Chapter 1 - Dust: Definitions and Concepts

Airborne contaminants occur in the gaseous form (gases and vapours) or as aerosols. In scientific terminology, an aerosol is defined as a system of particles suspended in a gaseous medium, usually air in the context of occupational hygiene, is usually air. Aerosols may exist in the form of airborne dusts, sprays, mists, smokes and fumes. In the occupational setting, all these forms may be important because they relate to a wide range of occupational diseases. Airborne dusts are of particular concern because they are well known to be associated with classical widespread occupational lung diseases such as the pneumoconioses, as well as with systemic intoxications such as lead poisoning, especially at higher levels of exposure. But, in the modern era, there is also increasing interest in other dust-related diseases, such as cancer, asthma, allergic alveolitis, and irritation, as well as a whole range of non-respiratory illnesses, which may occur at much lower exposure levels. This document aims to help reduce the risk of these diseases by aiding better control of dust in the work environment.

The first and fundamental step in the control of hazards is their recognition. The systematic approach to recognition is described in Chapter 4. But recognition requires a clear understanding of the nature, origin, mechanisms of generation and release and sources of the particles, as well as knowledge on the conditions of exposure and possible associated ill effects. This is essential to establish priorities for action and to select appropriate control strategies. Furthermore, permanent effective control of specific hazards like dust needs the right approach to management in the workplace. Chapters 1 and 2, therefore, deal with the properties of dust and how it causes disease. Chapter 3 discusses the relationship of management practice and dust control.

1.1 Dust as an occupational hazard

According to the International Standardization Organization (ISO 4225 - ISO, 1994), *"Dust: small solid particles, conventionally taken as those particles below 75 µm in diameter, which settle out under their own weight but which may remain suspended for some time".* According to the "Glossary of Atmospheric Chemistry Terms" (IUPAC, 1990), *"Dust: Small, dry, solid particles projected into the air by natural forces, such as wind, volcanic eruption, and by mechanical or man-made processes such as crushing, grinding, milling, drilling, demolition, shovelling, conveying, screening, bagging, and sweeping. Dust particles are usually in the size range from about 1 to 100 µm in diameter, and they settle slowly under the influence of gravity."*

However, in referring to particle size of airborne dust, the term "particle diameter" alone is an over simplification, since the geometric size of a particle does not fully explain how it behaves in its airborne state. Therefore, the most appropriate measure of particle size, for most occupational hygiene situations, is **particle aerodynamic diameter,** defined as **"the diameter of a hypothetical sphere of density 1 g/cm^3 having the same terminal settling velocity in calm air as the particle in question, regardless of its geometric size, shape and true density."** The aerodynamic diameter expressed in this way is appropriate because it relates closely to the ability of the particle to penetrate and deposit at different sites of the respiratory tract, as well as to particle transport in aerosol sampling and filtration devices. There are other definitions of particle size, relating, for example, to the behaviour of particles as they move by diffusion or under the influence of electrical forces. But these are generally of secondary importance as far as airborne dust in the workplace is concerned.

In aerosol science, it is generally accepted that particles with aerodynamic diameter >50 µ m do not usually remain airborne very long: they have a terminal velocity >7cm/sec. However, depending on the conditions, particles even >100 µ m may become (but hardly remain) airborne. Furthermore, dust particles are frequently found with dimensions considerably <1 µ m and, for these, settling due to gravity is negligible for all practical purposes. The terminal velocity of a 1-µm particle is about 0.03 mm/sec, so movement with the air is more important than sedimentation through it. Therefore, summarizing in the present context, it is considered that *dusts are solid particles, ranging in size from below 1 µm up to at least 100 µm, which may be or become airborne, depending on their origin, physical characteristics and ambient conditions.*

Examples of the types of dust found in the work environment include:

- **mineral dusts,** such as those containing free crystalline silica (e.g., as quartz), coal and cement dusts;
- **metallic dusts,** such as lead, cadmium, nickel, and beryllium dusts;
- **other chemical dusts,** e.g., many bulk chemicals and pesticides:
- **organic and vegetable dusts,** such as flour, wood, cotton and tea dusts, pollens;
- **biohazards,** such as viable particles, moulds and spores

Dusts are generated not only by work processes, but may also occur naturally, e.g., pollens, volcanic ashes, and sandstorms.

Fibrous dusts, such as asbestos and other such materials, have been shown to present special health problems primarily related to the shape of the particles. In relation to health, particles with diameter < 3 µ m, length > 5 µ m, and aspect ratio (length to width) greater than or equal to 3 to 1, are classified as "fibres" (WHO, 1997). Examples of fibres include asbestos (comprising two groups of minerals: the serpentines, e.g., chrysotile, and the amphiboles, e.g., crocidolite - "blue asbestos"). Other examples include synthetic fibrous materials such as rockwool (or stonewool) and glass wool, as well as ceramic, aramid, nylon, and carbon and silicon carbide fibres.

Although in occupational hygiene, the term "airborne dust" is used, in the related field of environmental hygiene, concerned with pollution of the general atmospheric environment, the term "suspended particulate matter" is often preferred.

The aerodynamic behaviour of airborne particles is very important in all areas of measurement and control of dust exposure. Detailed information, including the relevant physics, can be found in the specialized aerosol science literature (Green and Lane, 1964; Fuchs, 1964; Hinds, 1982; Vincent, 1989 and 1995; Willeke and Baron, 1993).

1.2 Penetration and deposition of particles in the human respiratory tract

For better understanding of this section, a schematic representation of the respiratory system is presented in Figure 1-1, indicating the different regions, namely, nasopharyngeal (or extrathoracic region), tracheobronchial region and alveolar region.

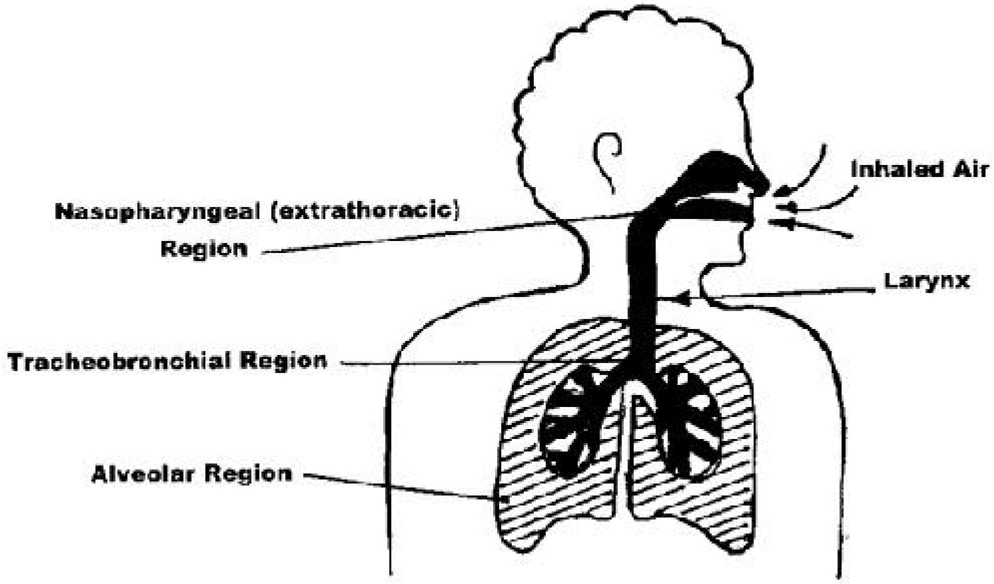

Figure 1-1 - Schematic representation of the human respiratory tract

Particles small enough to stay airborne may be **inhaled** through the nose (nasal route) or the mouth (oral route). The probability of inhalation depends on particle aerodynamic diameter, air movement round the body, and breathing rate. The inhaled particles may then either be deposited or exhaled again, depending on a whole range of physiological and particle-related factors. The five **deposition mechanisms** are sedimentation, inertial impaction, diffusion (significant only for very small particles < 0.5 μ m), interception, and electrostatic deposition. Sedimentation and impaction are the most important mechanisms in relation to inhaled airborne dust, and these processes are governed by particle aerodynamic diameter. There are big differences between individuals in the amount deposited in different regions (Lippmann, 1977).

The largest inhaled particles, with aerodynamic diameter greater than about 30 μ m, are deposited in the airways of the head, that is the air passages between the point of entry at the lips or nares and the larynx. During nasal breathing, particles are deposited in the nose by filtration by the nasal hairs and impaction where the airflow changes direction. Retention after deposition is helped by mucus, which lines the nose. In most cases, the nasal route is a more efficient particle filter than the oral, especially at low and moderate flow rates. Thus, people who normally breathe part or all of the time through the mouth may be expected to have more particles reaching the lung and depositing there than those who breathe entirely through the nose. During exertion, the flow resistance of the nasal passages causes a shift to mouth breathing in almost all people. Other factors influencing the deposition and retention of particles include cigarette smoking and lung disease.

Of the particles which fail to deposit in the head, the larger ones will deposit in the tracheobronchial airway region and may later be eliminated by mucociliary clearance (see below) or - if soluble - may enter the body by dissolution. The smaller particles may penetrate to the alveolar region (Figure 1-1), the region where inhaled gases can be absorbed by the blood. In aerodynamic diameter terms, only about 1% of 10-µm particles gets as far as the alveolar region, so 10 µ m is usually considered the practical upper size limit for penetration to this region. Maximum deposition in the alveolar region occurs for particles of approximately 2-µ m aerodynamic diameter. Most particles larger than this have deposited further up the lung. For smaller particles, most deposition mechanisms become less efficient, so deposition is less for particles smaller than 2 µm until it is only about 10-15% at about 0.5 µm. Most of these particles are exhaled again without being deposited. For still smaller particles, diffusion becomes an effective mechanism and deposition probability is higher. Deposition is therefore a minimum at about 0.5 µm.

Figure 1-2 illustrates the size of the difference between nasal and oral breathing, and the role of physical activity on the amount of dust inhaled and deposited in different regions of the respiratory airways. It presents the mass of particles that would be inhaled and deposited in workers exposed continuously, during 8 hours, to an aerosol with a concentration of 1 mg/m^3, a mass median aerodynamic diameter equal to 5.5 µm and a geometric standard deviation equal to 2.3. The calculations were performed using a software developed by INRS (Fabriès, 1993), based on the model developed by a German team (Heyder et al., 1986; Rudolf et al., 1988). Workers' respiratory parameters (tidal volume, Vt, and frequency, f) were associated with their physical activity as follows:

$$Vt = 1450\ cm^3\ f = 15\ min^{-1}\ \text{(moderate physical activity)}$$

$$Vt = 2150\ cm^3\ f = 20\ min^{-1}\ \text{(high physical activity)}$$

The results show very clearly that oral breathing increases dust deposit in the alveolar (gas-exchange) region when compared to nasal breathing, indicating the protective function of the nasal airways. A higher activity can dramatically increase dust deposition in all parts of the respiratory airways.

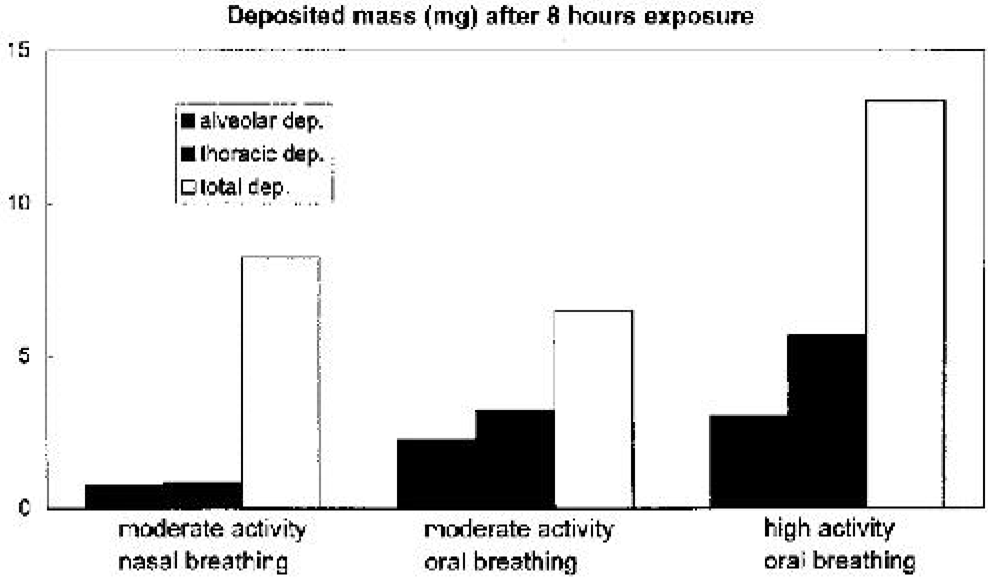

Figure 1-2 - Difference between nasal and oral breathing and the role of physical activity on the amount of dust inhaled and deposited in different regions of the respiratory airways (Fabriès, 1993) (by courtesy of J. F. Fabriès, INRS)

Fibres behave differently from other particles in their penetration into the lungs. It is striking that fine fibres even as long as 100 μ m have been found in the pulmonary spaces of the respiratory system. This is explained by the fact that the aerodynamic diameter of a fibre, which governs its ability to penetrate into the lung, is primarily a function of its diameter and not its length (Cox, 1970). However, for longer fibres, deposition by interception becomes increasingly important.

1.3 Clearance of particles from the respiratory tract

After deposition, the subsequent fate of insoluble particles depends on a number of factors. (*Soluble* particles depositing anywhere may dissolve, releasing potentially harmful material to the body.)

1.3.1 Mucociliary clearance

The trachea and bronchi, down to the terminal bronchioles, are lined with cells with hair-like cilia (the ciliated epithelium) covered by a mucous layer. The cilia are in continuous and synchronized motion, which causes the mucous layer to have a continuous upward movement, reaching a speed in the trachea of 5-10 mm per minute. Insoluble particles deposited on the ciliated epithelium are moved towards the epiglottis, and then swallowed or spat out within a relatively short time. It is interesting to note that the rate of clearance by the mucociliary mechanism may be significantly impaired by exposure to cigarette smoke.

1.3.2 Bronchiole movement

Intermittent peristaltic movements of the bronchioles, and coughing and sneezing, can propel particles in the mucous lining towards the larynx and beyond.

1.3.3 Phagocytosis

The epithelium of the alveolar region is not ciliated; however, insoluble particles deposited in this area are engulfed by macrophage cells (phagocytes), which can then (1) travel to the ciliated epithelium and then be transported upwards and out of the respiratory system; or (2) remain in the pulmonary space; or (3) enter the lymphatic system. Certain particles, such as silica-containing dusts, are cytotoxic; i.e. they kill the macrophage cells.

Defence or clearance mechanisms for the retention of inhaled insoluble dusts have been broadly classified, based on results of experiments with rats, as (Vincent, 1995):

- a *fast-clearing* compartment, linked to the ciliary clearance process in the tracheobronchial region (clearance time of the order of half a day);
- a *medium-clearing* compartment, linked to the "first-phase" macrophage clearance action in the alveolar region (clearance time of the order of 10 days);
- a *slow-clearing* compartment, linked to the "second-phase" macrophage clearance action in the alveolar region (clearance time of the order of 100 -200 days), and,
- a "sequestration" compartment in which particles are stored permanently (e.g.,"embedded" in fixed tissue).

It has also been shown that the accumulation of large enough burdens of insoluble particles in the lungs leads to impaired clearance. This so-called "dust overload" condition may occur as a result of prolonged occupational exposures, even at relatively low levels. Some researchers (e.g., Morrow, 1992) have suggested that such overload may be a precursor to the formation of tumours, even for substances which have previously been regarded as relatively innocuous. With this in mind, some standards-setting bodies (e.g., ACGIH) have revised their documentation for "particulates not otherwise classified" (previously referred to as "nuisance dusts") to take this risk into account.

1.4 Risk to health

Wherever the particles are deposited, either in the head or in the lung, they have the potential to cause harm either locally or subsequently elsewhere in the body. Particles that remain for a long time have increased potential to cause disease. This is why inhaled particles are important in relation to environmental evaluation and control.

1.5 Particle size fractions: conventions for dust sampling

As described above, the fractions of the airborne particles inhaled and deposited in the various regions depend on many factors. However, for sampling purposes conventions have been agreed in terms of aerodynamic diameter, which say what should be collected, depending on which region is of interest for the substance and hazard concerned. The American Conference of Governmental Industrial Hygienists (ACGIH), the International Organization for Standardization (ISO), and the European Standards Organization (CEN) have reached agreement on definitions of the ***inhalable, thoracic*** and ***respirable*** fractions (ACGIH, 1999; ISO, 1995; CEN, 1993; ICRP, 1994). Depending on the health effects, one or another region will be of interest. Further details on health effects are presented in Section 2.2 and on use of the size fractions in Section 4.3.

Inhalable particulate fraction is that fraction of a dust cloud that can be breathed into the nose or mouth. Examples of dusts for which any inhalable particle is of concern include certain hardwood dusts (which may cause nasal cancer), and dusts from grinding lead-containing alloys (which can be absorbed and cause systemic poisoning).

Thoracic particulate fraction is that fraction that can penetrate the head airways and enter the airways of the lung. Examples of dusts for which this fraction is of particular concern include cotton and other dusts causing airway disease.

Respirable particulate fraction is that fraction of inhaled airborne particles that can penetrate beyond the terminal bronchioles into the gas-exchange region of the lungs. Examples of dusts for which the respirable fraction offers greatest hazard include quartz and other dusts containing free crystalline silica; cobalt-containing and other hard metal dust produced by grinding masonry drill bits; and many others.

Finally in this section, it should be noted that other dust characteristics besides composition and particle aerodynamic diameter can be important in dust control, for example, adhesion, light scattering, absorption capacity, solubility and hygroscopicity. For better understanding of these issues, the reader may consult Vincent, 1995 (Chapters 1, 5 and 6); Parkes, 1994; or Hinds, 1982.

