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Hazard Prevention and Control in the Work Environment:
Airborne Dust

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HAZARD PREVENTION AND CONTROL IN THE WORK ENVIRONMENT:

AIRBORNE DUST

Occupational and Environmental Health
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Hazard Prevention and Control in the Work Environment

AIRBORNE DUST

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EXECUTIVE SUMMARY

PURPOSE

Airborne contaminants can occur in the gaseous form (gases and vapours) or as aerosols, which include airborne dusts, sprays, mists, smokes and fumes. Airborne dusts are of particular concern because they are 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. 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 has therefore been produced to aid dust control and the reduction of disease.

Whenever people inhale airborne dust at work, they are at risk of occupational disease. Year after year, both in developed and in developing countries, overexposure to dusts causes disease, temporary and permanent disabilities and deaths. Dusts in the workplace may also contaminate or reduce the quality of products, be the cause of fire and explosion, and damage the environment.

As a matter of social justice, human suffering related to work is unacceptable. Moreover, appreciable financial losses result from the burden of occupational and work related diseases on national health and social security systems, as well as from their negative influence on production and quality of products. All these adverse consequences, which are economically costly to employers and to society, are preventable through measures which have been known for a long time, and which are often of low cost.

The aim of this document is to help educate and train people in the prevention and control of dust in the workplace. It also aims at motivating employers and workers to collaborate with each other, in tandem with occupational health professionals, for the prevention of the adverse effects caused by dust in the workplace. Of course, dust is only one among the many workplace hazards, which include other aerosols (such as fumes and mists), gases and vapours, physical and biological agents, as well as ergonomic factors and psychosocial stresses.

RECOGNIZING THE PROBLEM

Definitions and examples

Dusts are solid particles ranging in size from below 1 μm up to around 100 μm, which may be or become airborne, depending on their origin, physical characteristics

1 Prepared by T. L. Ogden
and ambient conditions. This document does not deal specifically with other aerosols (such as fumes and mists), with very fine particles resulting from chemical reactions in the air, or with air pollution outside the workplace. However, in many cases similar principles of control apply to these as to dusts.

Examples of hazardous dusts in the workplace include:

- mineral dusts from the extraction and processing of minerals (these often contain silica, which is particularly dangerous);
- metallic dusts, such as lead and cadmium and their compounds;
- other chemical dusts, such as bulk chemicals and pesticides;
- vegetable dusts, such as wood, flour, cotton and tea, and pollens;
- moulds and spores.

Asbestos is a mineral fibre, which is particularly dangerous, and is found, for example, in maintenance and demolition of buildings where it had been used as insulation material.

Size fractions

In occupational hygiene, particle size is usually described in terms of the aerodynamic diameter, which is a measure of the particle’s aerodynamic properties. Whether or not an airborne particle is inhaled depends on its aerodynamic diameter, the velocity of the surrounding air, and the persons’ breathing rate. How particles then proceed through the respiratory tract to the different regions of the lungs, and where they are likely to deposit, depend on the particle aerodynamic diameter, the airway dimensions and the breathing pattern. If a particle is soluble, it may pass dissolve wherever it deposits, and its components may then reach the blood stream and other organs and cause disease. This is the case, for example, of certain systemic poisons such as lead. There are particles which do not dissolve, but cause local reactions leading to disease; in this instance, the site of deposition makes a difference. When a relatively large particle is inhaled (say 30 μm), it is usually deposited in the nose or upper airways. Finer particles may reach the gas-exchange region in the depths of the lungs, where removal mechanisms are less efficient. Certain substances, if deposited in this region, can cause serious disease, for example, free crystalline silica dust can cause silicosis. The smaller the aerodynamic diameter, the greater the probability that a particle will penetrate deep into the respiratory tract. Particles with an aerodynamic diameter > 10 μm are very unlikely reach the gas-exchange region of the lung, but
below that size, the proportion reaching the gas exchange region increases down to about 2 μm.

The depth of penetration of a fibre into the lung depends mainly on its diameter, not its length. As a consequence, fibres as long as 100 μm, have been found in the pulmonary spaces of the respiratory system.

Whenever exposure to airborne dust needs to be quantitatively evaluated, instruments must be used which select the right size range for the hazard concerned. There are conventions for the size ranges of particles to be measured; it is usual to collect either the inhalable fraction, i.e. everything that is likely to be inhaled, or the respirable fraction, i.e. the particles likely to reach the gas-exchange region of the lung. For example, if silica is present, it is necessary to measure the respirable fraction of the airborne dust.

**Dust generation**

Mineral dusts are generated from parent rocks by any breaking down process, and vegetable dusts are produced by any dry treatment. The amount, hence the airborne concentration, is likely to depend on the energy put into the process. Air movement around, into or out of granular or powdered material will disperse dust. Therefore handling methods for bulk materials, such as filling and emptying bags or transferring materials from one place to another, may constitute appreciable dust sources. Coarse materials usually have a dust-sized component as a result of attrition. If dust clouds are seen in the air, it is almost certain that dust of potentially hazardous sizes is present. However, even if no dust cloud is visible, there may still be dangerous concentrations of dust present with a particle size invisible to the naked eye under normal lighting conditions.

Unless its generation is prevented or it is removed from the air, dust may move with ambient air and reach even persons who are remote from the source and whose exposure is unsuspected.

Damp materials are less likely to release airborne dust, but of course this does not apply if they dry up later.

**Sources of exposure**

Work processes likely to generate dust include the following:

- mining, quarrying, tunnelling, stone masonry, construction, and any process which breaks or separates solid material;
• foundries and other metallurgical processes, especially the cleaning of casting and breaking of moulds;

• any process using abrasive blasting, such removal of paint and rust, cleaning of buildings and small objects, and etching of glass (N.B., use of sand for these processes is often unnecessary, and if uncontrolled can cause serious health impairment, and even fatalities, among the operators, even in a few months);

• manufacture of glass and ceramics;

• handling of powdered chemicals in the chemical, pesticide, rubber manufacturing and pharmaceutical industries;

• agricultural work involving exposure to soil, intensive animal husbandry, dry vegetable products, or agro-chemicals;

• food processing, especially where flour is used;

• any process involving weighing, bagging, bag-emptying or dry transport of powdered or friable materials.

Fire and Explosion

This document is concerned with preventing disease. Nevertheless, safety hazards (which pose immediate danger of accident) cannot be overlooked. Any airborne flammable dust in sufficient concentrations can explode. Combustible dust on the ground may become airborne and increase and propagate an explosion which is started by flammable gas ignition. This can occur with vegetable and organic materials, as well as with metal and other oxidizable dusts. Static electricity can also pose hazards. Preventive measures include good housekeeping to prevent build-up of dust deposits, prevention of ignition, provision of explosion relief valves, dusting with non-flammable dusts, and confinement in low-oxygen environments.

