CONTROL MEASURES AND MANAGEMENT SYSTEMS

CONTENTS

SUMMARY

- Most PGMs are integral to the workplaces in which they are used, and typically cannot be eliminated or readily substituted. This chapter focuses on effective management of the level of exposure for a workplace activity involving PGMs, with emphasis on the control of inhalation exposures.

- Protection of workers from exposure to chemical agents is a regulatory requirement. Whilst most PGM substances possess low to moderate toxicity, some are of sufficiently high toxicity (Chapter 6) to compel stringent exposure control, *e.g.*, complex halogenated platinum salts (CHPS) such as chloroplatinates, and Pt-containing anticancer drugs ("platins").

- Employers should evaluate exposure potential taking into consideration local legal requirements. This can be achieved through workplace monitoring (Chapter 8), or estimated using predictive tools and models.

- A hierarchical approach is recommended for exposure control. Elimination or substitution of the hazardous material are preferred options. If neither is possible, engineering controls are the next best option.

- Engineering controls achieve containment
    - Barrier systems such as gloveboxes, which separate the operator from the hazardous activity
    - Managed airflow that entrains dust away from the operators breathing zone
    - Contained transfer systems which connect two items, *e.g.*, from a dryer to a container
    - Automation and robotics that remove the operator from the exposure area.
  The desired target exposure level for a hazardous substance drives selection of the optimal control technology.

SUMMARY

- The most effective engineering controls for reducing exposures to PGM substances, especially for High hazard category substances, are barrier systems designed to provide total containment. Such containment is typically feasible in PGM refinery processes involving milling and blending, solvent extraction, separation/filtering, and calcining. This approach may also be adopted for other activities, *e.g.*, certain process catalyst installations.

- Administrative controls include reducing either the number of workers in an area or operator residency time, and increasing the distance between workers and the exposure source.

- Personal protective equipment (PPE) including respirators, coveralls, gloves, and eye protection should be considered when other exposure controls are insufficient by themselves, or are otherwise infeasible.

- Attention needs be paid to a variety of PPE factors including: chemical compatibility; assigned protection factors (APF); training in use; fit testing; tolerability and comfort considerations; decontamination and cleaning; storage; and medical fitness to use.

- PPE can be particularly appropriate in non-routine and exceptional exposure circumstances such as during maintenance activities and where equipment integrity is disrupted, *e.g.*, during stock-take.

- Good hygiene practices (for example skin surface washing and decontamination) are also key to minimising personal exposures. Worker awareness and training must cover control measures (their necessity, function, use, reporting of defects etc.).

Note: Throughout this chapter the inclusion of a particular image or reference to a specific item of manufacturer equipment should not be considered to be an endorsement nor a critique of that item.

9.1

RISK OF EXPOSURE (EXPOSURE POTENTIAL)

Potential for exposure to PGM substances can occur throughout the PGM production and product formulation process, commencing with sampling of incoming raw materials, evaluation stages, smelting, refining, chemical production, catalyst coating etc. This applies not only to production operations, but also to cleaning, maintenance, laboratory analysis, and in research and development activities.

The risk of worker exposure is a function of the substance hazard and the probability that it will cause harm (exposure). The potential health hazards of PGMs have been discussed in Chapter 6, whilst Chapter 10 covers occupational exposure limits (OELs) and other benchmark values relevant to PGM exposure control, such as control bands. For the purpose of defining engineering controls, the key parameter is the *target exposure level, e.g.*, based on the OEL, or other such value. How this will be applied to the control strategy will be explored in later sections.

In an existing facility, exposure monitoring and observation of a task can determine the *exposure potential*. The following parameters should be included for consideration:

- Process activity (nature of the activity).

- Duration and frequency of the activity.

- Form of material handled and its intrinsic fugacity (*i.e.*, dustiness/volatility).

- Quantity handled.

- Concentration of a substance.

- Physical conditions, including workplace environmental factors.

- Operator proximity and intervention.

- Operator compliance (*e.g.*, to standard operating procedures).

When applied in a qualitative predictive manner, exposure potential has no determinable numeric value. However, in this case some authorities have provided guidance by rationalising exposure potential to only the scale of operation (*i.e.*, amount of hazardous substance being handled) and its dustiness/ volatility, and then linking this to a suitable engineering control for a given workplace activity. The International Labour Organisation Chemical Control Toolkit (ILO, 2006) is one such approach. The result may offer only one control solution option for each

activity, but it does indicate the type of technology that may be appropriate, and therefore has utility (particularly when monitoring data is unavailable, such as in process design stages). When handling highly hazardous materials at industrial scale, ILO directs the readers to seek specialist help. Sections in this chapter do provide guidance on exposure control solutions for such situations. It should be noted that a number of other models and tools of varying complexity and applicability domain have been developed for workplace chemical exposure assessment (ECHA, 2012).

Conclusions on exposure potential and any target exposure level definition should form part of the workplace activity risk assessment, and normally be documented (see Chapter 10).

Manufacturing scenarios involving Pt-containing anticancer pharmaceuticals ("platins") are within scope of this chapter, but protection of health care workers handling and administering these drugs is a more applied exposure control situation, and readers should instead consult other specific sources, for example US NIOSH (2004).

9.2

REMOVE, REPLACE OR REDUCE THE HAZARD

As prescribed by many health and safety authorities, the starting point in considering how to control a hazardous activity involving a chemical agent is via use of a hierarchical approach. In some countries this stance is a legal requirement and a company may need to demonstrate that it has been followed.

options for the elimination and substitution of a hazard.

If elimination or substitution is infeasible, then other controls must be sequentially considered and implemented, as shown in descending order of preference in Figure 9-1. Engineering controls should first be evaluated (to

contain a material at source), before administrative controls or personal protective equipment (PPE) are examined.

THE HIERARCHY OF CONTROLS

In the conventionally recognised 'Hierarchy of Controls' (Figure 9-1), removal of a hazard from the workplace is the most effective method of minimising exposure. Therefore, elimination of a hazardous substance from a process, substituting a less hazardous alternative, or reducing the amount or working concentration are the preferred approaches. Where higher hazard PGM substances such as chloroplatinates are concerned, if possible, less hazardous alternatives should be identified. Process development and facility design stages often provide the best opportunity to implement
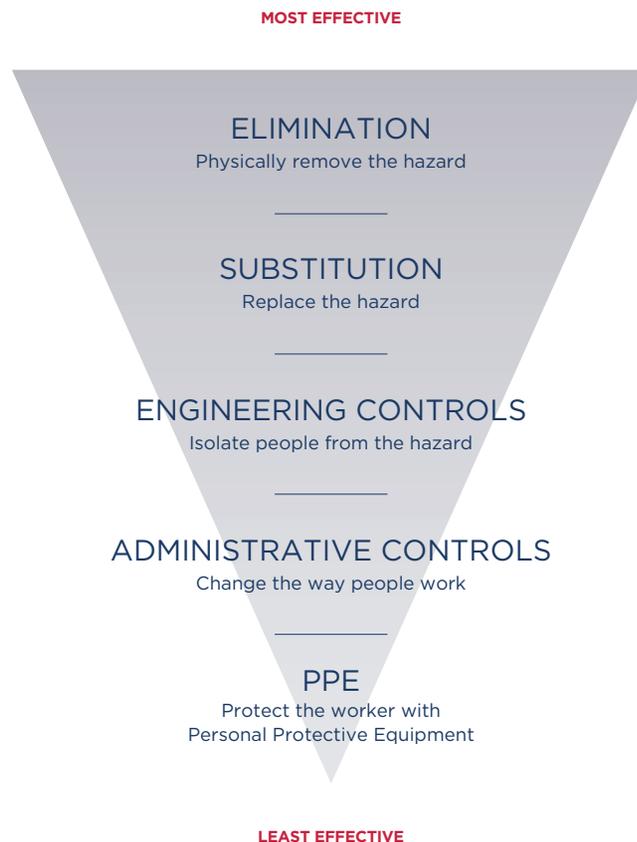
MOST EFFECTIVE

ELIMINATION
Physically remove the hazard

SUBSTITUTION
Replace the hazard

ENGINEERING CONTROLS
Isolate people from the hazard

ADMINISTRATIVE CONTROLS
Change the way people work

PPE
Protect the worker with
Personal Protective Equipment

LEAST EFFECTIVE

Figure 9-1: Hierarchy of controls

9.2

REDUCE EXPOSURE POTENTIAL

The aim of the hierarchy of controls is to eliminate or reduce exposure to a hazardous substance. Elimination or reduction of risk may also be achieved by improving exposure potential sub-criteria. Examples of how exposure potential can be reduced include:

EXPOSURE POTENTIAL SUB-CRITERION	IMPROVEMENT MEASURE
Process activity	Select processes that involve fewer transfer steps, or have closed transfers, or select equipment that generates less dust or generates dust at lower escape velocities.
Form of material handled	Keep particulate materials in solution or suspension to avoid dust generation. Use pellets or granules rather than fine powders. Use wet/damp powders (*e.g.*, from filtration rather than a drying step). Chemically deactivate materials in-situ prior to opening or dismantling equipment.
Quantity handled	Use smaller amounts of material/reduce batch sizes. Use vessels/receptacles that can be connected and filled in a contained manner.
Physical conditions	Reduce airborne dust by wetting or misting contaminated equipment surfaces before opening them.
Operator intervention	Design robust processes, or use automation or robotics to obviate or reduce the necessity for operator intervention.
Operator training/ compliance	Provide training on hazard awareness and control measures (especially for operators who are new to a process/activity).