1.6 Mechanisms of dust generation and release

This section aims to present the main mechanisms of dust generation/release, as well as drawing attention to the complexity of the behaviour of powders, and the uncertainties that still exist.

In order to ensure efficient and safe process design (the preferable approach), or to effectively modify a certain process or operation to decrease dust exposure, many factors must be considered; inputs from aerosol sciences and engineering (Vincent, 1995; Faye and Otten, 1984) are essential. Success can often only be achieved through teamwork involving occupational hygienists, production personnel, engineers, aerosol technology specialists and other professionals.

1.6.1 Mechanical breakdown

Dusts usually originate from larger masses of the same material, through a mechanical breakdown process such as grinding, cutting, drilling, crushing, explosion, or strong friction between certain materials (e.g., rocks). Dust thus generated is often called "primary airborne dust." The composition of mineral dusts is not necessarily the same as that of the parent rock since different minerals may break down or be removed at different rates.

Vegetable dusts can originate in the same manner from a work process, for example: wood dusts produced in sawing and sanding, cotton dust in ginning, carding and spinning operations, and wool dust in shearing sheep.

The rate of dust generation increases with the energy associated with the process in question. For example, a grinding wheel will produce more dust when it operates at higher speeds. Although friability, that is ability to be broken down, is another important characteristic, more friable does not necessarily mean more hazardous; *for* example, very hard quartz, once submitted to strong enough forces that break it down to microscopic sizes, is a much more serious health hazard than the more friable marble.

1.6.2 Dust dispersal

Instead of resulting directly from the breakage of a bulk material, airborne dust may arise from dispersal of materials in powder or granular form. Dust is released whenever processes involve free falling or handling of such materials, e.g., transferring, dumping, filling (bagging) or emptying bags or other containers, dropping material from a hopper to a weighing station, weighing, mixing, conveying and so on. Moreover, air currents over powdered materials may be important.

These mechanisms not only release dust, they also generate it, because smaller particles may be formed from larger ones by impaction and friction. The particle size distribution of a dust cloud may be different from that of the powder it originated from; this should be investigated for each situation, as it depends on the type of material and on the forces it underwent during its handling or processing.

In order to decrease dust emissions from such operations, it is important to understand the mechanisms of its generation and release. Studies on dust generation by free falling powders have demonstrated that the manner in which the powder is handled may be as important as the dust generating capacity of the bulk material, in terms of the resulting exposure (e.g., Heitbrink et al., 1992). Falling height has an important influence on dust generation and release for more than one reason. The higher the impact, the more dissemination of dust there is. Moreover, the greater the falling height, the greater flow of entrained air, which favours dust dissemination. This shows the importance of process design and adequate work practices.

A British Occupational Hygiene Society (BOHS) Technical Committee studied the "dust yield" defined as "the mass of aerosol produced per mass of powder dropped" (BOHS, 1985). It was shown that initially increasing the mass increases the dust yield, but a point is reached when the dust produced per unit mass levels off and then decreases. Other studies have confirmed this (Cheng, 1973; Breum, 1999), and one concluded that "dust generation can be minimized by having powders fall as large, discrete slugs instead of a stream of small clumps; slugs should be as large as possible to minimize the exposure of the powder to the airflow" (Heitbrink et al., 1992). The explanation is that with higher material flow, there is more material at the centre of the falling mass, and this central part is less exposed to surrounding air, and hence less likely to disperse.

It should be noted that moisture content increases the interparticle binding forces, which leads to less dust generation; however, how much less depends on the material, its surface properties and hygroscopicity. With this in mind, moisture - in the form of water - can be introduced in the process as a means of control; however, there are limitations in view of process requirements, as well as some associated problems such as clogging, freezing, or evaporation. Furthermore, it should be noted that wetted materials may eventually become dry again and be subsequently redispersed.

There have been many interesting studies on material flow which demonstrate that the influence of the various factors is not so obvious. For example, it is sometimes erroneously assumed that a powdered material with a larger proportion of coarse particles offers less dust hazard; however, a higher proportion of coarse particles in the bulk material may actually increase dustiness due to a "decrease in the cohesion of the material as the proportion of coarse particles increases" (Upton et al., 1990), and also due to the agitation of the fine particles as there are more collisions with large particles. The higher the impact between particles, the more dissemination of dust there is.

Moreover, the type of material influences dust generation. Differences between materials were demonstrated, for example, by a study of falling bulk powders (Plinke et al., 1991), which investigated how the rate of dust generation depends on the relation between two opposing forces: one that separates and the other that binds materials. The determinant factors studied were amount (mass), particle size distribution, falling height, material flow and moisture content. External factors such as air movement may also play a role particularly concerning further dispersion of dust released from the process. The separation and binding forces of falling particles were studied for *sand* and *limestone* (which are inorganic crystalline materials, nonporous and non-reactive with water), *cement* (which is inorganic but internally porous and reactive with water), and *flour* (which is organic, porous and reactive with water).

In the practical application of such knowledge, however, the limitations imposed by, and the need not to interfere with, the process requirements must be kept in mind. For example, if one tries to decreases dustiness by increasing cohesion among particles, the powder handling equipment might get clogged; in certain situations, exposure could even be increased because workers would have to shake the equipment. The implications of process changes, in terms of maintenance requirements, must also be considered. The problems of wetting have already been noted.

Finally, all the work carried out so far to understand the nature of dust dispersion during materials handling has been very empirical and so has not provided much basic insight into the physical processes which are involved. Therefore, this is an area for future research.

Meanwhile, the results of the work carried out so far should be interpreted with caution.

1.6.3 Dustiness indices

The concept of a "dustiness index" was proposed to enable comparison among dust-producing capacities of different bulk materials. Dustiness estimation methods were developed with a view to establishing relative Dustiness Indices (BOHS, 1985 and 1988; Lyons and Mark, 1994; Upton et al., 1990; Vincent, 1995; Breum et al., 1996). The objective is to provide criteria for the selection of products that will lead to less dust emissions.

The dustiness tests utilize gravitational, mechanical and gas dispersion techniques (Vincent, 1995). These methods trigger the formation of a dust cloud, which is then assessed by sampling and analysis, or, by direct reading instruments. The **gravity dispersion** method creates a dust cloud by dropping known masses of the bulk material under study, in a well-defined enclosed space, from a constant falling height. This relates to operations such as transferring bulk material from one container to another, emptying a bag, etc. In the **mechanical dispersion** method, the bulk material is dispersed by agitation with a rotating drum; this relates to operations such as mixing batches of dry materials. The **gas dispersion** method involves passing an air jet over the bulk material and relates to situations when air currents sweep piles of bulk materials.

Each method provides a different index, in arbitrary units, which enables materials to be placed in rank order of dustiness.

It is important to note, however, that different dustiness methods will produce different rank orderings. Table 1-I presents examples of relative ‘dustiness’ for a range of common industrial materials as obtained by two different methods. The numbers in this table are the ratio of the dustiness for the material in question to the average value for all the materials tested by that method, and (in brackets) the rank orders of dustiness as measured by the method.

Although dustiness indices may be useful in comparing different materials and perhaps predicting the resulting "dust yield", field evaluations have indicated that dustiness test results do not consistently correlate with actual workers’ exposure. One study (Heitbrink et al., 1992) evaluated the correlation between dustiness test results and dust exposure at bag dumping and bag filling operations. In one case, dust exposure could be well predicted; however, this was not consistent in all experiments, which led to the conclusion that each situation has to be studied individually as there are many other factors than the dustiness itself which may influence the resulting exposure.

Table 1- I - Examples of relative 'dustiness' for a range of common industrial materials as obtained using the gravity dispersion and rotating drum methods (modified from Vincent, 1995)

Material	*Method*	
	Gravity drop	*Rotating drum*
Sulfur	0.20 (1)	0.20 (2)
Oil absorber	0.95 (2)	0.05 (1)
Chalk	1.39 (3)	0.22 (3)
Silica	1.41 (4)	2.81 (4)
Charcoal	2.92 (5)	4.5 (5)

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Chapter 2 - Recognizing the Problem: Exposure and Disease

2.1 Dust exposures

Many work processes involve operations which, if not properly planned, controlled and managed, may cause appreciable dust exposure and pose serious health risk. The following points should be kept in mind.

The appearance of a dust cloud may be misleading.

The interaction of electromagnetic radiation (e.g. visible light) with a system of airborne particles is very complex. So the visual appearance of a dust cloud will be strongly dependent on
the wavelength of the light and the angle of viewing with respect to the light source, as well as particle size, shape, refractive index and, of course, dust concentration. With this in mind, and depending on the conditions, it is usually fair to assume that a dust cloud that is visible to the naked eye may represent a hazard. However, it should not be assumed that the lack of a visible cloud represents "safe" conditions. A respirable particle is too small to be seen with the unaided eye

A dust release can be localized and only affect the immediate worker, or it may spread throughout the workplace and affect everybody else.

This happens if the release is large enough and uncontrolled, particularly if the dust particles are very fine, thus able to stay airborne for a long time. Airborne dust poses an inhalation hazard; however, after it has settled, it can create a problem through contact with the skin and ingestion.

A dust source may not be obvious, or control may be inadequate.

For instance, even if dust is controlled by means of a local exhaust ventilation system, there may be leaks that allow fine, possibly invisible, respirable dust back into the workroom. Or side drafts may disturb the capture efficiency of the system. Therefore, even if there is the impression that the situation is under control because there are ventilation systems, these should still be periodically checked to make sure they are actually adequate and efficient (Chapter 7).

This section presents some examples, which are by no means exhaustive.

2.1.1 Dusty occupations

Dust exposure is linked to occupations and workplaces, both in the industrial and agricultural settings, for example:

- mining, quarrying and tunnelling;
- stone-working and construction;
- foundries and other types of metallurgical activity;
- shipbuilding (abrasive blasting);
- manufacture of glass, ceramics (pottery, porcelain and enamel) and stone objects;
- etching glass;
- manufacture of cleansing agents and abrasives;
- chemical and pharmaceutical industry (handling of powdered chemicals);
- rubber manufacturing industry;
- manufacture of lead storage batteries (bulk lead oxide);
- removing paint and rust from buildings, bridges, tanks and other surfaces;
- formulation of pesticides;
- agricultural work (ploughing, harvesting, grain storage);
- food industry (bakeries, animal products);
- forestry and woodworking.

2.1.2 Dusty processes

As already seen, dust releases in the workplace may result from any form of mechanical breakdown, such as occurs in mining and quarrying, machining and other process operations, or from the movement of dusty materials.

Specific dust-producing operations include sandblasting, rock drilling, jack hammering, stone cutting, sawing, chipping, grinding, polishing, breaking of sand moulds, "shake-out", cleaning foundry castings, use of abrasives, plus all the powder and granule handling operations such as weighing and mixing (common to most batch processes) and transferring dusty raw materials and products (e.g., bag filling, conveyor belts, transfer from one container to the other).

One type of emission source, often overlooked, is the **transportation of bags, or any containers with dusty materials**; this may constitute an important and moving dust source, particularly if bags have holes, or containers are not properly closed. Disposal of empty bags can also be an important source, especially if the bags are manually compressed to save space. These will probably not be listed as specific operations in the plant, being consequently disregarded as potential emission sources which require control. Transportation paths should be followed and carefully observed. Other areas where appreciable hazards may be overlooked are **storage rooms**.

It should be emphasized that **any abrasive blasting**, even if the abrasive material does not contain silica, may create serious health hazard if it is used to remove hazardous materials, for example, remains of sand moulds from metal castings or lead paints from bridges. The same reasoning applies to **grinding wheels**; even if made of non-silica materials, their use may involve serious exposure to, for example, toxic metals. If the grinding wheels or abrasive contain a hazardous substance like silica, there is an extra risk, which is likely to be high.

Machining operations, using tools such as lathes, grinders, turning and milling machines, can produce large amounts of dusts, as well as cutting oil mists. The dimensional cutting of metals and other materials is usually a high energy process that produces dust in a wide range of particle sizes which are then carried in the flow of air. The hazard often comes from the part being worked, for example, carbide steel alloys contain metals which include nickel, cobalt, chromium, vanadium and tungsten. Many hard metals are used in the manufacture of special tools and parts, and it may happen that workers machining or sharpening them have no idea of the original composition, often believing that the dust produced is quite harmless.

However, health hazards cannot be linked solely to occupations, but must be linked to the working environment. It often happens that dust-producing occupations are carried out alongside others which offer practically no risk, particularly in small industries. For example, it may happen that a harmless operation, such as preparing cardboard boxes for shipping, is carried out in the same environment as sandblasting. It may even happen that one work environment is polluted by another neighbouring factory.

2.1.3 Particular hazards

Whenever there is breakdown of sand, rocks or ores containing free crystalline silica, there may be very serious hazard, which increases with the proportion of “respirable” particles and the free silica content of the dust. Free silica can occur in three crystalline forms, i.e, quartz, tridymite and cristobalite. By far the commonest of these in minerals is quartz, which occurs in rocks such as granite, sandstone, flint, slate and many others, as well as in certain coal and metallic ores. The dangers of sandblasting have already been mentioned

Large amounts of silica-containing dust are produced when explosives are used on rock faces, when granite is drilled, or when metals casts made in sand moulds are cleaned. In construction sites, cutting of concrete and stone, even in open air, generates huge dust clouds, which contain varying degrees of quartz (Thorpe et al., 1999).

Other components of rocks and ores can also be very harmful, for example, lead, beryllium, and other toxic or radioactive metals, although some ores, such as galena (lead sulfide), are so insoluble in body fluids that the risk may be very low.

Exposure to asbestos occurs in asbestos mines and quarries, manufacture and cutting of asbestos cement products, demolition work where asbestos was used as insulating material (no longer permitted in most jurisdictions), shipyards, manufacture and replacement of brake linings, and asbestos removal and disposal. Asbestos was previously widely used in construction products, so exposure is always a possibility during building maintenance.

In electroplating processes, very toxic compounds (such as cadmium oxide) are weighed before being added to a plating bath. In the rubber industry, over 500 chemicals are utilized, many of which are purchased as powders. One study (Swuste, 1996) found, in larger compounding departments of the rubber manufacturing industry, that about 35% of the accelerators, anti-degradants and retarders, in the categories of carcinogens and systemic poisons (acute or chronic), were powders.

Woodworking can produce large amounts of dust, particularly at sawing and sanding operations; these need to be controlled both for health reasons (nasal cancer, allergies, irritation) and for safety reasons (as large amounts of fine wood dust may create a risk of fire or explosion - see Section 2.4.1).

Organic dust is often associated with endotoxins, mycotoxins and microorganisms (Zock et al., 1995), thus posing multiple hazards; such problems are often found in agricultural and food industries. Grain and similar products produce large amounts of dust when being transferred on conveyors, being added to, or emptied from hoppers or ship holds.

2.1.4 Examples of Exposure

Although there is no global database on dust exposure, there are probably hundreds of millions of people worldwide exposed to hazardous dusts in the course of their work. Agriculture, basic food processing and extractive industries are very widespread before industrialization, and can all lead to dust exposure. As an economy develops, the usual pattern has been for development to lead to greater production and more dust exposure before it leads to the introduction of better controls. For example, in the Vermont granite-cutting industry, hand tools were succeeded early this century by pneumatic tools, which produced much more dust. There was a rapid rise in the silicosis rate, followed in the late 1930s by the introduction of local exhaust ventilation, which then led to a decline and virtual elimination of silicosis (Burgess et al., 1989). In the British coal industry, improved dust control methods from the 1940s to the 1970s struggled to contain the extra dust produced by rapid mechanization, but nevertheless the respirable dust concentrations overall were reduced by a factor of three (Jones, 1979). Amont later-industrializing countries, Chung (1998) has described the rapid growth in occupational health risks and the slightly later growth in occupational health provision in Korea. Zou et al. (1997) have documented the large pneumoconiosis problem in China, and the effect of dust reduction measures.

Without careful control, work which generates dust easily leads to exposures of more than ten and sometimes hundreds of mg/m^3. To take a few from many examples, such exposures have been documented in mining or quarrying in Brazil (Ribeiro Franco, 1978), Britain (Maguire et al., 1975), China (Zou et al., 1997), India (Durvasula, 1990) and the United States (Ayer et al., 1973); in grain silo cleaning and poultry catching in Britain (Simpson et al., 1999); timber milling in Canada (Teschke et al., 1999); foundation drilling in Hong Kong (Fang, 1996); machine harvesting of nuts in the US (Nieuwenhuijsen et al., 1999); in lead battery manufacture in India (Durvasula, 1990); and in wool textile manufacture in Britain (Cowie et al., 1992). Uncontrolled removal of asbestos insulation is said to produce exposures of hundreds or thousands of fibres/ml, and asbestos spinning without modern controls is known to have given exposures of tens of fibres/ml (Burdett, 1998). The uninformed worker will often continue to work in such conditions, although if the dust is hazardous, disabling or fatal diseases can rapidly develop, as described in the next section. However, implementation of control measures can reduce such exposures to satisfactory levels (e.g. Swuste et al., 1993; Swuste, 1996; Fang, 1996). Some of these measures, which are often simple, are described later in this report.

2.2.Problems caused by dusts

2.2.1 Routes of exposure

Most attention is given to dust exposure by inhalation, and the problems by this route are dealt with in Sections 2.2.2 to 2.2.11 However, other routes are often important.

Skin absorption (or percutaneous absorption) can occur, for example, if water-soluble materials dissolve in sweat and pass through the skin into the bloodstream, causing systemic intoxication. Although this report does not deal with liquid aerosols, it must be noted that spraying will often lead to skin exposure and absorption, even when protective clothing is worn. This can lead to substantial risk when pesticides are sprayed (e.g., de Vreede et al., 1998; Garrod et al., 1998).

