CASE STUDIES AND SPECIAL APPLICATIONS

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1. VENTILATION FOR TOXIC AEROSOLS

The primary function of a ventilation system for handling toxic material is to **Capture** releases of aerosols or vapours, so preventing their entry into the breathing zone of the operator. **Dilution** ventilation, whereby the concentration of an aerosol or vapour is steadily reduced by mixing with fresh air, is a useful second line of defence in an emergency, but should not be considered as anything more than a secondary function in most ventilation systems. The problem with dilution ventilation is that it is based on process engineering with fixed contamination levels. It does not accommodate change in **processes** or change in **standards**. Dilution ventilation systems may be employed where the aerosol is not toxic or nauseous, or where the room being ventilated is only briefly occupied, for example, a solvent store. Note that some capture ventilation systems, such as fume cupboards, automatically provide dilution ventilation to other parts of the laboratory.

1.1 First Principles

The principle behind the ventilation of any building, handling toxic or radioactive materials, is that the air should flow from clean areas into areas of potentially greater contamination and only rarely the reverse.

Thus plenum make-up air is usually supplied to both corridor and laboratory in such a manner that the air flow is from corridor into the laboratory and thence to the fume cupboard, glove-box, shielded cell or exhaust register, so forming both secondary and primary barriers to the spread of contamination. The airflow pattern within each laboratory should be low in turbulence and free from strong draughts, even though laminar flow through the room is impossible to achieve and a certain degree of recirculation of the air is inevitable.

Most chemical or radiochemical laboratories are operated slightly below atmospheric pressure, so that additional secondary or tertiary barriers to the spread of contamination will be set up automatically, making it unnecessary to seal every wall penetration in the building.

1.2 Containment

At certain critical points (e.g., the sash opening on fume cupboards, and the inlet registers between corridor and laboratory) escape of aerosols and vapours is prevented by the establishment of a steady inward flow.

A flow of 0.5 m/s has been found to be optimal in most situations, since this is sufficient to overcome the turbulence generated by normal operator movement (say walking, not running). Sources of greater turbulence or draughts, which might overwhelm this velocity, are better dealt with directly; either eliminated or re-directed to less sensitive areas of the room.

In areas of very low turbulence, or where control is less critical, a reduced velocity of 0.3 m/s may be adequate. Air velocities less than 0.3 m/s are usually insufficient to overcome the turbulence generated by gentle operator movement.

2. ASEPTIC CLEAN ROOMS

Where the laboratory is also a positively pressurised Clean Room, it is rather more difficult to create a secondary barrier to the spread of contamination, since to do so, the corridor has to be at least as clean as the laboratory. Where the laboratory is aseptic, this would be impossible to achieve, so that the air must flow, via an airlock, or preferably a pair of airlocks, from the laboratory towards the corridor in order to maintain a particle-free environment.

Satisfactory secondary containment at the entrance to an aseptic room may be achieved by the use of a double airlock, with the outer airlock maintained by an exhaust register at a lower pressure than either the corridor or the inner airlock. The inner airlock can also double as the changing room. However, attention must be given to any pass-through hatches that may be fitted, as these provide an alternative escape route for accidental aerosol releases, unless the hatches also open into the exhausted outer airlock.

2.1 Pressurisation

The regulations demand that the Clean Room should be at least 15 Pa above the pressure of the inner airlock, which should be at least 15 Pa above the pressure of the outer airlock or corridor. With a double airlock arrangement the minimum pressures would be:

Corridor	15 Pa
Outer Airlock	10 Pa
Inner Airlock	25 Pa
Aseptic Clean Room	40 Pa above atmospheric pressure

If the Aseptic Clean Room has an outer wall with windows facing South or West, a pressure around 70 Pa above atmospheric pressure may be required to prevent the entry of dirty air in periods of high wind. If the Aseptic Room has cavity walls without windows facing South or West, the 40 Pa pressurisation should suffice.