RECOGNIZING AND EVALUATING THE PROBLEM

If any dusty process is being carried out, an assessment should be made to establish if people are at risk from dust exposure. This requires looking systematically at the workplace to see whether there is a problem and in general terms what could be done to prevent risk. The assessment should determine which hazardous materials are in use, in what amounts, and how much dust of which fraction may become airborne and lead to exposure, among other factors. An initial “walk-through” survey of the workplace should be conducted. The controls in use should be examined to determine their effectiveness, and the eventual need for other or additional controls should be
considered. Maintenance and cleaning procedures should be examined, to ensure that they are effective and do not give rise to excessive exposure. The position of workers and the organization of their tasks should be appraised in view of the location and nature of the dust sources. The level of training and information of the workforce should also be assessed. It should be ensured that management favours work practices which reduce or eliminate risks. The advice from competent professionals, preferably occupational hygienists, should be sought; this is indispensable whenever dealing with complicated situations, or with hazardous substances.

The walk-through survey will not usually include detailed measurement, although direct-reading instruments may be used to gain a rough picture of the risks present. Obvious and avoidable risks can be dealt with immediately, and schemes exist for using basic substance and use information to decide what controls are appropriate.

Quantitative evaluations of airborne dust may be performed for a number of reasons, for example: to assess workers’ exposure in relation to an adopted standard, to determine the need for control measures or to assess the effectiveness of control strategies.

The results of quantitative evaluations are usually compared with occupational exposure limits either of the country concerned, or of an international agency, or of some other authority. The evaluation strategy and methods should be those laid down by this authority. The determination of the dust air concentrations to which workers are exposed involves air sampling and further analysis of the collected dust sample, chemically, gravimetrically or microscopically.

Sampling for exposure assessment is usually carried out by means of a personal sampler, attached to the worker, and which comprises of a pump (air mover) and a sampling head located in the worker’s breathing zone. The sampling head consists of a filter holder, with a filter where the dust sample is collected, preceded by a pre-collector to separate the fraction of interest. Sampling heads should be designed to collect either the inhalable or respirable fraction of the airborne dust. The worker’s average exposure during a shift or part of a shift, as laid down in the exposure limits, can then be estimated.

Other measurements may be helpful to understand where dust is coming from, or at what moment(s) of the work cycle it is being emitted. These measurements may rely on fast-response direct-reading instruments, but simpler qualitative means such as forward light scattering (dust lamp) techniques to illuminate the dust, or smoke tubes to trace air movement, may be all that is needed. Often, but not always, the workers involved may be able to say where and when dust is emitted. There are systems, which combine video imaging with dust concentration measurements, thus allowing the visualization of how exposure changes as workers perform their tasks. This is
useful to evaluate the effectiveness of control systems and also to compare different controls (e.g. exhaust ventilation or wet methods).

If the situation is unsatisfactory, control strategies should be designed and implemented, as will be discussed in later chapters. Afterwards, the situation should be re-assessed, and a programme of periodic re-assessment should be planned and carried out.

CONTROL APPROACHES AND STRATEGIES

The prevention of occupational hazards is much more effective and usually cheaper if it is considered at the planning stage of any work process and workplace, rather than as control solutions of already existing hazardous situations. This applies first to the planning of new processes or factories, to ensure that hazardous substances are only used if necessary. If they are necessary, then emissions inside and outside the workplace, as well as waste generation, should be minimized, considering the whole life of the process and the products. The workplace and the job should be planned so that hazardous exposure is either avoided or kept to an acceptable minimum. Incentives should reward work practices which minimize exposure. The same considerations should apply to the introduction of new or modified processes and procedures. The order of priority should be to:

(1) "Plan out" the exposure, by not using hazardous substances, or using them in such a way that no one is exposed;

(2) If (1) does not completely prevent exposure, prevent or minimize emission of the substances to the air, or the presence of workers in the neighbourhood;

(3) If it is not possible to prevent exposure by any other method, then give personal protective equipment, including respiratory protective equipment (RPE), to the workers and other persons, as needed.

It is essential to adequately plan for supervision and maintenance, in order to ensure that controls are used and continue to be effective. Workplace control of exposure must be integrated with other measures, such as control of emissions to the atmosphere and waterways, and waste disposal, so that all these measures work together. (Of course, elimination of the hazardous substances prevents all these problems.) Similarly, the control of any hazardous substance in the workplace should be part of an integrated control system encompassing other hazards, such as noise and heat, as well as the ergonomic design of tasks and workplaces.

Control of exposure to dusts, alongside other health and safety measures and environmental protection, should be a key priority of the top level management, and
workers should continually be made aware that this is a management priority. Incentive systems for supervisors and workers should be designed to encourage safe procedures and not just productivity.

Prevention and control measures should not be applied in an ad hoc manner, but integrated into comprehensive, well-managed and sustainable programmes at the workplace level, involving management, workers, production and occupational health professionals.

ELIMINATION AT THE SOURCE

Elimination at the source can involve three different items: the production process, the hazardous substance and the work practices. A production process can be changed by applying a production method which generates less dust. This is a sensible approach at the design stage of a production process or when production lines are changed due to the introduction of new product lines.

A hazardous substance may be eliminated by changing the process so that the substance is no longer needed, or by using a less hazardous substance as a substitute. It is, of course, necessary to assess all of the effects of the change, taking into account other hazards such as noise, and any effects on the performance of the product, particularly effects on its safety. If substances are changed, it will be necessary to assess and control any eventual new risks.

If substitution is not feasible, ways should be sought of reducing dust generation. For example, substances might be used as pellets or in liquid suspension, rather than as powders, or, brought in as pre-formed blocks, rather than being cut in the workplace. Any wet method is likely to cause less dust exposure than a dry one. In breaking and drilling, it is much more effective to keep the substance wet at the point of dust generation than to try to capture already airborne dust by spraying it. Moreover, it is necessary to prevent subsequent drying out of dusty material, eventual slipping hazards due to wet surfaces, electrical hazards, and heat stress from the increased humidity. It is also necessary to plan for the adequate disposal of any contaminated liquid effluent.

CONTAINMENT AND VENTILATION

Containment consists in placing a physical barrier between the substance and people, for example putting a process inside a box. It is usually necessary to have a ventilation system that keeps the enclosure under negative pressure, so that there is no emission at cracks or at points where material moves in or out of the enclosure. The design should be such that maintenance and cleaning can be performed without
causing high exposure; unplanned breakdowns, which may tempt workers to open the enclosure, should be foreseen.