Table 9-1: Examples of how exposure potential can be reduced

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ENGINEERING CONTROLS

Where eliminating the hazardous substance is not possible, the next hierarchy step is an evaluation of engineering controls. The provision of engineering controls to reduce exposure to acceptable levels is generally known as *containment*.

The process for arriving at the best engineering control solution can be complex. Quantifying or qualitatively estimating the exposure potential, and then matching that and the material hazard to the optimal technology takes experience. A good knowledge of the process and the engineering control technology is also needed to ensure that satisfactory operability of the process is achieved in the case of new facilities, or maintained for existing ones.

Provision of engineering controls can involve significant capital cost. In general, the higher the level of containment, the higher the cost, and the less flexible and operable will be the solution. Therefore, it is important to provide a level of control which is adequate but not excessive. In similar vein, it is often less expensive to design-in engineering controls rather than retrofit them to a process.

In some jurisdictions, if the hazardous substance has significant health risks then enhanced controls are required under local regulations. In relation to respiratory sensitisers, such as CHPS, several territories require exposure to be as low as reasonably achievable. In the EU additional provisions are applicable where workplace exposure to carcinogens and mutagens occurs. The EU Carcinogens and Mutagens Directive (EC, 2004) states: *"Where it is not technically possible to replace the carcinogen or mutagen by a substance, preparation or process which, under its conditions of use, is not dangerous or is less dangerous to health or safety, the employer shall ensure that the carcinogen or mutagen is, in so far as is technically possible, manufactured and used in a closed system. Where a closed system is not technically possible, the employer shall ensure that the level of exposure of workers is reduced to as low a level as is technically possible."* As platins can fall into this category of carcinogenic hazard, local regulations and an organisation's own policies should be reviewed before selecting controls.

9.3

HAZARD CLASSIFICATION

For hazardous materials — especially those with significant hazards via the inhalation route —it is good practice to assign a target exposure level, typically via reference to an occupational exposure limit (OEL) or else via exposure limit banding. The latter approach, which requires less data than needed for OEL setting, still allows a risk-based set of engineering controls to be selected to prevent exposure to the substance during work processes. Furthermore, official OELs are not set for all chemical substances (including certain PGM substances), and this is particularly true for new chemical

entities in development which may have incomplete toxicity data (*e.g.*, novel pharmaceutical drugs or new chemical products). Use of exposure limit banding / control banding is often assigned to such substances as a basis for defining a target exposure level.

Such banding systems can vary between companies and jurisdictions, but a logarithmic-step scale is common. A further categorization of the numeric bands into low / medium / high and very high hazard may be applied. A typical schema is shown in Figure 9-3.

In the context of the PGM industry some examples of categorisation would be as follows [1]:

- Pt metal – OEL: 1000 $\mu g/m^3$; Hazard category = Low.

- Soluble Pt salts – OEL: 2 $\mu g/m^3$; Hazard category = High.

- CHPS – OEL: 2 $\mu g/m^3$ (but

under consideration for step-change reduction); Hazard level = Very High.

- Pharmaceutical platins – OEL: 1 $\mu g/m^3$ to < 0.1 $\mu g/m^3$; Hazard level = Very High.

How these bands are used to aid selection of engineering controls will be discussed later.

CONTAINMENT PERFORMANCE TARGET

Handling of solid materials including pellets, granules and powders can create dust, which may be inhalable/respirable. The amount of dust is dependent on some of the parameters also impacting on exposure potential, *i.e.*:

- Process activity.

- Duration and frequency of activities.

- Quantity handled.

- Form of material handled.

The concentration of dust (particulate) in the air is expressed in microgram (μg)/m^3 or mg/m^3 (as per OEL values). Liquids can also pose an inhalation risk if they become aerosolised. The airborne concentration can be quantified in the same manner as for dusts.

CONTROL BAND	Target Exposure Level / Exposure Banding ($\mu g/m^3$)	Hazard Category
1	1000-10000	LOW
2	100-1000	
3	10-100	MEDIUM
4	1-10	HIGH
5	0.01-1	
6	<0.01	VERY HIGH

Table 9-2: Example of Control Banding/Target Exposure Level/Hazard categorization

[1] Taking into account typical jurisdictional OELs for these substances, or other norms applied by industry.

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For consistency, the units for particulate/aerosol concentration in air have been standardised to µg/m³ in the remainder of this chapter.

In general industrial situations, typical total airborne dust levels which have been observed for some uncontrolled operations are:

ACTIVITY	DUST CONCENTRATION (µg/m³)
Charging of tray with damp powder (drying oven) by scooping	1,000 – 5,000
Discharge of filter or centrifuge (damp powder)	1,000 – 10,000
Reactor charging (by hand scooping into manway)	10,000 – 50,000
Emptying tray by scooping or tipping into sacks	20,000 – 100,000
Discharge of dry material to drums	50,000 – 100,000
Milling (*e.g.*, basic comminuting-type mill)	50,000 – 100,000
Sieving (open sieve)	50,000 – 100,000

Table 9-3: Example of exposure ranges by activity

Current regulatory OELs for inhalable nuisance dust[2] levels are commonly set at 10,000 µg/m³ in a number of jurisdictions (or between 3,000 to 5,000 µg/m³ as respirable dust). With reference to the above table it may be seen that for many operations the dust concentrations produced could be a concern even in relation to standards applicable to nuisance dusts, and more so if a lower OEL is assigned to a particular substance.

Engineering controls operate by reducing the dust concentrations to an acceptable level. The level of reduction depends on the technology used. The dust concentration or exposure concentration produced by an operation when combined with an engineering control is called its containment performance level, and the goal set when specifying and purchasing such a control device is called the containment performance target (CPT).

For new engineering control equipment, the CPT will often be first verified using a surrogate marker material during factory testing and then tested later during process operation. For an existing operation, the CPT of the control will be verified using workplace exposure monitoring. The CPT is typically specified and tested over an operational period (activity-based) rather than as a 8-hr time-weighted average (TWA) value. This CPT result can then be used by an industrial hygienist to determine the overall control strategy for worker protection.

ENGINEERING CONTROL TECHNOLOGIES

Engineering controls achieve containment via four basic modes:

1. A physical **barrier** that separates the operator from the hazardous activity.

2. **Managed airflow** that entrains dust away from the operators

[2] Also known as Particulates Not Otherwise Classified (PNOC) or Particulates Not Otherwise Regulated (PNOR).

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breathing zone and captures it by using filtration.

3. **Contained transfer systems** than can be made and then broken with limited release of hazardous materials. They are used to connect two items to effect a transfer of material, *e.g.*, from a dryer to a container.

4. **Automation and robotics** which remove the operator from the exposure area.

More than one technology can be used to achieve the desired overall CPT.

Exposure control performance levels stated in the remainder of this chapter are indicative only and are not assured values (actual performance is dependent on multiple variables such as specific manufacturer's equipment performance, local conditions, correct installation etc.). However, the control performance figures provided should permit the reader to appreciate the typical order of containment achieved by various technologies and to make comparisons.

Aside from standard explosive atmospheres (ATEX) protection, if PGMs are present consideration should be given to reactive hazards management and implications for control design. Reactive PGMs, such as finely divided Pt, can present a chemical reactivity/fire risk, particularly if significant levels of fallout dust accumulate in ducts and other dead spaces.

BARRIERS

Barriers work by providing a high integrity enclosure that physically separates the process materials and the operator. Examples are as follows:

GLOVEBOX / ISOLATOR

If the barrier operates at a negative internal pressure, to reduce escape of dust via apertures/joints, and provides gloved access to the operations within, they are called containment isolators or gloveboxes. Such containment equipment is typically custom-made.

Gloveboxes can be manufactured in a range of materials including soft walled polymers, acrylic, stainless steel and alloys such as Hastelloy®. Acrylic materials are commonly used where acid resistance is required, *e.g.*, for enclosing filtration of chloroplatinate suspensions.

The containment performance of a glovebox can depend on the techniques used for transferring materials into and out of it. Some very high integrity methods have been developed for use with barriers, *e.g.*, the rapid transfer port. Other methods are pass-in/pass-out chambers and continuous liners. (See Contained transfer systems).

