator from the outside
(c) Place new bag on adapter ring
(d) Lift and eject old bag.
FIG. 60. Horizontal bag transfer system
1. Tunnel in shielding with two shielding doors working as radiations lock
2. Shielded container with door and scoop
3. Bag fitted outside the cell

Introduction
(a) Open outer door, place container in front of transfer lock, open in-cell door,
(b) Open container door, operate scoop
(c) Close in-cell door, remove container, put in new bag (see Fig. 9)

Extraction
(d) as (a) and (b), then pick up object with scoop in bag
(e) Pull bag inside out, close container door when scoop is in container
(f) Close in-cell door, weld, cut, etc.

FIG. 61. Vertical bag transfer system
(a) Seal with bag and remove welded bags (see Figs 9 and 53 c), drain with argon
(b) Connect container, open shielded doors and transfer object
(c) Close doors, valves, weld and cut.

1. Sealing bag 4. Welded and cut
2. Disposal cut bag pouch 5. Shielded
3. Gastight seal doors
FIG. 62. Double-door transfer system
1. Shield wall with rotating valve
2. Containment box
3. Container with screwed valve (see Fig. 49 c)
4. Sealed capsule with door having triple-effect joint
5. Operating rod
6. Box door with triple-effect joint
7. Tray
(a) Place container in position
(b) Open rotating valve in wall and screw plug in container, push operating rod forward until capsule door makes contact with box flange, rotate rod to connect capsule door with cell door
(c) Open cell door with capsule door attached and remove tray with cell manipulator.
FIG. 63. System for transfer and transport of active liquor
1. Container and protective cover for laboratory storage
2. Coupling and plastic pipe for transfer of medium active liquor
3. Shielded coupling platform
4. Washout container
5. Service plug with air pump
6. Sampling unit
7. Waste bag with extractor for washed coupling gaskets
8. Unshielded coupling platform
9. Shielded transfer unit for highly active liquor
10. Handling stand
11. Vacuum pump
12. Dynamometer measuring quantity of liquor
13. Air filters
14. Protective cover used when transporting
15. Additional protection for external transport

Containers of the same size may have thin shielding and large capacity, or heavy shielding and small capacity.
FIG. 64. Bypass system for fume cupboard
1. Inlet ventilation flow
2. Room exhaust flow
(a) When the front panel is opened inlet ventilation flow serves as a curtain in front of the opening – part of the flow comes from the room exhaust flow
(b) When the front panel is closed the fume cupboard is still strongly ventilated partly by direct ventilation flow and partly by the air exhausted from the room. The room exhaust flow is minimal.

FIG. 65. Glove box extract ventilation system
(see also Fig. 7)
1. Diaphragm controls the regulating valve
2. Weight calibrating the depression in the box
3. Exhaust filters
4. Inlet filters
5. Valve control pipe
6. Alarm switch

In normal conditions depression is controlled for any movement of glove or small leakage. When by accident the largest port is opened, the valve opens automatically, provides 0.5 m/s air velocity through the port, and the switch gives the alarm.
FIG. 66: Typical active waste liquor delay tank installation

1. Low activity tanks 8. Laboratory
3. Medium activity tanks 10. Active sink
4. Sampling 11. Covered duct asphalt-lined
5. Drain to low-level effluent treatment plant 12. Pump house
    effluent treatment plant
6. Hand basins 13. By tanker to medium-level
7. Showers effluent-treatment plant.
FIG. 67. Typical changing room, Zone I to Zone II, or Zone II to Zone III
1. Zone I or Zone II
2. Zone II or Zone III
3. Cold wardrobe
4. Clean overshoes container
5. Barrier bench
6. Contaminated overshoes container
7. Hot wardrobe
8. Hand and foot monitor
9. Port monitor
10. Active container
11. Wash basin.

FIG. 68. Typical changing room, Zone III to Zone IV
1. Changing room area
2. Zone IV or access to Zone IV
3. Entrance corridor
4. Maintenance area
5. Clean pressurized-suit wardrobe
6. Control window
7. Exit air lock
8. Suit decontamination shower
9. Lock chamber
10. Glove box area for disrobing with aid from maintenance area
11. Underwear disrobing area and personnel shower
12. Air lock
13. Barrier bench.

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FIG. 69. Newt suit, seen from the hot zone
1. Containment panel
2. Port for bagging wastes.
FIG. 70. Double-helmet suit
1. Fixed or mobile intervention box
2. Double helmet
3. Harness to hold helmet
4. Breathing and telephone lines
(a) Intervention box is connected to active zone;
   open double helmet and the operator enters suit through the
   flange
(b) Double helmet is closed, outside helmet is locked. Operator
   unlocks inside helmet.
(c) Operator enters active zone;
   breathing lines and telephone cables enable operator to
   move about in active zone and keep in touch with
   control point.
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