It may be satisfactory to partially enclose a process, for example, by having an opening at the front of an enclosure for the operator to reach in (however, the worker should never have the breathing zone between the contaminant source and the hood). Effective design is difficult, because the flow of air into the opening must be sufficient to prevent escape of the airborne material, including when people move across the opening.

Local exhaust ventilation is the removal of airborne contaminants, close to their source of generation or release, before they can spread and reach the worker's breathing zone. For this, it is necessary to ensure that the airflow is sufficient and its direction appropriate, particularly where the process generates air movement, such as a grinding wheel, or a hot process. For the same exhaust volume, the velocity of air being drawn towards the hood opening rapidly decreases with the distance (from the opening); considering that a minimum air velocity is required to ensure the capture of an airborne contaminant, it follows that the hood must be as close as possible to the point of dust generation.

General ventilation is usually desirable to control the temperature and humidity of the environment, and a properly designed system can act as a back-up control of exposure to airborne substances, by providing continual dilution of any accidental emissions. In certain cases, general ventilation can be used to control widely disseminated low toxicity contaminants.

Ventilation must be so designed that movements of personnel and vehicles, or the opening of doors and windows, cannot jeopardize its effectiveness. The design of ventilation systems should always be the responsibility of specially trained professionals. The task is particularly difficult where one fan exhausts from a set of ducts and hoods (multi-hood systems). It is easy to accidentally arrange a system so that very little air is exhausted from one or more of the openings, or to badly design a ductwork system so that it has an unnecessarily high resistance to flow. The design of the ductwork must take into account the need for cleaning (which may involve exposure of the cleaning staff) and the abrasive effect of dust.

It is essential that managers ensure a continued and effective inspection and maintenance programme, so that ventilation systems continue to work as designed, and that workers are properly informed and trained about their use.

It is necessary to ensure that ventilation does not move contaminated air to unsuspecting workers downstream, and that hazardous substances are not exhausted to the general environment in an unplanned and undesirable way. When dealing with
toxic contaminants, air cleaning devices must be incorporated to ventilation systems, in order to prevent their discharge to the outside environment, and also to prevent its re-circulation to the workplace. The disposal of collected toxic dusts must so as to minimize exposure of the responsible workers and avoid environmental effects.

WORK PRACTICES

The manner in which a worker performs a task can appreciably affect exposure, so it is important to train workers in good work practices. Video recording of tasks, with simultaneous measurement of airborne concentrations, can be a useful tool for designing and training in adequate work practices. In the case of dusts, it may be effective (and cheaper) to use a dust lamp to make the dust visible, and to use this in conjunction with video filming. Work practices which affect exposure include:

- the manner in which containers are handled and lids removed;
- the care taken in transferring dusty materials;
- work speed;
- the way in which empty containers are handled.

If the material is likely to offer an ingestion hazard, smoking, eating and drinking in the workplace should be forbidden; such activities should be restricted to designated areas, with adequate washing facilities. Personal care, including teeth brushing, washing hands and cleaning nails, showering and washing hair, before eating and after the work are important measures whenever there is the possibility of dust contamination. Workers must be properly trained about the hazards and risks from the substances used, the control measures, and any exposure monitoring. The workers are often the people who have the fullest knowledge of what happens during work, and their views should be sought on what leads to exposure and the effectiveness of control.

PERSONAL MEASURES

Every attempt should be made to avoid or minimize exposure by other methods before resorting to personal protective equipment (PPE), especially respiratory protective equipment (RPE). A respirator, particularly of the mask type, is not easy to wear for long periods; it can be very uncomfortable, especially in hot or cramped conditions, and workers may be tempted to remove it. Moreover, uncontrolled airborne dust may spread and affect people who are distant from the task, so it is better to prevent the occurrence of dust exposure in the first place. Another problem is that PPE is fallible, and may not give the protection assumed; moreover, it offers no
environmental protection. Finally, PPE and especially RPE must be conscientiously cleaned and maintained to remain effective, which often makes them a costly option; poor maintenance makes any PPE ineffective.

Nevertheless, there may be some operations, such as cleaning and maintenance, where RPE is the only practical control method. It is very important that such equipment be selected by trained personnel, taking into account the type of hazardous materials it should protect from, the nature of the work, the expected exposure, and the facial characteristics of the wearers; proper fit is of paramount importance. Workers, supervisors and maintenance staff must be properly trained in the use, maintenance and limitations of the equipment.

The tasks for which PPE is prescribed should be periodically re-assessed to see if other control measures have become applicable. Gloves and other skin protection are necessary if the dust may pose a hazard through skin absorption or ingestion, or can have a direct effect on the skin.

Substances should only be purchased from suppliers who adequately label containers and who supply adequate material safety data sheets. A management system should ensure that the necessary information is passed on to all who may be potentially exposed. Areas, where there is a need for the use of PPE or other precautions, should be clearly indicated by warning signs.

Work clothing should not allow the collection of dust, problems such as gathering dust in pockets and shoes should be foreseen. Laundering of clothing contaminated with toxic materials should be done safely, under controlled conditions, never in the homes of workers.

**ENVIRONMENTAL PROTECTION**

Prevention and control systems should be designed to protect both workers’ health and the general environment. Environmental consequences include the effect of fine particles on atmospheric visibility, damage to buildings, effects on vegetation and animals, and health effects on people outside the plant. As in the workplace, the first priority is to prevent the generation of airborne dust, and, if generation cannot be prevented, then secondly, its removal. Measures, which minimize waste generation, should be given priority, and any inevitable waste disposal should be so planned as to avoid environmental damage.
HAZARD PREVENTION AND CONTROL IN THE WORK ENVIRONMENT:

AIRBORNE DUST

PREFACE

Occupational diseases and health impairments occur every day throughout the world, due to lack or inadequacy of prevention and control measures in the workplace.

Work is indispensable for the individual, for society, and for the development of nations. Unfortunately, work processes and operations are often associated with exposure to harmful agents and stressors - such as chemicals, mineral and vegetable dusts, noise, heat, radiation, micro-organisms, ergonomic and psychosocial factors - which, if uncontrolled, will eventually lead to adverse effects on worker's health and well-being. A number of agents may go beyond the workplace and cause environmental damage.

The profession that aims at anticipating, recognizing, evaluating and controlling such workplace agents and factors is occupational hygiene. Agents, which occur as airborne contaminants, include gases, vapours, fumes, mists and dusts, and these can occur in any combination.

