LABORATORY BIOSAFETY MANUAL
FOURTH EDITION
AND
ASSOCIATED MONOGRAPHS

BIOLOGICAL SAFETY CABINETS AND OTHER PRIMARY CONTAINMENT DEVICES

World Health Organization

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Biological safety cabinets and other primary containment devices

(Laboratory biosafety manual, fourth edition and associated monographs)

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Glossary of terms

Aerosol: Liquid or solid particles suspended in air and of a size that may allow inhalation into the lower respiratory tract (usually less than 10 micrometres in diameter).

Aerosol-generating procedure: Any procedure that intentionally or inadvertently results in the creation of liquid or solid particles, which become suspended in the air (aerosols).

Biological agent: A microorganism, biological toxin, protein (prions) or human endoparasite, either naturally occurring or genetically modified, which may have the potential to cause infection, allergy, toxicity or otherwise create a hazard to human health, animals or plants.

Biosafety: Containment principles, technologies and practices that are implemented to prevent unintentional exposure to biological agents or their inadvertent release.

Calibration: Establishment of the relationship between the measurement provided by the instrument and the corresponding values of a known standard, allowing correction to improve accuracy. For example, laboratory equipment such as pipetting devices may need calibration periodically to ensure proper performance.

Certification: A third-party testimony based on a structured assessment and formal documentation confirming that a system, person or piece of equipment conforms to specified requirements, for example, to a certain standard.

Clean: Visually free of soil and below specified levels of analytes.

Consequence (of a laboratory incident): The outcome of an incident (exposure to and/or release of a biological agent) of varying severity of harm, occurring in the course of laboratory operations. Consequences may include a laboratory-associated infection, other illness or physical injury, environmental contamination, or asymptomatic carriage of a biological agent.

Containment: The combination of physical design parameters and operational practices that protect personnel, the immediate work environment and the community from exposure to biological agents. The term "biocontainment" is also used in this context.

Contamination: The introduction of undesired biological agents into tissues and specimens or onto surfaces.

Decontamination: Reduction of viable biological agents or other hazardous materials on a surface or object(s) to a pre-defined level by chemical and/or physical means.

Disinfectants: Agents capable of eliminating viable biological agents on surfaces or in liquid waste. These will have varying effectiveness depending on the properties of the chemical, its concentration, shelf life and contact time with the agent.

Exposure: An event during which an individual comes in contact with, or is in close proximity to, biological agents with the potential for infection to occur. Routes of exposure can include inhalation, ingestion, percutaneous injury and absorption and are usually dependent upon the characteristics of the biological agent. However, some infection routes are specific to the laboratory environment and are not commonly seen in the general community.

Fumigation: Use of a poisonous gas or vapour to remove contamination of a biological agent from a surface, piece of equipment or area.

Good microbiological practice and procedure (GMPP): A basic laboratory code of practice applicable to all types of laboratory activities with biological agents, including general behaviours and aseptic techniques that should always be observed in the laboratory. This code serves to protect laboratory personnel and the community from infection, prevent contamination of the environment, and provide protection for the work materials in use.

Hazard: An object or situation that has the potential to cause adverse effects when an organism, system or (sub)population is exposed to it. In the case of laboratory biosafety, the hazard is defined as biological agents which have the potential to cause adverse effects to personnel and/or humans, animals, and the wider community and environment. A hazard does not become a "risk" until the likelihood and consequences of that hazard causing harm are taken into account.

Laboratory-associated infection: Any infection acquired or reasonably assumed as a result of exposure to a biological agent in the course of laboratory-related activities. A person-to-person transmission following the incident may result in linked secondary cases. Laboratory-associated infections are also known as laboratory-acquired infections.

Maximum containment measures: A set of highly detailed and stringent risk control measures described in the fourth edition of the WHO *Laboratory biosafety manual* that are considered necessary during laboratory work where a risk assessment indicates that the activities to be performed pose very high risks to laboratory personnel, the wider community and/or the environment, and therefore an extremely high level of protection must be provided. These are especially needed for certain types of work with biological agents that may have catastrophic consequences if an exposure or release were to occur.

Pathogen: A biological agent capable of causing disease in humans, animals or plants.

Primary containment device: A contained workspace designed to provide protection to its operator, the laboratory environment and/or the work materials for activities where there is an aerosol hazard. Protection is achieved by segregation of the work from the main area of the laboratory and/or through the use of controlled, directional airflow mechanisms. Primary containment devices include biological safety cabinets (BSCs), isolators, local exhaust ventilators and ventilated working spaces.

Risk: A combination of the likelihood of an incident and the severity of the harm (consequences) if that incident were to occur.

Risk assessment: A systematic process of gathering information and evaluating the likelihood and consequences of exposure to or release of workplace hazard(s) and determining the appropriate risk control measures to reduce the risk to an acceptable risk.

Sharps: Any device or object that is a puncture or wound hazard because of its pointed ends or edges. In the laboratory, sharps can include needles, syringes with attached needles, blades, scalpels or broken glass.

Sterile: The state of having a complete absence of viable biological agents and spores.

Sterilization: A process that kills and/or removes all biological agents including spores.

Validation: Systematic and documented confirmation that the specified requirements are adequate to ensure the intended outcome or results. For example, in order to prove a material is decontaminated, laboratory personnel must validate the robustness of the decontamination method by measurement of the remaining biological agents against the detection limit by chemical, physical or biological indicators.

Executive summary

Biological safety cabinets (BSCs), isolators and local exhaust ventilators are enclosed, ventilated working spaces that can be used in laboratories as primary containment devices. These devices protect the operator, the laboratory environment and/or the work materials from exposure to infectious aerosols and splashes that may be generated when manipulating materials containing biological agents. Infectious aerosol particles may be created during a laboratory activity with liquid, semi-liquid and/or dried material, particularly if the material contains high concentrations of biological agents. Laboratory activities, such as streaking agar plates, pipetting liquid suspensions of infectious agents and homogenizing infectious materials, can generate infectious aerosols if done by personnel who have not been trained in good microbiology practices. Primary containment devices, when properly used and maintained, have been shown to be highly effective in reducing laboratory-associated infections in practice. This monograph provides information on BSCs and other primary containment devices, such as isolators and local exhaust ventilation devices, in order to guide the appropriate selection and use of such devices for individual needs to help ensure laboratory biosafety. The targeted readership for this monograph is laboratory personnel working with BSCs or other primary containment devices, laboratory personnel doing the risk assessment and people involved in planning or renovating a laboratory, such as the senior management or the laboratory manager.

The information in this monograph on biological safety cabinets and other primary containment devices is designed to accompany and support the fourth edition of the WHO *Laboratory biosafety manual* (core document) and other associated monographs. The manual and the monographs adopt a risk- and evidence-based approach to biosafety rather than a prescriptive approach in order to ensure that laboratory facilities, safety equipment and work practices are locally relevant, proportionate to needs and sustainable. Emphasis is placed on the importance of a "safety culture" that incorporates risk assessment, good microbiological practice and procedure and standard operating procedures, relevant introductory, refresher and mentoring training of personnel, and prompt reporting of incidents and accidents followed by appropriate investigation and corrective actions. This new approach aims to facilitate laboratory design and ways of operating that ensures greater sustainability while maintaining adequate and appropriate control of biosafety.

The other associated monographs provide detailed information and help implement systems and strategies on the following specialized topics: risk assessment, laboratory design and maintenance, personal protective equipment, decontamination and waste management, biosafety programme management and outbreak preparedness and resilience.

This monograph describes the different types of BSC and other primary containment devices and best practice for working with these devices. The technical features of primary containment devices, such as directional airflow, are explained and methods for their decontamination are discussed.

SECTION 1

INTRODUCTION TO PRIMARY CONTAINMENT DEVICES

Biological safety cabinets (BSCs), isolators and local exhaust ventilators are enclosed, ventilated working spaces that can be used in laboratories as primary containment devices. These devices protect the operator, the laboratory environment and/or the work materials from exposure to infectious aerosols and splashes that may be generated when manipulating materials containing biological agents. Infectious aerosol particles may be created during a laboratory activity that imparts energy to liquid, semi-liquid and/or dried material, particularly if the material contains high concentrations of biological agents *(1–3)*. Laboratory activities, such as streaking agar plates, pipetting liquid suspensions of infectious agents and homogenizing infectious materials, can generate infectious aerosols if done by personnel who have not been trained in good microbiology practice *(3)*. Processes such as centrifugation of infectious liquids can also generate infectious aerosols, but these activities are now normally undertaken in intrinsically contained devices (for example, sealed centrifuges).

The information in this monograph on biological safety cabinets and other primary containment devices is designed to accompany and support the fourth edition of the *WHO Laboratory biosafety manual (4)* (core document) and other associated monographs. The manual and the monographs adopt a risk- and evidence-based approach to biosafety rather than a prescriptive approach in order to ensure that laboratory facilities, safety equipment and work practices are locally relevant, proportionate to needs and sustainable.

The other associated monographs provide detailed information and help implement systems and strategies on the following specialized topics: risk assessment *(5)*, laboratory design and maintenance *(6)*, personal protective equipment *(7)*, decontamination and waste management *(8)*, biosafety programme management *(9)* and outbreak preparedness and resilience *(10)*.