Ingestion is likely when poor hygiene allows eating, drinking or smoking in contaminated or dirty workplaces. Particles do not need to be airborne. For example, many cases of lead poisoning have occurred in poorly kept small potteries, in which ingestion of lead salts has been an important route. Obviously, entry by this route can be significantly reduced by good housekeeping, personal hygiene and adequate work practices. Many inhaled particles are swallowed and ingested, but for control and measurement purposes these are usually considered with the inhalation route.

Effects on the Skin. In addition to the risk of absorption through the skin, many dusts may affect the skin directly, causing various types of dermatoses, which are a widespread and often serious problem, or even skin cancer. Cement is an important cause of dermatitis. For such substances, dust of any size has health significance, even if it never becomes airborne. Some allergens (see Section 2.2.9) act on the skin, including many wood dusts, such as dogwood, poison ivy, mahogany, pine, birch, poison oak, and beech. This is important for the woodworking industry as well as for rural workers, e.g., in agricultural and forestry.

2.2.2 Potential health effects by inhalation

If dust is released into the atmosphere, there is a good chance that someone will be exposed to it and inhale it. If the dust is harmful, there is a chance that someone will suffer from an adverse health effect, which may range from some minor impairment to irreversible disease and even life-threatening conditions.

The **health risk** associated with a dusty job depends on the **type of dust** (physical, chemical and mineralogical characteristics), which will determine its toxicological properties, and hence the resulting health effect; and the **exposure**, which determines the dose. Exposure depends on the **air (usually mass) concentration** and **particle aerodynamic diameter** of the dust in question, and **exposure time** (duration). The dose actually received is further influenced by conditions that affect the uptake, for example, breathing rate and volume (as already seen in Chapter 1, Figure 1-2).

Particle aerodynamic diameters will determine if and for how long dusts remain airborne, their likelihood of being inhaled, and their site of deposition in the respiratory system. Dust concentration in the air and the aerodynamic diameter of the particles will determine the amount of material deposited, hence the dose received at the critical site.

As already mentioned in Chapter 1, very soluble substances can be absorbed from all parts of the respiratory tract, so for soluble particles the site of deposition (and hence aerodynamic diameter) is of less importance. For insoluble particles, the site of deposition in the respiratory system is of fundamental importance, which means that the aerodynamic properties of the particle, shape (fibres), dimensions of the airways and breathing patterns are relevant.

Health effects resulting from exposure to dust may become obvious only after long-term exposure; this is often the case with pneumoconioses. It may happen that effects appear even after exposure has ceased, thus being more easily overlooked or mistakenly attributed to non-occupational conditions. For example, mesothelioma resulting from exposure to crocidolite has appeared after latency periods of 40 years or more after beginning of exposure. Therefore, the fact that workers do not have any symptoms, or that symptoms appear after a long time, should be no excuse for inactivity concerning avoidance of exposure to known hazards.

However, many dusts have effects that result from shorter exposures to higher concentrations. Even when dealing with pneumoconioses-producing dusts, there are cases of acute effects.

Detailed discussion on occupational diseases and impairments resulting from exposure to dusts is beyond the scope of this document. Nevertheless, brief comments on some occupational diseases caused by dust are hereby presented in order to highlight the importance of preventing exposure. For more information readers should consult the extensive available literature and data bases on toxicology and occupational diseases, such as those listed in Section 2.2.11.

Health effects, which may result from exposure to different types of dust, include pneumoconioses, cancer, systemic poisoning, hard metal disease, irritation and inflammatory lung injuries, allergic responses (including asthma and extrinsic allergic alveolitis), infection, and effects on the skin. The same agent can cause a variety of adverse health effects, for example, certain wood dusts have been known to cause such impairment as eye and skin irritation, allergy, reduced lung function, asthma, and nasal cancer.

2.2.3 Pneumoconioses

One of the definitions of pneumoconiosis (ILO) is: “pneumoconiosis is the accumulation of dust in the lungs and the tissue reaction to its presence”. The lung changes in pneumoconiosis range from simple deposition of dust, as in the case of siderosis (deposition of iron dust in lungs, clearly observed by X-ray examination but with no clinical manifestations), to conditions with impairment of lung function, such as byssinosis (caused by cotton and flax dust) and to the more serious fibrotic lung diseases such as silicosis (caused by free crystalline silica dust).

Coal-miners' pneumoconiosis may be a serious problem in countries where coal mining is appreciable. On the other hand, in countries where strict prevention and control measures have been well established this does not occur. For example, in Australia, where coal mining is a major industry, there has not been a new case of coal miners' pneumoconiosis in the last 10 years, due to strict enforcement of occupational exposure standards and compulsory medical surveillance of all workers in the industry every two years.

Asbestosis may be a very serious problem wherever asbestos is mined and/or processed, but the cancers it causes (see section 2.2.4) are a problem at low exposures also.

Other pneumoconioses may be produced by inhalation of excessive amounts of the following dusts: beryllium (berylliosis); kaolin (kaolinosis); barium (baritosis); tin (stannosis); iron oxide (siderosis); talc; graphite; and mica. With the exception of berylliosis, these other pneumoconioses are relatively benign.

Silicosis

Silicosis is a fibrotic lung disease that is caused by overexposure to dusts composed of or containing free crystalline silica. It is irreversible, progressive, incurable, at later stages disabling and eventually fatal. The silicosis risk depends on the amount of free crystalline silica inhaled and actually deposited in the alveolar region (hence on the air concentration of respirable dust and its content of free crystalline silica, as well as on the exposure time and breathing pattern).

Pulmonary silicotic lesions have initially a nodular appearance (simple silicosis); however, as the disease progresses two or more nodules may coalesce to form larger masses (massive fibrosis; conglomerate silicosis). The first symptom of silicosis is dyspnoea (breathing difficulty), which may become increasingly serious. In view of the restrictive nature of this lung disease, compensatory emphysema (destruction of the alveolar walls) may occur. The most usual complication of silicosis, and a frequent cause of death in silicotic persons, is tuberculosis (silico-tuberculosis). Respiratory insufficiency due to the massive fibrosis and emphysema, sometimes accompanied by *cor pulmonale* (enlargement of the heart due to the continued effort to breathe with a restrictive lung disease), is another cause of death. Although silicosis is a typical occupational disease, it can be, and often is, diagnosed as a non-occupational condition.

Silicosis, like most pneumoconioses, is a chronic disease, taking many years to appear. However, if exposure is massive enough, it may occur in the accelerated (acute) form. For example, Fang (1996) reported silicosis cases among drill operators within 1 year of starting work under conditions of massive exposure: air concentrations of dust of the order of 2000 times the accepted occupational exposure limit, as a result of drilling granite in closed spaces (caissons 1-4 m in diameter, 10-30 m deep).

Byssinosis

Byssinosis is an obstructive lung disease, usually characterized in the initial stages by shortness of breath, chest tightness and wheezing on the first day after returning to work, but with symptoms increasing and becoming more permanent as the disease progresses. The increasing dyspnoea leads to varying degrees of incapacity. Byssinosis (also referred to as "brown lung") is caused by overexposure to dusts from cotton (mainly in operations such as ginning, carding and spinning), flax, sisal and soft hemp.

2.2.4 Cancer

Many dusts are confirmed carcinogens, for example: asbestos (particularly crocidolite), which may cause lung cancer and mesothelioma, free crystalline silica (IARC, 1997), hexavalent chromium and certain chromates, arsenic (elemental and inorganic compounds), particles containing polycyclic aromatic hydrocarbons, and certain nickel-bearing dusts. Certain wood dusts have been recognized as causing nasal cancer (IARC, 1995). Deposited radioactive particles expose the lungs to significant doses of ionizing radiation, which may cause carcinoma of the lung tissue, or they may be transported from the lungs and damage other parts of the body. Soluble carcinogens may pose a risk to both lungs and other organs. It should be mentioned that, in the case of lung cancer, cigarette smoke constitutes a confirmed non-occupational causal agent. Moreover, there is a strong synergistic effect between cigarette smoke and certain airborne dusts, for example asbestos, by which the potential risk is enormously increased. For this reason, any meaningful control strategy to avoid occupational exposure should be linked to some smoking cessation campaign.

Cancers due to asbestos, particularly mesothelioma, have been clearly linked to occupations such as building maintenance, where exposure is incidental, and would be expected to be low (Peto et al., 1995). This has clear implications for ‘recognition’: there may be an asbestos-cancer risk where people are working with asbestos-containing materials in building maintenance.

The establishment of cause-effect between chemicals in the work environment and cancer is complicated by factors which include: the lapse of time between exposure and disease (latency period); exposure to multiple agents; and the fact that cancers from occupational and non-occupational causes are often pathologically identical.

2.2.5 Ischaemic heart disease

Dusts may have health effects on organs other than lungs. Recently several studies have found effects on the cardiovascular diseases related to dust exposure (Seaton et al., 1995). There is a possible association between occupational exposure to dust and ischaemic heart disease (IHD) (Sjögren, 1997).

2.2.6 Systemic poisoning

Some chemical dusts can enter the organism and pass to the bloodstream, thus being carried through the organism and exerting toxic action on one or more organs or systems, e.g., kidneys, liver, blood. Systemic intoxication can be acute (i.e., of rapid onset and short duration), or chronic (of long duration and usually slow onset), depending on the type of chemical and degree of exposure. Toxic metal dusts - such as lead, cadmium, beryllium and manganese - may cause systemic intoxications, affecting blood, kidneys or the central nervous system. Although less usual, certain toxic dusts may also enter the organism by absorption through the skin, e.g. pentachlorophenol crystals may dissolve in sweat and easily penetrate through intact skin.

There are some wood dusts which can also be toxic if inhaled or ingested, for example, East Indian satinwood, ipe, South African boxwood. Wood toxins are usually alkaloids.

2.2.7 Hard metal disease

Overexposure to certain hard metal dusts (e.g., cobalt and tungsten carbide) or hard metal-containing dusts may lead to a diffuse pulmonary fibrosis, with increasing dyspnoea. Severe cases may progress even after cessation of exposure. This disease is often complicated with occupational asthma.

2.2.8 Irritation and inflammatory lung injuries

Although most widely associated with gases and vapours, irritation to the respiratory system may be caused by airborne particles. Certain dusts have irritant effects upon the upper respiratory tract and can produce chronic bronchitis from continuous irritation, which can lead to chronic emphysema. Exposure to irritants may also lead to tracheitis and bronchitis, pneumonitis, and pulmonary oedema. Airborne irritant particles include: beryllium (acute chemical pneumonitis), vanadium pentoxide, zinc chloride, boron hydrides, chromium compounds, manganese, cyanamide, phthalic anhydride, dusts of some pesticides, and some vegetable dusts.

Vegetable dusts such as tea, rice and other grain dusts may cause lung disorders, such as chronic airways obstruction and bronchitis. Some of these conditions are often referred to as mill fever.

2.2.9 Allergic responses

Some dusts may cause allergic reactions, either in the respiratory system (asthma-like), or skin (rashes and eruptions). Most sensitizers have a gradual effect, which appears only weeks or even years after exposure started. The sensitizer induces certain specific cellular changes so that, after a period of latency, further contact results in an acute allergic reaction. Cobalt, for example, can cause asthmatic effects, which may be crippling.

The two main respiratory diseases of allergic type caused by occupational exposure to particles are occupational asthma and extrinsic allergic alveolitis. **Occupational asthma** may be caused by certain grain dusts, flour and wood dusts (e.g., African maple, red cedar, oak, mahogany), and metals (e.g., cobalt, platinum, chromium, vanadium, nickel). **Extrinsic allergic alveolitis** is caused by moulds (and their spores) that grow on other materials, particularly under damp conditions. This is the case of farmer's lung, bagassosis, suberosis and other types, as exemplified in Table 2-I.

Table 2-I. Examples of extrinsic allergic alveolitis

Disease	***Agent***
Farmers' Lung	Mouldy grains, straw, hay (*Micropolyspora faeni, Thermoactinomyces vulgaris)*
Suberosis	Cork dust
Bagassosis	Mouldy sugar cane (*Thermoactinomyces vulgaris)*
Malt Workers' Lung	Mouldy barley (Aspergillus)
Wheat disease	Wheat flour (*Sitophilus granarius*)

2.2.10 Infection (biological hazards)

Inhalation of particles containing fungi, viral or bacterial pathogens may play a role in the transmission of infectious diseases. For example, pulmonary anthrax - a serious and often fatal disease - results from the inhalation of dusts from animal products (e.g., bones, wool or hides) contaminated with the anthrax bacillus. The highly dangerous pulmonary form is rather rare, the most usual form of anthrax being through skin contact.

Exposures to heavy concentrations of organic dusts (contaminated with microorganisms) may lead to serious respiratory and systemic illness, such as *organic dust toxic syndrome* (ODTS). NIOSH has estimated that 30%-40% of workers exposed to such organic dusts will develop ODTS (NIOSH, 1994). Examples of health effects resulting from exposure to a number of airborne dusts are presented in Table 2-II.

Table 2-II. Examples of health effects

Type of dust	*Main health effect*	*Target organ*	*Fraction of interest*
Free crystalline silica	Silicosis (lung fibrosis); progressive and irreversible restrictive lung disease; also carcinogenic	Lungs, gas-exchange region, alveoli	Respirable fraction
Coal dust	Coal workers' pneumoconiosis; restrictive lung disease	Lungs; gas-exchange region; alveoli	Respirable fraction
Asbestos	Asbestosis; lung cancer; mesothelioma	Lungs; bronchial and gas-exchange region;	Thoracic and respirable fraction
Lead dust	Systemic intoxication (blood and central nervous system)	Through respiratory system into the bloodstream	Inhalable fraction
Manganese	Systemic intoxication (blood and central nervous system)	Through respiratory system into the bloodstream	Inhalable fraction
Wood dusts	Certain hard woods cause nasal cancer	Nasal airways	Inhalable fraction
Cotton dust	Byssinosis; obstructive lung disease	Lungs	Thoracic fraction
Dried sugar cane dust	Bagassosis (extrinsic allergic alveolitis)	Lungs	Respirable fraction
Cement dust	Dermatoses	Skin	Any particle size
Pentachlorophe nol	Systemic poisoning	Through skin into blood stream	Any particle size

2.2.11 Other sources of information concerning health effects

For further information on health effects, see for example ILO (1997), Klaassen (1995), Levy and Wegman (1995) and NIOSH (1997). Occupational lung disorders have been specifically and thoroughly discussed by Parkes (1994), Levy and Wegman (1995) (Chapter 22) and Wagner (1998).

Relevant professional journals (see Chapter 11) are very useful as these bring up-to-date information to the readers. For example, the health effects resulting from exposure to crystalline silica were thoroughly discussed during an international conference (ACGIH, 1995); two subsequent conferences (ACGIH, 1996 and 1997) discussed, respectively, mineral industries and the health of miners.

Many relevant international sources of information are available (IARC, ILO-CIS, IPCS, UNEP-IRPTC), as well as many possibilities for electronic access and online information (further details and relevant addresses are presented in Chapter 11). IPCS and various national organizations periodically publish criteria documents or risk assessment documents on particular hazards.

2.3 Examples of prevalence of dust-related diseases

Although there are no global statistics on occupational diseases, surveys and studies in different countries have demonstrated high prevalence of health impairment among groups of workers overexposed to known hazards. Some published data on the prevalence of silicosis, byssinosis and lead poisoning are presented as examples.

Metadilogkul et al. (1988) reported that in villages in Northern Thailand, called the "villages of widows", a large number of the mortar-and-pestle-making workers die early deaths from silicosis. The situation there will not be much better than that in the mines of the Carpathian Mountains described by Agricola centuries ago when he wrote "women are found to have married seven husbands, all of whom this terrible consumption (most probably silico-tuberculosis) has carried off to a premature death."

A study in India (Durvasula, 1990) reported on the prevalence of silicosis among workers engaged in the quarrying of shale sedimentary rock and subsequent work in small poorly ventilated sheds, as follows: "Adults last about 14 years in this trade and are often replaced by their children who become severely ill within 5 years. An estimated 150 die every year and about 3500 have died in the last 25 years. The prevalence of silicosis is 54.65%, with 50% of male silicotics below 25 years of age". The same author reports, in small potteries, levels of respirable dust exceeding 25 to 90 times the occupational exposure limit then recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) and a prevalence of silicosis of 31%.

Silicotic pencil workers in Central India (Saiyed and Chatterjee, 1985) were followed up for 16 months; it was demonstrated that 32 % had progressed, and that mortality was high.

The mean age of the workers who died was 35 and the mean duration of exposure was 12 years.

Studies in Malaysia (Singh, 1977) demonstrated a silicosis prevalence of 25 % among quarry workers and 36% among tombstone makers. In diatomite mining in Kenya, Kurppa et al. (1985) demonstrated that 40 to 50 % of workers had silicosis, after 20 years of exposure.

Studies in Latin America have demonstrated up to 37% prevalence of silicosis among miners (PAHO, 1990). Data by the "Instituto Salud y Trabajo", in Lima, indicate that in the mining district of Morococha, the prevalence of pneumoconioses among miners is from 10-30%, depending on age and length of exposure. However, among those over 50 years old, the prevalence goes up to 50%.

In a study in granite quarries in Brazil (Ribeiro Franco, 1978), the prevalence of silicosis (with very definite X-ray confirmation) was found to be 33% among truck-loaders (the highest), followed by 19% among stone breakers, and 18% among hammerers.