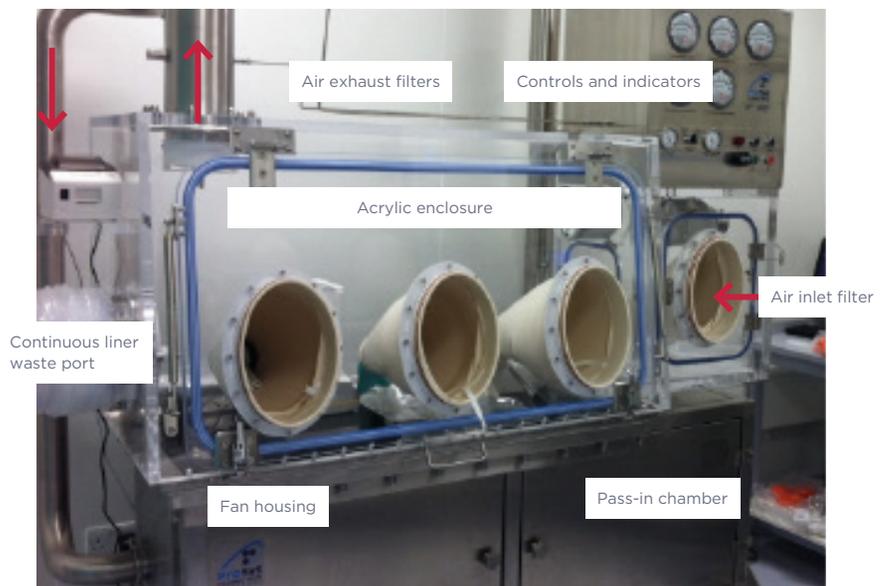Figure 9-2 illustrates some typical glovebox components.

Figure 9-2: Acrylic glovebox

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The exhaust air can either be High-Efficiency Particulate Air (HEPA) filtered on exiting the glovebox, or can be directed to a common exhaust system. The former is preferable as the dust is contained at source without contaminating long stretches of duct (which can be difficult to clean and present a hazard during dismantling). The inlet air is also fitted with a HEPA filter to protect the environment should a malfunction cause the unit to become positively pressurised with respect to the workplace environment.

For metal rigid walled isolators, windows and doors are provided in glass or acrylic. These can be sealed to the isolator body using static or inflatable seals.

Operations or manipulations performed within the isolator are accessed by the operator via gloves mounted in glove ports (usually in the windows). Glove ports are assembled from either side of the glove port aperture, to present a smooth internal profile and a two-groove spigot on the outside. Glove port shields can be installed to add integrity to the enclosure when gloves are not in use (see Figure 9-3; a glovebox used for housing filters for soluble Pt compounds). Interlocked versions are also available.

Either a 3-piece sleeve (glove and cuff arrangement) or a one-piece gauntlet can be used. The three-piece unit has a material sleeve that is attached to the glove port

and a plastic cuff ring to which a hand glove is attached. The gauntlet attaches to the glove port and encloses the whole arm and hand. The gauntlet is the most widely used and the most secure method. The 3-piece system allows for different size gloves to be fitted to suit different sized hands and can therefore offer greater dexterity.

Gloves are available in many elastomeric materials. Most common are latex, neoprene, nitrile, butyl, EPDM and CSM (also known as chlorosulphonated polyethylene, or by the former brand name Hypalon®). When selecting glove materials, consideration should be given to chemical compatibility, chemical permeability, robustness, comfort, electrostatic properties, and cost. Sample gloves should be obtained and tested prior to purchase. A

Figure 9-3: Glovebox with gloveport shields

glove that is shaped close to the arm from the wrist to the glove port—and therefore minimises excess volume in the glove—restricts arm movement less and is therefore easier to use. This will be more apparent at lower (more negative) isolator internal pressures.

If flammable solvents, gases or powders are handled within the glovebox, the internal environment can made be inert using a gas such as nitrogen. In these cases, additional controls and interlocks will be needed and a full design safety review should be conducted.

Manufacturing lead times for gloveboxes can be extensive for metal wall types (up to 9 months); 4-6 months for acrylic wall types; and a few weeks for flexible wall variants. For this reason and their relatively lower capital cost, flexible wall units (Figure 9-4) have become popular for short-term high hazard challenges.

The bodies of flexible wall isolators are fabricated from PVC or polyurethane sheeting up to 0.5 mm thick. This material is transparent and provides good visibility. The sheets are welded together using radio frequency welding to ensure high integrity joints. External support frames can be fabricated from plastic, aluminium or stainless steel. This system provides rigidity to the flexible wall isolator so it retains its shape. The units operate under

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negative pressure, and are usually supplied with inlet and extract HEPA filters.

Compared to rigid types, such isolators have flexibility of design and improved ergonomics as the operator can extend the reach of glove sleeves. However, they are not as robust: the flexible wall can be quite easily damaged, and may need periodic replacement. Decontamination can also be more complex.

It is essential when designing a glovebox to perform an ergonomic assessment using a physical model.

Most suppliers produce 3D CAD models which provide a

good early indication of the access being proposed, but it is still necessary to view a model constructed in materials such as model board, metal, or plastic to judge ergonomics and operability. The model should be robust enough to simulate full scale material handling trials to assess factors including:

- Operator access to perform the tasks.

- Operation vision.

- Dexterity necessary to perform tasks.

- Weight to be manipulated.

- Comfort of stance during manipulation.

The ergonomics assessment should cover all operation, maintenance and cleaning activities where operator manipulation is required. Where possible, operations personnel should be involved. This will help to ensure the operators understand and participate in the design evolution and are therefore more likely to accept the final design.

Gloveboxes/isolators, combined with the appropriate transfer techniques and decontamination regimes, can offer the highest levels of containment with CPT below 0.1 µg/m^3. They are therefore suitable for operations involving Very High hazard categories and significant exposure potential, including the handling of CHPS, such as chloroplatinates, and platins and their precursors. They are also suitable for chemical materials requiring a closed handling system and controlled environment due to their reactivity.

Figure 9-4: Flexible wall glovebox (courtesy of Solo Containment)

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Figure 9-5(a): Glovebags used in vacuum transfer of material from dryer bowl and for sampling containment (courtesy of Solo Containment)

Figure 9-5(b): Glovebags used in vacuum transfer of material from dryer bowl and for sampling containment

GLOVEBAGS

Glovebags are fabricated from polyethylene, PVC or polyurethane film. They differ from a flexible wall glovebox in that the glovebag operates in most cases at ambient pressure and therefore does not provide the same level of integrity. The bag itself is often considered as a disposable item. Glovebag use is increasing to overcome short-term containment challenges, or where enclosure geometry to provide good ergonomics would be too difficult with a rigid wall.

An internal or external support frame can be provided fabricated from plastic, aluminium or stainless steel, or the bag can be self-supporting. There are various methods by which the bag can be attached to the framework, pipes, reactor necks, drums or equipment, but the norm is a taped seal. This sealing method can provide a gas/liquid-tight seal.

Pass-in chambers can be created with a zip or similarly sealable door for material entry, whilst sealing within a bag prior to removal ("bagging out") is almost universally used for taking out material. Glove design can be similar to flex walled isolators and similar glove materials can be used but often the glove is welded into the bag.

During decontamination, misting of the internal environment can be used to reduce levels of airborne particles. Washing with a spray lance is usually difficult due to the absence of a drain and taped seals trapping the contaminated wash liquors. Loss of containment usually occurs during removal of bag.

Due to the low cost and short lead-time the design can be improved quickly after the first trial use.

Examples of glovebags in use are shown in Figures 9-5(a) and (b).

Where glovebags are correctly fitted, used and decontaminated, CPTs of 5-10 $\mu g/m^3$ can be achieved, making them suitable for containing High hazard category materials.

9.3

MANAGED AIRFLOW

Managed airflow devices can be broadly separated into three categories:

- Booths.
- Cabinets.
- Local Exhaust Ventilation.

BOOTHS

Booths may enclose the operator and the process, or just the process with the operator standing outside. The former work by having the operator positioned either parallel to or upstream of the dust generating activity and by having the dust entrained in the airstream to be extracted to a capture device (filter).

The most effective method, and hence that providing the highest degree of containment, is the **downflow booth (DFB)**, Figure 9-6.

The downflow booth provides a laminar flow of downward air at 0.5 m/s over the entire working area of the booth. A fan circulates air within the booth, of which 5-10% is discharged to the room and made-up by fresh air. A fine dust filter and HEPA filter remove particles from the airflow. A second HEPA is recommended either in the rear of the booth or the ceiling in case of a breach of the primary HEPA filter. The filters in the rear of the booth are normally located in safe change housings and can be designed to be accessed from either the front or the rear of the booth.

A safe working line is provided for demarcation of protected and

non-protected areas. In practice the best containment is achieved toward the rear of the booth.

Booths with well-designed workstations can provide CPTs of 100-200 µg/m^3 for carefully controlled operations, making them suitable for Low and Medium hazard category activities. Performance is very dependent on the nature of the operation and the care taken by the operator and hence operator training is crucial. If combined with an additional barrier, such as a screen or curtain, then containment levels can be improved such that CPTs of 1-10 µg/m^3 can be achieved, making such booths useful for High hazard category situations.

A booth can also provide excellent secondary containment to a primary system, where the latter on its own is not suitable for High hazard category materials.

Another booth configuration is the horizontal laminar airflow booth, in which the air can travel into the booth from the room or horizontally across the booth, see Figures 9-7 and 9-8.

The horizontal flow booth is a development of local exhaust ventilation (LEV) as a technique which improves the performance of simple local hood designs by creating an air-swept enclosure to prevent material escaping laterally.