Primary containment devices, when properly used and maintained, have been shown to be highly effective in reducing laboratory-associated infections in practice *(11)*. They protect operators from exposure to infectious aerosols in two main ways. Firstly, they provide a contained workspace so that activities with a higher risk of generating aerosols can be segregated from the main area of the laboratory. Secondly, and perhaps most importantly, these devices use various methods to pass a controlled, directional airflow across the workspace which draws any aerosols generated into its path and away from the work area.

This directional airflow is created using specialized fans attached to or housed within the primary containment device. Particles that enter and move with the directional airflow can then be directed into a filter before being exhausted from the device and/or the laboratory.

There are various types of primary containment device, each of which uses different mechanisms to introduce an airflow into the device, treat the circulating air and exhaust it from the device and/or the laboratory. BSCs are the most commonly used primary containment devices, and three different classes of BSC exist. These cabinets differ by the type and level of protection their directional airflow provides for laboratory personnel (device operators), the environment and/or the work materials inside and whether external fans and ductwork are required for proper operation of the primary containment device.

The three classes of BSC are:

- **Class I BSCs –** open-fronted enclosures that draw an inward airflow across the work surface through the front opening. The air passes upwards through a high efficiency particulate air (HEPA) filter before being exhausted. They provide personnel and environmental protection, but do not offer product protection for materials located in the work area.

- **Class II BSCs –** open-fronted enclosures, similar to Class I BSC, in which air enters the cabinet through the front opening to provide operator protection. The inward air bypasses the work area by being pulled through the front grille and underneath the workspace and then travels through a plenum (an enclosed air space) to the BSC blower, where it is either exhausted through a HEPA filter or directed into the work area after passing through a separate downflow (supply) HEPA filter. Some of the now-clean air passes over the work surface as a downward flow of air (that is recirculation) in order to protect work materials from contaminated room air ("product protection") and is then recirculated through front and rear vents. The surplus air in the plenum is not recirculated but passes through a separate HEPA filter and is exhausted. The National Sanitary Foundation (NSF) standard defines five types of Class II cabinets: A1, A2, B1, B2 and C1 *(12)* (More information on Class II BSC types is given in subsection 4.2).

- **Class III BSCs –** a closed, sealed, negative-pressure enclosure to which HEPA-filtered air is supplied; this air then passes through another HEPA filter on extraction. The enclosure is sealed to ensure safe gaseous decontamination. Operators access the working area using integrated gloves or gauntlets. Class III BSCs are normally fitted with a pass box (often independently ventilated) or dunk tank to facilitate the movement of potentially contaminated work materials in and out of the cabinet. An autoclave may also be attached for waste management, mainly in facilities with a maximum containment cabinet line. A sealable and detachable front window may be fitted to allow the occasional movement of large equipment into and out of the cabinet, after fumigation. These devices offer the highest degree of operator protection as the user is physically separated from the device interior.

Several other types of equipment may be used as primary containment devices, and provide similar levels of primary containment as BSCs. Although there are many similarities between these devices and BSCs, some of their features do not comply with international standards for the construction and operation of BSCs. (It should be noted that horizontal and vertical outflow cabinets ("clean-air work stations") are not primary containment systems and should not be used as such). There are two additional primary containment devices.

- **Isolators –** closed boxes, similar to Class III safety cabinets but which do not comply with any international standards for testing and certification. These may be manufactured from flexible or rigid materials and can be constructed in a range of sizes. The work surface is normally accessed by operators using integrated gloves or half suits and they may have pass boxes or dunk tanks to allow inflow and outflow of materials. Isolators may also be used to house robotic equipment and, in some cases, animals. The fact that isolators can be designed to incorporate any process gives them advantages over standard cabinets.

- **Other local exhaust ventilation devices –** partially open-fronted enclosures which perform in a similar way to Class I cabinets. They may give a similar degree of protection but do not always have terminal HEPA filtration. Local exhaust ventilation devices are primarily used to protect users undertaking activities with a low likelihood of producing infectious aerosols. They use only directional airflow and are sometimes known as a ventilated work station *(13)*. Local exhaust ventilation devices may meet some, but not all, of the requirements outlined in international standards.

The design, construction and testing of BSCs are governed by national and international standards, for example those in Australia, China, the European Union, Japan and the United States of America *(12,14–17)*. In recent years, designs of primary containment systems that do not comply with such standards have come into use for several reasons; these include cost, portability and the requirement for bespoke designs – for example to accommodate large equipment or infected animals, or to allow rapid deployment to the field and avoid the complex installation requirements of some BSCs. For this reason, isolators were widely used in diagnostic laboratories in the response to the West African Ebola outbreak that started in 2013 *(18)*.

This monograph describes the usual practices and procedures for the use of primary containment devices, including more detailed explanations of the features of each device type, how they can be most effectively used, and the various testing and calibration requirements that ensure correct performance. It must be remembered that these devices can only enhance the safety of personnel if used in conjunction with the good microbiological practice and procedure (GMPP) described in the *Laboratory biosafety manual (4)*, section 3 core requirements.

SECTION 2

WORKING WITH PRIMARY CONTAINMENT SYSTEMS

2.1 Best practice for working with open-fronted devices

Open-fronted primary containment systems are Class I and Class II BSCs, and local exhaust ventilation devices.

- The use and limitations of the device should be explained to all potential operators, with reference to the relevant standards and literature. Written protocols, or safety operations manuals, should be issued which should cover movement of material into and out of the cabinet. Appropriate training in GMPP must also be provided. At the same time, it should be recognized that primary containment devices may not protect the operator from exposure caused by poor technique or ignoring protocols and procedures.

- The device must not be used unless it is working properly. Alarms and indicators that show the device is operating safely should be checked before each use. Sashes and sliding front windows on class II BSC, should remain at the correct height when the cabinet is in use. Glass viewing panels, installed over the front opening, must not be opened when the device is in use.

- Disruption to the airflow must be avoided by ensuring that minimal equipment and materials are kept inside the device, and that the air-intake grill at the front (and the rear) is clear of obstructions (for example, pipettes).

- Bunsen burners or alcohol lamps must not be used inside the device as the heat produced may distort the airflow and/or damage filters. An electric microincinerator (bacti-cinerator or similar) is permissible, although disposable sterile transfer loops are preferred.

- Ultraviolet lights are not recommended as the only method of sterilizing the device. If they are used, they must be cleaned weekly to remove dust or dirt that may reduce the germicidal effectiveness of the light. Ultraviolet light intensity should be checked during device recertification to ensure that light emission is appropriate.

- Work should be carried out in the middle or rear part of the work surface to reduce airflow obstruction and improve visibility through the glass viewing panel for the operator.

- Human traffic behind the operator should be kept to a minimum.
- Cabinets should not be sited close to any potentially interfering air movement from air conditioners or opening and closing doors.
- Operators should not disturb the airflow by repeated removal and reintroduction of their arms.
- The surface of the biological safety device should be wiped using an appropriate disinfectant after work is completed and at the end of the day.
- Device fan(s) should be run for some time before beginning work and after completion of work in the device, according to the manufacturer's instructions or until the device indicators show that it is safe to use.
- Paperwork should never be placed inside primary containment devices as it may be entrained in the airflow and partially block the extract duct, disrupting the airflow system.
- An uninterruptible power supply should be fitted, in line with the mains electrical supply, so that there is no interruption to the electrical supply of the device in the event of an electrical outage. This may also act as an electrical line conditioner to stabilize the electrical supply if there are issues with voltage stability. An interruptible power supply cannot be used in devices with an external exhaust fan or blower unit, such as a Class II B2 device.

2.2 Working with enclosed devices: additional considerations

Enclosed primary containment systems include Class III BSCs and isolators. Users of these fully contained systems should also consider the following areas, as applicable.

- The condition of gloves or half suits should be checked for damage before and after use. If damage is found, then gloves/suits should be replaced using safe change procedures, or specified repair should be undertaken.
- As far as reasonably practical, the use of sharps, scissors or other equipment that may cut or damage integrated gloves or half suits should be avoided.
- Protocols for safe introduction and removal of materials must be in place and be complied with.

2.3 Decontamination of safety cabinets and isolators

2.3.1 Liquid decontamination

The surface of all items within primary containment devices, including equipment, should be decontaminated before being removed. The interior surfaces of the device should be decontaminated before and after each use. The work surfaces and interior walls should be wiped with a disinfectant validated to inactivate any microorganisms that might be found inside the device. When a corrosive disinfectant such as bleach is used, surfaces should then be wiped with sterile water or a 70% alcohol solution to remove residues that may cause degradation. It should be checked that any disinfectant is compatible with the construction materials of the containment system. This is particularly important for isolator systems, which may have a wider range of materials used in their construction.

2.3.2 Gaseous/vapour decontamination

Based on the risk assessment, primary containment devices may be required to undergo gaseous/vapour decontamination before being physically moved, before filter changes, between work activities with different agents, and to allow potentially contaminated equipment to be removed. Decontamination should be carried out by a trained individual using a validated method. During decontamination, open-fronted safety cabinets should have doors fitted to seal the opening, and monitors should be used to detect any leakage. Alternatively, cabinets can be decontaminated in sealed bag systems. It should be noted that national regulations may also stipulate when gaseous/vapour decontamination is required. More information on gaseous decontamination can be found in *Monograph: decontamination and waste management (8)*.