Occupational hygienists must look at the work environment and the workers as a whole; all agents and factors that may lead to any harmful exposure must be assessed, with a view to preventing or controlling them. However, this document focuses on only one agent - airborne dust; it does not cover other aerosols and, even in the category of dusts, it does not cover radioactive materials, as these require very specialized preventive approaches. This document is intended as a contribution to the dissemination of only one aspect of the comprehensive knowledge and experience required to ensure a healthy workplace and a healthy workforce.

As a matter of social justice, significant human suffering related to work is unacceptable. Ramazzini said, about 300 years ago: "It is but a sad profit which is achieved at the cost of the health of workers..." Another aspect is that harmful workplace agents and factors often result in appreciable financial loss due to the burden on health and social security systems, to the negative impact on production and to the associated environmental costs. People should not have to endure, and countries cannot afford, such damaging effects (Goelzer, 1996).

Many studies have demonstrated that occupational diseases constitute serious health and economic problems to nations. It should be kept in mind that most cases of occupational

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1 Prepared by B. Goelzer
diseases are never diagnosed and/or reported as such. In Latin America, for example, it has been estimated that only about 1-4% of occupational diseases are duly reported (PAHO, 1998). Very often, signs and symptoms obviously related to occupational exposure, such as advanced silicosis, are observed among workers who have never made work-related complaints.

One example of under-reporting was given in a study in a Brazilian hospital, involving 3,440 tuberculosis patients among whom 119 had silico-tuberculosis. These 119 patients, who had been previously diagnosed as having only tuberculosis, had worked in rock grinding and drilling (granite quarries), sandblasting, foundries and in ceramics and glass industries (Mendes, 1978).

If the vast available knowledge on hazard prevention and control were correctly applied in good time, exposure to hazardous agents and hence the associated harmful effects, could be avoided or greatly reduced. Alice Hamilton, pioneer occupational physician and hygienist, said: "...obviously, the way to attack silicosis is to prevent the formation and escape of dust..."

A classic example is the case of the Vermont granite-cutting industry: around the beginning of this century, pneumatic tools were introduced which generated much larger amounts of airborne dust (containing free crystalline silica) than previously generated by hand cutting tools. This was followed by a dramatic rise in the death rate of what was first considered to be tuberculosis and later found to be silicosis. In the late 1930s, local exhaust ventilation was introduced and silicosis gradually disappeared until it was virtually eradicated in these Vermont quarries by 1967 (Burgess et al., 1989). Another example is Australian coal mining, in which there has not been a new case of coal miners' pneumoconiosis in this major industry in the last 10 years, due to strict enforcement of occupational exposure limits. Studies in different countries have shown declines in the prevalence of occupational respiratory disease as the result of the introduction of dust control measures (Lee, 1997; Uragoda, 1997).

Unfortunately, the available knowledge on hazard prevention and control is not yet adequately and universally applied; for example, although silicosis has been known for centuries, exposure to dusts containing free crystalline silica remains uncontrolled in countless workplaces throughout the world, mostly but not exclusively in developing countries, still leading to "text book" cases of this preventable disease.

It often happens that more resources are placed into dealing with the consequences of harmful occupational exposure than into actually preventing them.
Even in countries where occupational hygiene is well developed, fully understood and widely practiced, there is still need to further promote hazard prevention and control. This is well illustrated by a study in the USA, which estimated the long-term cost of coal miners pneumoconiosis ("black lung"), in terms of benefit compensation costs, for 1991-2010; for the same period, research expenditures on dust control by the responsible U.S. agency are expected to be of the order of only 0.44% of such projected compensation costs (Page et al., 1997). From this, one can imagine what the imbalance must be in other parts of the world!

There is a worldwide need to effectively apply existing knowledge into appropriate preventive strategies in the workplace. As very well said in a Zen proverb: "Knowing and not applying is the same as not knowing".

In order to contribute to wider and more effective application of technical and scientific knowledge in hazard prevention and control, the occupational health programme of the World Health Organization launched the "Prevention And Control Exchange" (PACE) Initiative (Swuste et al, 1994), with the following long term objectives:

- to promote awareness and political will concerning the need for prevention and control as a priority element of occupational health programmes, and,

- to strengthen or develop, at the national level, technical and managerial capabilities for the utilization of successful approaches to the prevention and control of health hazards in the workplace, integrated into efficient and sustainable programmes, emphasizing anticipated preventive action, source control, safe work practices, workers' participation and environmental protection.

The activities envisaged for the achievement of these objectives rely basically on awareness-raising, exchanges of information, development of human resources and promotion of applied research on pragmatic control solutions, which can also be applied in small-scale enterprises. The outputs from such activities, disseminated worldwide, will hopefully contribute to the protection of workers' health and of the environment, as well as to a sustainable development. The first step was to prepare and widely distribute a PACE document for decision-makers at different levels (WHO, 1995a).

It should be mentioned that the World Health Organization, together with its network of Collaborating Centres for Occupational Health, has developed a "Global Strategy on Occupational Health for All" (WHO, 1995b), in order to identify the main needs and establish priorities for action, both at the country and global levels, as well as to trigger the necessary awareness and political commitment to develop appropriate occupational health services, through intersectoral coordination and international collaboration. The recommended key
principles for international and national occupational health policies include, among others: avoidance of hazards (primary prevention); safe technology; optimization of working conditions; and integration of production with health and safety activities.

Yet another international initiative should be mentioned, the “ILO/WHO International Programme on the Global Elimination of Silicosis”, launched in 1995, in response to a need clearly demonstrated by the worldwide prevalence of this serious occupational disease. This programme includes the formulation of national, regional and global action plans, mobilization of resources and strengthening of the required capabilities for the establishment of efficient national programmes, involving the application of primary and secondary prevention, as well as epidemiological surveillance, monitoring and evaluation of results. This programme will greatly rely on cooperation among governments, institutions and different organizations (trade, employers, non-governmental, professional), both in industrialized and developing countries, and international agencies.

In view of the worldwide magnitude of occupational exposure to dust and the acute need for increased preventive action in this respect, an activity on “Hazard Prevention and Control in the Work Environment - Airborne Dust” was started, as a component of the PACE initiative. This activity, which is also highly relevant to both the “Global Strategy on Occupational Health for All” and the “ILO/WHO International Programme on the Global Elimination of Silicosis”, has the following long term objective: “to promote and strengthen national capabilities in the field of prevention and control of dust exposure in the work environment, by contributing to the development of the required human resources”.

Initial steps involve the preparation of educational materials, namely this document, and videos illustrating and comparing preventive principles by means of “visualization” techniques, such as the “Picture Mix Exposure - PIMEX” (Rosén, 1993) and light scattering.