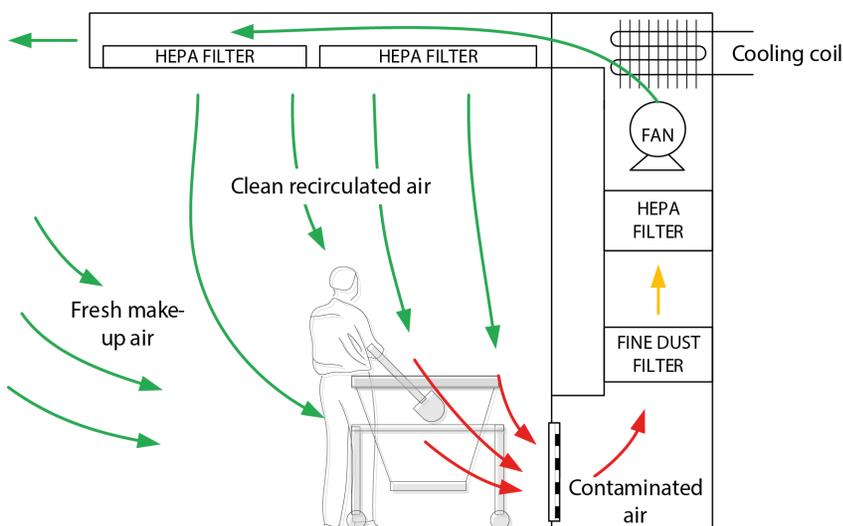The booth may be small, located around the emission source

Figure 9-6: Downflow booth schematic

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allowing only hand access into the area (for example a sack tip extract hood); or else a large booth that the operator stands within to carry out the operations.

For smaller booths containment relies on a booth face velocity (typically 0.7 m/s) to prevent dust escaping from the booth. For larger walk-in booths the dust is entrained in the airstream and directed away from the operator. Large booths require vast quantities of air to be moved and filtered. This configuration supplies air to the side of the booth and extracts it from the other side, entraining dust particles. It is less effective than when extracting air from the rear as it does not create a face velocity. Performance is dependent on dust being generated at a lesser velocity than that of the air stream.

Operators may be required to place their hands inside the booth leading to a contamination risk. There is also a contamination risk from materials and equipment brought out of the booth. Some suppliers provide a screen with glove access to the front of the booth.

This encloses the operation and provides for good containment during operation, similar to that of a glovebox. Materials still need to be passed in and out and therefore opening the system to achieve this can result in loss of containment as can the possibly high surface contamination on the exiting items.
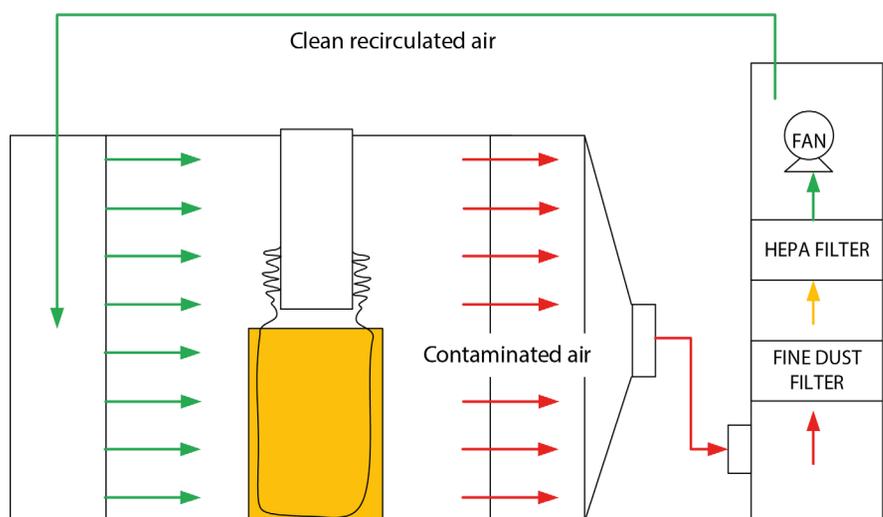
Open-fronted horizontal booths achieve containment levels of 100-500 µg/m³ so should be used on Low hazard category materials (unless used to provide secondary containment to support a primary system).

Open-fronted horizontal booths achieve containment levels of $100\text{-}500\ \mu g/m^3$ so should be used on Low hazard category materials (unless used to provide secondary containment to support a primary system).
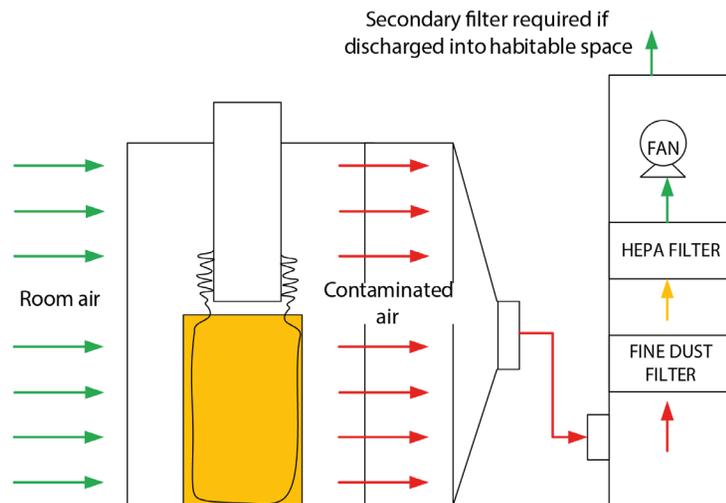
Figure 9-7: Horizontal laminar flow booth schematic (side view)

Figure 9-8: Horizontal laminar flow booth schematic (front view)

9.3

CABINETS

Cabinets are used for mid- and small-scale operations or dispensing.

A few different operating modes exist. The type of **airflow cabinet** shown in Figure 9-9 functions by providing a barrier air curtain that separates the activity from the environment. Dust is captured by the barrier curtain and directed to the extraction via the sides of the units and then can either be fed into the exhaust air system or returned through filters. Extraction slits are located in the table front or in the upper door area. The barrier nozzles are located in the upper hood area.

Materials are generally passed into and out of the unit via the front. The units can be fitted with rigid or flexible type gloved screens that fully enclose the operation, such that the performance is similar to that of an isolator. Bag-
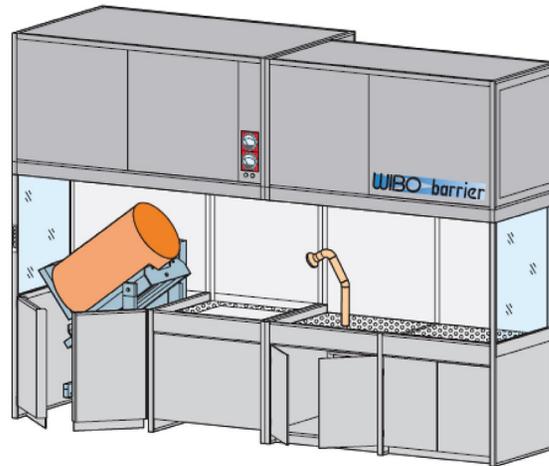
Figure 9-9: Airflow cabinet, using air curtain

Figure 9-10: Cytotoxic cabinet

out ports can be provided in the sides of the unit.

Without a front screen, containment performance is around 100 µg/m^3 (although to achieve this, operators and equipment must be decontaminated prior to exiting). With added screens, levels of ~1 µg/m^3 have been achieved making the cabinet suitable for high hazard categories.

Cytotoxic cabinets work by providing downward laminar air and a front face velocity to protect the operator (Figure 9-10).

They are predominantly used in small scale or laboratory environments. Contaminated air is HEPA filtered then both exhausted and recirculated. The operator works via a variable height sash.

These units are often used in laboratories or in health care worker protection scenarios. In the former case, they should always be used in preference to a fume cupboard (hood) which should not be used for significant handling of hazardous solids as a fume cupboard (hood) provides no particulate filtration.

Containment levels of <1 µg/m^3 can be achieved when handling low solid volumes, and if good glove and surface decontamination practices are used by the operators.

Ventilated safety cabinets (Figure 9-11) provide an inexpensive method for handling low volumes of high hazard category substances.

The enclosures are ventilated by a separate fan, usually positioned under the unit, which draws air through safe change HEPA filters
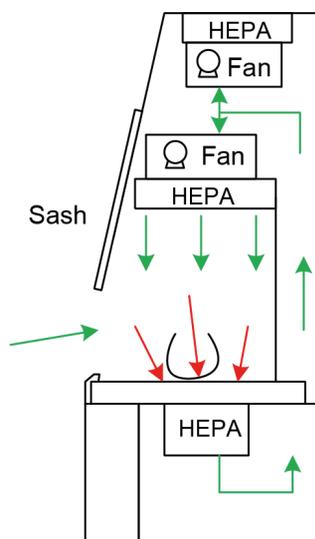
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connected to the rear exhaust duct via trunking.