SECTION 3

DIRECTIONAL AIRFLOW

As previously mentioned, primary containment devices act as risk control measures by providing a segregated workspace within which to perform higher-risk activities. Much of their protection is provided by the integration of fan mechanisms to create directional airflow. This controlled movement of air allows contaminated/potentially contaminated aerosols to be captured within filters, thus preventing exposure of laboratory personnel, the surrounding environment and/or the work materials within the device to such aerosols.

A directional airflow is created using one (or more) specialized fans connected to, or housed within, the primary containment device which force the air to move in one direction. Laboratory air entering the device from the outside may become contaminated by aerosols generated in the workspace as a result of specimen manipulation and processing. The fans pull this air away from the workspace and direct it, in most cases, through a special filter able to capture and hold biological agents until such time as the filter itself can be safely decontaminated. After passing through the filter, the remaining "clean" air may either be:

- reused: by recirculating it within the primary containment device, or by sending it into the laboratory, or

- exhausted: by directing the filtered airflow out of the primary containment device, via an exhaust duct, to an external location (usually the outside environment).

The fan is the part of the system that generates air movement. It does this by generating a pressure gradient. Between the containment device and the fan the pressure is negative with respect to the surrounding space. From the fan to the discharge point, the air pressure is positive with respect to the surrounding space. The pressure differences would be rapidly lost in the event of an electrical or equipment failure, and, without mechanical intervention, the air pressure would naturally equilibrate and control of the directional airflow would be lost. For this reason, primary containment devices should be fitted with airflow monitoring systems and alarms indicating safe and unsafe conditions, so that corrective action may be taken in the event of a mechanism failure. These could include systems that indicate airflow velocity or volumetric flow (anemometer) and, for full enclosures, the negative pressure (manometer) of the air in the primary containment device.

There are numerous configurations of fans, filters and exhaust mechanisms and the correct configuration is essential. The following subsections outlines some of the key features of directional airflow mechanisms and air exhaust configurations. These must be understood and correctly used to ensure the safe and effective operation of primary containment devices.

3.1 High efficiency particulate air filtration

HEPA filters were originally designed to filter airborne radioactive particles but are now used in a wide variety of applications such as vacuum cleaners, motor vehicles, aerospace, clean rooms including high technology and pharmaceutical clean rooms, hospitals and laboratory facilities. HEPA filters are composed of many randomly oriented fibres that create a fibrous matrix through which air can pass. Particles travelling with the air may be captured by the fibres, effectively filtering the air. Various mechanisms are used to capture and filter particulate matter including the following:

- **Inertial impaction** – as large particles flow through the air towards the fibres, their size prohibits them from effectively adjusting to the altered airflow around the fibre, causing them to impact the fibre directly.

- **Interception** – smaller particles flow less than one-particle diameter away from the fibres, close enough to touch and adhere to them.

- **Diffusion** - collision, especially of the smallest particles being filtered, occurs with other air/gas molecules, altering the path of motion of the particle. This diffusion of energy between particles impedes and delays their path through the filter and increases the probability that they will be stopped either by interception or impaction.

Through the combination of the filtering mechanisms described above, HEPA filters are capable of capturing small particles that pass through them, including biological agents. There are various classes of HEPA filter, with different filtering efficiencies of the material used. The efficiency is often determined according to the criteria outlined in global standards *(19–21)*. Most HEPA filters have a filtering efficiency of more than 99.97% for particles of 0.3 µm in diameter, the most penetrating particle size *(22,23)*. Particles with a lower or higher diameter will be removed with a higher efficiency.

It is important to note that HEPA filters are not designed to filter gases or vapours. If protection is needed against both biological agents and gases/vapours, then a suitable total exhaust system should be used. If this is not possible, then additional chemical filters should be used in conjunction with the HEPA filters. Exhaust of chemicals requires specialist installations and is beyond the scope of this monograph.

As with any equipment, it is important that HEPA filters are used, maintained and replaced when necessary according to manufacturers' instructions to ensure their effectiveness. However, it has been shown that HEPA filters can maintain performance for long periods of time and filter failure is comparatively rare *(24)*.

3.2 Direct recirculation

In some cases, the air leaving the primary containment device is returned directly to the laboratory after passing through a HEPA filter. This is commonly used as an affordable and practical solution for many laboratories because of its simplicity and the absence of complex ducting systems. However, this may be associated with a higher risk of exposure to workers in the rare event of a failure of an exhaust HEPA filter. This highlights the need for regular performance monitoring and justification of selecting this method of exhausting based on a thorough and appropriate risk assessment. In some circumstances, two HEPA filters may be installed in series to mitigate the risk. It should also be noted that volatile or toxic chemicals must not be used in containment devices that recirculate exhaust air to the laboratory.

3.3 Hard ducting

Hard ducting is an exhaust arrangement in which the primary containment device is firmly connected, without any openings, to the general building exhaust system or (preferably) to a dedicated laboratory exhaust duct system. The containment device may also be directly connected to a dedicated, standalone cabinet exhaust system, which can also be used to maintain laboratory ventilation during operation. Due to the complex mechanisms involved in directing airflow, certain types of Class II BSCs must always be hard-ducted, preferably to a dedicated exhaust fan and duct (NSF types B1 and B2), whereas others may not be designed to connect to a hard-ducted system (certain NSF A2 devices). For more information on Class II BSC types and airflows, see subsection 4.2.

To facilitate proper functioning and continuous airflow in hard-ducted primary containment devices, building exhaust extraction systems must be precisely matched to the airflow requirements for both the volume and static pressure of the containment device, as specified by the manufacturer. It should be noted that the level of protection provided by the containment device is heavily dependent on the quality of the maintenance of this airflow set-up and the integrity of the duct work. Some countries may have building standards or regulations that specify the minimum requirements for duct work. It is important to ensure that any hard ducting that contains potentially contaminated air is properly sealed to prevent leaks, especially at the time of installation. However, this is less important for ducts containing air that has already passed through HEPA filtration, unless gaseous disinfection is to be used.

Certification of hard-ducted containment devices may be more time-consuming than that with other exhaust configurations because holes may need to be drilled in the sealed duct work to gain access to HEPA filters for integrity checks or to place devices to determine that the airflow volume being extracted is appropriate. This must be taken into account if considering a hard-ducted system. During maintenance of the containment device, the condition of the associated duct work and terminal fans must be considered.

Hard-ducted primary containment devices can dispose of the exhaust air in two ways.

- External ducting. Air leaves the containment device and passes into the hard duct where it is exhausted straight out of the laboratory to the external environment. Note: this exhausting cannot be done with certain Class II BSCs (NSF type A1 and A2).

- Ducting to a heating, ventilation, and air conditioning (HVAC) system. Air leaves the containment device through the hard duct which is connected to the exhaust ducts of a dedicated laboratory HVAC system. This system must not recirculate air to the building. This allows the exhaust air from both systems to be combined and disposed of from a single extraction point, which reduces the need for multiple complex ducting systems for the laboratory.

3.4 Anti-blowback valves

In some circumstances, airflow within the duct may be disrupted because of unexpected events or forces such as wind turbulence in the external environment. This turbulence may cause a temporary reduction in directional airflow, or even a reversal, allowing air to flow backwards through the duct and into the containment device.

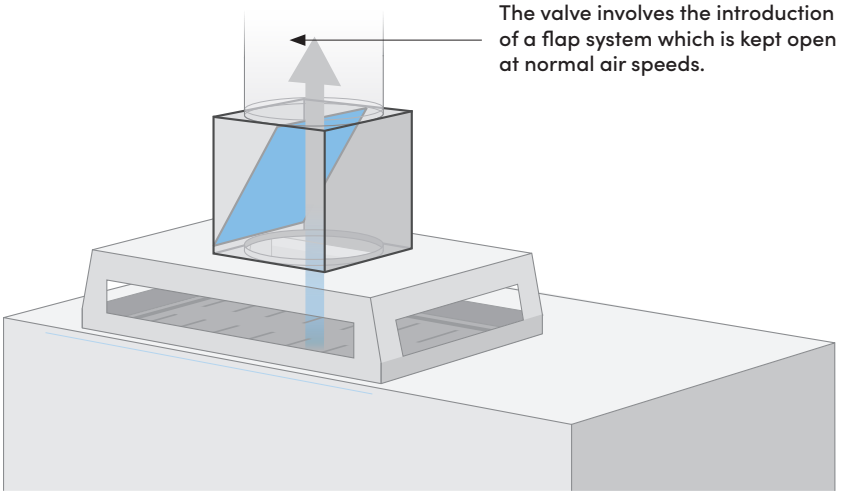

Figure 3.1 Anti-blowback valve

In order to prevent blowback and reduce the risk of contaminated air re-entering the laboratory, anti-blowback valves should be installed in the ventilation system. The valve is essentially a flap system that is kept open at normal air speeds. If air speed decreases, due to external inward velocity, the flaps will retract automatically, cover the duct and prevent air from flowing backwards to the containment device and the laboratory. An example of an anti-blowback valve can be seen in Figure 3.1. However, different versions of the valves may be used depending on local laboratory conditions (for example, severe weather) and/or the type of containment devices in use.