Silicosis is also a problem in industrialized countries; for example in the USA, according to Robert B. Reich[5], "every year more than 250 workers in the United States die with silicosis, an incurable, progressive lung disease caused by overexposure to dust containing free crystalline silica. Hundreds more become disabled by this disease. Every one of these cases is an unnecessary tragedy, because silicosis is absolutely preventable." An example is given by Wiesenfeld and Abraham (1995), who reported an "epidemic of accelerated silicosis" among sandblasters in the West Texas Oilfield, where "Working conditions were extremely dusty, little or no respiratory protection was provided…Workers worked in the midst of an aerosol so dense they could not see" (Abraham and Wiesenfeld, 1997).

A study on lead poisoning in Malaysia (Wan, 1976) disclosed that 76% of workers in a lead storage battery factory had excessively high blood lead levels, while 37.3% were observed to have high urinary-ALA concentrations. Durvasula (1990) also reported high prevalence of lead poisoning, with 67% of the workers in the same branch of industry presenting clinical symptoms.

A study in India demonstrated byssinosis prevalence of 29%; studies in Egypt, prevalence of 26% - 38%, particularly in ginneries. In 5 ginneries in Sri Lanka, 17% of workers showed chronic bronchitis while 77.8% had symptoms of mill fever (Uragoda, 1977). A study among tea blenders in Sri Lanka (Uragoda, 1980) demonstrated that 25% of the workers had chronic bronchitis and 6% had asthma.

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[5] Secretary of Labour, USA, in the preface of the booklet, *A guide to working safely with silica: If it's silica, it's not just dust.* US Dept of Labour and NIOSH.

The health impact of exposure to sawdust on 59 sawmill workers from Southwest Nigeria was studied (Fatusi and Erbabor, 1996), and the results showed a high prevalence of respiratory symptoms, principally cough, chest pain and sputum production, among the workers; moreover, most of the workers also had high prevalence of conjunctivitis and skin irritation. This study highlighted the need for improved dust control methods in factories with high dust levels, particularly in the developing world.

2.4 Safety and other issues

2.4.1 Fire and explosion hazards

A cloud of dust of a combustible material behaves similarly to a flammable gas mixed with air in its ability to propagate a flame if in sufficient concentration; in a confined space it can produce an explosion. Pressure waves from the initial explosion can throw deposited dust into the air in front of the advancing flame with the result that the explosion may be extended far beyond the original dust cloud in the form of a "secondary" explosion.

Safety issues are outside the scope of this report, but clearly must be taken into account in workplaces. Only a brief account of this hazard and related control measures are presented here. For fuller information, see specialist publications such as HSE (1994).

Dust fires and explosions in the presence of a source of ignition are dependent on a number of factors, which include the following.

Materials

Typical combustible dusts may be derived from:

- natural materials, e.g. wood, resins, paper, rubber, drugs, sugar, coal, starch, flour;
- synthetic materials, e.g., dye stuffs, plastics, hexamine and practically all carbon compounds, and,
- inorganic materials, e.g. sulfur, iron, magnesium, aluminium and titanium.

Consequently potential hazards will exist in agricultural work, in the chemical, metallurgical and process industries, flour milling and coal mining among others. Inorganic mineral dusts are not combustible and, therefore, not susceptible to explosion. In coal mining, they are in fact used for dust explosion suppression.

Risk and sources of ignition

In general, a high risk of explosion exists where concentrations of combustible dust exceed 10 g/m^3. Sources of ignition include accidental fires, and operations involving the use of flame, from radiant heat ignition and from sparks arising from electrical apparatus, static electrification and the presence of ferrous metal and flints in materials being processed. These may ignite gas explosions, which raise settled dust into the air and cause dust explosions.

A minimum temperature is required for ignition and explosive clouds may ignite in hot enclosures at temperatures above 400°C. Static electrification is of special interest because it is associated with the properties of the cloud itself. Details on the conditions under which ignition of dust clouds by electrostatic discharge takes place have been discussed in the specialized literature (HSE, 1994).

Characteristics of dust in the air

For an explosion to occur in a dust-air mixture, the dust concentration must be above the lower limits. Particle size plays a large role in dust explosions: the finer the dust, the greater the likelihood of an explosion. Characteristics such as lower flammable limits of combustible dusts, or explosion characteristics of dusts are found in the specialized literature.

Moisture content

High moisture content of the dust and a high relative humidity of the air can prevent ignition and consequent ignition. The presence of moisture is of obvious importance in preventing static electrification and the transmission of flame.

Control measures against fire and dust explosions follow the general principles of prevention of ignition, isolation and cleaning of machines in which dust may exist and the provision of explosion reliefs including the admixture of inert materials (stone-dusting) to prevent propagation of flame. The primary concern should be the prevention and avoidance of explosive dust clouds. In powder handling and powder-storage equipment, this can be achieved in practice by introducing incombustible gases such as carbon dioxide or nitrogen so as to limit the oxygen content of the atmosphere to below 5% by volume. Proper designs to ensure the construction of dust tight plants, installation of exhaust ventilation, good maintenance and housekeeping significantly reduce the risk of dust fires and explosions.

2.4.2. Other issues

Dust clouds in a working area considerably reduce visibility, and deposited dust may cause slipping. Dust, therefore, increases the risk of accidents. It may also affect the quality of products and raw materials. Dust deposition on various structures, machinery and equipment may lead to degradation of materials and environmental pollution. The increase in cleaning costs and machinery maintenance may be appreciable particularly in view of the "wear and tear" caused by some hard or corrosive particles.

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Chapter 3 - Dust Control and Good Management

3.1 General considerations

It is tempting to consider dust control just as a technical problem that can be solved with a few instruments and possibly some new ventilation equipment. However, recent research on occupational health and safety has been giving increased emphasis to risk management. This chapter, therefore, considers how management approaches affect risk control in the workplace. Subsequent chapters deal with detailed approaches to dust assessment and control, but these are unlikely to be fully effective unless the best management practices are in place as well.

Classic explanations for accidents, in terms of either technical deficiencies or human errors, have been losing ground. This was triggered by the analysis of some major accidents in industries and services with complex and well-defined technologies, like the nuclear, chemical and oil-producing industry, as well as public transport (Bensiali et al., 1992; Department of Energy, 1990; Kjellèn, 1995; Kjellèn and Sklet, 1995; Reason, 1991; Salminen et al., 1993; Wilpert and Qvale, 1993). The main emphasis in recent accident investigation reports has been on the failure of management to ensure that their plant or activity was designed, operated and maintained in an adequate manner with regard to safety and health. The impact of these considerations over the whole field of occupational health and safety has been considered in an ILO publication (Brune et al., 1997).

Regulatory interests, stimulated by the changing philosophy in safety and health legislation in member states of the European Union, and by the European Framework Directive of 1989, constitute a further reason for the increased attention being paid to risk management (European Communities, 1989). Such legislation moved from detailed technical health and safety concerns to issues of decision-making and management formulated within a health and safety policy. Enterprises must now be able to prove that they have planned systematic approaches for the design and improvement of workplaces and products.

Risk management has become a conscious and important part of industry's responsibilities. Enterprises are required to account for their health and safety performance both to their employees and, through various regulatory bodies, to the public. Industry has also become increasingly convinced that it makes good economic sense to analyse and plan the safety, health and environmental aspects of their activities with the same level of care and sophistication as the quality or productivity aspects.

Several models have been suggested to specify and classify the elements required for sound risk management. The approach drawn from quality management, as developed in the last decades in many companies and often based on the ISO 9000 series (ISO, 1987), uses the Deming Cycle, which is a model with four steps, representing a feedback loop, as follows:

(1) PLAN

(2) DO

(3) CHECK

(4) ADJUST

This has been used as the basis for the identification of necessary actions to solve quality problems. A variant of this approach is the risk assessment and control cycle (Hale, 1985 and Hale et al., 1997) which can be used for occupational safety, health and environmental problems during plant operations or (re)design of installations or production lines. This cycle is also known as the "problem-solving cycle" (Table 3-I).

Table 3-I The problem-solving cycle

current condition - desired condition (criteria, standards, laws, policy)

–

problem recognition and definition

–

problem analysis

–

priority allocation

–

solution generation

–

choice of solutions

–

implementation

–

monitoring and evaluation of effects

–

planning for contingencies

3.2 Establishment of hazard prevention and control programmes

Programme implementation requires the involvement and cooperation of management, production personnel, workers and occupational health professionals, including occupational hygienists, occupational physicians, occupational nurses, and ergonomists, among others.

Management must provide the required resources and administrative support, but will have the benefit of a healthier and happier work force and increased productivity. Workers whose health is preserved will enjoy better quality of life and greater productivity. In protecting the health of workers, government satisfies a fundamental obligation and promotes the economic well-being of the country.

Specific control measures should not be applied in an *ad hoc* manner, but integrated into comprehensive and well-managed hazard prevention and control programmes, which require:

- political will and decision-making;
- commitment from top management;
- adequate human and financial resources;
- technical knowledge and experience; and
- competent management of programmes.

Decision-making is based on political will and motivation, both of which require awareness of the problems and knowledge of their possible solutions, as well as understanding of the resulting impact in terms of human health, environment and economics. Decision-makers must be aware of the ill effects of uncontrolled hazards in the workplace, as well as of the possibilities for their prevention, and the resulting social and economic benefits.

As long as risk management is not included in the priorities of the top management and is not considered as important as productivity and quality, there is very little chance that efficient prevention and control programmes can be implemented in a workplace.

Good management is built up from the following elements:

- a clear and well circulated official policy;
- elaboration of management tools;
- implementation and use of these tools;
- monitoring of the system performance; and
- continuous improvement of the system.

The importance of a multidisciplinary approach to the design, implementation, and maintenance of control strategies cannot be overemphasized. Only through joint efforts involving all stakeholders and drawing from the relevant environmental and medical sciences, is it possible to achieve good protection of workers' health and of the environment.

An initial step should be the institution of multidisciplinary teams and the elaboration of mechanisms for efficient teamwork. In many countries (e.g., Canada), the establishment of joint labour-management occupational health and safety committees is mandatory. At this point, a clear assignment of responsibilities and resources to teams and individuals, as well as the establishment of lines of communication, within and outside the service, are essential.

3.3 Required resources

Even when the need for control measures has been established and the decision to implement them has been taken, practical difficulties may arise, one usual “stumbling block” being the shortage of adequately trained personnel. Hazard prevention and control require specialized “know-how”, involving both technical (engineering) and managerial competence. The former would include, for example, the selection of alternative technologies or the design of industrial ventilation systems, and the latter, the integration of specific measures into efficient programmes.

As in other areas of science and technology, the design and implementation of hazard prevention and control strategies and measures require a combination of knowledge and experience. Academic training without experience is likely to lead to deficiencies in the design and use of hazard controls. On the other hand, experience without sound knowledge can be unreliable and costly. The use of adequately trained and certified professionals can provide greater confidence in the delivery of the required services.

Appropriate knowledge is gained by long term formal education, by attending short courses and similar training activities, by the use of educational materials, and by obtaining advice from experts. Information on possibilities for training in control technology can be obtained from relevant international and national organizations. Experience is obtained, for example, by internships and practical work under the supervision of well-qualified professionals. The World Health Organization has published a review of the requirements for professional occupational hygienists (WHO, 1992).

Resources must be allocated within a framework of priorities, always keeping the required balance among the different components, namely facilities, human resources, field equipment and information systems, never overlooking operational costs, including update of information systems and maintenance of staff competence. Many programmes fail because operational costs were not correctly and realistically foreseen.

3.4 Clear policy and management tools

A clear policy, discussed, well understood and agreed upon by all stakeholders is essential. The objectives of the programme, the steps to be followed and the available mechanisms for implementation should be clearly defined and presented to all concerned. People must know what to expect and what to hope for; unrealistic and unattainable goals are very frustrating. Top management should be committed to and provide the means for the implementation of the policy.

Different tools have to be developed to efficiently implement the official policy.

The following list, which is not exhaustive, provides some examples of the system elements:

- Clear organization of responsibilities and of lines of communication
- Clear working procedures
    - standard operating procedures
    - maintenance, inspection

    * abnormal situation/emergency

- Risk detection and evaluation programmes
- Human resources programmes
    * selection
    * education and training
    * information
    * maintenance of staff competence
- Development of performance indicators
    * acute risks
    * chronic risks
    * cost-benefits
    * legal and internal requirements
- Establishment of monitoring programmes
    * internal
    * external (audits)
- Development of harmonized and coherent standards
    * health and safety
    * environment
    * quality
- Development of internal processes
    * continuous improvement
    * staff motivation
    * “sentinel” systems
    * guidelines

For the success of a hazard prevention and control programme, measures and actions should never be imposed, but rather discussed, with active participation from all concerned, namely occupational health professionals, production personnel, management and workers. All can make a contribution and all must be part of it, if the programme is to be continuously efficient in the long run.

For the risk management approach at the workplace level, the “decision-making ladder” can be used to analyse the decision-making process concerning hazard control in workplaces, as well as to pinpoint where blockages occurred, or are likely to occur, with a view to avoiding them. The steps in the ladder are:

1. Be aware of the problem

2. Accept there is a problem

3. Know/find out the cause

4. Learn of/develop solution

5. Accept solution

6. Know supplier (of solution)

7. Finance

8. Implement measures

9. Evaluate

If it is well understood where and why a blockage occurred, it will be easier to overcome it. A study, utilizing this ladder (Antonsson, 1991), demonstrated how blockages can occur at different stages of the decision-making process, thus requiring different strategies to be overcome.

3.5 Continuous improvement

A risk management system is a complex matter. It cannot remain static and has to be adapted and tailored to the needs of the workplace in question, as well as to changes in the technological and socio-economic environment. The approach followed by quality management systems and programmes for occupational health and safety in different countries stresses the continuous improvement of management systems.

It is important to periodically reassess the whole system in order to check if it is still relevant and up to date, or if adjustments are needed; the Deming Cycle principle can be very useful in this respect.

Teamwork, including workers’ participation, is essential, and should be established in a form adapted to the size and the culture of the enterprise. In fact, the culture itself often needs to be progressively modified. Resort to external consultants, who perceive things objectively and are not tied up to “old habits”, may be helpful as they may bring in new ideas and creative approaches.

Risk management also helps to develop a broad risk prevention culture which may outreach the workplace and be beneficial to the whole community.

In order to ensure job satisfaction and achieve continuous improvement, an adequate system for the recognition of successes and failures is needed. Failures must be analysed critically, not with the objective of “finding the guilty” but of pinpointing possible sources of mistakes in order to correct and avoid them. Successes must be given ample credit and celebrated. It is important to use “positive reinforcement” by which more value is placed on successes than on failures.

3.6 Monitoring of performance

Programmes should be periodically evaluated in order to ensure continued efficiency and improvement. Different indicators may be used, based on data collected through, for example, environmental and health surveillance. Indicators should have general, scientific and user relevance.

3.6.1 General relevance of indicators

Indicators should be:

- based on known linkages between work environment agents or factors, and health;
- directly related to specific occupational health issues which require action;
- able to detect changes either in work environment conditions or health effects;
- able to detect if an organization is capable of fulfilling the Deming Cycle.

3.6.2 Scientific relevance of indicators

Indicators should be:

- unbiased, reliable and valid;
- based on data of a known and acceptable quality;
- unaffected by minor changes in methodology or in the scale used for their construction;

- comparable over time and space.

3.6.3 User relevance

Indicators should be:

- easily understood by and acceptable to all stakeholders;
- based on data which are readily available, easily collected and of acceptable cost *(a good guideline is "never generate data only for the indicators, but rely on data that is relevant and useful for the level at which it is collected");*
- timely to allow for appropriate policy and decision-making, or, adequate to monitor the resulting action.

3.6.4 Health surveillance

Results from health surveillance may serve as indicators for the efficiency of control systems. However, as already mentioned, health surveillance should be considered as a complement to but never as a replacement for primary prevention.

Continuous communication, teamwork and exchange of data between health personnel and occupational hygienists are essential for a thorough assessment of occupational hazards and to ensure adequate follow-up of hazard prevention and control programmes.

3.6.5 Environmental surveillance

Continuous or intermittent monitoring is a means to detect any alteration in the exposure conditions. This may result, for example, from: changes in the process or materials utilized; accidental occurrences, such as leakages, fugitive emissions, valve breakdown; deficiencies and breakdown in the existing controls. Monitoring systems should be chosen which are 'fit for purpose', that is of sufficient quality and reliability to justify the decisions which will be based on them. This means that direct-reading instruments, as well as "visualization" techniques (e.g., video exposure monitoring, dust lamps), have wide application in this respect (see Section 4.5).

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Chapter 4 - Recognizing and Evaluating the Problem - the Systematic Approach

The recognition of hazards involves the study of work processes, to identify possible generation and release of agents which may pose health and safety hazards. This is a fundamental step in the practice of occupational hygiene. The most sophisticated instrumentation cannot make up for careless recognition; hazards which are not recognized will be neither evaluated nor controlled (Goelzer, 1997).

An unrecognized hazard can never be controlled.

Recognition requires the basic background information outlined in Chapters 1 and 2. But to apply it in the workplace requires a systematic approach, consisting of gathering of information and a workplace survey, not necessarily involving measurement. However, a quantitative evaluation of the risks and of the necessary control measures may then be needed. These steps are outlined in this chapter. Guidelines on this have been established, at both international level, e.g. European Standard EN 689 (CEN, 1994), and national level (e.g. HSE, 1997a).

4.1 Methodology for the recognition of hazards

Appropriate hazard recognition requires knowledge of work processes and operations, raw materials and chemicals used or generated, final products and by-products, as well as an understanding of the possible interactions between workplace agents and the human organism, and the associated health impairments. Some aspects have been summarized in Chapters 1 and 2, but for more details see Burgess (1995); ILO (1997); Patty/Clayton and Clayton (1991, 1993/1994); Patty/Harris et al. (1994); Patty/Cralley et al. (1995).