Like all devices that use a face velocity to prevent dust particles from leaving the cabinet, they rely on good operator practices to achieve containment levels (*e.g.*, slow movements, decontaminating items prior to removal from the enclosure, and optimal glove procedures). The enclosures are bench mounted or can be provided on a mobile frame.
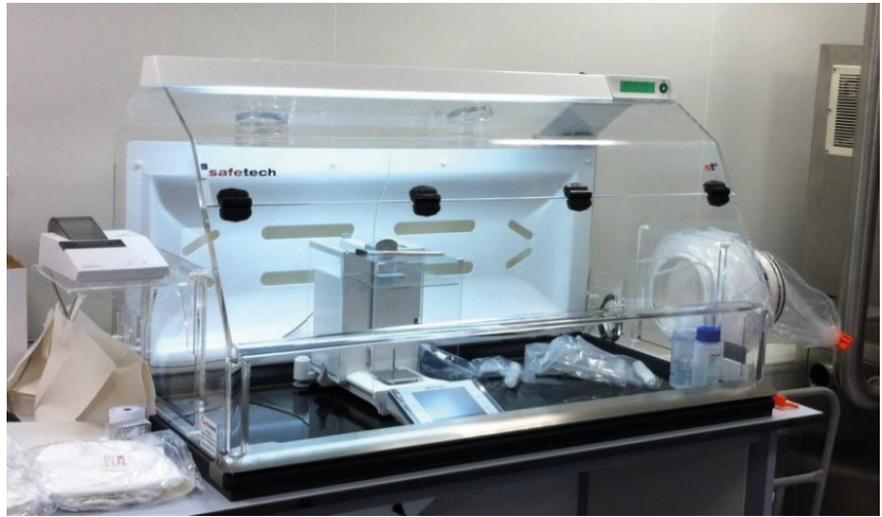
Containment levels of <1 µg/m^3 can be achieved provided that best practices are followed and a "bag-out" port is used.

LOCAL EXHAUST VENTILATION

Local exhaust ventilation (LEV) systems comprise all or some of the elements shown in Figure 9-12.

Air movement at the capture hood entrains dust particles,

Figure 9-11: Ventilated safety cabinet

which are transported along a duct, by the suction provided by a fan. The air is cleaned by a filtration system before being exhausted, often to the building external environment.

To produce an effective hood design, the activity must be

carefully studied to evaluate how and where the dust is generated, at what velocity, and how the resultant dust cloud behaves. There are many examples of hood design for specific operations, obtainable from sources such as:

- The ACGIH manual on industrial ventilation practice and design (ACGIH, 2013).

- UK HSE (2011) HSG258, Controlling airborne contaminants at work: A guide to local exhaust ventilation (LEV).

For the system to function correctly each of the elements must be correctly designed. The ACGIH manual provides guidance to sizing all elements of the system. The capture velocity (that required to entrain the dust cloud into a hood) and the transport velocity (that required to convey the particles along
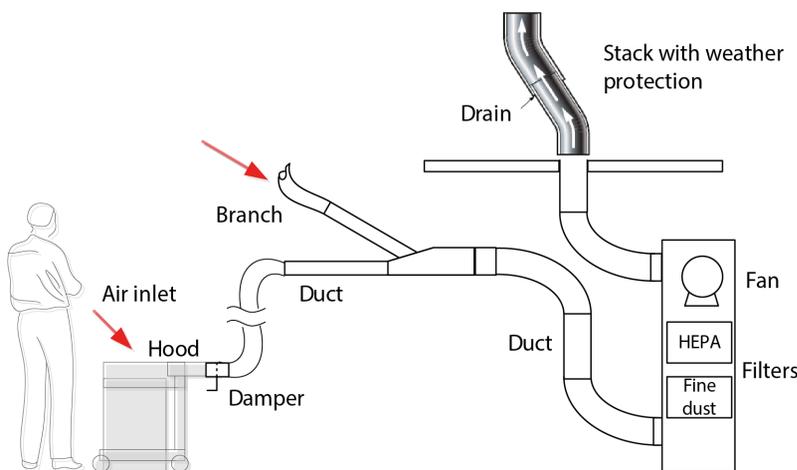

Figure 9-12: LEV Components

9.3

the duct) are critical design parameters. Capture velocity varies depending on the energy of release and particle size, and transport velocity varies depending on particle size. The above reference sources provide the recommended velocities for given conditions.

As these two documents provide excellent reference material for all elements of the system design this section will focus on the most common errors observed in practice, which are:

1. **Poor hood design**
Hood design is frequently not appropriate for the task. Often the design only addresses part of the activity in which dust is generated. An example may be hand scooping material from a container to a sieve. The sieve may be protected by a hood but the hand scooping and scoop movement are not. Because only a few off-the-shelf hood designs are available (*e.g.*, cones) these tend to be used whether they are appropriate to the task or not. Note: The velocity from an open ended duct or cone falls by 90% within one diameter of the cone face.

2. **Hoods with insufficient capture velocity or ones situated too far from the activity**
Extra hoods can only be added to a system that has the necessary capacity; otherwise an additional hood can change the system dynamics

and may detrimentally affect the performance of the other hoods.

3. **Operators adjusting the position of manual dampers**
Dampers can be provided in a system to aid balancing, *i.e.*, to adjust the static pressure in a branch such that the correct volume is obtained in each branch. Therefore, these should not be closed to "save energy" or opened more fully to get more volume. Once set-up, damper handles should be removed or locked in position.

4. **Poor ductwork design**
Ductwork branches teeing into a main line at 90 degrees, or duct diameter not changing to cope with different velocities when two branches meet, can give rise to higher pressure losses than allowed for in the fan design calculations. This leads to lower fan volume and lower transport velocities.

5. **Insufficient transport velocity in the duct**
This can be due to poor design, poor fan maintenance, or by increasing the size of a duct to add branches to a system without checking the design of the whole system. Insufficient transport velocity will cause dust to settle and accumulate, which then exacerbates the situation. Build-up of reactive particulates in ductwork has led to fires in several PGM facilities.

6. **Contamination of workers during maintenance or modification of ductwork**
Ductwork with inadequate transport velocities will become contaminated and can present exposure concerns to workers who access the system internals or those in the workplace (especially if main ductwork branches run at high level through a facility). Ductwork should be designed to be cleanable or plastic liners placed around joints such that the duct ends can be tied off when the duct is removed. The duct can then be decontaminated.

7. **Dust collection units**
Dust filtration units, such as those with shaker-type or blowback filters, often have poor containment at the dust collection point. This engineering control technology needs to be matched to the target exposure level for the hazardous substance(s).

LEV containment performance is highly variable but generally will reduce dust concentration by a factor of between x2 and x10. For this reason, it is seldom an optimal control approach for other than low hazard category situations.

In some countries it is a legal requirement to have a periodic thorough examination and test of a system (*e.g.*, at least every 14 months in UK), and a record of this must be kept for at least 5 years.

9.3

CONTAINED TRANSFER SYSTEMS

Most PGM processes involve the transfer of material from a container to a process equipment item, between equipment, or from equipment into a container. Equipment to equipment transfers can be hard-piped, in which case they are considered closed and therefore contained. Other transfers can be open, *e.g.*, scooping into a vessel manway or dropping material from a filter discharge port into a receiving container, in which case airborne dust concentrations, as described in the section: Containment Performance Target (page 9), can be high.

The alternative method is to connect the container to the process equipment item, to allow a more contained transfer.

The following systems that achieve this are described:

- Bag over bag.
- Continuous liner.
- Flexible containment solutions: systems.
- Split butterfly valves.
- Cone valves.
- Double valve with air- or liquid-wash.
- Rapid transfer ports.

BAG-OVER-BAG

One of the most common material transfers for product or waste material is the discharge from a process equipment item to a bag. If the bag is tied or taped to the discharge chute there will be dust released when the bag is removed. The bag-over-bag technique, illustrated in Figure 9-13, significantly improves the containment level:
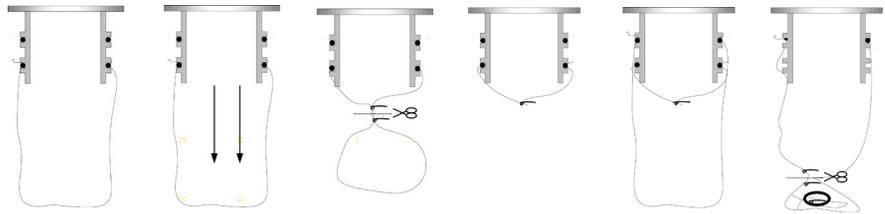

Figure 9-13: Bag over bag sequence of operation

The sequence of operation is:

1. Secure bag using o-ring on the lower o-ring grove.
2. Fill.
3. Seal (by using twist, tape and double tie method) or crimp.
4. Cut.
5. Place new bag over remainder of old and secure with o-ring.
6. Remove stub end and old o-ring (by manipulating through new bag).
7. Seal, then cut and remove (with a "swan-neck" of the sealed end to increase integrity).
8. Slide o-ring to lower groove

The disadvantage of this technique is that the o-ring becomes a consumable.

Figure 9-14 illustrates an alternate technique by which some flexible intermediate bulk containers (FIBCs)/big bags are connected and disconnected in a contained manner. The neck of the big bag contains a pocket to store the old liner tail. Such approaches can be useful to minimise the number of transfers and avoid the cleaning and storage associated with rigid containers.

Containment levels of 1-10 µg/m^3 can typically be achieved using this technique.