2.2 Spread of Contamination

If a double airlock cannot be fitted, the consequences of an accidental release of toxic or active material may still be acceptable, provided that the total volume of potentially contaminated air swept into the corridor is minimised and that early warning can be given to the rest of the building of a need to evacuate.

The flow of air from the aseptic room to the corridor, via the pass-through hatch and airlock, can be reduced by exhausting from the hatch and airlock, while improving the sealing round the outer doors of both to maintain the necessary intermediate pressure differential at the reduced flow.

2.2.1 Warning of need to evacuate

Early warning of a need to evacuate a radioactive laboratory can easily be given by continuously monitoring an air sampler for activity. It is desirable to locate such air monitors at strategic locations inside and around clean rooms handling more than a few curies of radioactivity, even if double airlocks are fitted to the aseptic rooms. An

obvious position for such a sampler is in the outer airlock. Similar monitoring arrangements may be possible in a pharmaceutical Clean Room for some toxic chemicals.

2.2.2 Containment

It is essential to thoroughly seal all joints, cracks, service ducts and cable conduits in the Clean Rooms, especially where they penetrate the wall between the pressurised and the unpressurised areas. Access to unpressurised ceiling spaces and lofts should be from outside the pressurised area.

Satisfactory containment at emergency exits, from the pressurised areas to the outside of the building, may be provided by fitting an airlock, exhausted below atmospheric pressure. The airlock should be large enough to accommodate two or three people without both doors having to be open simultaneously.

Containment at normal exits from the pressurised area, which are in common use, may be achieved by fitting an airlock supplied with HEPA-filtered air to maintain a pressure higher than the positively pressurised side. The airlock doors should be of the spring-loaded, transparent, flexible plastic type and the airlock should be of sufficient size that each side closes before the other is reached.

2.3 Air Quantities

Aseptic rooms should be continuously supplied with sufficient HEPA-filtered air for at least 20 changes per hour in the room, from a supply system with automatic change-over capability to a standby fan. The HEPA filters should be located within the room at the termination point of the ducts and be changed from within the temporarily declassified Clean Room without exposing the room to dirt from the ceiling space or loft.

The filters will require changing, after several years operation, when the air flow rates can no longer be restored to 20 air changes per hour, either by adjustment of the control damper on the inlet fan, or if a variable speed inlet fan is used, when the fan is running at full speed. After changing, the filters must be re-tested and the room sterilised to return it to an aseptic condition.

The air sweeping out of the Aseptic Room should provide at least 60 changes per hour in the Changing Room and 120 changes per hour in any pass-through hatch, in order to sweep away any dirty air carried into the airlock or hatch during transfer operations, before the inner door is opened.

2.4 Handling of Toxic Materials in Clean Rooms

It is recommended that any material, which may produce a toxic vapour or aerosol, should be handled in a Clean Room only in a fume cupboard, glove-box, or other primary containment device, whose exhaust is not recirculated. If a laminar flow Bio-Hazard, Cyto-Toxic, or other form of recirculating fume cabinet is preferred, it must be demonstrated that the cabinet's exhaust filter is both efficient and reliable in trapping any toxic aerosols and vapours, produced within the cabinet, for the whole of the working life of the filter.

2.4.1 Particulate Material

For aerosols, this is comparatively easy to do, since regular testing of the HEPA filter trapping efficiency is normal, and HEPA filters become more efficient as the dust loading increases. It is then just a matter of changing the filter, whenever the dust build-up causes the airflow to fall below the minimum acceptable value.

2.4.2 Vapours

Where toxic vapours may be released in the cabinet, it is much more difficult to prove that hazardous situations could not unwittingly arise. To absorb the vapour, most of the recirculating cabinets rely on a relatively small amount of charcoal, which may be unknowingly poisoned by a variety of extraneous agents. Some of the vapours, especially low boiling point organic vapours, are only delayed on the charcoal by physical adsorption before being slowly emitted into the laboratory. For most toxic vapours, therefore, it is safer to employ non-reirculating fume cupboards or ventilated enclosures, in spite of the increased running costs.