The steps for an adequate hazard recognition are:

- initial collection of information on the process in question and potential associated hazards, from the literature and/or previous surveys, if any;

- actual visit to the workplace for detailed observation (usually referred to as "walk-through" survey); and,
- subsequent analysis of the observations.

The first step is collection of information to optimize the actual observations. In order to avoid overlooking potential hazards during the walk-through survey (see below), it is important to get a list of raw materials and chemicals purchased by the plant, as well as their consumption rate (weekly or monthly) and information on how and where each is used.

Collection of information about hazards will continue during the walk-through survey. Containers in storage areas should be examined (Goelzer, 1997). It is also necessary to look into products, by-products and wastes, all of which may either contribute to, or be a dust source. However, the walk-through survey will also review how materials are being used, what potential for airborne dispersal (or other exposure) exists, what control measures (if any) are in place, and the degree to which these appear to be performing effectively.

Questions to be asked during the information-gathering and walk-through survey, therefore, include the following

- Which substances are used?
- In what amounts are they used?
- What is their toxicity?
- What is their dustiness?
- If a process step generates dust, is it necessary, and if so can it be done another way?
- Is the process fully enclosed? If not, where are the most significant emission sources?
- Is local exhaust ventilation (LEV) supplied at these points?
- Does LEV appear to be working?
- Is it possible to trace the ventilation system from hood to exhaust, and does the design seem effective? Are the original plans available?

- Is it possible to perform a job task analysis (JTA), i.e. itemize each of the tasks with respect to potential for exposure? What does the worker think is the worst exposure?
- Does the worker ever appear to have his/her breathing zone impacted by the dispersed dust?
- Is this because the layout of the workstation permits this?
- What does the worker think of existing controls, in terms of ease of use? What does the worker suggest?
- Do workers have any symptoms or other health effects, which may be attributed to occupational exposure?

Although it is usually easier to recognize dust than gases or vapours (particularly those which are colourless and do not have strong odour or irritant properties), not all dust sources are obvious. Freshly generated dust clouds usually contain a larger proportion of the more visible coarse particles. However, these settle more rapidly and the remaining fine particles may be difficult to see. A coating of dust on horizontal surfaces shows that there is or has been dust in the air, even if it is now invisible.

For this reason, various instruments are useful on the walk-through survey. Direct-reading instruments are available, which display the dust concentration (see Section 4.5.2). These are often not very accurate for dusts, but can give an indication of where and when the concentration is highest, so that the need for quantitative measurement can be assessed. Special illumination techniques can show up dust invisible under ordinary illumination (HSE, 1997b); these dust-lamp techniques are less quantitative than direct-reading instruments, but usually cost less. More sophisticated techniques combine direct-reading instruments and video imaging, and can record for later analysis which parts of a process or work practice generate the dust, for example (e.g. NIOSH, 1992; Rosén, 1993; Martin et al., 1999). These instruments and techniques are further discussed below.

It may also be useful to have smoke tubes, to see if LEV systems are working and the air from the dust source is really collected by the exhaust.

Whenever hazards are evident and serious, the qualitative hazard assessment made during the recognition step, particularly the information obtained during the walk-through survey, should be enough to indicate the need for control measures, regardless of further quantitative exposure assessment. Priorities for follow-up action should be established taking into account the severity of the likely health risks and the number of workers likely to be exposed. For example, there is an unquestionable need for control when operations such as sandblasting, hard wood sanding, dry drilling of granite, or bagging of toxic powders, are performed without the required controls. In such cases, the walk-though survey will provide enough information to recommend immediate preventive measures, without the need for measurements. A more detailed survey for less obvious sources will still be needed later.

Collaboration with management, production engineers and workers, as well as health personnel, is of fundamental importance to help understand work processes, associated agents and their potential effects. It is particularly important to learn about conditions which may be absent at the time of the walk-through survey. Although any survey should preferably be conducted under normal operating conditions, abnormal or infrequent exposure episodes must be taken into account. Information concerning the health status of workers, such as medical records, may greatly contribute to the identification of workplace hazards.

4.2 Control in straightforward cases: the control-banding approach

The traditional approach in occupational hygiene has been to follow the walk-through survey with a more detailed quantitative assessment, which guides choice of control. However, the difficulty of ensuring that expert advice is used by all small and medium-sized enterprises has led to approaches which enable employers to choose control solutions based on simple observations coupled with the hazard information which must usually be supplied with toxic materials. Of course this approach cannot be used with substances that are not supplied, for example minerals being extracted, or substances being manufactured. Also, if particularly toxic materials are being handled, then expert advice should always be sought, and expert checking of control solutions should always be beneficial. It is, for example, false economy to install anything more than the simplest local exhaust ventilation system without expert help (see Section 7.4). However, in straightforward cases the new approaches enable the employer to choose appropriate control solutions without delay.

This section outlines, as an example, the “COSHH Essentials” approach, applied in Britain by the Health and Safety Executive (HSE, 1999a). The idea is that the employer uses the toxicity information from the safety data sheet or label, and estimates the dustiness of the substance and the quantity in use. From these three pieces of information, a table gives the general level of control required as one of four strategies: general ventilation, engineering control, containment, and 'seek specialist advice'. Within those four strategies, detailed guidance is available on various operations, as (at present) 60 single-sheet 'Control Guidance Sheets'. The approach is detailed in HSE (1999a). The technical background is given in HSE (1999b), and the derivation and validation was published earlier in a series of papers by Brooke (1998), Maidment (1998), and Russell et al. (1998). HSE adopted the approach after a market survey found that most chemical users in Britain did not understand the legislation or exposure limits, and got most of their information from the suppliers. It is intended that small enterprises will be able to use the scheme easily.

The main elements are summarized below as an illustration of this type of approach: HSE (1999a) should be consulted before this particular scheme is used.

4.2.1 Hazard bands

Substances are allocated to one of 6 bands depending on their hazard classification. The guidance gives a table by which chemical users within the European Union can allot a substance to one of the bands depending on the risk phrases which must be shown on label and Safety Data Sheet under the Dangerous Substances Directive. Further details are given in HSE (1999a) and by Brooke (1998). The main features can be summarized as follows.

Hazard Group A: Skin and eye irritants; substances not allocated to another band.

Hazard Group B: 'Harmful' substances under the EU scheme.

Hazard Group C: 'Toxic' substances under the EU scheme; severe and damaging irritants; skin sensitizers.

Hazard Group D: 'Very toxic' substances under the EU scheme; possible human carcinogens; substances that may impair human fertility or affect an unborn child.

Hazard Group E: More severe effects, e.g. probable carcinogens, inhalation sensitizers.

A sixth group deals with skin and eye contact, but does not lead to controls of airborne dust.

4.2.2 Finding the control strategy

Having picked the appropriate Hazard Group, the employer then considers the amount of material in use - grams, kilograms, or tonnes - and estimates the dustiness of the material. Dustiness is classified as high, medium, or low, as follows.

High: Fine, light powders. When used, dust clouds can be seen to form and remain airborne for several minutes. For example: cement, titanium dioxide, photocopier toner.

Medium: Crystalline granular solids. When used, dust is seen, but settles out quickly. Dust is seen on surfaces after use. For example: soap powder, sugar granules.

Low: Pellet-like, non-friable solids. Little evidence of any dust observed during use. For example: PVC pellets, waxes.

Of course, where possible a low dustiness material should be substituted for a medium and a low or medium for a high; smaller quantities should be used rather than larger. When this has been done, the control strategy can be derived using Table 4-I.

The Approaches are given in detail by Maidment (1998), and have been further developed in the guidance sheets mentioned above. The **Control Approaches** may be summarized as follows.

Control Approach 1: Good general ventilation, maintenance, housekeeping, and training. Protective clothing required, and possibly respiratory protective equipment (RPE) to deal with cleaning and maintenance.

Table 4-I. Derivation of the Control Approach from the quantity and dustiness (from HSE, 1999a)

	Low dustiness	**Medium dustiness**	**High dustiness**
Hazard Group A			
Grams	1	1	1
Kilograms	1	1	2
Tonnes	1	2	2
Hazard Group B			
Grams	1	1	1
Kilograms	1	2	2
Tonnes	1	2	3
Hazard Group C			
Grams	1	1	2
Kilograms	2	3	3
Tonnes	2	4	4
Hazard Group D			
Grams	2	2	3
Kilograms	3	4	4
Tonnes	3	4	4
For all Hazard Group E substances, choose Control Approach 4			

N.B.: The numbers 1 to 4 in the above cells refer to the Control Approaches hereby outlined.

Control Approach 2: Local exhaust ventilation; restricted access; good housekeeping; protective clothing, and eye and skin protection depending on substance, and possibly RPE to deal with cleaning and maintenance; specific training on hazards and control.

Control Approach 3: Containment; controlled access to labelled areas; 'permit to work' for maintenance, with written maintenance procedures; protective clothing, eye and skin protection depending on substance, and suitable RPE to deal with cleaning and maintenance; specific training on running of plant, maintenance, control, and emergencies.

Control Approach 4. Seek specialist advice**.**

All the Control Approaches must be integrated into an effective management and supervision system.

4.3 Quantitative evaluations

4.3.1 Objectives

Unless an approach like that in Section 4.2 clearly removes any likelihood of exposure, it is likely that the walk-through survey will be followed by a quantitative survey, involving measurement of worker exposure to the dust. Possible purposes include the following:

- Initial study to see if there is a need to control or improve controls, including controls installed under procedures like that in Section 4.2.
- Follow-up monitoring to confirm that control is still satisfactory.

Exposure measurement may also be required for the following reasons:

- Initial establishment of base-line exposure data

- Epidemiological studies, to establish exposure-effect relationships
- Other studies for research purposes

Measurements are usually made by collection of a sample from the air, and subsequent analysis for the substance of interest. In all cases, it is important that the quality of the measurements should be good enough to justify the decisions which are based on them. For example, whenever exposure data is to be linked with epidemiological studies, the quality of exposure assessment results is critical. Where applicable occupational exposure limits exist (see Section 4.3.2), measured exposures will usually be compared with these to decide whether control is satisfactory.

The ideal situation would be to always keep precise and accurate exposure assessment records because these may be needed in the future to establish what the exposures were at a certain time in the past. However, this is seldom feasible due to lack of the required resources.

An air sampling or monitoring exercise, if done in an accepted and defensible manner, can provide objective rationale for taking or not taking specific action. This may be something large-scale, such as a new ventilation system, or something smaller, such as relocation of existing local exhaust ventilation or training the worker in a different work practice. The monitoring results can be retained as justification for the action, and for comparison with later results (Section 4.4).

In addition to measurement of airborne concentration of a substance, bulk samples of materials used may also be analysed to determine whether they contain any substances with potential to cause harm. However, for many substances, the proportion of different substances in the parent rock or a coarse bulk sample may be very different from their proportions in the airborne cloud, so bulk analysis is never a substitute for analysis of the samples of appropriate fractions of the airborne material.

4.3.2 Occupational exposure limits

Occupational Exposure Limits (OELs) are a key element in risk management and are often incorporated in legal standards (Vincent, 1998). Although obvious exposure to known harmful agents should be controlled regardless of any existing regulation, establishment of a control limit often draws attention to a substance.

Occupational exposure limits are usually expressed in one of the following forms:

- Time-weighted average concentration (TWA), which is the average concentration over a full shift, usually 8 hours.
- Ceiling concentration, which is an instantaneous concentration (in so far as this can be measured) not to be exceeded at any time.
- Short-term exposure limit (STEL), which is the average concentration over a specified time, e.g. 15 minutes.

For dusts whose effects depend on long-term average exposure, such as the pneumoconioses-producing dusts, OELs are given as time-weighted average concentrations, whereas for substances which are fast acting, OELs are given as short term or ceiling limits.

Occupational exposure limits are initially based on dose-response, or exposure-effect assessments. The establishment of the "health-based occupational exposure limits" (WHO, 1980) requires consideration of the questions: "How much exposure causes what effect?" or "What exposure level causes no harm ?" A health-based limit can then be established at a lower level. For example, health-based occupational exposure limits for mineral dusts were the subject of a WHO publication (WHO, 1986).

However, in some cases it is not possible to establish such a level, or the level may be impossible to achieve in practice. Authorities may then promulgate "operational exposure limits" (WHO, 1980), which involve yet another question: "how much effect is acceptable, if any". This involves a decision-making process, which requires consideration of technical and socio-economic issues (Ogden and Topping, 1997).

It should be kept in mind that OELs, even when established on sound scientific bases, are not necessarily adequate in all situations. Exposures below the OELs do not mean that *all* workers are protected, for reasons that include concomitant exposures to other substances and individual sensitivities; it is accepted that occupational exposure limits do not usually protect the hyper-susceptible workers.

Moreover, values established for one country will not necessarily protect workers in another country where a number of factors, including duration of working week, climate and work schedules, may differ. Also, risk assessment is a dynamic process and a substance, once thought to be relatively harmless, may suddenly be proven to be the etiologic agent of a serious disease.

In any case, occupational exposure limits cannot be used as “fine lines between safe and dangerous”; professional judgement must be exercised at all times, accounting for the degree of uncertainty that exists not only in the establishment of these limits, but also in the assessment of the exposures which actually occur in the workplace.

Nevertheless, occupational exposure limits provide occupational health professionals with a useful tool for assessing health risks and deciding whether a certain exposure situation is acceptable or not, and whether existing controls are adequate. Exposure in excess of these limits requires immediate remedial action, through the improvement of existing controls or implementation of new ones. Many authorities have established action levels at ½ or 1/5 of the OEL, at which preventive action should begin.

National or local regulations and standards concerning dust exposure should be followed. However, in the absence of exposure values acceptable by law in the jurisdiction in question, values adopted internationally (e.g., by the European Union), or in other countries (e.g., ACGIH, 1999a) are often used. Although “imported” values may serve as initial guidance, prompt action should be taken to establish relevant national regulations. In any case, lack or inadequacy of regulatory instruments should never be an obstacle to the recommendation and implementation of necessary preventive measures.

It should be kept in mind that simplistic approaches of just measuring concentrations and comparing results with values in a table may be misleading, as many factors influence the consequences of exposure to a certain hazardous agent. The interpretation of exposure assessment results has to be made by adequately trained professionals. Moreover, there are not yet (and there will probably never be) established occupational exposure limits for all of the currently utilized substances. Therefore occupational hygienists should be well acquainted with and have access to sources of information concerning risk assessment and toxicology (including publications and data bases) in different countries, as well as in international agencies (IARC, ILO-CIS, IPCS, IRPTC-UNEP, WHO - see Chapter 11). If hazard information is available, then the control-banding approach (Section 4.2) may give useful guidance on controls.

4.3.3 Sampling strategy

In any work environment there are spatial and temporal variations in the concentration of airborne contaminants, so that exposure may differ with workers' movement as well as with time of the day, week, or even month. There are also sampling and analytical errors: some can be avoided by careful procedures, while others are inherent to a certain methodology and have to be accounted for when deciding on the degree of reliability required for the estimation of the true value of the exposure parameter.

Therefore, a sampling strategy, accounting for all factors that may lead to any variation in the results, must be designed and followed, so that the data obtained is representative of the workers' exposure, thus ensuring a reliable exposure assessment. Important factors include:

- the day, week, or month sampling is performed,
- production rate,
- raw materials,
- work shift,
- task performed,
- individual performing task,
- dust control measures,
- technology used,
- number of workers,
- climate,
- other nearby processes,
- distance of worker from source, and
- errors in sampling and analytical procedures

If the national authority responsible for the adopted OELs has laid down an accompanying assessment strategy, this should be followed. If not, the responsible professional should design and follow a suitable strategy. CEN has produced a European Standard (EN 689) which gives practical guidance for the assessment of exposure to chemical agents and measurement strategies (CEN, 1994). In any case, professional judgement during an assessment is indispensable.

The classic questions when designing a sampling strategy are: Where to sample? For how long to sample? When to sample? How many samples to collect? This subject has been widely discussed in the specialized literature (e.g., BOHS, 1993). However, although specific methodological principles have been well established, there are nuances in their application. Obviously any sample must be representative of the worker's exposure, which usually determines where and when to sample. Also, for the same type of agent and the same type of collecting medium, the recommended duration of sampling will be of the same order. However, specific situations may dictate differences in the number of samples required for an evaluation, because this, together with the quality of the measuring system, will determine the accuracy and precision of the obtained results, and the degree of reliability required will depend on the objective of the hazard evaluation.

For the assessment of inhalation exposure, it is necessary to characterize the air that workers are actually inhaling; therefore, the samples should be collected in the "breathing zone," which is usually defined as a hemispherical zone with a radius of approximately 30 cm in front of the head.

Some design considerations should include "worst case" exposure sampling or sampling a representative numbers of workers indicative of all job categories. Sampling should be of full-shift duration or for the complete length of a process cycle, if the objective is to determine a time-weighted average concentration. Due to the variability in results and the probable lognormal distribution of dust exposures, sampling needs to be conducted over several shifts and during several days to best characterize the workplace exposures.

When assessing exposure to fast-acting substances (seldom the case with dusts) that can cause irreversible damage even on brief high exposures, sampling of very short duration (at the right time) is required, in order to detect concentration peaks, particularly if there are appreciable concentration fluctuations. High concentrations occurring for short periods can remain hidden, and undetected, if a sample is collected over a longer period of time during which very low concentrations also occur. Infrequently performed tasks also need to be characterized so that potential short duration but high concentration or peak exposures can be documented.

For the same exposure situation (including the expected environmental fluctuations), if the coefficient of variation of the measuring procedure is known and constant, it is possible, through the application of inductive statistical methods, to determine how reliable an estimate is, or what degree of uncertainty can be expected from a certain number of samples or measurements. This will guide the decision on how many samples to collect or how many measurements to make. The better the sensitivity, accuracy and precision of the measuring system and the greater the number of samples, the closer the estimate will be of the true concentration.