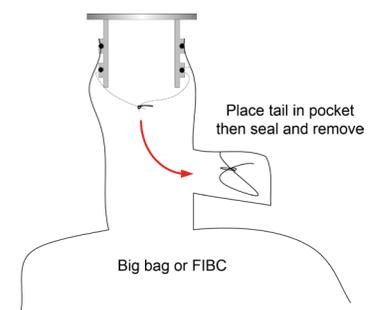Place tail in pocket then seal and remove

Big bag or FIBC

Figure 9-14: Contained connection of FIBC

9.3

CONTINOUS LINER

A continuous liner is a long length of a lay-flat tube. The liner is manually loaded onto a spigot, designed for the purpose (Figure 9-15). This is suitable for small quantities of liner, up to 10m in length. The liner can be safely changed using the bag-over-bag technique (described on page 20).

As an alternative, the liner can be purchased as a proprietary item (Figure 9-16) where the liner is loaded into a cassette that slots over the discharge chute. Up to 80m of liner can be handled in this way, and with this method the liner can also be changed safely.

In both cases the liner is sealed at one end to form a bag and then closed after filling to form a sealed bag and to provide the base of the next bag.

Figure 9-16: Cassette preloaded with liner

Typical containment levels of 1 μg/m^3 can be attained using this technique making it suitable for High hazard materials. With added secondary containment measures <1 μg/m^3 can be achieved, making it applicable for Very High hazard category materials. It is a common technique for removing product and waste from gloveboxes.
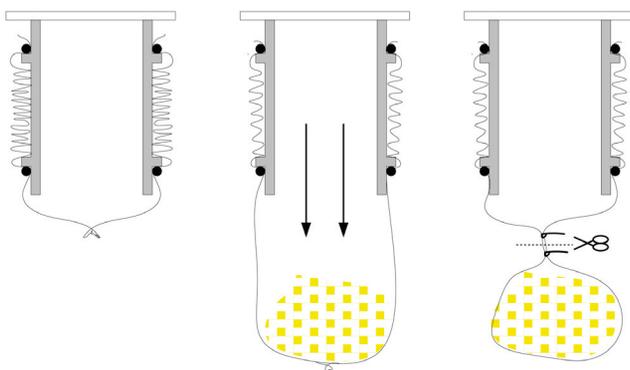
FLEXIBLE CONTAINMENT SOLUTIONS

There are a number of flexible containment solutions that have a proprietary containment technology involving an alpha part connected to the process and a beta part welded to a bag (Figure 9-17).

Various operational issues have arisen with this type of system, and experience suggests they are most suitable to low volume operations where very careful handling can be guaranteed. Capital costs for this class of containment solution are typically low, but consumable costs are comparatively high. Extensive "actual use" type testing is recommended prior to purchase.

Typical containment levels of 1-5 μg/m^3 can be achieved using this technique making it suitable for High hazard category materials.

Figure 9-15: Continuous liner on spigot

Figure 9-17: Flexible containment solutions

9.3

SPLIT BUTTERFLY VALVE

A split butterfly valve (Figure 9-18) can be considered as a single butterfly valve that has been split in half through the disc and one half is fitted to the filling vessel and the other to the receiving unit.

Neither half will operate until the two halves have been brought together and locked. The half that includes the actuation device is nominated as the active part and the other is called the passive part.

Containment is achieved whereby the two external mating faces of the halves seal together to prevent powder ingress when the valve is opened into the product stream. When the valve is closed and undocked the external faces remain relatively uncontaminated. In reality the sealing is not perfect so some residual surface contamination remains with corresponding release of dust on separation.

Figure 9-18: The passive half of a split butterfly valve attached to a container

There are a number of systems available, with a variety of docking systems and features, including air-washing when the valve is partially undocked to provide better containment. Split valves are widely used to connect containers of all sizes to process systems, both for filling and discharge, especially for rigid intermediate bulk containers (IBCs).

Split valve systems are mechanically complex, with performance relying on the close coupling of highly engineered mating faces and seal systems. The valves are often sequenced by the main plant control systems including multiple position sensors to ensure correct operation. As a result, it is essential that maintenance activities are rigorously followed; a degree of outage due to equipment failures should be anticipated. Split valve technology has developed rapidly since the 1990's and suppliers are providing new options all the time. Care should be taken when selecting a valve to ensure that any recent developments are well established and their possible impact on containment performance is understood.

Typical simple split valves will achieve exposure levels of 1-10 $\mu g/m^3$, making them suitable for High hazard categories, though this performance is heavily dependent on powder physical properties and methods of operation, cleaning and maintenance.

CONE VALVES

The cone valve system (Figure 9-19) operates on a similar principle to the split butterfly valve but the passive part is a cone mounted in the base of an IBC. The actuated active part is located in a discharge station, which when the two are docked, lifts up to allow powder to flow around the cone, down a chute and into the vessel below. The base of the cone and the top face of the actuator are kept clean through the use of seals and close tolerances. In addition, the cone can be lifted in cycles and vibrated to further aid flow.
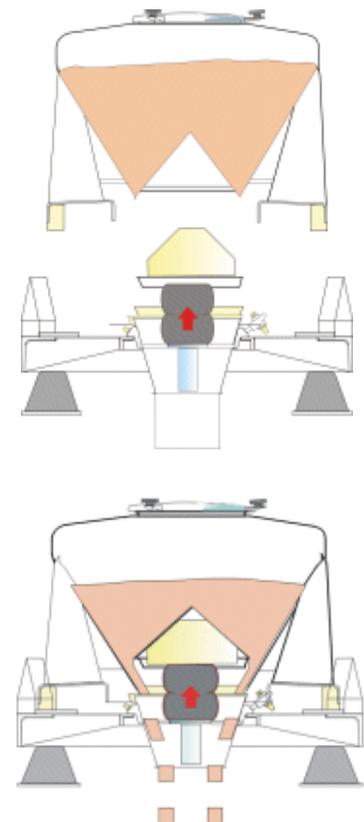

Figure 9-19: Matcon™ cone valve system

9.3

When not docked to the actuator, the cone is held in place by the weight of the material and can be clamped with an additional travel cap to provide greater security.

Cone valves are widely used with IBC systems where powder flow characteristics may be poor, where pre-set weights of powder may be required, or where rapid feeding is required.
High containment versions are available, for which the manufacturers have used closer tolerances and LEV as secondary containment.

The containment performance of the valve without secondary protection around the make and break position is 10-50 µg/m^3. This can be improved by the inclusion of air-wash or LEV, adjacent to the coupling, reducing exposure levels to 1-5 µg/m^3, and hence being suitable for High hazard category materials. Discharge can be performed remotely, with automation, therefore obviating a need for the operator to be near the coupling. Containment performance has been seen to decline rapidly if the seals are not maintained regularly.

DOUBLE VALVE AIR- OR LIQUID-WASH

If two valves are located in close proximity in a chute, then breaking the connection between them will release airborne material into the surrounding environment. Such contamination can be removed if a liquid-wash or air-
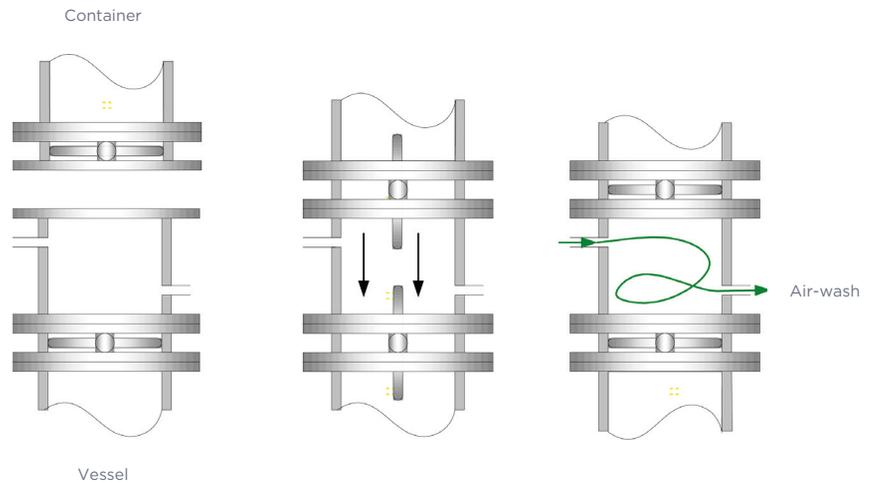

Container

Vessel

Figure 9-20: Air-wash

Air-wash

wash is introduced prior to the valves being uncoupled.

Using a liquid-wash is not a common technique because of the difficulty in situating pipework to form an effective drain, the length of time it takes to dry the pipework, and the possibility of having residual moisture in the system when starting the next transfer.

One technique is illustrated in Figure 9-20, whereby a product container with a standard butterfly valve attached is connected to discharge pipework containing a second butterfly valve, *e.g.*, a charge chute. Both valves are opened and product is discharged. Both valves are closed and air-wash is introduced and removed tangentially to the separating pipework, creating a swirling effect.

The system can equally be used

in reverse for filling a container. The air-wash waste air must be directed to a safe-change filtration/extraction system.

Due to surface flooding, a liquid-wash system can be suitable for very high hazard categories. With an air-wash, typical operational exposure levels of 5-10 µg/m^3 have been achieved.

This is heavily dependent on a powder's physical properties, such as its propensity for clumping.