The target audience for these educational materials is primarily occupational hygienists in training; however, the aim is also to contribute to continuing education activities, including for other occupational health and safety professionals involved with dust problems, as well as for occupational health and safety managers, ventilation engineers, production engineers and process designers.

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The **objective** of this document is to provide general advice and to illustrate important aspects to be considered, if acceptable levels of dust control are to be achieved. For a successful control approach there needs to be:

- *Commitment from management and workers to the goal of dust control and elimination of occupational disease and other adverse effects of dust exposure;*
- *Recognition and acceptance of dust problems;*
- *Capability to estimate the magnitude of the problem;*
- *Understanding of control principles and options;*
- *Design and implementation of effective prevention and control measures;*
- *Establishment of sustainable preventive programmes, including mechanisms for continued evaluation and improvement.*

The different chapters of this document present: dust definitions and mechanisms of generation; illustrations of occupational exposure to dusts and resulting problems, particularly health effects; principles for the recognition and evaluation of dust problems in the workplace; preventive principles and strategies; specific measures to control dust at the source, such as substitution, and to control dust transmission from the source to the workers, including engineering measures (e.g., exhaust ventilation) and personal measures (e.g., work practices and personal protection). The importance of integrating specific measures into sustainable hazard prevention and control programmes is emphasized, including how management procedures impact on dust control. The relation to environmental protection is discussed, and, guidance is provided as to where further information can be found.

This document was discussed by a group of specialists, during a WHO Consultation (see Annex I), who also identified gaps in knowledge and made recommendations for further research (Annex II). Annex III presents an analysis of the production process with a view to controlling it. Annex IV presents case studies, including a proposed format; it would be greatly appreciated if new case studies on this subject were sent to WHO³, for worldwide dissemination.

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References for the Preface


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Chapter 1 - Dust: Definitions and Concepts

Airborne contaminants can 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 which, 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/cm³ 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 μm do not usually remain airborne very long; they have a terminal >7 cm/sec. However, depending on the conditions, particles even larger than 100 μm may become (but hardly remain) airborne. Furthermore, dust particles are frequently found with dimensions considerably less than 1 μm 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, 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 μm, length > 5 μm, 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.

![Schematic representation of the human respiratory tract](image)

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 μm), 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 μm, 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 μm 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 μm 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/m³, 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:

\[
Vt = 1450 \text{ cm}^3 \quad f = 15 \text{ min}^{-1} \quad \text{(moderate physical activity)}
\]
\[
Vt = 2150 \text{ cm}^3 \quad f = 20 \text{ min}^{-1} \quad \text{(high physical activity)}
\]

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 deposit in all parts of the respiratory airways.

**Deposited mass (mg) after 8 hours exposure**

![Deposited mass chart]

**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 μm 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 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 which 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 at presenting 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, and, cotton dust in ginning, carding and spinning operations, 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 by 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. 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 hence 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 increase” (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.

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 Indexes (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 piles of bulk materials are swept by air currents.

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 indexes 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 1-1 - 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)

<table>
<thead>
<tr>
<th>Material</th>
<th>Gravity drop</th>
<th>Rotating drum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur</td>
<td>0.20 (1)</td>
<td>0.20 (2)</td>
</tr>
<tr>
<td>Oil absorber</td>
<td>0.95 (2)</td>
<td>0.05 (1)</td>
</tr>
<tr>
<td>Chalk</td>
<td>1.39 (3)</td>
<td>0.22 (3)</td>
</tr>
<tr>
<td>Silica</td>
<td>1.41 (4)</td>
<td>2.81 (4)</td>
</tr>
<tr>
<td>Charcoal</td>
<td>2.92 (5)</td>
<td>4.5 (5)</td>
</tr>
</tbody>
</table>

References to Chapter 1.


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, which 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. For some dusts, a hazard may exist even when the cloud is invisible.

*A dust release can be localised 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);
million 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. 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 steels 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 of 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 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 mechanisation, but nevertheless the respirable dust concentrations overall were reduced by a factor of three (Jones, 1979). Amongst 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/m³. 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 instanced in the next section. However, implementation of control measures described later in this report, often very simple ones, can reduce such exposures to satisfactory levels (e.g. Swuste et al., 1993; Swuste, 1996, Fang, 1996).

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 watersoluble 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 symptom, 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 (kaolinitis); 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 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; the mixed agents to which workers are before the cancer appears; 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 other organs 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), 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**

<table>
<thead>
<tr>
<th>Disease</th>
<th>Agent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmers’ Lung</td>
<td>Mouldy grains, straw, hay (<em>Micropolyspora faeni, Thermoactinomyces vulgaris</em>)</td>
</tr>
<tr>
<td>Suberosis</td>
<td>Cork dust</td>
</tr>
<tr>
<td>Bagassosis</td>
<td>Mouldy sugar cane (<em>Thermoactinomyces vulgaris</em>)</td>
</tr>
<tr>
<td>Malt Workers’ Lung</td>
<td>Mouldy barley (<em>Aspergillus</em>)</td>
</tr>
<tr>
<td>Wheat disease</td>
<td>Wheat flour (<em>Sitophilus granarius</em>)</td>
</tr>
</tbody>
</table>

**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 estimates 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

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

#### 2.2.11 Other Sources of Information Concerning Health Effects


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.

Metadilokkul 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 tombstones 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, “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” amongst 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 lead blood 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.

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.

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1 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.
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/m³. 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 (stondusting) 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; Kjellén, 1995; Kjellén 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 the 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 analyze 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>
<thead>
<tr>
<th>Table 3-I  The Problem-solving Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>current condition - desired condition (criteria, standards, laws, policy)</td>
</tr>
<tr>
<td>problem recognition and definition</td>
</tr>
<tr>
<td>problem analysis</td>
</tr>
<tr>
<td>priority allocation</td>
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<tr>
<td>solution generation</td>
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<tr>
<td>choice of solutions</td>
</tr>
<tr>
<td>implementation</td>
</tr>
<tr>
<td>monitoring and evaluation of effects</td>
</tr>
<tr>
<td>planning for contingencies</td>
</tr>
</tbody>
</table>
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, 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;
- 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
- 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, it is 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, 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 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 analyze 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 analyzed 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).
References for Chapter 3.