3.5 Thimble ducts

A thimble duct, or canopy hood, is a specialized duct fitting designed to link primary containment devices to an exhaust system. A dedicated terminal exhaust fan, which may be part of the room HVAC, draws the exhaust air out of the device while at the same time drawing in room air. This can be done either through vents or gaps in a fitting connected to the containment device, which gives it a "canopy" shape (Figure 3.2), or through a similar arrangement in the room exhaust system to which the containment device can be connected. The inwards flow of air into the thimble will prevent leakage through its openings. The additional extracted air through the thimble will reduce the room pressure further, improving any pressure cascade. Furthermore, even when primary containment devices are turned off when not in use, the exhaust may continue to extract room air to ensure the pressure differential is maintained and no backflow can occur. Thimble ducts also allow the safe removal of gaseous disinfectants during ventilation of the cabinet without the need for hard ducting.

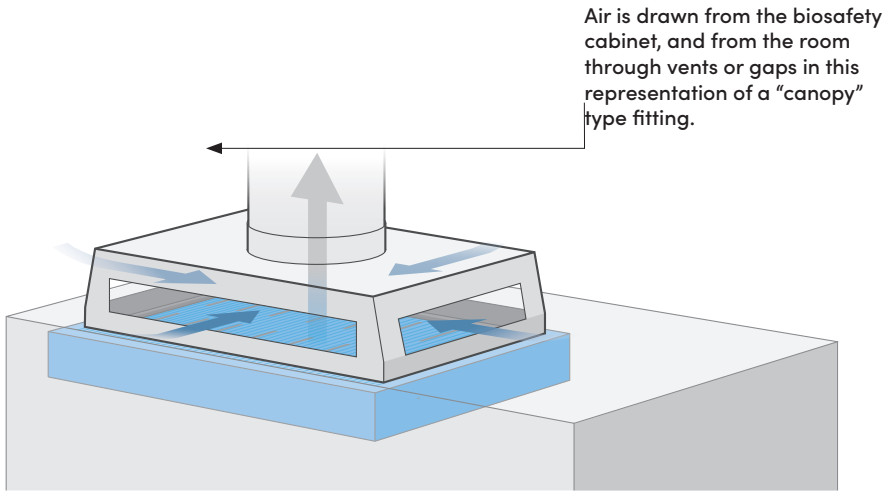

Figure 3.2 Thimble duct/canopy hood

It is important to ensure that the building duct system has sufficient capacity for both the inward flow of room air and the exhaust of the containment device. The dedicated exhaust fan of the thimble duct must extract a higher volume of air than the containment device to prevent any overflow of air into the room.

The thimble duct, or canopy hood, is designed for use with some Class I and Class II BSCs (all NSF type A1, A2, and their European equivalents; for more information on the types of Class II BSC, refer to subsection 4.2). However, the thimble should preferably be removable or carefully designed to allow for proper operational testing of the primary containment device, such as measurement of exhaust airflow rates from the device, and/or to allow access to HEPA filters for testing, decontamination and replacement.

SECTION 4

SELECTING A PRIMARY CONTAINMENT DEVICE

Selection of a primary containment device should be based mainly on the type of protection required (that is operator protection, environmental protection and/or product/work material protection) and the risk that needs to be controlled. The selection of any primary containment device should therefore be based on the outcomes of a risk assessment to identify and control the risks posed by the procedures being performed and biological agents being handled. Each primary containment device uses a different mechanism to create and maintain directional airflow. As introduced in section 3 (directional airflow), some devices will have specific requirements for airflow volumes and exhaust configurations to create the pressure differences needed to maintain directional airflow, even in the event of device failure. Compatibility of the primary containment device with specialized exhaust configurations may also become a selection factor, especially where a negative pressure may need to be maintained in the laboratory even when the primary containment device is not in operation. Table 4.1 provides a summary of the features of various primary containment devices and their unique specifications that may affect which device is most appropriate for selection.

Table 4.1 Key considerations in the selection of a primary containment device

CLASS	WORKSPACE OPENING	PROTECTION	AIRFLOW SET-UP	EXHAUST REQUIREMENTS	KEY CONSIDERATIONS
Class I	Fixed, open-fronted	Operator and environment protection	Inward direction airflow from the front opening, through a HEPA filter at the top of the cabinet	Exhausted to the outside (remote fan) or to the room through a HEPA filter (integral fan)	Simple airflow design is resistant to disruption Offers a similar level of operator protection as BSC Class II No product protection offered

Table 4.1 Key considerations in the selection of a primary containment device (continued)

CLASS	WORKSPACE OPENING	PROTECTION	AIRFLOW SET-UP	EXHAUST REQUIREMENTS	KEY CONSIDERATIONS
Class II[a]	Fixed, sliding or hinged open-fronted	Operator, environment and product protection Some types using single-pass air are suitable for protection from chemical vapours	Directional airflow includes both an inwards flow of air from the front opening and a downward flow of HEPA-filtered air from the top of the cabinet onto the work surface Laminar airflow in the working area protects against cross contamination within the working area	Exhausted to the room through a HEPA filter or to the environment through an exhaust canopy	Addition of HEPA filtered downward airflow offers product protection Different types of Class II BSC exist with varying airflow set-ups Multiple complex airflow patterns may be highly sensitive to disruption A plenum space may act as a secondary safety mechanism Type A2 BSC is most widely used in clinical and public health laboratories
Class III	Completely sealed, access by glove ports	Enhanced, high-level operator and environmental protection Provides product protection	Single-pass airflow with dedicated HEPA-filtered supply and exhaust air	Exhausted to the outside, through HEPA filters with a remote fan; hard-ducted. If recirculating air, a second HEPA filter is often used	Complete seal provides highest level of operator protection Seal allows for gaseous decontamination/ fumigation Specialized procedures are required for the introduction and/ or removal of work materials and equipment

Table 4.1: Key considerations in the selection of a primary containment device (continued)

CLASS	WORKSPACE OPENING	PROTECTION	AIRFLOW SET-UP	EXHAUST REQUIREMENTS	KEY CONSIDERATIONS
Containment isolators	Fixed, sliding or hinged open-fronted	May give enhanced, high-level operator protection Provides product protection	Dedicated supply of both HEPA-filtered inflow and exhaust air. May involve double HEPA filtration to allow direct recirculation to the work surface	Exhausted to the outside, through 1 or 2 HEPA filters, with a remote fan; hard-ducted	Available in various sizes, shapes and design specifications (bespoke design) Rapid installation for emergency use Able to house large equipment and/or animals

HEPA = high efficiency particulate air; BSC = biological safety cabinet.

[a] For more detailed information on various Class II cabinet types, refer to Table 4.2.

The following subsections describe in more detail the operating mechanisms of the various primary containment devices, including testing and certification procedures that may be necessary to create and monitor correct performance.

4.1 Class I BSCs

Class I BSCs are designed to protect the operator and the environment from infectious aerosols generated within the BSC. They do not provide protection against contamination of materials on the work surface.

Class I BSCs have a very simple airflow design, which allows them to maintain performance in most laboratory circumstances. Room air is drawn in through the front opening at a minimum velocity that meets applicable standards. The air passes over the work surface and is discharged from the cabinet through an exhaust duct. The front opening allows the operator's arms to reach the work surface inside the cabinet while he or she observes the work surface through a glass window at the front. After completion of work activities, the window can be fully raised to provide access to the work surface for cleaning or other purposes.

Figure 4.1 provides a schematic diagram of a Class I BSC. For simplicity, this shows one option of a directly recirculating Class I cabinet; however other exhaust set-ups can also be used. The air from the cabinet can be exhausted through a HEPA filter and then either recirculated to the laboratory or exhausted to the outside through an exhaust duct. Class 1 cabinets can also be connected through a thimble duct to the laboratory HVAC that uses a 100% exhaust system (that exhausts all the air to the outside).