9.3

RAPID TRANSFER PORTS

The rapid transfer port (RTP), also known as an alpha-beta door, is designed to allow the contained transfer of hazardous materials, typically into and out of gloveboxes. The basis of its operation is similar to the split valve in that the door is made up of two elements, the alpha and beta parts.

The alpha element consists of a door and frame mounted to an isolator wall. The beta element consists of a door and frame mounted to a container. The beta element is inserted into the alpha element and rotated. The rotation engages the alpha frame within the beta frame and the alpha door with the beta door. The alpha/beta door can then be opened as a single door from within the isolator via gloves to allow passage of materials (Figure 9-21(a) & (b)).

Containment is achieved by ensuring that external or contaminated faces of the alpha/beta doors are sealed together, the only weak point being the periphery of the seal. The beta flange can be connected to a number of transfer containers:

- Rigid containers often referred to as 'beta canisters'.

- Bag out ports (sometimes with continuous liner attached - see Section Continuous Liner, page 21).

- Bags for product (with inner chute to protect the door seals).

Powder should not be fed directly through the door, unless the door peripheral seal faces are protected. If the door is opened whilst the isolator is contaminated, the door seal will become contaminated and should be cleaned using a wet wipe or swab before closing. Standardisation within a facility (and even between facilities) can allow use of common transfer containers.

The RTP provides a highly secure transfer system and an isolator utilising RTPs for transfers can achieve very low exposure levels <0.01 µg/m^3. If levels below this are required, then dust evolution within the isolator must be minimised so dust cannot transfer across RTP seals.

Figure 9-21(a): Beta canister docked to isolator

Figure 9-21(b): Alpha door opened to allow passage of material

AUTOMATION

Automation of the process is an effective risk management measure. This can involve operators located in control rooms (*e.g.*, in a centralised operations area in the PGM refinery) with fewer persons actually stationed in process areas.

Automation of material transfers depends on mechanically, robotically or hydraulically transferring PGM materials thus reducing manual intervention and coincident exposure potential.

9.3

ENGINEERING CONTROL TECHNOLOGIES PERFORMANCE

Claims made for CPTs attained by engineering controls may be based on ideal conditions or brand-new systems, or with highly-trained operators, and can include results time-weighted over several hours or a full shift rather than being activity-based. Performance is of course very dependent on extant airborne dust levels, *i.e.,* apparently rigorous containment performance can be achieved by many technologies on small scale non-dusty processes.

Figure 9-22 indicates likely performance for the technologies covered in this chapter under typical industrial conditions, and also the best control level that is likely to be achieved if all containment enhancements are provided.

Operational exposure levels

| 1000μg/m³ | 100μg/m³ | 10μg/m³ | 1μg/m³ | 0.1μg/m³ |

MANAGED AIRFLOW SYSTEMS

- LEV
- DFB
- DFB WITH SCREEN
- DFB WITH GLOVED SCREEN
- VENTILATED CABINET

CONTAINED TRANSFER SYSTEMS

- DOUBLE BUTTERFLY WITH AIRWASH
- CONE VALVE WITH LEV
- SBV
- SBV WITH WASH

FLEXIBLE CONTAINMENT SYSTEMS

- RTP
- CONTINUOUS LINER
- BAG OVER BAG

BARRIER SYSTEMS

- ISOLATORS
- GLOVEBAGS

| 1000μg/m³ | 100μg/m³ | 10μg/m³ | 1μg/m³ | 0.1μg/m³ |

KEY

Poorest result expected — Acheivable result — Best result expected

LEV = Local exhaust ventilation   DFB = Downflow booth
SBV = Split butterfly valve   RTP = Rapid transfer port

Figure 9-22: Control technology performance chart

9.3

LOSS OF CONTAINMENT

After designation of the target exposure level and selection of the main engineering control solution(s) for an activity involving a hazardous substance, operations likely to result in a loss of containment also need to be considered. Experience in the PGM industry suggests that these circumstances could typically involve:

- Sampling input material; or sampling material in process.

- Charging materials to equipment from a container; or discharging materials into a container.

- Residual material removal, *e.g.*, filter heels.

- Dispensing materials.

- Equipment breakdown or unforeseen conditions.

- Routine maintenance operations.

- Cleaning equipment internals; or cleaning of re-useable containers.

- Waste disposal.

- Venting/emergency venting of equipment.

For each foreseeable circumstance further control measures including adjunctive engineering controls should be selected.

9.4

ADMINISTRATIVE CONTROLS

Administrative controls include a range of measures such as reducing the number of workers in an exposure area or operator residency time, or increasing distances between workers and PGM exposure sources. Administrative controls are usually used in conjunction with other measures, *e.g.*, personal protective equipment (PPE).

They rely on adherence to specific work instructions, and often require supplemental training.

Facility areas may be segregated to limit worker access and exposure, for instance, where respiratory sensitiser forms of Pt are present. Segregation of hazardous areas can include partitioned locations with access restriction (*e.g.*, card entry systems), and the use of atmospheric pressure differentials to confine hazardous materials and reduce contaminant transfer.

Another approach may be to schedule higher hazard tasks when areas are unmanned or have fewer personnel present (*e.g.*, calcining of chloroplatinates overnight). As inhalation exposure of employees to PGMs is determined by both airborne concentrations and exposure duration, limiting the residency time in a work area

can reduce overall exposure. Use of time limitation must be administered carefully, and is rarely used as a primary control measure (it can also require additional employees for activity rotation). Increasing distance between an operator and a PGM exposure source also normally reduces personal exposure.

The measures outlined in this section also assist in the minimization of skin contact with PGMs (although process design should again be the first consideration).

For example, skin exposure can be reduced by automation or by increasing the distance between operator and source.

Practices which help ensure that administrative controls are effective include: development of standard operating procedures (SOPs); clear labelling of all containers and workplace signage (especially of hazardous areas or equipment); training programmes; regular workplace inspections; and periodic procedural audits (with subsequent improvement action follow up).

9.5

PERSONAL PROTECTIVE EQUIPMENT

Use of Personal Protective Equipment (PPE) should be regarded as a means of providing additional exposure control where other measures alone are insufficient. PPE includes respiratory protection, coveralls, aprons, gloves, gauntlets, eye protection, hearing protection, safety footwear and safety head gear.

All of these are used in the PGM industry but this chapter focuses on selection and use of Respiratory Protective Equipment (RPE) and skin protection.

In terms of operational deployment of PPE, due attention should be paid to a variety of key factors including, but not limited to: chemical compatibility; assigned protection factors (APF); training in use; testing for good fit; tolerability and comfort considerations; decontamination and cleaning; storage; and the medical fitness of personnel to use a specified protective item.

PPE can be particularly appropriate in non-routine exposure circumstances such as during maintenance activities and where equipment integrity is disrupted, *e.g.,* stock-take.
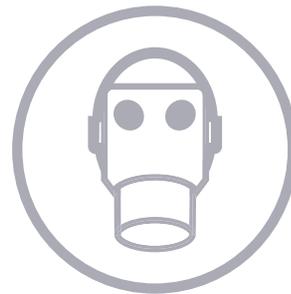
Respirators must
be worn in this area

9.5
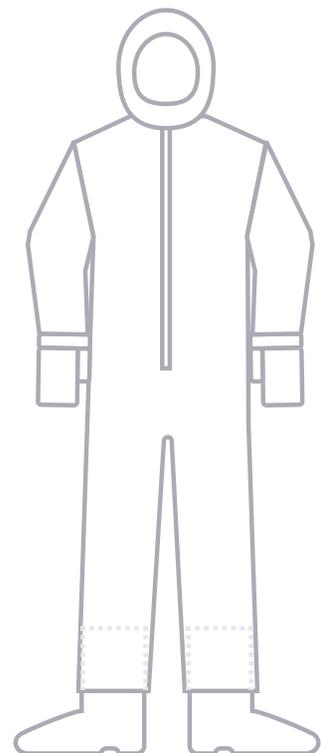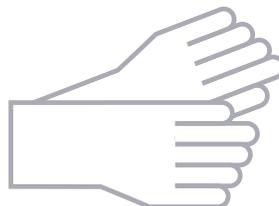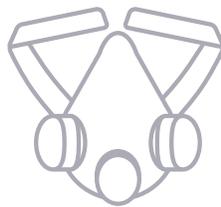
RESPIRATORY PROTECTIVE EQUIPMENT

In selecting RPE it is necessary to consider: (a) the nature of the hazardous material; (b) its workplace airborne concentrations; (c) its form; and (d) other chemicals which may also be present. Most exposure to PGM substances is in the form of a particulate (fume, dust, or liquid aerosol). Using the example of Pt refining operations, airborne particulates may be emitted when handling solids at the start of the process, *e.g.*, when smelting the raw materials, when processing chloroplatinate intermediates, and at end-stage handling of elemental Pt powder.

The degree of protection required should preferably be based on airborne monitoring (see Chapter 8), or other exposure assessments, such that the chosen RPE will reduce the actual exposure of the wearer to levels which are health-protective. Therefore, RPE must be selected to comply with local jurisdictional Assigned Protection Factors (APF) see below. It has also to be suitable for the wearer, task, and workplace environment. UK HSE (2013) provides useful guidance on the selection and use of adequate and suitable RPE.