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 with 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 “COSH 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 earlier published 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 substances 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 medium for a high; and 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 RPE to deal with cleaning and maintenance.
Table 4-I. Derivation of the Control Approach from the quantity and dustiness
(from HSE, 1999a)

<table>
<thead>
<tr>
<th></th>
<th>Low dustiness</th>
<th>Medium dustiness</th>
<th>High dustiness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hazard Group A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grams</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Kilograms</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Tonnes</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Hazard Group B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grams</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Kilograms</td>
<td>1</td>
<td>2</td>
<td>2</td>
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<tr>
<td>Tonnes</td>
<td>1</td>
<td>2</td>
<td>3</td>
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<tr>
<td></td>
<td>Hazard Group C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grams</td>
<td>1</td>
<td>1</td>
<td>2</td>
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<td>Kilograms</td>
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<tr>
<td>Tonnes</td>
<td>2</td>
<td>4</td>
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<td></td>
<td>Hazard Group D</td>
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<td>Grams</td>
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<tr>
<td>Tonnes</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

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 analyzed 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 (insofar 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 basis, are not necessarily adequate in all situations. Exposures within 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 to 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
- 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 their "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 eventual 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 to allow for potential short duration but high concentration or peak exposures to 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).
<table>
<thead>
<tr>
<th>Aerodynamic diameter (μm)</th>
<th>Inhalable fraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>1</td>
<td>97</td>
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<tr>
<td>2</td>
<td>94</td>
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<tr>
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<td>10</td>
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<td>40</td>
<td>54.5</td>
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<td>50</td>
<td>52.5</td>
</tr>
<tr>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Aerodynamic diameter (μm)</th>
<th>Thoracic fraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>94</td>
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<tr>
<td>4</td>
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<td>6</td>
</tr>
<tr>
<td>25</td>
<td>2</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Aerodynamic diameter (μm)</th>
<th>Respirable fraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>1</td>
<td>97</td>
</tr>
<tr>
<td>2</td>
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</tr>
<tr>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

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

Size-selective samplers for removing the non-respirable fraction in respirable dust sampling can be based on different principles, for example, elutriators, cyclones,
impactors, or some combination of these (ACGIH, 1995; Vincent, 1995). Also filters are the usual means of collecting the respirable component. As already mentioned, OELs are usually in terms of either the inhalable fraction or the respirable fraction. The inhalable fraction is usually collected with a specially designed filter holder (Kenny et al., 1997). To collect the respirable fraction, there must be a size selector in the airstream before the collection medium, to remove the larger particles. For personal sampling, the size selector is usually a cyclone, but other size selectors are available, and 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 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 a dust particle impinges directly and at a high velocity against a flat surface, it separates from the air stream as a result of the sudden change in direction. The
collection efficiency depends on the aerodynamic diameter and velocity of the air stream. The multistage jet impaction principle has been used to separate fractions of different particle sizes, for example, the Andersen sampler for viable particles. The principle of dry impaction is combined with subsequent dust collection in a liquid medium, for further analysis.

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. Filters, which are most commonly used to reduce mass gain or loss from humidity, are polyvinyl chloride (PVC) or Teflon (PTFE) filters. 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 is 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 on the initial walk-through survey. They are also very useful to identify dust sources by moving the instrument around the plant. If leaks are suspected from ventilation ductwork or enclosures, such instruments can be used to determine where dust is coming from. 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 dataloggers 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 sized dust often 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 however possible 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 eventual 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 “behaves”.

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;

- 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).

References for Chapter 4.


ACGIH (1999a) *1999 TLVs and BEIs (Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices)*. American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, USA. ISBN 1-882417-32-1. Updated annually.


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 whilst 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, which 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 eventual exposure can be divided into emission, transmission, and exposure/uptake (Table 5-1). This applies to all hazards related to energy or toxic materials (Haddon et al., 1964; Johnson, 1975). Emission is the generation of a hazard from a source. After release, the hazardous energy
or material is transferred through a medium, e.g. the ambient air, water or food. This is called transmission, and transmission controls interfere with this transfer. Preventive measures related to emission are source-oriented, and those related to exposure and uptake are worker or operator-oriented.

Table 5-1  The Hazard Process

<table>
<thead>
<tr>
<th>Source</th>
<th>Emission</th>
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<tbody>
<tr>
<td>Medium</td>
<td>Transmission</td>
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<tr>
<td>Receptor</td>
<td>Exposure and Uptake</td>
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</tbody>
</table>

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 which 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, which 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.

Anticipated 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;

- 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.

References for Chapter 5.


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;
- 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;
- 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 hazard 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

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.

1 Based on information provided by NIOSH.
Examples of available blasting abrasives to be used instead of silica sand include olivine, staurolite, steel grit, aluminium oxide, crushed glass, 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, eventual 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 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 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 pelletised 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 to minimise the possibility of exposure;

toxic powders 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;

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 m³, 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 sulphide 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, which 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;
• 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.

References for Chapter 6


UN (1994) *Consolidated List of Products whose Consumption and/or Sale have been Banned, Withdrawn, Severely restricted or not Approved by Governments*, 5th issue. United Nations, Department for Policy Coordination and Sustainable Development, New York
Chapter 7 - Control of Dust Transmission

Section 5.3 explained how dust could be controlled at emission, transmission or exposure stages. Chapter 6 dealt with dealt with control of emission. If dust emissions cannot be eliminated or reduced to the desired level by control of the source, ways to prevent dust transmission throughout the work environment must be considered, and that is the subject of this chapter. The principle is to separate the workers from the dust, either by containment (Section 7.1), or by using general (7.3) or local exhaust (7.4) ventilation to remove the dusty air before it reaches the worker.

7.1 Containment (or isolation) and enclosures

Containment or isolation consists basically of placing a barrier between the dust source and the workers. It can be applied at the source or beyond the source, at any point up to the immediate surroundings of the workers. Isolation of the source implies a barrier between the hazard source and the work environment, while isolation of the workers means, for example, a crane operator in a ventilated cabin. The containment/isolation principle also has simple applications: for example, placing a lid on a sieve can have a major impact in reducing exposure to fine powders.

As explained in Section 5.3, it is in principle always preferable to control at or close to the source, so enclosure of the source is preferable to enclosure of the worker. Enclosure of just one worker allows a continuing risk of exposing others, and of contaminating the environment. Source enclosures are usually coupled with exhaust ventilation so they are kept under negative pressure; in this way contaminants are removed from the workplace, and any leakages are from the workplace into the ventilation system, so that dusty air does not re-enter the workplace.

Control of exposure by total enclosure of process or handling system, if feasible, usually results in large exposure reductions. Examples include:

- enclosure of conveyor systems and successive transfer points where large amounts of material are being moved in mineral processing;
- total enclosure of the early stages of cotton processing including bale opening, blowing and carding;
- totally enclosed systems for operations involving toxic materials in the chemical industry.