However, it must be admitted that recirculating cabinets, sometimes known as "ductless fume cupboards", have been successfully employed for high boiling point solvents, say greater than 100°C, such as xylene, where its moderate toxicity and odour permit early and safe detection of the need to replace the charcoal absorber. They have also been used in radioactive laboratories, in combination with continuous air monitoring to detect early signs of absorber failure, for work with moderate amounts of radio-iodine.

2.5 Recirculation of Air

Recirculation of air from a laboratory is usually considered, with good reason, to be bad practice.

However, since the conditions for safe operation imposed by positive pressurisation of a Clean Room are similar, but often more restrictive, than those required for recirculation, limited recirculation of air may be permitted in a Clean Room laboratory, provided that:-

1. None of the air from the primary containment devices (such as fume cupboards) is recirculated, or that it can be demonstrated that releases of aerosols or vapours from primary containment devices (such as Bio-Hazard cabinets) can be adequately controlled at all times by efficient and reliable filtration.

2. The toxic material, if to be handled in the open Clean Room, is in a form unlikely to generate an aerosol and extremely unlikely to generate a vapour.

3. All of the air being recirculated passes through HEPA filters before being re-supplied to other parts of the laboratory.

4. The recycled air must be monitored continuously, so that, early warning can be given of any accidental release of a toxic aerosol or vapour within the Clean Room and the building rapidly evacuated, if necessary.

5. The operators have a proven record for performing similar operations without releasing toxic aerosols or vapours.

3. ANIMAL LABORATORIES

Animal laboratories and holding areas need to be well ventilated to remove odour, with an inwardly directed air containment barrier to prevent the smell permeating the building. It is also necessary to ventilate to remove animal dander and reduce the incidence of allergic reactions among the personnel of the animal laboratory. Around twenty air changes per hour are recommended, with air temperature held at 22±2°C by air conditioning.

3.1 Anaesthetic Vapours

It is recommended that all anaesthetic procedures in animal laboratories be performed on a downdraught ventilated bench. This would have the capability of not only removing the dense anaesthetic vapours, so largely removing the need for flameproof fittings, but would also serve to remove any radioactive or pathogenic aerosols liberated on or above the working surface. It has the further advantage of allowing unlimited access from several sides, unlike the fume cupboard it would replace. Small but heavy objects, such as lead pots, may be supported by a central pedestal.

The room should also have an exhaust just above the floor to remove dense vapours and precautions should be taken to keep all electric appliances at least 30 cm above the floor.

3.2 Pathogen-Free Laboratories

If germ-free conditions are required, the laboratory should be pressurised with HEPA-filtered air and precautions taken to prevent the entry of disease-carrying insects, i.e. insect-proof seals on all doors; non-opening windows; local filters on all air vents, including the downdraught bench or fume cupboard; no floor drains. Animals should be stored in laminar flow Bio-Hazard cabinets.

4. PATHOGEN-FREE ANIMAL HOUSES

An over-riding consideration in the design of a pathogen-free animal house is the need to fumigate the HEPA filters and the animal house. The normal terminal position for HEPA filters in Clean Rooms cannot be used, since the animal house must remain sterile at all times, even during a filter change.

Instead main and standby HEPA filters are employed. Each set of filters is contained in its own hermetically sealed housing, which can be fumigated separately from each other, without affecting the animals in the animal house. Provision is also made for performance testing the filter before and after fumigation, before the housing is re-connected to the ventilation system.

4.1 HEPA Filter Housing

The filter housing should be split along the sealing face, so that the plate, against which the HEPA filters seal, protrudes all round the housing. Both sides of the casing of the filter housing should seal against this plate. This ensures that there can be no bypass leakage routes in the construction of the housing. Failure to do this means a long and costly period of sealing, testing and rejection, until all hidden bypass routes are located and sealed.

The insulation on the ventilation should be on the outside of the ductwork to reduce the surface area requiring fumigation.