It is usually accepted that, if measurements are needed, they should be as accurate and precise, that is as "reliable", as possible. However, there is the issue of the associated cost and, in practice, an acceptable and feasible degree of reliability must be established, according to the purpose of the investigation and in view of the available resources. One approach is to look at the purpose of the results. For example, in determining control measures the results should be reliable enough to decide what control action is necessary. A different accuracy may be required if the measurements are part of an epidemiological investigation.

If it seems too costly and difficult to establish compliance (or non-compliance) with a standard, it may be better just to reduce the exposure. Considering that new knowledge on risk assessment often leads to a decrease in acceptable exposure limits, good practice should aim at controlling exposures to the lowest possible level. The required reliability depends largely on the consequences of making a wrong decision on the basis of the collected data.

4.3.4 Size-selective sampling

Dust exposures can span a wide range of particle sizes with health effects dependant upon the region of deposition in the lung. For this reason, size selective dust sampling is performed. As explained in Section 1.5, the ACGIH, ISO and CEN have reached agreement as to particle size-selective sampling criteria and defined three fractions for health-related measurement, namely *inhalable, thoracic* and *respirable,* as follows:

Inhalable Fraction for those materials that are hazardous when deposited anywhere in the respiratory tract;

Thoracic Fraction for those materials that are hazardous when deposited anywhere within the lung airways including the gas-exchange region; and,

Respirable Fraction for those materials that are hazardous when deposited anywhere in the gas-exchange region.

There has been international agreement that OELs for particles should normally be specified as one of the above fractions. Modern exposure limits for dusts are usually expressed in terms of the inhalable or respirable fractions. The fractions as recommended by CEN, ISO and ACGIH are given in Tables 4-II to 4-IV, using the figures given by ACGIH (1999a).

Aerodynamic diameter (μm)	**Inhalable fraction (%)**
0	100
1	97
2	94
5	87
10	77
20	65
30	58
40	54.5
50	52.5
100	50

Table 4-II The fraction of the airborne material which a sampler should collect where the inhalable fraction is of interest (ACGIH, 1999a)

Aerodynamic diameter (μm)	**Thoracic fraction (%)**
0	100
2	94
4	89
6	80.5
8	67
10	50
12	35
14	23
16	15
18	9.5

20	6
25	2

Table 4-III The fraction of the airborne material which a sampler should collect where the thoracic fraction is of interest (ACGIH, 1999a)

Aerodynamic diameter (mm)	**Respirable fraction (%)**
0	100
1	97
2	91
3	74
4	50
5	30
6	17
7	9
8	5
10	1

Table 4-IV The fraction of the airborne material which a sampler should collect where the respirable fraction is of interest (ACGIH, 1999a)

4.3.5 Measuring equipment

As previously mentioned, measurements can be made by:

- the use of direct-reading instrumentation, to obtain results in (near) real time, and,
- collection of samples, for weighing or subsequent laboratory analysis.

Each has its advantages and disadvantages and has its recommended application, as will be seen in the next sections.

Sampling for airborne particles requires instruments that extract them from a measured volume of air and collect them in a manner that permits subsequent weighing and/or chemical analysis, or particle counting under a microscope. These instruments comprise a sampling head, an air mover (with a power source) and a flowmeter.

The sampling head must be designed to collect the fraction of airborne particles to which the OEL applies. The head will therefore consist of a collecting device (e.g., a filter in a filter holder), and a pre-collector such as a cyclone for the respirable dust fraction (see Section 4.3.6), or a specially designed entry if the inhalable dust fraction applies. This is fully explained in the specialized literature (ACGIH, 1995, 1999b; Courbon et al., 1988; Fabriès et al., 1998; Kenny et al., 1997; Mark and Vincent , 1986; Vincent, 1989 and 1995).

It is essential that the air mover (sampling pump) functions at a measurable and practically constant flow rate and that the flow is always checked before and after sampling with a properly calibrated flowmeter. Analysis of air samples should be performed by a qualified laboratory which has an established quality assurance/quality control programme.

For exposure assessment, the best practice is to utilize personal samplers, which are portable sampling units carried by the workers as they move around. A common procedure is to attach the air mover to the belt, and the sampling head (which should be in the breathing zone) to the lapel of the worker's clothing. Care must be taken, however, when evaluating exposures to airborne particles, because it may happen that particles collected in the clothing are re-entrained into the sampling unit thus introducing a bias in the sampling, as demonstrated by Cohen et al. (1984).

4.3.6 Principles of size-selective samplers

An OEL which is expressed in terms of the inhalable or respirable fraction requires a sampling method which can collect particles of the desired size distribution. The objective of inhalable or respirable dust sampling is thus to separate out the larger particles from the dust stream, and to collect the remaining dust fraction on a filter or other media. The removal of the noninhalable or nonrespirable fraction by size-selective samplers such as elutriators, cyclones, and impactors is usually dependent on the greater mass and inertia of these larger particles (see ACGIH, 1995; Vincent, 1995; Kenny et al., 1997). Because of their size and operating requirements, elutriators are used for area sampling. Cyclones and impactors are available for personal and for area sampling. Brief details follow.

Elutriators

The dusty air is sucked along a vertical or horizontal channel, and the particles separated according to their settling velocities. Elutriators must be used in their design orientation, so they cannot be used for personal sampling.

Cyclones

Cyclones use centrifugal force to remove dust. A particle in a rotating air stream is subjected to a centrifugal force that accelerates it towards a surface where it will impact and lose momentum, thus being removed from the air stream. These cyclones are usually of small sizes, from 10 mm to no more than 50 mm in diameter. They have been widely used since the 1960s to collect the respirable fraction. In a typical cyclone pre-collector, the air enters tangentially at its side and swirls around inside. Particles above a certain size are thrown to the cyclone walls and collected at its base ("grit-pot"). The air containing the respirable dust leaves through the central exit in the top of the cyclone, and the air is filtered to collect the dust.

Because of the complexity of fluid behaviour in cyclones, it is difficult to predict mathematically their collection characteristics and they are based on empirical design. To achieve the proper size selection, however, the air sampling pump must be calibrated to provide the appropriate flow throughout the cyclone opening, within a specified variability, and the flow must be smooth. If the pump is not calibrated correctly, the selection will be shifted, either to larger (for low flow) or smaller (for high flow) aerodynamic diameters. Once calibrated, cyclones can be used for all particles, but are not generally used for fibres. The cyclones available on the market to be used as pre-collectors in two-stage samplers are usually made of nylon or aluminium. Different cyclone designs and manufacturers each have their own specific operational flow rates and filter cassette configuration (2-piece or 3-piece).

Impactors

When an dust-laden airstream is forced to make a sudden change in direction, as when it flows directly and at high velocity against a flat surface, the momentum of the larger dust particles causes them to hit the surface. The particles may be collected on a liquid or gel surface for further analysis. The collection efficiency of an impactor, which relies on this principle, depends on the aerodynamic diameter of the particles and the velocity of the air stream. The multistage jet impactor, e.g., the Andersen sampler for viable particles, is used to separate fractions of different particle sizes.

Filters

Filtration is in fact a combination of principles as it involves direct interception, inertial collection, diffusion, electrical forces, adhesion and re-entrainment. Filtration efficiencies vary depending on parameters which include particle shape, density, surface characteristics, amount, humidity and collection velocity, but the filters used with dust samplers are close to 100% efficient. A great variety of filters are commercially available, for example: silver membrane, Nuclepore, cellulose ester membrane, glass fibre, plastic fibre, etc., and the choice is usually determined by the analytical method to be used.

If the filter is to be weighed, it is necessary to ensure that it is not significantly affected by changes in relative humidity. Polyvinyl chloride (PVC) or Teflon (PTFE) filters are most commonly used to reduce mass gain or loss from humidity,. Information provided by filter and sampling equipment manufacturers will usually aid filter selection.

4.4 Re-evaluation

Exposure measurements should be repeated after controls have been put in place, to check that controls are effective. It will be necessary to repeat the process described in this chapter periodically, to check that substances used and processes have not been changed, and that controls have been properly maintained and are still effective.

If the original assessment showed that exposures were well below OELs, and effectiveness of controls is obvious (see Chapters 6 to 8), then the re-evaluation may not require measurement. If this is not the case, then a fairly frequent re-evaluation should take place. This should take into account newly available possible methods of control, for example, new possible substitutes.

If a repeat measurement survey is necessary, methods should permit comparison with the original results. In comparing the results, the random variability of concentrations should be taken into account, as well as any possible changes related to the day of the week and the season of the year (for example, related to heating and ventilation), and the different work practices of individual workers.

4.5 Measurement for dust control

4.5.1 Looking for dust sources

If exposure assessment indicates that control is unsatisfactory, then dust sources must be looked for. At all stages, it is useful to talk with the workers, who can often provide important information about sources of dust and its spread. It may also be helpful to make direct measurements to identify where the dust is coming from, and at what part of a work cycle the dust is released. Measurements for these purposes differ from exposure assessment (Section 4.3) in that:

- fast-response, direct-reading instruments are more useful;
- stationary (or area) monitoring may be satisfactory, and
- the aim is to identify when and where dust arises, not to establish a time-weighted average concentration.

As with personal exposure measurements, it is necessary to take into account the variability of concentrations. Stationary samples may show less variability than personal exposure measurements, but the variability may still be substantial. Also, short samples may show more variability than long samples. A real-time direct-reading instrument may be used to determine how variable the concentration is with time and place; alternatively, it may be necessary to take a series of stationary samples to determine the variability. This is necessary to distinguish dust sources from random variation. Finally, measurement may be needed to determine the size distribution of dust from different sources in order to design or select the most appropriate control measures. This is not straightforward, but can be done using impactors (Section 4.3.6), or by microscopy.

4.5.2 Direct-reading instruments

A direct-reading instrument measures the concentration in a period of minutes, or seconds, or even less, and displays the concentration on a dial or chart or similar record.

Most modern direct-reading dust samplers work by drawing the dusty air into an enclosed chamber and measuring the intensity of light scattered by the dust from a beam of light such as from a laser. Many such instruments can be hand held, and some are small enough to be carried by the worker, for example, attached to a belt. Because the amount of light scattered is not directly dependent on mass, it is necessary to calibrate such instruments, and even then, a change in size distribution or particle composition can change the relation between light scattered and mass concentration. Therefore, these are usually only rough measurements, but the fast response of these instruments makes them very useful for comparative evaluations.

As already discussed (Section 4.1), direct-reading instruments can be used for quick screening of environments or to identify dust sources on the initial walk-through surveys. If leaks are suspected from ventilation ductwork or enclosures, such instruments can be used to determine the dust source. Sometimes dust enters the air at a particular point in a work cycle, and a direct-reading instrument placed beside the worker can identify this. Similarly, direct-reading instruments can indicate when a control measure is switched on or off. They can also be used to establish the route by which dust moves through the workplace. In all of these applications, it is necessary to make enough measurements to allow for their variability; otherwise, a random change in concentration may be wrongly attributed to a dust source or a change in a control measure.

Many direct-reading instruments incorporate or can be used with portable data-loggers so that the variation in exposure can be examined later.

4.5.3 Stationary sampling

Stationary samples are not useful for measuring personal exposure, but a sample taken at a particular place, perhaps for part of a shift, can show the contribution to the exposure of a worker who spends some of the shift there. Stationary samples can, therefore, help identify sources of exposure. In order to relate stationary samples to personal exposures, similar instruments should be used. Particularly in the case of the inhalable dust fraction, measurements are dependent on the external airflow pattern; therefore, a stationary sampler will not give the same result as if it were worn by a worker.

4.5.4 Visual techniques

The spread of smoke from special smoke tubes can show how dust disperses from a source to the area near workers. Workers themselves may also have information on dust/air flow patterns. The dust lamp and video-imaging techniques described below will give more specific information on dust sources.

The dust lamp (Tyndall beam)

A simple visual test can be carried out with a “dust lamp” located so that the dust of interest scatters the light, making visible the very fine respirable dust, which is invisible to the naked eye. The UK Health and Safety Executive has produced a guidance note on the use of the dust lamp (HSE, 1997b). The dust is best seen against a dark background, looking towards the light, while shielding the eyes or camera against direct glare. Spot lamps with an elliptical reflector make the ideal source; for practical reasons they need to be portable and battery powered. The light source needs to be on a stand, such as a tripod, or clipped to a girder so that it can be directed into the dust cloud being released from a production process. If the lamp is correctly positioned it is possible to observe the movement of dust in relation to, for example, an exhaust system and the worker’s breathing zone, thus facilitating a judgement on the success of contaminant capture (see Chapter 7). It is not possible, however, to assess concentration accurately with a dust lamp.

Video imaging

Excellent visualization techniques using video imaging have been developed; for example, the NIOSH system (NIOSH, 1992), the PIMEX (Rosén, 1993) and the CAPTIV (Martin et al., 1999). Such techniques involve combining the signal from a video camera, which records the work activity, with the output from a direct-reading instrument, which continuously measures dust concentrations and has a very fast response (within 1 second), in order to follow very rapid fluctuations occurring in the work cycle. The direct reading instrument is worn by the worker, with the sampling head located in the breathing zone. The results from the direct-reading instrument are sent, by radio telemetry, to a video mixer which converts these signals to a moving bar graph, displayed at the edge of the video picture; the height of the bar is proportional to the measured concentration. The image of the worker and the bar graph are simultaneously recorded and this mixed image can be viewed on a TV screen, thus making it possible to visualize how exposure varies.

Video exposure monitoring is an effective technique to:

- discover or confirm emission sources, and to establish their relative importance;
- compare the relative efficiencies of different control measures, such as enclosures and exhaust ventilation, in combination with work practices such as worker position;
- research capture efficiencies of different hoods for local exhaust ventilation;
- research best work practices for a particular task; and
- train for better work practices and use of control.

For example, Zimmer (1997) used video imaging to comparatively evaluate dust control technologies on three track-mounted, percussion rock-drilling rigs. He was able to demonstrate the effect of drill rig, dust suppression, work practice and worker position.

4.6 Resources

Information on dust evaluations may be obtained from national institutes for occupational health and from professional associations, including the International Occupational Hygiene Association. Most of these institutions have information on sampling strategies, measurement methods, instrumentation, and manufacturers of equipment. There is also a wide range of available literature (books and journals), as well as on-line information on the Internet, where details on dust evaluations can be found. Chapter 11 includes information on these and other sources. Catalogues from manufacturers are also a helpful source of information on sampling and analytical instruments.

Equipment for the determination of airborne dust has to be carefully selected according to the purpose of the evaluation. International standards on performance of instruments for measurement of airborne particles (CEN, 1998) and on general requirements for the measurement of chemical agents (CEN, 1994) should be taken into consideration when selecting equipment.

Preference should always be given to equipment with known reliability, that means equipment which has been validated. According to the European Standard EN 482 (CEN 1994) the assessment of performance criteria of procedures or devices may be undertaken by the manufacturer, user, or testing institution, as is most appropriate. Expensive certification of instruments by an accredited laboratory is not generally necessary, although it may be required for some applications, such as mining (Leichnitz 1998).

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Chapter 5 - Control Approaches and Strategies

5.1 Approaches to solutions for occupational hazards

A renewed interest in preventive measures and control solutions was triggered about 10-15 years ago, by the introduction in various countries of legislation that stipulates a systematic approach in introducing solutions for the prevention and control of exposure to hazardous substances in workplaces (Buringh et al., 1992; Boleij et al., 1995). From the same period onwards, occupational hygiene societies in different countries, for example, the British Occupational Hygiene Society (BOHS) and the Dutch Occupational Hygiene Society (DOHS), paid renewed attention to strategies of controlling occupational exposure and the implementation of control measures during their annual conferences.

After the foundation of the International Occupational Hygiene Association (IOHA), in 1987, the issue of preventive measures was the subject of discussions and presentations during the first, second and third international conferences respectively at Brussels, Hong Kong and Crans Montana. Nevertheless, publications in the professional and scientific press, on research and experience on the introduction of prevention and control measures (such as before-and-after assessments) in specific branches of industry have remained rare.

Most scientific reports and articles dealing with various occupational hazards are restricted to mentioning the need for adequate solutions and preventive measures while failing to make concrete suggestions. This lack of interest may, in part, be explained in terms of the *ad hoc* way in which much of the health and safety improvements are made. Preventive measures may trigger a sequence of adjustments that sometimes create other problems at different points in the workplace or in the process. For instance, certain control measures may disrupt the work, affect the operators' comfort or influence production quality or speed. Control solutions are interdependent, and interact with other workplace issues. Some aspects of this interdependence will now be considered.

5.2 The need for a strategic approach

The factors that affect exposure are interdependent; therefore, all need to be addressed if dust exposure is to be successfully controlled. Some of the many factors that have an impact on occupational exposure are shown in Figure 5-1. There is no point in making costly changes in a process if, for instance, maintenance staff is not properly trained to efficiently check and maintain dust control equipment and/or intervene safely in case of process breakdown.