Automated production and remotely controlled operations can be carried out inside enclosures without the presence of workers. Because protection will depend on the effectiveness of the enclosure, it is important to routinely check such systems for leaks or any other type of loss of containment. Moreover, special procedures for maintenance and
repair are required and anyone entering the enclosed area for any reason should be very well protected in order to avoid extreme exposure (Section 5.6.1).

Containment of a larger area can also be done as a means of preventing wider contamination, e.g., temporary enclosure during asbestos insulation removal. However, if work is then carried out inside the enclosure, the enclosure becomes a workplace, and the rules of dust control must be applied inside it. Dust production must be minimised, for example by use of wet methods. It is wrong to rely on personal protection of workers just because they are in an enclosure, but for a substance like asbestos the workers must nevertheless be very well protected inside the enclosure, with measures to prevent contamination as they leave, such as decontamination procedures, double lockers, etc. (HSE, 1990, 1999).

7.2 Ventilation principles

Buildings are usually ventilated for control of temperature, odour, and general airborne contaminants. If suitably designed, this general ventilation can also be used as a control of airborne dust, and this also often helps reduce skin and clothing contamination, and dust deposition on surfaces. If air is extracted from the locality where dust is produced, it is known as local exhaust ventilation. Principles of general ventilation are covered in Section 7.3, and of local exhaust ventilation in Section 7.4.

The aim of these sections is to present basic principles and concepts, so that readers can work with ventilation engineers to make sure that designs adequately meet the needs for a safe work environment. The sections should also serve as an introduction for a more detailed course in industrial ventilation for readers who wish to become proficient and have the required technical background.

Detailed technical information on the design of industrial ventilation systems is beyond the scope of this document; this subject has to be covered in specialized sources. ACGIH (1998) provides detailed technical information covering many specific installations. Gill (1995) gives a general introduction going into more detail than these sections. Comprehensive treatments include Burgess et al. (1989) and Burton (1997). National agencies have also provided valuable specific guidance, for example, HSE (1990, 1992, 1993, 1997, 1998, 1999), INRS (1984, 1985, 1986, 1992, 1993, 1996) and NIOSH (see Website in Chapter 11).

The existence of a ventilation system is no guarantee that airborne contaminants are under control; quality assurance on installation of the system and routine checks thereafter are essential, in order to ensure effective and continued performance. Many mistakes may occur in the design and installation. Moreover, even well designed and initially efficient systems, if not well maintained, will eventually deteriorate, which results in decreased performance,
and insufficient protection. For example, if the leads to a centrifugal fan motor are accidentally reversed (and this does happen), it will still apparently function but will only provide about 20% of the original flow.

Such situations are particularly dangerous because workers will then be unknowingly overexposed, and will not take other preventive precautions since they will have a false belief that they are already protected. The cost of installing and operating a poorly designed, hence inefficient, system may be as great as, or greater than, a well designed effective system.

7.3 General ventilation

The term general ventilation refers to the supply and exhaust of large volumes of air at a workplace, with the purpose of diluting or displacing airborne contaminants, with or without local exhaust ventilation, and for ensuring thermal comfort. It can be effective in controlling relatively low concentrations of low toxicity airborne contaminants originating from many scattered sources in a workroom. However, it is not recommended for control of large amounts of contaminants, which should be removed before being spread into the workroom. There is always a danger that general ventilation will increase exposure of people distant from the dust source or outside the workplace. In the special circumstances of underground mining, general ventilation is often necessary to control fire risk and the thermal environment; and it then becomes an important means of dust control also; but mine ventilation is a specialized field.

General ventilation may be natural or forced. Natural ventilation makes use of the buoyancy of the inside warm air. Outlets at the ceiling, perhaps aided by exhaust fans, and inlets of cooler air at floor level, can induce a steady flow. However, this may not give satisfactory thermal control, and may be particularly susceptible to changes in outdoor weather conditions. Forced ventilation is driven by inlet and exhaust fans, supplying air to the workplace and then removing it.

When using general ventilation, whether natural or forced, the correct location of air inlets and outlets, any exhaust fans, dust sources, workstations and workers are of paramount importance. Contaminants should be directed away from the workers’ breathing zone, which may be difficult to achieve, particularly when operations are scattered. A bad arrangement can mean that air moves from inlet to exhaust bypassing workers and dust sources. Clearly, workers should where possible be on the ‘clean’ side of the dust sources. Even when the arrangement is right, it must be remembered that dust usually mixes with ventilation air and does not move in a stream from the source to the outside through the fan. Turbulent mixing will spread the dust through a large part of the air of the room, as indicated in Figure 7-1. Another problem is that an air current coming from the back to the front of the body, can form turbulent eddies which bring the contaminated air up to the breathing zone, as illustrated in Figure 7-2.
Figure 7-1 - Schematic Visualization of General Ventilation (INRS, 1996: by courtesy of INRS - Institut national de Recherche et de Sécurité, France)

Figure 7-2 - Effects of Air Displacement in Ventilation, seen from above: (a) eddies of contaminated air pull the contaminant directly into the worker's breathing zone; (b) satisfactory position for worker in order to avoid inhaling contaminant (WHO, 1992)
In order to be effective, clean air should sweep through the work area, between the floor and a height of 3 metres. Even in warm climates, workrooms often lack open windows and doors for security reasons. It is then necessary to install fans directed into the workplace to provide replacement air. Often, supply and exhaust fan systems are coupled electrically to ensure that the whole ventilation system is always correctly operated.

A simple check of air movement can be made by generating smoke (in fire hazard areas to be done using chemical smoke or mist) and watching its movement. In many situations, particularly for very large workrooms that require a high rate of air exchange, natural ventilation alone will not be adequate and motor driven fans must be used to provide the desired air velocities and flow patterns. It is also possible to measure the overall air-exchange rate in a workplace by measuring the dilution rate of a tracer gas (HSE, 1992). This will indicate the potential of general ventilation for diluting contaminants, but it will still be necessary to investigate details of the air movement to ensure that sources are in fact diluted.

### 7.4 Local Exhaust Ventilation

Local exhaust ventilation extracts air close to the source of the dust, and aims to capture the dust and remove it before it can spread through the workplace and reach the breathing zones of the workers. It also serves to recover process materials (which can be economically important), protect process equipment, maintain product quality, and contribute to good housekeeping.