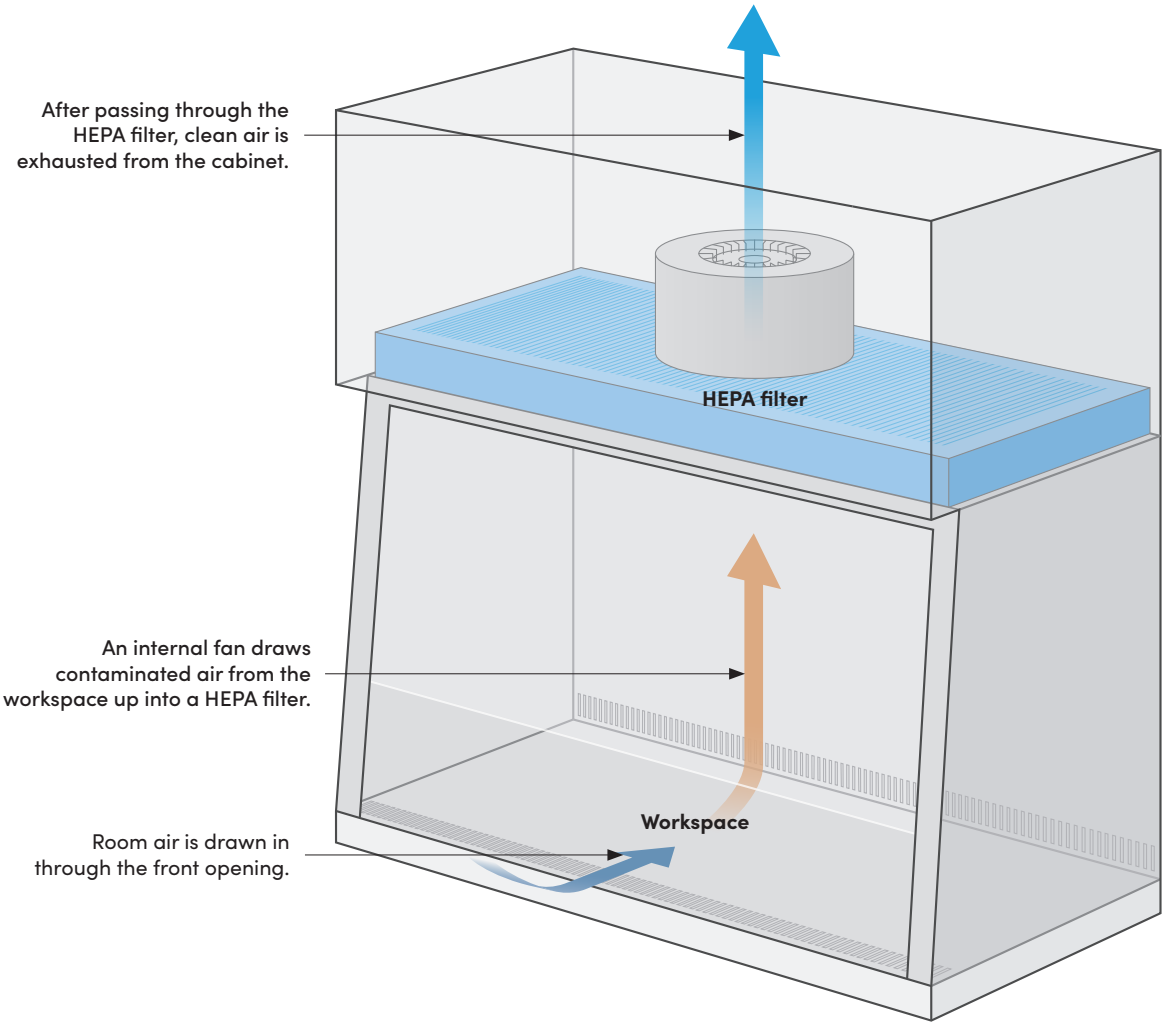

Figure 4.1 Class I biological safety cabinet

Class I BSC performance is easy to monitor using an anemometer to measure the velocity of the inflow air entering the BSC through the opening. This is done by taking a series of readings across the plane of the front opening, such as those shown in Figure 4.2. From these readings, the average inflow velocity can be calculated and compared to that specified by the manufacturer or in the applicable standard. The airflow velocity should be constant across the front opening; if significant variance is noted in a single point, this may indicate a problem with the cabinet or its installation. According to EN 12469:2000 *(16)*, the airflow velocity should be within the range 0.25 – 0.50 m/s. Additionally, no individual measurement should differ more than 20% of the value indicated by the manufacturer.

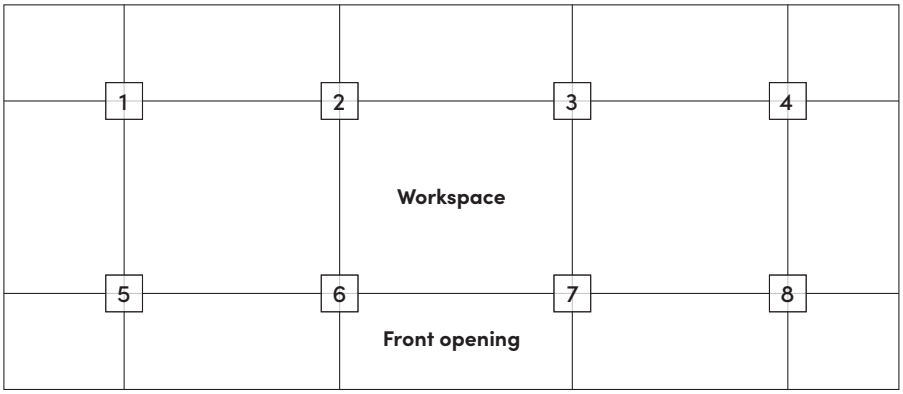

Figure 4.2 Anemometer reading for a Class I biological safety cabinet – the squares 1 to 8 indicate the positions where readings should be taken

The integrity of the inflow can also be confirmed using smoke pencils or smoke generators which help visualize the airflow and ensure it is directed inward over the whole area of the front opening. Visualization should be done under normal working conditions, for example with the operation of independent room HVAC systems. Smoke pencils/generators can also be used to assess the effect on ventilation of any equipment used within the cabinet (for example, a centrifuge). HEPA filters installed with Class I BSCs should be tested at least annually to confirm they perform according to the manufacturer's specifications. The correct operation of all alarms and indicators should also be confirmed, as should the functioning of anti-blowback valves, if installed.

4.2 Class II BSCs

The Class II BSC is designed to provide personnel and environmental protection as well as protection for work surface materials from potentially contaminated room air. The airflows inside Class II BSCs are considerably more complex than in other BSC classes because of the addition of airflows designed to provide product protection. HEPA-filtered air is driven as a downward airflow from the top of the cabinet onto the work surface. This is in addition to the inward flow of air at the front opening, which provides operator protection in a similar way to Class I BSCs. This system often involves partial recirculation of air within the cabinet; filtered air is divided between an exhaust and the downward flow mechanism.

Five types of Class II cabinets currently exist and are defined in the United States NSF standard as NSF types A1, A2, B1, B2 and C1 *(12)*. Each NSF type uses different mechanisms for the intake, recirculation and exhaust of air to achieve the inward and downward airflow combination.

The comparable European standard (EN 12469) outlines a single design type, which is broadly in line with the NSF A2 type of cabinet. Many manufacturers therefore build cabinets that conform to both EN 12469 and the NSF A2. The important shared design features specified in the two standards for Class II BSCs is the fail-safe mounting of filters to prevent leaks across the filter seals, and the use of pressure plenums. NSF/ANSI 49 – 2016 states that Class II cabinets should be designed to have all biologically contaminated ducts and plenums under negative pressure or surrounded by negative-pressure ducts and plenums. In most cases, this plenum is held at a negative pressure so that if any leakage occurred across the filter seals or from contaminated ducts, the contaminated air would be drawn back into the cabinet, thus preventing release of potentially infectious aerosols into the laboratory or to the outside environment. These designs hold the body of the cabinet at negative pressure, preventing any unfiltered air escaping through construction joints and seals.

NSF type A1 cabinets are no longer widely used, in part due to the lower inward airflow requirements and, more importantly, because older models do not meet the negative pressure design requirements outlined earlier. In such cabinets, the contaminated air is driven into a positive-pressure plenum that is not firmly bonded or airtight before it is passed through a HEPA filter for exhaust or recirculation as a downward airflow. As the plenum may be under direct positive pressure to the laboratory, contaminated air could escape the containment system through construction joins and seals in the cabinet body. Furthermore, in such designs, air can escape before reaching the HEPA filters, leading to containment being breached and air being passed to the environment and laboratory, or possibly contaminating the workspace. For such cabinets, the integrity of the seals of the positive pressure sections of the cabinet body should be routinely tested. Replacement of type A1 cabinets with cabinets that are fully compliant with current standards should be considered.

NSF type B cabinets use a primarily (in B1 cabinets) or exclusively (in B2 cabinets) single-pass airflow whereby air removed from the workspace is not mixed and recirculated as downward airflow. The proportion of air recirculated in NSF type B1 cabinets varies between models but is typically less than 50% *(12)*. This makes B1 cabinets suitable for use with hazardous chemicals where recirculation of vapours must be avoided. However, this single-pass airflow, particularly in the case of B2 cabinets, is highly sensitive to changes in the room ventilation rate as well as pressure differences. Furthermore, an intake with a pre-filter exists at the top of B2 BSCs to provide the single-pass downward airflow. This pre-filter is prone to drawing in dust and other particulate matter from the room and may become blocked causing alarm systems to activate. Opening a door to an anteroom may result in a B2 cabinet failing to meet the manufacturer's performance specifications. Because of the single-pass directional airflow of B1 and B2 cabinets, they are not able to use a thimble duct so they must be hard-ducted to the outside environment with an integral blower unit, or be connected to a dedicated laboratory HVAC exhaust system.

NSF type C1 cabinets usually operate in a similar way to a B1 cabinet, with a low air recirculation rate (typically less than 50%), but they have more flexibility in their exhaust system, which may be hard-ducted, thimble-connected or directly recirculated.

Table 4.2 gives a comparison of Class II BSCs.