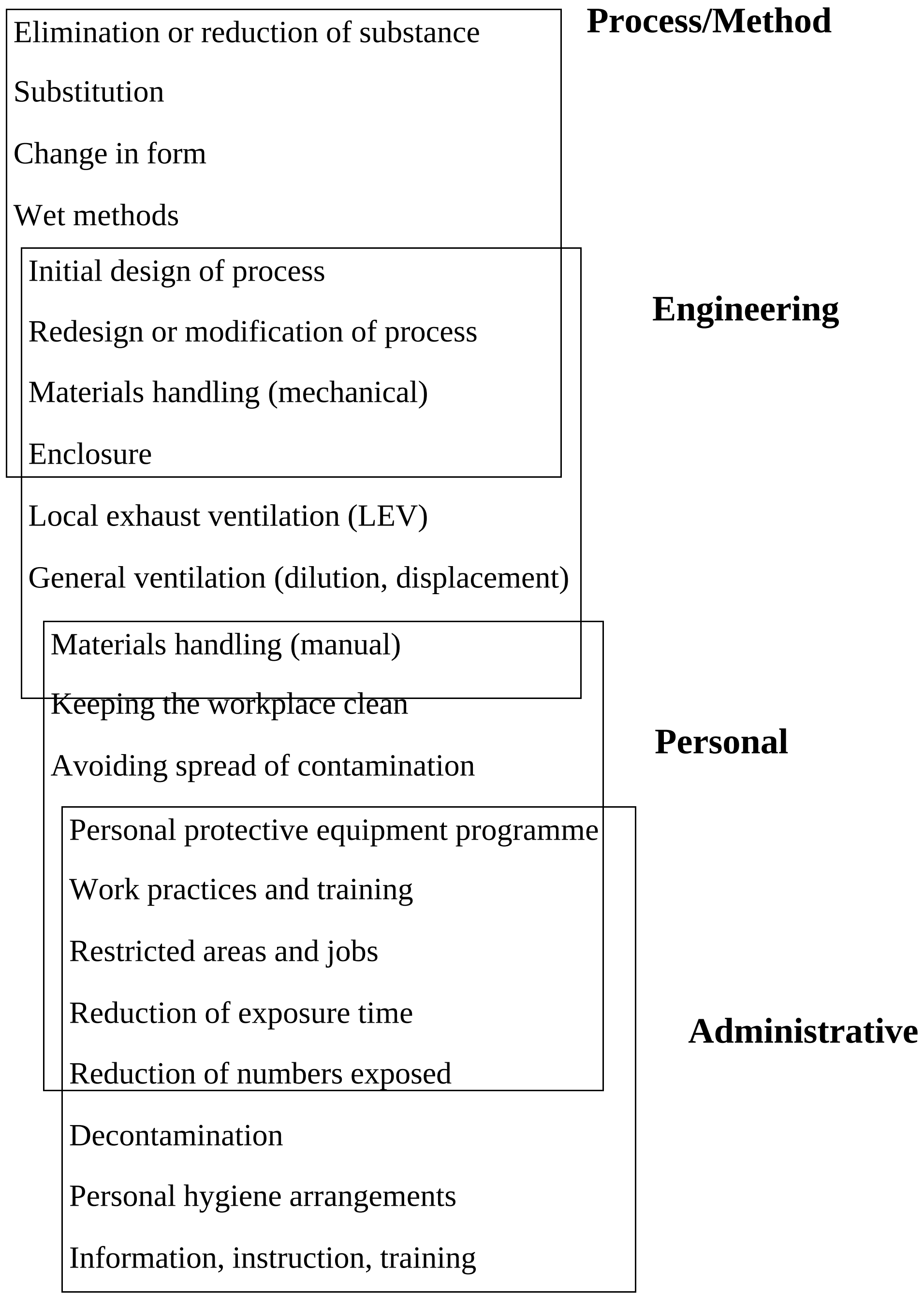

Figure 5-1 - Examples of Factors Affecting Hazard Control in the Workplace (by courtesy of A. Phillips, HSE)

Similarly, it is ineffective and inefficient to install an expensive ventilation system if other control aspects are overlooked, for example, safe storage of substances, prohibition of eating, drinking and smoking in the workplace, facilities for washing, adequate storage of materials, proper handling and laundering of contaminated clothing.

It should be kept in mind that dust does not occur alone in the workplace; many other hazards and factors need to be considered and controlled. Moreover, whenever suggesting some dust control measure, the occupational hygienist will be aware of any possibility for creating other hazards. For example, noise generated by certain types of control systems is an important consideration, as well as workplace design and many other factors.

Some of the erroneous notions that have hindered efficient hazard prevention and control in many places include:

- narrow focus in the proposal of control solutions, concentrating on ‘end of the pipe’ measures, which are often not applicable and can be expensive (e.g., local exhaust ventilation in very small workplaces), or not acceptable by workers (e.g. respirators in hot climates), with the result that people give up the idea of controlling hazards;
- allowing preventive action to be blocked when hazards and the need to control are obvious, because quantitative exposure assessments have not been carried out;
- lack of multidisciplinary approaches and intersectoral collaboration and coordination.

Solutions are often implemented on a trial and error basis, whereby stepwise alterations are made in the process or the work practice. The problem is deemed to be controlled as soon as explicit adverse effects seem to have disappeared. Although such approaches will no doubt continue to be used, they are not recommended as they can result, for example, in the introduction of new hidden hazards or other unexpected consequences. For these reasons, there is growing interest in planned and more systematic approaches towards control solutions, together with methods for predicting the effect and effectiveness of solutions.

The importance of proper management systems has been discussed in Chapter 3. A systematic approach to specific problems requires classification of the stages that interact to produce risk to the worker, and this classification will now be considered.

5.3 Classification as an aid to strategy

Classification of hazards is a fundamental element. For a large group of occupational and environmental hazards, the process from hazard generation to exposure can be divided into emission, transmission, and exposure/uptake (Table 5- I). This source – path – receiver model can be applied to all hazards related to energy or toxic materials (see Haddon et al., 1964; Johnson, 1975). Emission is the generation of a hazard from a source. Preventive measures related to emission are source controls. After release, the hazardous energy or material is transferred through a medium, e.g. the ambient air, water or food. Transmission or path controls interfere with this transfer. Worker or operator-oriented controls reduce exposure and uptake by the receiver.

Table 5 - I The Hazard Process

Source	→	**Emission**
Medium	→	**Transmission**
Receptor	→	**Exposure and Uptake**

Source-related solutions are generally accepted as being the most effective. Although this assumption has hardly been tested in research, it has served as a “rule of thumb” in the past four decades, as can be seen in the specialized literature (Barnett and Brickman, 1986), and has been incorporated in official requirements in certain countries. The argument is usually that if the source is controlled, no one will be exposed. Putting control in the transmission or uptake stages, without controlling the source, means that someone else could be unexpectedly exposed from the same source.

The classification according to the hazard process (Table 5-I) provides a classification of solutions in terms of where the intervention takes place. However this classification omits solutions which change the activity or work process in such a way that the hazard situation is fundamentally changed. An alternative approach in terms of the production process is outlined in Annex III. This is likely to prove increasingly fruitful in future, but the remainder of this chapter and Chapters 6 to 8 will concentrate on the approach in Table 5-I.

5.4 Options for control

The first steps are to recognize the dust problem (e.g., workers’ exposure, environmental pollution) and consider the options for exposure control; useful questions include:

Where does it occur?

Why does it happen?

What can be done about it?

In order to design a control strategy, it is essential to predict or identify and understand the various emission sources and the transmission factors which determine exposure, keeping in mind that the dust frequently needs to be captured as close as possible to its source, and not allowed to spread throughout the workplace. For each process and for each workplace, there is a best solution which is not necessarily the most refined technically, as many factors, such as socio-economic and cultural context, must be taken into account if solutions are to be effective, and control programmes sustainable.

It is often all too easy to come to the conclusion that emission and transmission control is impractical or too difficult and personal protective equipment is the only option left; this erroneous approach should be avoided. Usually a control solution is provided by a combination of selected methods. Basic consideration of the design of the process may result in some surprisingly cost-effective solutions to problems.

As a starting point in the design of a control strategy for any job with potential to produce unacceptable dust exposure, some questions should be asked, reflecting the factors in Figure 5-1. The questions include the following.

Source (Emission) Questions:

- Is the operation really indispensable?
- Could the process be carried out without the use of a dusty material?
- Does this operation have to be carried out this way?
- Can the process be automated?
- Is it really indispensable to use this particular harmful substance? Would it not be possible to just eliminate the use of this substance? Is there a less dusty or less toxic alternative? Could not suppliers provide raw materials in a less friable or dusty form, or in a different shape?

Transmission Questions:

- What options are available for controlling dust releases by engineering methods?

- If dust cannot be avoided, can the process be enclosed?
- If release is inevitable, can it be prevented from reaching the worker's breathing zone?
- Can the process be segregated? Do other workers need to be in the area?
- Is the work area kept clean to avoid secondary exposure sources by re-entrainment of settled dust?
- How effective are the existing controls, e.g., ventilation systems?

Exposed Person Questions:

- Does the operator need to be close to the process?
- Can the operator be moved away from the emission source?

Managerial Questions:

- Are control measures integrated into well-managed programmes, with effective workers' participation, and including periodic assessment of efficiency?
- Is the workforce well informed about substances, processes and associated risks?
- Is the workforce properly trained in best work practices?
- Which are the maintenance issues involved (frequency, cost, required skills)?
- What level of responsibility is given to whom?

Answering these questions contributes to the understanding of the many factors and variables that should be addressed in order to achieve a good level of dust control in a certain workplace. Systematic approaches to hazard control have been developed and discussed in the literature (Swuste, 1996). In view of the available knowledge on operations and materials, it is possible to predict the potentially associated occupational exposure.

As emphasised in Section 5.2, it is necessary that control of dusty materials is not considered in isolation. For example, it is not acceptable to change a process or to move an operator if this worsens the working position from an ergonomic point of view and increases the risk of musculoskeletal injury. Similarly, any impact of proposed workplace controls on environmental emissions or waste disposal must be considered. The whole effect of proposed changes must be taken into account.

Lack of political will and motivation can be a barrier to achieving good levels of control in the workplace. On the part of owners and managers there should be commitment and sensitivity towards the needs of workers, and on the part of workers there should be acceptance that certain agents are harmful and that health must be protected.

5.5 Anticipated preventive action

Most often, occupational hygiene practice focuses on hazardous conditions already occurring in workplaces. Then, the required corrective action is not only technically more difficult but also more costly, particularly considering that on-going production or services have to be stopped for retrofitting. The ideal approach is to anticipate potential health and environmental hazards during the planning and design of work processes, equipment and workplaces, in order to avoid them. Alternatives which are apparently more expensive may prove to be more economical in the long run. A useful parameter, which has seldom been estimated, is the cost of “not controlling” (Goelzer, 1997).

Whenever designing, or selecting, and installing new workplaces, work processes, equipment, or machinery, the best approach is to utilize the knowledge on hazard recognition to foresee the potentially associated hazards, and to utilize the knowledge on hazard control for preventing them before any harmful exposure may occur. Teams in charge of locating, designing and licensing new workplaces should include specialists in occupational health and safety, as well as on environmental matters. This requires a high level of training of occupational hygiene professionals, so that they can participate in the design of new processes and plant to ensure that more healthy options are presented (WHO, 1992).

There is, fortunately, an emerging and increasing tendency to consider new technologies from the point of view of their possible negative impact and its prevention, from the design and installation of the process to the handling of the resulting effluents and waste.

Environmental specialists have developed the cleaner production approach (UNEP, 1993) which not only protects the environment but also workers’ health; the link between the two is undeniable. The UNEP has a Cleaner Production programme which aims at promoting cleaner production policies, strategies, management systems and technologies to increase eco-efficiency and reduce risks to humans and the environment; this includes a database with case studies (UNEP/ICPIC).

Life cycle assessment (LCA) is an emerging approach (UNEP, 1996) through which the effects that a product has on the environment, over its entire life cycle, is evaluated. This covers extraction and processing, manufacture, transport and distribution, use, reuse and maintenance, recycling and final disposal. It is a complete approach to look at the interaction between products and the environment, including the work environment. It is a “cradle to grave” analysis, which can be used to study the environmental impact of either a product or the function a product is designed to perform, since it reviews the environmental effects of all aspects of the product under investigation. LCA may strongly influence purchasing decisions and lead to actions such as, for example, the prohibition of certain agents (e.g., highly toxic or carcinogenic) from entering a country, which is particularly important wherever there is no possibility to enforce the required controls. For example, chemicals that can only be used under very strict control should not be allowed in places where measures, such as “leak-free” enclosures and high-efficiency exhaust ventilation, are not feasible from the point of view of either implementation or operation/maintenance.

The practice of occupational hygiene must account for these new dimensions; reasoning in terms of adequate selection of work processes and cleaner production must be widely promoted. This is particularly important for countries at the industrializing stage, so that correct approaches may be followed from the start and errors already committed by other nations avoided.

Safer and cleaner production processes, even if initially more costly, are certainly worthwhile in the long run, including from the financial point of view. In this respect, there is much room for international collaboration: sharing technological knowledge and practical experiences, both positive and negative, can appreciably contribute to “safer and healthier” development everywhere.

Anticipatory preventive action should be promoted worldwide (Goelzer, 1997), including:

- occupational and environmental health impact assessments, prior to the design and installation of any new facility for industry, energy production, agriculture and food production, as well as for certain types of services such as vehicle maintenance, dry cleaning, etc;

- careful study of all feasible alternatives, for the selection of the most suitable, safest and healthiest, as well as the least polluting technology, keeping in mind that an initially less expensive alternative may turn out to be more costly in the long run;

- adequate location, in relation to geography, topography and meteorological conditions (e.g. dominant winds);
- correct design, accounting for all the possible health and safety hazards, with adequate lay-out and incorporation of appropriate control technology as an integral part of the project, including provision for safe handling and disposal of the resulting effluents and waste; and
- elaboration of guidelines and training on the operation and maintenance of workplaces and equipment, including adequate work practices, never overlooking preparedness for emergency situations.

Provision (e.g., facilities, personnel and operational costs) should be made for maintenance of equipment, of the facilities and of the preventive measures (e.g. ventilation systems), hazard communication schemes, education and training programmes for workers, as well as routine environmental and health surveillance.

5.6 Special issues

5.6.1 Maintenance and repair work

Maintenance, repair and other non-routine activities usually receive less attention than required. Experience shows that such jobs may involve gross exposure and heavy contamination, since workers often make repairs when work processes are still operational. Whenever possible, processes should be shut down for maintenance and repairs; substances likely to cause problems should be cleaned away. Substances known to have acute toxic effects should be of particular concern. Many fatal accidents have occurred because proper control procedures were not put into operation during such non-routine operations.

Staff involved in non-routine activities usually need to wear personal protective equipment, sometimes even in cases when process operators in routine activities do not wear it. The training of such staff will, therefore, be an important aspect of the control package (see Section 6.5 and Chapter 8). Particularly high-risk occupations include work on process plants handling toxic chemicals, or on dust collection facilities.

Once a control system has been decided upon and put into operation, it is necessary to make sure that the level of protection is maintained or improved. In order to obtain the best possible performance from a certain strategic approach, all control measures need to be maintained in efficient working order.

For engineering controls, such as local exhaust ventilation, regular planned maintenance, examination and testing are needed in order ensure that the desired level of protection is attained. In some countries there are specific legal requirements in this area and the competence of the person who carries out this work is an important issue.

It is important to test whether hazardous substances are being controlled in totality and administrative controls are effective, e.g. correct use of segregated areas and respirator zones. Analysis of information from sources such as environmental monitoring and health surveillance, as well as maintenance records, allow proper evaluations to be made on the continuing effectiveness of the control strategy. If feasible, monitoring programmes are instrumental in determining exposure trends; any tendency towards increased exposure should be immediately investigated and the cause corrected.

5.6.2 Emergencies

Emergencies may arise during the running of a process and established procedures need to be in place to avoid eventual disasters. Emergencies may result from loss of containment of the substance, from unexpected chemical reactions, from failure of engineering controls, or even from operator illness and human error.

Obviously, it is not possible to plan beyond foreseeable situations but, whenever possible, processes should be designed to operate so that, if a failure occurs, they shut down safely. Emergency procedures require specific training of all staff. Since such procedures may rely heavily on personal protective equipment, it is vital that all staff who could be involved be properly trained and that the required equipment be easily accessible and always kept in good working order. In the case of loss of containment during transport, it is essential that individuals understand their limit of involvement and the circumstances in which they should call for external assistance. They need to be aware of any action that ought to be taken in the interim until assistance takes over.

Emergency preparedness requires basic training and regular revision, in view of the possibility of changing hazards and circumstances.

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Chapter 6 - Control of Dust Sources

Chapter 5.3 discussed classification of control approaches into controls of source (emission), medium (transmission) or receptor (exposure and uptake). This chapter presents preventive measures that consist of action at the source. Risk can be reduced by **eliminating** the use of the dust-producing materials, by **reducing** the amount used (if possible), by **substituting** them with less hazardous ones, or by **changing their form** so that exposure becomes negligible.

6.1 Elimination

Elimination generally means process alteration or a change in technology so that possibly hazardous substances are no longer needed. Benefits include:

- workers are no longer exposed; and
- the environment is no longer contaminated, through disposal of waste or unused materials, or through the output of ventilation systems.

Examples of elimination are the disappearance of the use of lead in printing processes, the introduction of cadmium-free silver solders, and the prohibition of asbestos in decorative plasters and insulating building materials. A move from chemical pesticides towards alternate pest control systems could be seen as the elimination of hazardous substances which affect both humans and the environment.

Elimination can be encouraged by national or international legislation. Many substances have been banned either completely or for certain uses. It is helpful to keep informed on substances and products which have been banned, withdrawn, or severely restricted in different countries; the United Nations has published such a list covering pharmaceuticals, agricultural chemicals, industrial chemicals and consumer products (UN, 1994). At the user's level, purchase specifications can encourage supply of non-hazardous substances.

6.2 Substitution of materials (nature, form)

If elimination is impossible, substitution of less hazardous materials is potentially the best way to reduce risk (but see Section 6.3, Problems of substitution). The workplace and environmental benefits of Section 6.1 apply, to the extent that the hazard is reduced.

Substitution has often been used with great success. For example, much effort and innovation on substitution has centred around the need to replace asbestos in many of its vast array of applications; alternatives to the use of asbestos have been discussed in the literature (Rajhans and Bragg, 1982; Hodgson, 1989). New materials and composites have been created which mirror some of the properties of the natural minerals, and sometimes completely new ways of working have evolved. Sometimes other less hazardous fibrous products have been developed for uses such as insulation. However, caution should always be exercised; with the rush to develop new materials, there is always the danger of creating products that along with the desired advantages, also create new hazards that are not fully understood.