4.2 Fumigation

Upon commissioning, animal houses and the HEPA filters are usually fumigated at least twice with formaldehyde. Any moveable furniture in the animal house is adjusted between each fumigation to expose all untreated surfaces.

To fumigate with formaldehyde, it is recommended that a concentration of 7 mg/litre be achieved in each of the rooms of the animal house, before the ventilation is switched off for a 24 hour period. This can be achieved by boiling off 18 cc of formalin in each cubic metre of air passing into the ventilation system. At least double the minimum quantity of formalin, based on internal volume of the animal house, should be employed to allow for the time taken to approach the equilibrium concentration.

The maximum rate at which the formalin can be boiled off should be determined and the airflow into the animal house reduced, by adjustment of the isolation valves on the filter housings, to achieve the desired concentration. All exhaust flow should be switched off to maintain a positive pressure in the animal house during the injection period.

The favoured position of the formalin boilers is in upstream half of the HEPA filter housings. Care should be taken to achieve good mixing of formaldehyde with the incoming air, in order to achieve reliable fumigation of the HEPA filters. This may require elephant trunking to deliver all the inlet air to the proximity of the formalin boilers. Note that mixing fans cannot be used, due to the danger of ignition of the flammable vapours. Care must also be taken to remove all sources of sparking (e.g., no simmerstats) from the formalin boilers.

Temperature of the air in the animal house during fumigation should be above 24°C, preferably around 28°C. To prevent condensation of water from the formalin, the humidity of the air entering the filter housing should be around 50%RH. It is obviously easier to meet these conditions in summer and scheduling of the building commissioning should keep this in mind.

When all the formalin is boiled away, the system is switched off and the animal house isolated for 24 hours to maintain the concentration of fumigant. Concentrations of formaldehyde in the vicinity of the building should be measured and barriers erected, wherever necessary, to prevent unauthorised entry. This is simpler to arrange over a weekend, than in normal working hours. Fumigation should therefore be scheduled over two Saturdays, in a row, preferably in summer.

After each fumigation, only the inlet ventilation is used to purge the building to maintain positive pressurisation. The ventilation should be adjusted to give the maximum rate of purging possible, which may not be as great as normal, due to the elephant trunking inside the filter housings. The building should be purged for at least 48 hours before the formaldehyde levels are tested for entry of the person to remove the spore strips and adjust the furniture. Entry may not be possible for several days and respirators and protective clothing may be required.

After it is decided that the second fumigation has been a success, the elephant trunking may be removed to restore normal flow. The exhaust ventilation may now be switched on and the building purged for several weeks, until the formaldehyde levels desorbing from surfaces in the building have reached acceptable levels.

5. FILTER TESTING

It is essential to test all High Efficiency Particulate Air (HEPA) filters, the seals and the housings by conducting "in situ" tests after installation or replacement of the filters. HEPA filters are notoriously delicate and easily damaged during transport and handling. Seals may become damaged during installation and filter housings may contain hidden bypass leakage paths, due to poor design or construction.

5.1 Cold DOP Testing

The most common procedure for the in situ testing of HEPA filters is to challenge the installation with a sub-micron aerosol of di-octyl phthalate (DOP) droplets. The DOP aerosol is generated by drawing the DOP liquid into an air-jet, using the Venturi effect, in a manner similar to a scent spray. The DOP spray impacts upon a collector plate, so that the large drops are returned to the DOP reservoir and only the small sub-micron satellite droplets escape from the generator. The droplets vary in size from around 0.1 to over 0.6 μm, with a mass median of around 0.6 μm.

The challenge aerosol is injected at sufficient distance upstream of the filter to allow good mixing of the aerosol in the airstream. The concentration of the aerosol is measured upstream and downstream of the filters, so that the trapping efficiency of the filter installation may be determined.