Table 4.2 Characteristics of different Class II biological safety cabinets

CHARACTERISTICS					
WORKSPACE OPENING	**MINIMUM AVERAGE INFLOW VELOCITY (M/S) [a]**	**RECIRCULATED AIR (%)** **EXHAUST AIR (%)**	**APPROXIMATE EXHAUST VOLUME (M^3/S) [b]**	**EXHAUST REQUIREMENT**	**INDICATIONS FOR THE USE OF TOXIC CHEMICALS AND RADIO-NUCLIDES**
		Class II cabinet type A1			
Sliding sash or hinged with a fixed opening	0.38	70 30	0.14 (for a 1.2 m cabinet) 0.19 (for a 1.8 m cabinet)	Exhausted to the room through a HEPA filter or to the outside through a thimble duct	Work does not include toxic chemicals or radionuclides
		Class II cabinet type B1			
Sliding sash or hinged with a fixed opening	0.51	< 50 > 50	0.12 (for a 1.2 m cabinet) 0.19 (for a 1.8 m cabinet)	Exhausted to the outside with a remote fan; hard-ducted	Small amounts of toxic chemicals or radionuclides
		Class II cabinet type B2			
Sliding sash or hinged with a fixed opening	0.51	0 100	0.28 (for a 1.2 m cabinet) 0.47 (for a 1.8 m cabinet)	Exhausted to the outside with a remote fan; hard-ducted	Small amounts of toxic chemicals or radionuclides Not suitable for dusty environment

Table 4.2 Characteristics of different Class II biological safety cabinets (continued)

CHARACTERISTICS					
WORKSPACE OPENING	**MINIMUM AVERAGE INFLOW VELOCITY (M/S) [a]**	**RECIRCULATED AIR (%)** **EXHAUST AIR (%)**	**APPROXIMATE EXHAUST VOLUME (M^3/S) [b]**	**EXHAUST REQUIREMENTS**	**INDICATIONS FOR THE USE OF TOXIC CHEMICALS AND RADIO-NUCLIDES**
		Class II cabinet type A2			
Sliding sash or hinged with a fixed opening	0.51	≈ 70 ≈ 30	0.14 (for a 1.2 m cabinet) 0.19 (for a 1.8 m cabinet)	Exhausted to the room through a HEPA filter or to the outside with a remote fan using a thimble duct	Work does not include toxic chemicals or radionuclides
		Class II cabinet type C1			
Sliding sash or hinged with a fixed opening	0.51	< 50 > 50		Suitable with any exhaust configuration	Small amounts of chemical or radionuclides

[a] = air speed; [b] = airflow.

Class II type A2 BSCs, or the European equivalent, are the most widely used Class II BSCs globally because their use of a negative-pressure plenum on the exterior of the BSC acts an additional safety feature. The operational principles of the Class II type A2 BSC are shown in Figure 4.3.

An internal fan(s) draws room air through the front opening and the front intake grill, and the air mixes with air from the work area. This air is passed under the work area and drawn up into a negative-pressure plenum. About 70% of this air is passed through a HEPA filter positioned across the entire width of the cabinet working area, providing a unidirectional downflow of filtered air over the work surface. This clean downflow of air is split between the front and back of the work surface with some being drawn through the front intake grills and the rest through the rear intake grills. Any small aerosol particles generated at the work surface are immediately captured in this downward airflow and passed through the front or rear grills, thereby providing the highest level of product protection. The remaining air (about 30%) drawn from the workspace is passed through a HEPA filter and discharged to the laboratory. The volume of air for recirculation or exhausting can be controlled using a variable volume damper which may help vary the volume of airflow to meet performance specifications independently of the duct pressure.

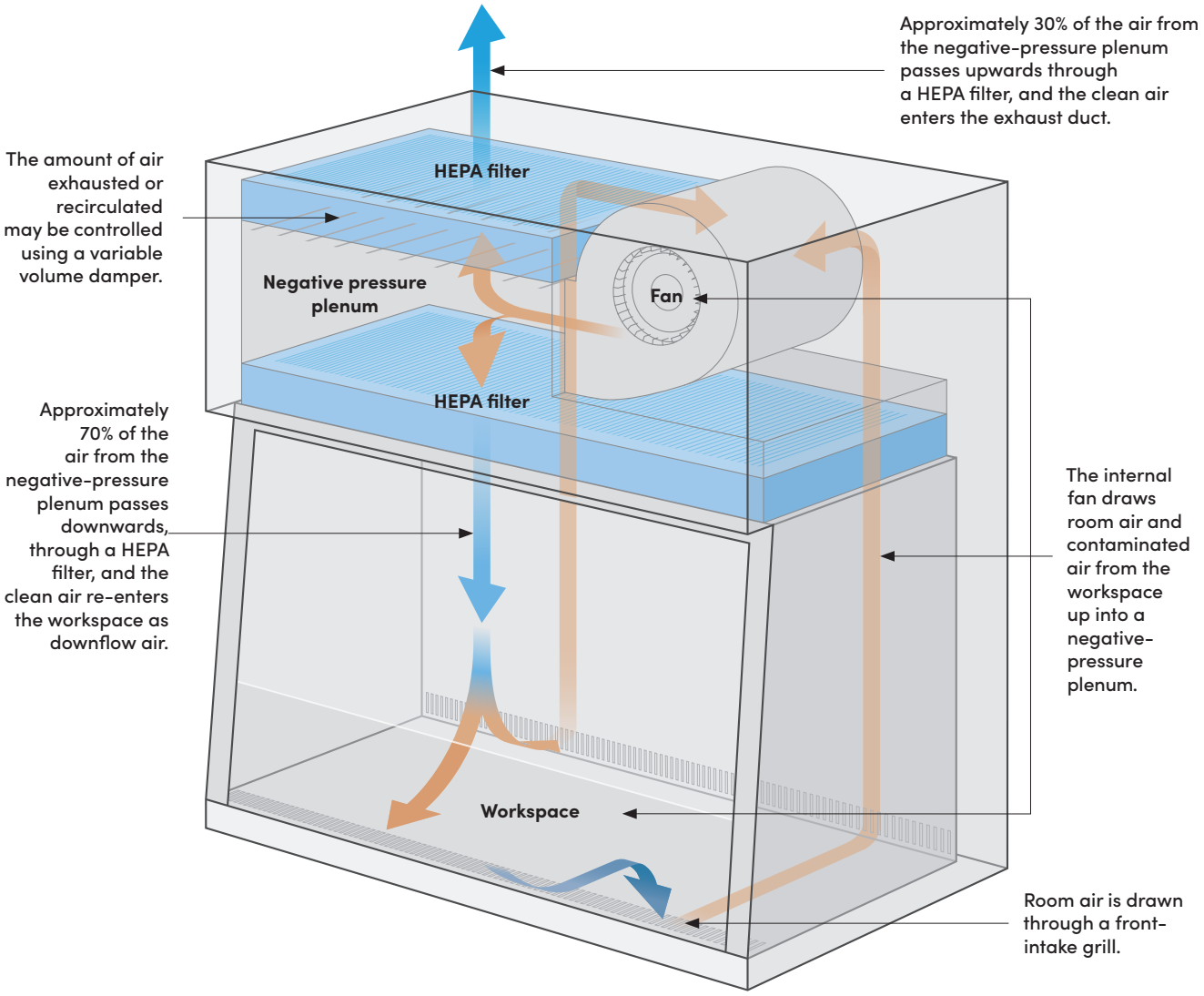

Figure 4.3 Class II type A2 biological safety cabinet

To exhaust air from a BSC II type A2, any of the exhaust configurations described in section 3 can be used; each has its own advantages. Air from the exhaust could be recirculated to the room, following HEPA filtration, which has the advantage of lowering building energy costs because heated and/or cooled air is not being passed to the outside environment, and is kept within the building. Exhaust air may also be hard-ducted to a dedicated laboratory HVAC exhaust system or to the outside of the building, which has the advantage that partial failure of the HEPA filter would not result in contaminated air being passed back into the room where it could endanger laboratory personnel. A thimble-duct connection can also be used for exhaust to the laboratory HVAC system, which allows type A2 cabinets to be turned off when not in use and negative room pressure to be maintained, thus reducing operating costs.

Because of the complex nature of the airflows in all Class II BSC types, containment performance is more easily affected by factors such as cabinet positioning, local airflows and working practices than other types of primary containment system. If not used correctly, the degree of protection they provide may be greatly reduced *(22)*. The velocity of the airstream flowing into the front opening can be easily disrupted by air currents generated by people walking too close to the BSC, open windows, air supply grills and ducts, and opening and shutting doors. Therefore, BSCs should be situated far away from human traffic and potentially disturbing air currents. It is particularly important to follow best working practices for minimizing airflow disruption outlined in subsection 2.1.