It often happens that a certain process or chemical is used out of habit and the possibilities for its substitution are just never fully considered. The need to use hazardous substances, in the form that they are commonly used, should always be re-examined. Approaches for substitution should be followed and this has been discussed in the literature (Goldschmidt, 1993; Filskov et al., 1996). In order to work systematically in finding possible substitution solutions, it is useful to divide the process in steps (HSE, 1994), as follows:

1. **Problem identification**
2. **Identification of a range of alternatives**
3. **Identification of consequences of the alternatives**
4. **Comparison of the alternatives**
5. **Decision**
6. **Implementation**
7. **Evaluation of the result**

Examples of substitution include the use of:

- leadless glazes in the ceramics industry;
- titanium dioxide and zinc oxide pigments as leadless paint pigments;
- non-silica parting compound for silica flour in foundries;
- non-silica moulding aggregates instead of quartz sand in foundries;
- steel shot, corundum or silicon carbide instead of quartz sand for abrasive blasting

(however, regardless of the abrasive used, serious dust hazards may still remain if and when parts to be cleaned contain surface sand, lead paints, etc.);

- synthetic grinding wheels (e.g. aluminium oxide, silicon carbide) instead of sandstone wheels; and
- non-silica materials for placing or setting sand in the ceramics industry.

6.3 Problems of substitution

Substitution may create its own problems which need to be considered, such as the following:

- A substitute may be less hazardous, but if its properties mean that airborne concentration or worker exposure increases, the risk may in fact increase. Or exposure may be decreased by the inhalation route, but increased through ingestion, or there may be greater effects on the skin.
- Substitution may reduce exposure to toxic substances, but increase other health or safety problems. For example, Bartlett et al. (1999) found that substituting solvents in the printing industry introduced ergonomic problems and slip hazards from spillages. The workers had to be involved in the changes, and given retraining. A substitute may be less toxic, but more flammable. Zirconia sand used as a substitute for silica in foundries is somewhat more radioactive than the silica, and this must be considered.
- The substitute may have compatibility problems with the rest of the process. For example, aluminium oxide, used as a substitute for silica as a placing medium in the ceramics industry, is abrasive and can cause erosion in plant and ventilation systems. Substitution of asbestos in brake pads was held up because the different frictional properties meant that the braking system had to be redesigned.

Therefore the factors which should be kept in mind include the following:

- the substitute material must have well known and appreciably lower toxicity;
- the substitute material must not introduce a hazard which is more difficult to control (a more serious hazard is not necessarily more difficult to control, but controls must be implemented);
- the substitution should be technically feasible;
- the substitute material should be available at reasonable cost.

It is **important to keep up-to-date on toxicological properties of chemicals** since chemicals thought at one time to be of very low toxicity have been found, later on, to be highly toxic or even carcinogens. Moreover, in the case of dust, substitution must be accompanied by other control measures to keep dust to a minimum, because overexposure to any dust, even of very low toxicity, should be avoided.

6.4 Substitutes for silica sand in abrasive blasting[6]

The substitution of silica sand in blasting is a controversial and important issue, in which regulations in the USA differ from those in many other countries. Silica sand as blasting material has been banned in many countries, for example: Belgium, Canada (British Columbia), Germany, Norway, Sweden, Switzerland, and United Kingdom (in part). In the United States, silica sand has been recommended to be banned (or banned) by NIOSH, SESAC (Shipyard Employment and Advisory Committee) U.S. Navy, MSHA and ANSI. A NIOSH toxicology panel has prepared a preliminary toxicity ranking for abrasive materials.

Examples of available blasting abrasives to be used instead of silica sand include olivine, staurolite, steel grit, aluminium oxide, crushed glass, and specular hematite. All of these hard abrasives contain <1% quartz, except staurolite (one brand has <5% quartz, and another brand has about 1% quartz). Garnet is also used but may contain quartz from undetectable levels to about 8%. Copper slag has also been used but it contains varying amounts of arsenic, beryllium, and other harmful metals. Steel grit is 95% to 99% iron but may contain some arsenic. Therefore, possible impurities in these materials should be investigated before assessing their potential hazard.

Some abrasives can be recycled, which lowers their operating costs significantly (e.g. steel grit can be recycled 100-500 times depending on the grades used). Some abrasives have faster blasting rates and lower consumption rates (amount of abrasive used to blast the same surface area).

Soft blasting abrasives include corn cobs, nut shells, glass beads, sodium bicarbonate, plastic media, polymer carbohydrate (wheat starch). The softer abrasives are generally used on softer substrates where the surface cannot tolerate any dimensional changes. Therefore, they generally have different applications than harder abrasives. However, some producers of sodium bicarbonate mix their abrasive with harder abrasives (garnet, staurolite, and sand) in order to improve blasting capabilities. Sponges, which require the use of special blasting

[6] Based on information provided by NIOSH.

equipment, can be mixed with garnet and staurolite to provide optimum blasting capabilities. Therefore, even “natural” abrasives may contain hazardous materials and potential hazards should be investigated.

Ground garnet, a white product, could be acceptable for blasting building facades and concrete structures where the objections to the use of silica-free abrasives have centred on the problems of discoloration.

6.5 Physical form

Although the **form** in which a certain chemical is used does not change its toxicological properties, it may change its likelihood of penetrating the human body and reaching a target organ. Therefore, it may be possible to effectively eliminate or decrease hazardous exposure by **changing the form** in which a substance is used. Discussing the matter with suppliers of raw or intermediate materials may lead to simple cost effective reductions in exposure. Examples are:

- some dusty materials can be pelletized or used in liquid suspension;
- the use of toxic materials in the form of pellets or flakes instead of fine powders is effective in reducing airborne transmissions;
- chemicals for addition to electroplating baths can be added by pump as concentrated solutions, rather than manually as dusty solids;
- in the paper industry, china clay may be supplied as a slurry, thus eliminating most of the potential dust problem;
- chemicals in the rubber industry that are pre-packed or incorporated in a rubber pre-mix for addition to the process can minimize the possibility of exposure;
- toxic powders can be used as a concentrated solution handled in a closed system (e.g., sodium hydroxide solution pumped from tank car to closed system);
- the use of wet instead of dry sand in foundry moulding substantially reduces the tendency of the fine particles to become airborne during blending, mould filling, and tamping; and
- the purchase of refractory bricks (for example, for replacement of kiln lining) already in the required dimensions avoids sawing in the workplace, thus preventing dust exposure from this source.

6.6 Process and equipment modification

This group of measures includes substitution or modification of processes, operations, and equipment with the objective of achieving appreciable reduction in contaminant generation (e.g., by reducing process speed), elimination or decrease in the formation of undesirable by-products, and elimination or minimization of physical contact between workers and hazardous agents (e.g., use of mechanical aids such as tongs, mechanization, etc.). This would include, for example, using wet milling rather than dry milling, or adapting covers for containers of dusty materials and for waste bins.

As in the case of substitution of materials, the development of new processes, operations, or equipment must not introduce new hazards and must be technically feasible and acceptable at the local level (see Section 6.3). A process that produces less dust but is appreciably noisier may not be an acceptable solution, since it may be preferable to control the dust by other measures.

A different manner to carry out an operation may reduce the hazard, for example, Figure 6-1 shows an interesting bag filling principle which decreases dust dispersion. Another example is presented in Figure 6-2, which shows a simple spiral mechanism to empty a bag of dusty material. In this example (INRS, 1994), a bag of a capacity of 1 to 2 m^3, fitted with two flexible handles (at the top and at the bottom), is placed on a support (like a hopper) with an open base. As the bag is open, the product falls by action of gravity; the bottom of the hopper is fitted with a device which contains a spiral inside which carefully moves the dusty material out thus avoiding abrupt fall and dust dispersion.

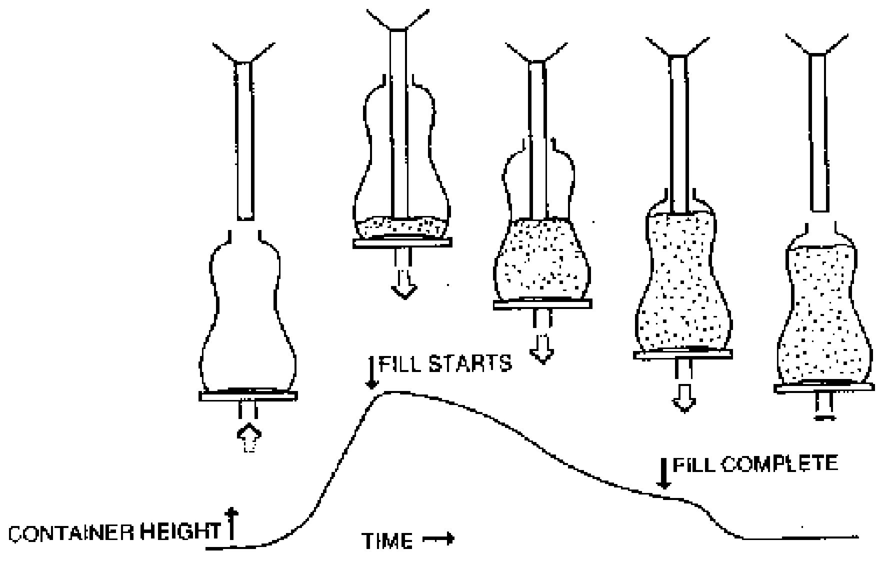

Figure 6-1 Bottom up filling principle (Transmatic Fyllan Ltd; by courtesy of A. Phillips, HSE)

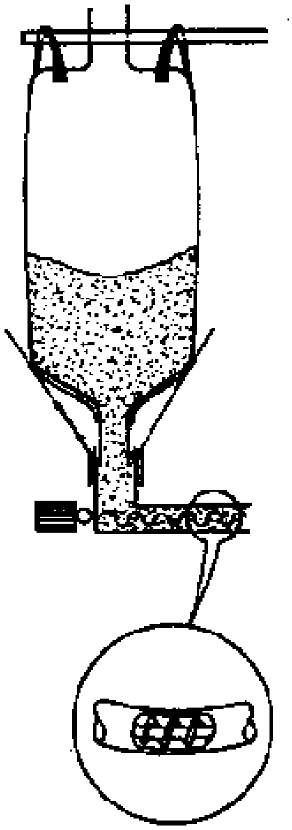

Figure 6-2 Emptying bag: spiral device for moving dusty material (INRS, 1994; by courtesy of INRS)

6.7 Wet methods

The commonest forms of process modification are the use of damp materials and wet methods, such as wetting down dusty products, wet drilling, water spraying at points of dust generation, wet cleaning of floors and work surfaces, and the use of stabilizers for stock or waste piles. Recent examples of this approach include Belle and Ramani (1997), Tien and Kim (1997) and Thorpe et al. (1999).

One of the ways in which wet methods reduce dust is that larger lumps are coated with a thin film of liquid, which encloses small dust particles that might otherwise become airborne. Wet methods are therefore more efficient when the water is introduced at the point of dust generation so that the particles become wetted before having a chance to disperse into the ambient air. In rock and coal cutting, as well as in drilling, this can be achieved by feeding water through the tool bit and onto the cutting face. This technique has been widely used to reduce dust exposure in mines and quarries. Many studies have shown sharp decreases in the occurrence of silicosis in mines and in granite quarries in the years following the introduction of wet drilling, which should be used whenever feasible. A great variety of wet drills is available in the market, as well as pneumatic jackhammers with continuous-flow water attachments.

However, even when wet drilling is used, there may still be some dust exposure because the originally dry dust is not always completely wetted and retained. Also, for certain positions of the drill (e.g. overhead drilling), the amount of water in the drilling hole may not be sufficient. Therefore, air in the breathing zone of the workers should be monitored and, if needed, ventilation and/or personal protection should be used as complementary measures. There is a danger that the presence of water sprays may give the workers an unjustified belief that there is no dust exposure.

Whenever wet methods are used, the evaporation of the dust-laden water may constitute **a secondary dust source**; this must be avoided or controlled. Another problem to be considered is the **increase of heat stress** caused by the increased humidity; particularly in hot places and under extreme situations, this may even exclude the use of wet methods. This can be of particular importance in underground mines.

Piped water can be used with portable tools. Thorpe et al. (1999) found that when power saws were used to cut paving slabs, a water system could reduce respirable dust by more than 90%.

Wet methods do not necessarily use water. For example, a dust control method based on sprinkling canola oil was effectively used in swine barns, resulting in improved indoor air quality and reduced acute health effects in healthy subjects (Senthilselvan et al., 1997). The addition of a small amount of mineral oil to mineral wools significantly reduces the emission of respirable fibres during application.

Oils or water have been added to solids to reduce dustiness in many situations. Examples are: the use of water as a wetting agent in connection with the bulk outdoor storage of certain dusty materials; wet processing of minerals; the use of slurries and wetted materials in the ceramics industry; and wet milling rather than dry milling.

It is important that the wetting liquid does not interfere with the subsequent processing of the material. Fulekar (1999) reported that quarry management gave this as the reason for not using wet methods in the very dusty production of ground quartz, even though regulations required control at source. One problem with using surfactants to improve the performance of water with minerals is subsequent interference with ore flotation processes.

Water sprays are often used in operations such as grinding, transport and transfer of dusty materials; over rocks and ores; or as a “curtain” to confine dust to certain areas and prevent it from dispersing over large portions of the work environment. There are two actions involved. First, such sprays add moisture to the working material, and so reduce the propensity of the dust to become airborne. Second, such sprays produce airborne droplets, which act as collectors for the airborne dust particles.

One problem with water sprays is that it is difficult to obtain an intimate contact between dust particles and water droplets (unless the dust is coarse). In addition, due to the movement of the dusty material (e.g. crushed ores transported on conveyor belts), dry areas may become continuously exposed and dust may be liberated before becoming wet. In such cases it may be necessary to apply the water spray continuously, as the material moves and dry dust is likely to be released. Gentle mechanical mixing greatly speeds up the process of spreading water over the rock surface, and can improve dust suppression on conveyor belts and during drilling.

When wetting rocks, the liquid has to spread over the entire surface, and it usually takes a long time for water to spread over the surface of a rock pile. The effectiveness of the control depends on the surface properties of the rock and of the liquid. Knight (1980) showed that most common rocks (except sulfide minerals and coking coals) were wettable, but that longer wetting time improved dust suppression, to an extent which varies with rock type. Knight found that addition of surfactant wetting agents speeded the process, especially for hard-to-wet rocks, but in general did not show any effect in mine trials. However, Tien and Kim (1997) found that they could make a big difference for some types of coal.

Feeding water to machines has two major problems (Knight, 1980): (1) the human one of ensuring that the water supply is connected and turned on (this can be avoided by interconnecting the water valves to the power supply), and (2) clogging due to dirt and pipe scale for which it has been recommended that spray orifices have a diameter of not less than 1.5 mm and be protected by filter screens on or close to the machine.

Most liquids are effective dust suppressors. Oils and salt solutions have been used specifically to avoid drying or freezing. Drying of settled dust in underground roadways has been prevented by using hygroscopic salt as a binder. Freezing of wet ore during surface transport in winter has been reduced by oil or salt solutions.

It is much more effective to reduce dust generation by wetting the source, than to try to capture airborne dust in a water spray, but sprays can be used in this way. The mechanism of collection is mainly impaction, and within certain limits this is more effective the smaller the droplets of the water spray and the larger the particles. Capture is less efficient for the finer dust particles. In fact, the most difficult dust fraction to control by means of wet methods is the respirable fraction, which is often the most important, but a successful example was given by Jones and James (1987). They used spray in tubes a few centimetres in diameter to induce airflow through the tubes, removing 90% of the respirable dust in the process.

Wet abrasive blasting is a technique which has been successfully used to prevent dust releases. On the other hand, wet grinding is not always efficient to control dust because it can escape before becoming adequately wetted, due to the velocity of its generation; in addition, the dust-laden water is thrown off as fine droplets which can evaporate before falling to the floor, thus liberating dust.

The use of water is very important in the **cleaning** of dusty workplaces, particularly when vacuum-cleaning equipment is not available. With concrete floors, the retention of water from routine wet cleaning keeps the floors moist for a while and thus reduces dust release. Interim water sprays may help to reduce dusting between clean-ups.

Whenever planning the use of wet methods, some aspects and **limitations that should be considered** include the following points:

- The water must not interfere critically with the process, and there must be no possibility of chemical reactions with water that might result in hazardous by-products.
- The dusty material should be "wettable".
- The extra humidity must not unduly aggravate heat stress.
- Wet floors (especially combined with poor housekeeping) can create an additional hazard of slips and falls from wet clay or other materials.
- Arrangements must be made for adequate disposal of the dust-laden water, which might otherwise eventually evaporate and release the dust.

6.8 Maintenance of Equipment

Well-maintained and well-regulated machinery and equipment generate less hazardous agents, such as airborne contaminants and noise. For example, important reductions in fugitive emissions into the workplace can be achieved by preventing leakages from closed systems, valves, pumps and sampling ports.

Maintenance programmes should include:

- inspection of all equipment in the plant, by trained personnel and on a regular basis;
- recording of equipment performance in logs that are regularly reviewed to detect any deterioration in performance;
- regular and routine service and adjustment of equipment; and
- repair of leaks or breakdowns as soon as possible, preferably before the leaks become catastrophic.

Any maintenance operation is likely to be a source of exceptional risk. Safety measures must be implemented to prevent, for example, machinery being started while under maintenance. Maintenance is likely to cause exposure, and maintenance staff must be fully considered in exposure assessment (Chapter 4), in controls (Section 5.6.1) and in health surveillance.

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