The usual instrument for determining DOP aerosol concentrations is the Forward Light Scattering Photometer, which compares the amount of light scattered in the forward direction by the fog of particles penetrating the filter with the amount scattered by the upstream sample. The instrument is calibrated to give a scale reading of 100% penetration on the upstream sample and zero on an internal clean air standard, then switched to give a direct reading on the downstream sample. The instrument sensitivity can be switch selected over five decades to give full scale on 10%, 1%, 0.1% and 0.01% penetration.

5.2 Laser Aerosol Spectrometer

Laser Aerosol Spectrometers may be used with a Cold DOP challenge aerosol in place of the Forward Light Scattering Photometer, provided that the upstream sample can be sufficiently diluted with clean air so as not to overwhelm the spectrometer. The degree of dilution must be both fixed and known. Calibration of the dilution apparatus is the most difficult part of the operation. The technique provides information about variation of penetration with particle size, which is unobtainable with the standard method.

5.3 Aitken Nuclei

Atmospheric condensation nuclei, or Aitken nuclei, are available in considerable numbers in the polluted air around our cities. They are produced by many industrial processes, including combustion engines. They begin as particles less than 0.01 μm in diameter, but rapidly coagulate to particles around 0.3 μm. They can be detected by a Laser Aerosol Spectrometer and can therefore be used as an alternative to the Cold DOP as a challenge aerosol. This is useful in those situations where a DOP aerosol cannot be used, for example, to test a filter upstream of a charcoal bed. The charcoal would be poisoned by the DOP vapour evaporating from the DOP aerosol trapped on the HEPA filter, if a Cold DOP test is performed on such a filter.

The only problem with using Aitken nuclei as the challenge aerosol is that the concentration varies with the wind direction. Concentrations in a sea breeze may be very low. However, if conditions are suitable, they may be employed, provided that upstream and downstream samples are sandwiched to compensate for variations in particle concentration with time.

6. PHOTOGRAPHIC DARKROOMS

Photographic darkrooms are often small and too inadequately ventilated even to remove the heat generated inside them. The toxicity of modern photographic chemicals is increasing, especially those used in colour processing, and good ventilation is essential in a modern darkroom.

Capture ventilation should be used wherever possible, even if it is not completely effective, to reduce the amount of chemical vapour mixing with the general air in the darkroom. The air withdrawn by the wall slots along the darkroom wet bench and the colour processing tanks will provide the dilution ventilation required to keep the concentration of chemical vapour to an acceptable level.

In some cases the toxicity of the chemicals in use, for example, glutaraldehyde, may warrant enclosing automatic developing tanks in a ventilated enclosure. Care should be taken that fumes do not return from any drains, etc.

Air must be allowed to enter the darkroom by an low-resistance, light-proof route to make up for the air exhausted. The air flow should give at least 10 changes per hour, unless the darkroom is exceptionally large and the capture ventilation near perfect. If the darkroom is cramped, 20 to 40 changes per hour may be required.

6. PHOTOCOPIERS

Electrostatic photocopiers produce small amounts of ozone. However, most modern photocopiers are fitted with an ozone filter, so that if serviced regularly, the level of ozone generation should remain at acceptable levels.

Heavy use of a photocopier may result in overheating of the machine and the release of breakdown products from the organic resins, as well as an increased production of ozone. During loading and use, there may be also releases of toner dust, which is known to irritate the respiratory tract.

Electrostatic photocopiers should be located in well ventilated areas, preferably on an outside wall. See AS 1668. A local exhaust fan, e.g., a Vent-Axia, mounted in the adjacent wall, level with the top of the machine, will capture most of the fumes generated by the copier, so reducing the amount released into the air circulating within the building.

Wet copiers release solvent vapours and some also release ammonia and formaldehyde. Wet copiers should be located in a room, or an alcove, dedicated to the purpose, with its own exhaust ventilation system, not connected to the rest of the building ventilation. It should be the aim to capture and exhaust all the fumes and vapours, so that none are recirculated through the building and the concentration in the room is acceptable for the operator. This may require some types of copier to be housed in a ventilated enclosures.