The functional operation and integrity of each Class II BSC must be certified – to national or international performance standards – both at the time of commissioning (also known as type testing) and again when installed to ensure that the cabinet continues to meet performance standards in situ (installation or field testing). In situ testing must be performed by qualified technicians, according to the manufacturer's instructions, and should be repeated regularly (usually at least annually) to ensure the BSC still functions properly. Evaluation of the effectiveness of cabinet containment includes testing HEPA filters, mapping downflow velocity, measuring intake airflow velocity at the front of the cabinet opening, measuring the negative pressure/ventilation rate, and testing containment, airflow smoke patterns and alarms and interlocks. Special training, skills and calibrated equipment will be required to perform these tests. Therefore, these evaluations should be done by a qualified professional who meets local regulatory requirements. For more details on Class II testing/certification, at both the design stage and after installation, refer to the relevant national and/or international standards. Whenever possible, adequate space should be available behind and on each side of the cabinet to allow easy access for maintenance. Adequate space above the cabinet may also be required for air velocity measurements across the exhaust filter and for exhaust filter changes. These spaces are usually in the range of 30–35 cm but may be greater depending upon the manufacturer's recommendations.

4.3 Class III BSCs

The Class III BSC (Figure 4.4) is designed to provide the highest level of protection to personnel. These cabinets are leak-proof and will be stringently tested to check leakage rates for the completed system at commissioning and installation. Both the supply and exhaust air is HEPA-filtered, and the rate of air change within the cabinet is normally high. Airflow is maintained by a dedicated exhaust system outside the cabinet, which keeps the inside of the cabinet under negative pressure to the surrounding laboratory space. Access to the work surface is by means of heavy-duty, chemically-resistant gauntlets or sleeves with integrated gloves, which are attached to ports in the cabinet.

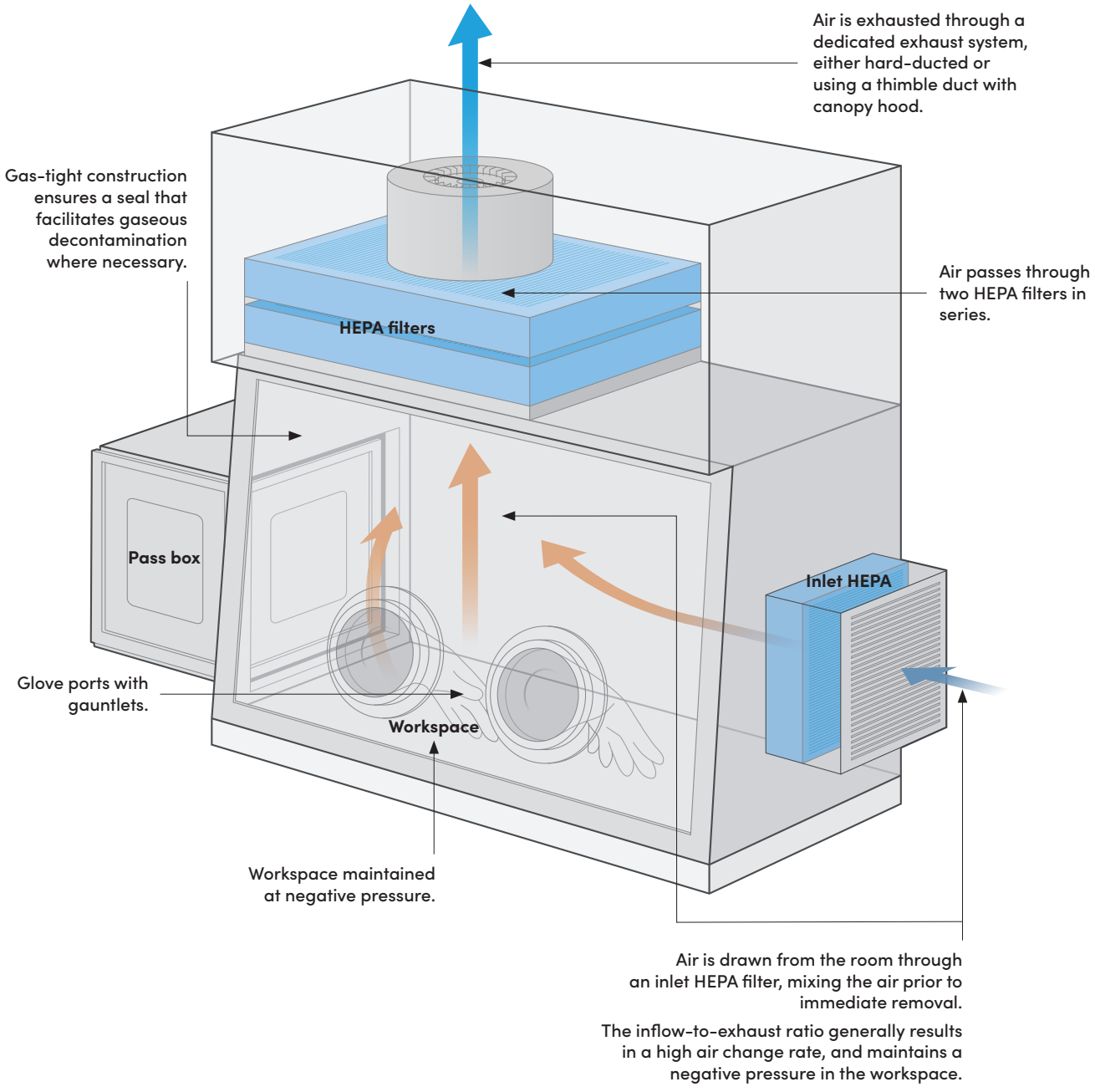

Figure 4.4 Class III biological safety cabinet

The Class III BSC therefore provides complete separation between the material being handled and the operator, laboratory and surrounding environment. The only potential for breach of containment is through damage to the integrated gloves or through the movement of materials in and out of the cabinet.

The Class III BSC may be constructed with a pass box in which work materials and equipment items can be decontaminated. These boxes may have dedicated ventilation systems. Cabinets may also be fitted with chemical dunk tanks that allow sealed materials to be passed to the outside environment. In some maximum containment laboratories, several Class III BSCs may be joined together to form a cabinet line with an extended work surface that may be connected to a double-door autoclave for decontamination of all materials entering or exiting the cabinet.

The integrated gloves should be regularly checked, inspected for damage and replaced during service if necessary. They should also be replaced on a regular basis. Procedures for safely changing gloves should be developed and all personnel must be trained to carry them out. In addition, all HEPA filters should be tested after installation and then on a regular basis, as indicated by the risk assessment. Alarms and indicators should also be regularly tested, and the cabinet manometer regularly calibrated. The rate of air change within the cabinet should be measured and any unequal airflow velocities determined through an open glove port. The negative pressure and airflow should all be within the manufacturer's specifications. Procedures should also be developed for the removal of specimens and waste from the cabinet. These will involve the use of different layers of containment and surface decontamination. Before starting work, the operator should check that the cabinet is working at the correct negative pressure by checking the anemometer or equivalent device.

Class III cabinets can have a simple construction as they consist of a box with an attached filter, windows and integrated gloves. If the cabinet is moved or modified in any way, then recommissioning tests need to be done. Suitable tests to monitor the leak-proof seal for safe gaseous decontamination should also be considered. The condition of seals and gaskets should be checked regularly. Local regulations may require specific risk assessments to be undertaken, which consider failure scenarios and back-ups such as uninterruptible power supply systems to maintain negative pressure in the event of loss of power.