Each RPE type/class has a numeric APF rating which indicates the protection level it is capable of providing. For example, RPE with an APF of 10 will reduce the wearer's exposure to an airborne contaminant by at least a factor of 10 if fitted and used properly, *i.e.*, the wearer will inhale one-tenth or less of substance concentration present in the workplace air. In practice, relatively few APF ratings are applied (Table 9-4 on page 32 summarises APF assigned by several regional organisations to various RPE types). After calculating the required minimum protection factor to reduce an exposure to below an occupational exposure limit (OEL) or comparable reference value, always select RPE with an APF which meets or exceeds the minimum protection factor. As an example:

- Measured airborne Pt metal concentration = 5 mg/m^3.

- Pt metal OEL (TWA-8h) = 1 mg/m^3.

- Required APF to reduce to OEL = 5/1 = 5.

- Select RPE with an APF greater than the required protection factor. In this case, RPE with an APF of 4 would be insufficient, and one with an APF of at least 10 should be chosen.

Various types of RPE used in the PGM industry include powered hoods, full-face powered respirators, full-face non-powered respirators, ori-nasal half masks,

and disposable masks.

Some companies specify that respirators with an APF of 40 are to be worn for all operations associated with: the intake of raw materials at materials reception; evaluation of raw materials in preparation; and processing associated with extraction and recovery of PGM, *e.g.*, the loading of chloroplatinate salts in the refinery.

For all RPE which relies on a tight seal with the wearer's face, the individuals must be face fit-tested to ensure the respirator seal is maintained when carrying out normal activities such as walking, bending and talking. The fit of the respirator should be checked on a regular basis as any changes can reduce the effectiveness of the seal, thereby reducing the protection provided. As the use of other protective devices such as safety glasses and hearing protection may impact on the seal of the respirator, the face fit-tests should be conducted with the wearer using any such items which could affect the seal integrity. Wearers must also be instructed in any checks to be performed each time they don the respirator, and be made aware of the impact of facial hair on respirator seal integrity.

Regardless of the type of RPE in use, it is good practice for it to be covered under a formal management procedure including the following:

9.5

- Responsibilities.

- Relationship to on-going air monitoring and exposure potential.

- RPE selection procedures.

- Training, for example on the need for wearing RPE, cleaning, storage, inspection, filter changes (if applicable), replacement etc.

- Face fit-testing; facial hair policy.

- Inspection of RPE.

- Cleaning and decontamination procedures.

- Maintenance, including criteria for replacement of filters and parts.

- Storage.

- Medical fitness to wear RPE.

GLOVES

Due to the skin permeation and sensitising properties of certain Pt salts, control measures will involve the selection and use of chemical protective gloves. Other PGM substances may also present contact hazards requiring gloves and supplementary skin protection strategies. These substances include corrosive or irritant PGM compounds, soluble palladium compounds (which are skin sensitisers), soluble rhodium compounds, and platinum anticancer agents (platins)—refer to Chapter 6 for a description of PGM substances presenting a potential hazard by skin contact. Chemical protective glove types are selected according to the nature of the substance, permeability characteristic of a particular glove type, and the nature of the exposure, *e.g.*, degree of contact (splash/immersion) and its duration.

In selecting protective gloves, any further hazards associated with the work activities should be considered, for instance, the risk of cuts and abrasion or other co-existent hazardous materials (*e.g.*, chlorine; or strong acids used in PGM operations). Thermally resistant gloves are required for any smelting and casting (in preparation and evaluation) and during reductive calcining or oven drying (during extraction/recovery).

Note: Advice on the selection of suitable and appropriate protective gloves can be obtained from a variety of references such as Forsberg et al. (2014).

9.5

PERSONAL PROTECTIVE EQUIPMENT

Figure 9-23: Examples of (a) disposable coveralls; (b) chemical suit; and (c) face shield

OTHER PPE

In terms of standard PPE ensembles, sites normally require hard hat, safety glasses, dedicated work shirt/trousers or coveralls, and protective footwear (safety shoes or boots) for working in the manufacturing process areas.

For eye/face protection, where more significant exposure from particulates or liquids could occur, chemical goggles and/or face shields are typically used.

Chemical-resistant disposable coveralls are useful in preventing contamination of skin surfaces or work garments, *e.g.*, if allergenic PGM substances are present. Where there is a potential for exposure to corrosive substances (*e.g.*, process acids) or other chemicals presenting a marked

contact hazard, upgraded protective ensembles are appropriate PPE, which dependent on specific circumstances can include face shields (or full-face respirator mask), impervious full chemical suits, and chemical-resistant boots.

WORK PLACE HYGIENE PRACTICES

Work hygiene practices such as removing protective clothing and washing hands/exposed skin surfaces whenever leaving the work area, and before eating or drinking, are essential in minimising worker exposures. Showering and changing into clean clothing at shift-end lowers body surface contamination, and also minimises the potential

for indirect exposures, *e.g.*, inadvertent contamination of transportation and home environments. Food and drink should be permitted only in designated clean areas, where PGMs or other workplace chemicals are excluded.

Changing facilities should have designated 'clean' and 'dirty' zones, with normal clothes being stored in the 'clean' side, and the workers donning workwear before entering the production areas. Workwear must be removed at the end of the work shift and when entering clean areas (*e.g.*, canteen/rest areas). Non-disposable workwear should be laundered either by the company (on the premises) or by a qualified external contractor. If disposable clothing is worn it should be changed every shift and disposed of in accordance with local waste regulations.

Good workplace housekeeping and cleaning regimes should be enforced (with operators receiving appropriate equipment, supplies, and instruction). As detailed in Chapter 8, surface wipe sampling for PGMs can underpin cleaning and decontamination practices. In-line or portable vacuum systems are normally preferred for cleaning, and to avoid the resuspension of dust in air, no cleaning using compressed air or dry brushing should be permitted. Use of high efficiency filters (*e.g.*, HEPA-type) on vacuum equipment is recommended.

9.5

<div align="right">

TABLE 9-4: INDICATIVE ASSIGNED PROTECTION
FACTORS (APF) FOR RPE

</div>

Type of RPE (respirator) [a]	US OSHA	US NIOSH	ANSI Z88.2	EN 529 (2005)	BS 4275 (1997)
APR - quarter mask	5	5	10	4-30	4-20
APR - filtering facepiece	10	10	10	4-30	4-20
APR - tight fitting half mask	10	10	10		
PAPR - tight fitting half mask	50	50	50	10-500	10-500
PAPR - tight fitting full facepiece	1000	50	1000 [c]	10-500	10-40
PAPR - helmet/hood	25/1000 [b]	25	1000 [c]	5-100	10-40
SAR - demand mode - half mask	10	10	10		
SAR - demand mode - full facepiece	50	50	100	1000	
SAR - continuous flow - half mask	50	50	50	100	
SAR - continuous flow – full facepiece	1000	50	1000	1000	
SAR - pressure demand - half mask	50	1000	50	30	
SAR - pressure demand - full facepiece	1000	2000	1000		
SCBA - demand mode - half mask	10	----	10		
SCBA - demand mode - full facepiece	50	50	100	∞	
SCBA - pressure demand - helmet / hood	50	----	----		
SCBA - pressure demand - full facepiece	10000	10000	10000 [d]	∞	
SCBA - pressure demand - helmet / hood	10000	----	----		

APR = Air-purifying respirator   PAPR = Powered air-purifying respirator
SAR = Supplied air respirator   SCBA = Self-contained breathing apparatus

Table 9-4: Indicative assigned protection factors (APF) for RPE

[a] Some commonly available RPE types/formats are shown, but the listing is not exhaustive.
[b] APF should always be re-confirmed using any official local guidance and/or manufacturers statement.
[c] The employer must have evidence provided by manufacturer that testing demonstrates performance at a level of protection of 1000 (or greater).
[d] For HEPA filter if used for particulate protection; if less than HEPA then APF=100.

9.6

WORKER TRAINING

Another important measure in reducing any risks associated with PGM workplaces is the provision of instruction, information and training. How workers must be informed about the hazards from materials and any related precautions is covered in Chapter 10. In relation to control measures, workers must be instructed in the purpose, correct selection and operation of controls, including the recognition and reporting of defects and impaired performance.

Such training must be provided when a person starts work in the workplace, *i.e.*, as part of initial training, and must be repeated at regular intervals thereafter (refresher training). Apart from formal training sessions and on-the-job instruction, so-called toolbox talks re-enforce initial training and also give individuals the opportunity to raise concerns or suggest improvements. Specific training may be required for persons changing roles, or in particular circumstances, *e.g.*, revisions in the exposure controls being used. Checking that the training has been effective will help to demonstrate competency of the individual.

All employees potentially exposed to hazards associated with PGMs need to be informed of:

- The nature of any health hazards, *e.g.*, via the inhalation or skin contact routes.

- The potential concentrations to which they are exposed during normal operations (and if controls are bypassed or if emergencies occur).

- Control measures to prevent adverse health effects, and how they operate.

- Why and how to report defects in plant, equipment or exposure controls that could lead to excessive exposure.

- Situations which may require adjustments in the normal control strategy, such as exceptional activities requiring ancillary use of PPE.

- Practical instruction on when and how to use PPE, its proper care and maintenance, and the limitations of the PPE provided.

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