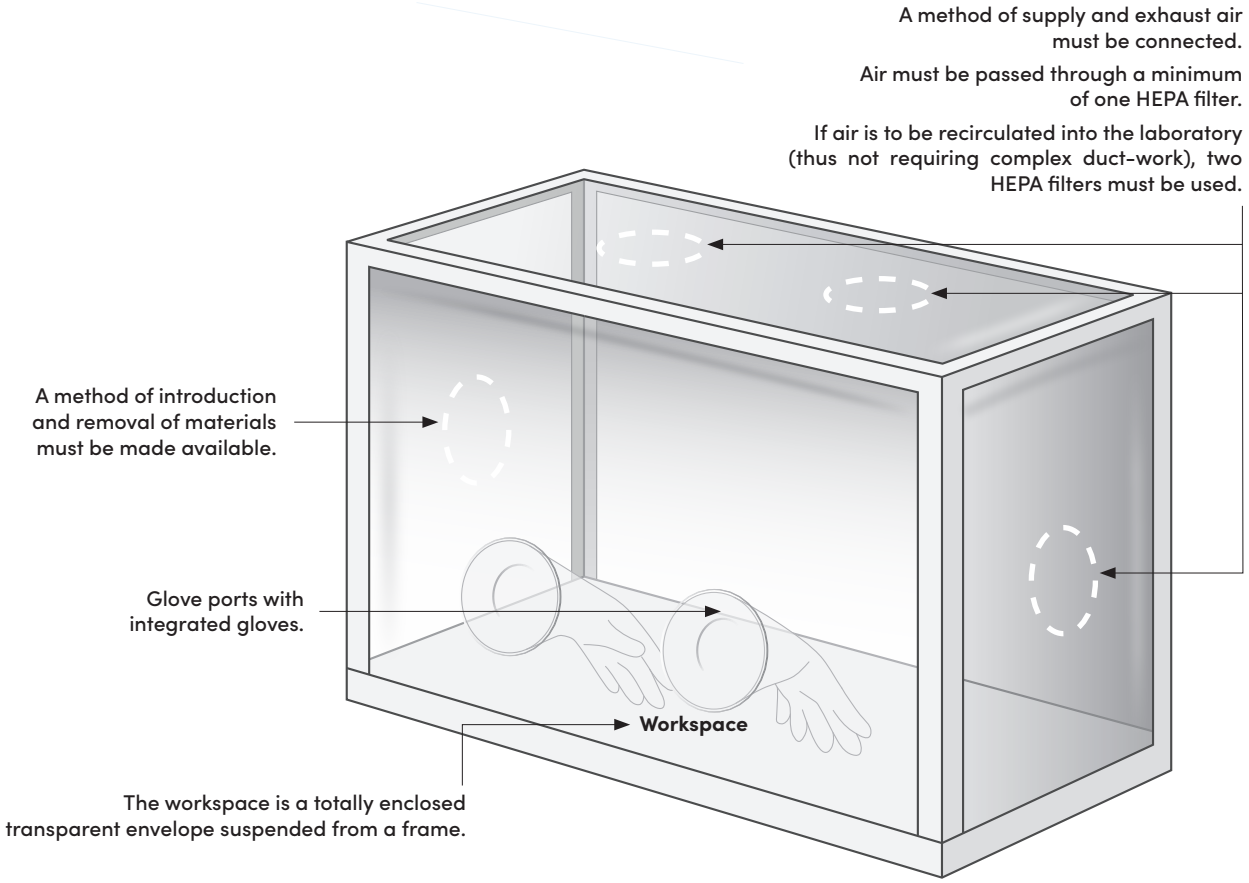

Figure 4.5 Flexible-film isolator

4.4 Containment isolators

4.4.1 Flexible-film containment isolators

The flexible-film isolator (Figure 4.5) is a self-contained primary containment device that provides a high level of user protection against hazardous biological agents. The workspace is totally enclosed in a transparent envelope suspended from a framework. The isolator is maintained at an internal pressure lower than the pressure of the surrounding space.

As with a Class III BSC, both inlet and outlet air are passed through one or two HEPA filters. This allows the air to be recirculated to the laboratory rather than having to discharge exhaust air outside the building. Flexible-film isolators operate at a lower negative pressure than Class II BSCs but they have been shown to be capable of achieving high levels of operator protection under a range of working conditions *(25)*. They give a high level of protection even when certain failures occur such as loss of pressure (because they are completely sealed) or major leaks (because they have high inflow velocity) *(26)*.

An advantage of flexible-film isolators over BSCs is that they can be designed for a specific task(s). Many factors can be taken into consideration in their design, such as workflows, waste streams and ergonomics, which should allow safe and effective use. Isolators range in size from small, mobile, one-person designs to large enclosures that can hold a range of laboratory equipment or animal cages. However, the life-span of a flexible-film isolator is likely to be shorter than that of a Class III BSC, they are more susceptible to damage and the flexible-film may need to be replaced on a regular basis.

Flexible-film isolators have been used for work with high-consequence pathogens during field work where it has not been feasible or appropriate to install or maintain conventional BSCs *(27)*. The flexible nature of isolators allows work to be done in many different and difficult conditions. For containment work, the primary aim is to prevent positive pressure developing during normal working conditions. If forced supply air is used, then there must be effective interlocks in the extraction system to prevent positive pressure developing if extraction is lost. The inside of the isolator is normally accessed through integrated gloves. As done for Class III BSCs, protocols should be established for the introduction and removal of materials (for example, reagents, single-use items such as pipette tips or tubes, specimens, waste). This may involve the use of transfer ports or surface disinfection. Ventilated pass boxes, dunk tanks or rapid transfer ports can facilitate the introduction and removal of materials. Effective pressure monitors and alarms are needed to ensure correct operation. For care of infected animals within the isolator, back-up systems may be needed to maintain both containment and allow access for animal care if failures occur.

Isolator systems have mostly been used by the pharmaceutical or nuclear industry. However, the specifications of these industries are not all directly applicable to biological containment systems. Other guidance documents for isolators specific to biological containment have been developed, for example in the United Kingdom *(28)*, but this is primarily for the use of isolator systems for animal containment. The United Kingdom guidance contains useful recommendations for both validation and routine testing of isolator systems. Apart from this, it is common practice to apply methods similar to those used for testing and validation of Class III cabinets to isolator systems. Routine tests should be undertaken to ensure the correct operation of alarms, indicators and back-up systems, if fitted. As no specific standards currently exist for the certification of isolators, airflows should be measured against the original design specifications. HEPA filters of isolators should be tested using a suitable method and shown to be in line with the manufacturer's specifications.

4.4.2 Rigid containment isolators

Rigid-walled isolator systems are a moveable alternative to the flexible-film model and can also provide the highest level of containment, using sleeved and half-suit designs. However, as with Class III BSCs, they need to be operated at much higher negative pressures than flexible-film isolators to prevent positive pressure developing during use. This is particularly important with half-suit designs where movement of the suit can significantly affect the pressure within the containment isolator.

4.4.3 Unventilated isolators

When having to provide a rapid response, deployable safety containment systems may be needed for use in the field or in temporary laboratories. In such cases, simple HEPA-filtered isolators have been used successfully for both semi-permanent *(18,27)* and mobile pop-up diagnostic facilities. However, the complexity and size of these systems need to be balanced against the ability to transport and install them in a field facility *(29)*. While ventilated, HEPA-filtered units offer the highest level of protection to the operators; the use of unventilated systems can also be considered, based on a risk assessment. If the aerosol risk is low, then simple film isolator pods or tents may offer high levels of physical separation from the material being handled, and allow the use of strong disinfection procedures, whilst minimizing operator exposure to both the agent and disinfectant. It must be noted that as the effectiveness of the containment system is reduced, safe working practices must be strengthened.

4.5 Other local exhaust ventilation types

4.5.1 Ventilated work stations

For some operations, a ventilated work station will be adequate to control any aerosols generated by a procedure. This may be one simple part of a process that has been identified as the only aerosol risk. These stations can be constructed by connecting a suitable box, with an open front or loose door, to a HEPA filter attached to a fan to provide an internal airflow and prevent release of potential pathogens from the process. Downdraft necropsy tables for postmortems can also be used to capture aerosols if the exhaust systems contain HEPA filters. However, unless specifically designed for biological containment work, the performance may not be in line with BSCs. Since these systems are not covered by biological containment standards, specific test protocols may need to be developed to ensure correct and satisfactory operation. Certain guidance documents may offer standardization for some disease-specific work, such as the use of ventilated work stations for sputum smears for acid fast bacterial staining in tuberculosis microscopy laboratories *(13)*.

Full containment systems are not always appropriate for animal work, especially for non-human primates and larger animal species. In such situations, the use of respiratory protective equipment may be required to protect against any aerosol exposure. However, the use of directional flow booths and containment systems with terminal HEPA filter extraction can be used for animal husbandry and to minimize the possible exposure of operators, thus reducing the amount of aerosol the respiratory protective equipment may have to filter. Such systems should be designed to provide good husbandry conditions, but also provide directional airflow away from the operators to allow safer operation. Again, there are no international standards for these systems and detailed validation when used in real-world situations is required for each installation.

There may be cases where dedicated HEPA-filtered ventilation systems are not available or practical because of the location and available resources. In such situations, other alternatives may be suitable. For diagnostic work, an alternative could be a simple system similar to a BSC I design, with air being drawn through an open-fronted box or cabinet by ducts connected to a remotely located terminal fan. The exhaust air can then be discharged at height to the atmosphere; this relies on the exhaust air being highly diluted to minimize environmental contamination. While such an approach does not prevent release to the environment, it provides high levels of protection for the laboratory personnel. However, the discharge needs to be carefully positioned to prevent any aerosols re-entering the laboratory area. In addition, without the protection of HEPA filters, the ducts and fan should also be considered potentially contaminated.

4.5.2 Individually ventilated cages

Individually ventilated cages are designed to house small laboratory animals and come in many forms. Early systems were designed either to protect the animals from external contamination or to minimize the release of animal allergens. In recent years, high-containment systems have been developed. Some are designed to operate at positive pressure, others at negative pressure so care is needed when selecting cages. To protect the operator, they must be used in conjunction with other types of primary containment for animal husbandry, normally a dedicated cage change system (for cleaning or removing an animal) or modified Class I or II BSC, and operational procedures must be followed. For highly hazardous work, the cage change systems should be designed to meet the performance criteria of BSCs.

Typically, the cages are held on a manifold rack system which will provide ventilation to each cage through a dedicated control unit. Depending on the use, both the supply and extracted air may be HEPA-filtered. For containment work, the system is balanced to keep the cages at negative pressure while on the rack. The cage design will depend on the proposed use, but two types are generally used. For lower-hazard work, the fully enclosed cage has a simple filter integrated in the cage top, allowing air from the laboratory to be drawn into the cage. This system only provides protection when the cage is held on the rack. For highly hazardous work, where the animal is likely to generate infectious aerosols, a fully sealed cage with an integral HEPA filter can be used; air is supplied and extracted only by the manifold. The cage should be sealed when removed from the system. This will allow it to be safely transported to a suitable containment cabinet before opening or handling. With these systems, the cage, including the external surfaces, can become contaminated, so effective decontamination steps are required to maintain safety.

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Further information

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