Local exhaust ventilation involves a controlled and directional airflow across an emission point and into a hood that is connected to a ductwork system. The components of a typical local exhaust ventilation system, presented in Figures 7-3 and 7-4, are the following:

- **enclosure or hood**, which may either partially enclose the operation or may be completely external;
- **ductwork** to carry the contaminants away from the source;
- **air cleaning device** (collector) to remove the dust from the air;
- **exhaust fan** to provide the necessary controlled airflow, and,
- **the stack** to carry the exhaust air away from the building.
Figure 7-3 Schematic representation of a classical exhaust ventilation system in the woodworking industry (INRS, 1992; by courtesy of INRS)

7.4.1 System design

In a simple system, like that shown in Figure 7-4, the fan produces a negative pressure in the duct immediately upstream, and this draws air through the system. There is a pressure drop across the air cleaner, and along each section of the duct. Finally there is a pressure drop at the entrance to the hood which draws air in from the workplace. In anything but the simplest system, ducts from several hoods are likely to lead to the same cleaner and fan, and skilled design is required to ensure that the pressures in the system are ‘balanced’, so that the velocity at every hood is high enough to capture the dust and to keep it airborne in the ducts. It is also necessary to design so that pressure losses are a minimum, so that the total flow can be provided by as small a fan as possible. The larger the fan, the more expensive, noisier and energy consuming it will be. A careful maintenance programme is required to ensure
that the system stays effective. Detailed methods are given in the works referenced in Section 7.2.

Figure 7-4 Schematic representation of the elements of a local exhaust ventilation system (NIOSH, 1973; by courtesy of the National Institute for Occupational Safety and Health, USA)

Unplanned additions may cause a system to fail, by changing the pressure distribution in the system and reducing face velocities at other hoods. In principle, changes should be avoided, and, if any are made, they must be carefully considered and engineered. A system designed for a type of contaminant cannot usually handle other contaminants.

7.4.2 Capturing the dust

The air velocity at the point of dust generation must exceed the capture velocity, i.e. it must be sufficient to carry the dust from the point of emission into the hood. The velocity at the opening of the hood (the face velocity) must be sufficient to maintain the capture velocity against disruptive air movements. The face velocity must also exceed the control velocity, the velocity necessary to keep the dust inside the hood against these disruptive draughts: 0.5 to 0.75 m/s is usually sufficient for this. The disruptive draughts may be generated by, for example, movement of work pieces into and out of ventilated enclosures, movement of workers and machines in the immediate vicinity of the hood, and, air currents from open windows and doors. Air currents generated by work activities seldom exceed 0.5 m/s near hoods, but air currents that sweep into the workroom from nearby open doors and windows
may reach several times this value. Therefore, operations requiring local exhaust ventilation should be placed in areas that are protected from draughts.

For a given airflow, good hood design can much increase the air velocity at the emission source - see Section 7.4.3.

Small light particles, perhaps generated from weighing operations in a booth-type partial enclosure, may typically be controlled by air velocities in the region of 0.5-1.0 m/s. Larger particles will require higher capture velocities, especially if they are generated by high-speed mechanical processes. In this case they may also possess considerable momentum, and entrain airflow by their motion. For example, particles will be ejected tangentially from the surface of a high-speed grinding wheel at speeds as great as 100 m/s, into air which is moved in the same direction by the wheel. The exhaust will then have to be designed to capture the larger, high-momentum particles, and also the respirable dust that follows the moving air. This requirement will dictate the velocities and exhaust volumes required. Hoods in general therefore need to be carefully designed and positioned to surround the source of emission and to ensure that the extraction air is moving in the same direction as air moved by the process.

The required capture velocity for a certain situation can be established in an empirical manner by utilizing a nozzle of any suction device and moving it closer to the emission source until the contaminant is efficiently captured. A smoke tube will show whether the air is moving into the exhaust, but a dust lamp (Section 4.5.4) or a direct-reading instrument (Section 4.5.2) will be necessary to show if the dust is captured. The velocity required can then be determined with an anemometer. The range of required capture velocities goes from 0.5 m/s to capture the evaporation of a solvent to 10 m/s to collect particles being generated by a grinding wheel. Examples in Table 7-1 provide only a rough guideline.

<table>
<thead>
<tr>
<th>Speed of Release of Contaminant</th>
<th>Ambient Air Movement</th>
<th>Required Capture Velocity, in m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Slight</td>
<td>0.5 - 1.0</td>
</tr>
<tr>
<td>Medium</td>
<td>Rapid</td>
<td>1.0 - 2.5</td>
</tr>
<tr>
<td>High</td>
<td>Very Rapid</td>
<td>2.5 - 10</td>
</tr>
</tbody>
</table>

It is important to keep in mind that the further the capture point is from the dust source, the higher the required face velocity and airflow for the same hood. The air velocity towards a hood falls off as the square of the distance from the hood face opening; this is illustrated in Figure 7-5. For example, at a distance of one duct diameter from the hood face, the air
velocity is only 10% of the face velocity. This means that it becomes increasingly difficult to achieve adequate capture velocities as the distance from the hood face increases, and the position of the work in relation to the hood must be carefully controlled - maintaining the hood-work distance is a constant problem of local exhaust ventilation. The problem of disturbing airflows also increases with distance.

\[ Q = \text{flow-rate required to ensure necessary capture velocity (V).} \]
\[ \text{In this example } Q = 20 \text{ m}^3/\text{min}. \]
\[ X = \text{distance between source of contaminant and hood.} \]

\[ Q = \text{flow-rate required to ensure same necessary capture velocity (V) as in (a).} \]
\[ \text{In this example } Q = 80 \text{ m}^3/\text{min} (4 \text{ times that in (a)}). \]
\[ Y = \text{distance between source of contaminant and hood (twice that in (a)}. \]

The required increase in flow-rate \((Q)\) with increase in distance between the source of contaminant and hood is a direct square relationship. The distance \((Y)\) in (b) is twice that \((X)\) in (a), whereas the required flow-rate \((Q)\) in (b) is four times that in (a).

Figure 7-5 - Relation between airflow and distance for an external hood (WHO, 1992)

As with general ventilation, it is important to consider the influence of the worker on local airflow, so testing must be done with the worker in position and performing normal tasks.

A related factor is that design must take into account the quantity of air induced into the system (Burgess et al., 1989). For example, falling granular material draws air from the top of a system enclosure and forces it out the bottom, carrying dust with it. If the system component (e.g. a bin) is tight, the induced air will reverse its path and carry the entrained
dust back through the upstream opening as shown in Figure 7-6. The local exhaust system must take this into account.

Figure 7-6 - Induced air concept showing how air induced into a bin from flowing granular material results in contamination of the workplace. (Burgess et al., 1989; reprinted by permission of John Wiley & Sons, Inc.)

7.4.3 Exhaust hoods

The hood is a crucial element of the local exhaust ventilation system and its proper design is a fundamental step. Hoods range in size from small nozzles to large booths and may be positioned above, below or to the side of the dust source. The hood type and the required airflow rate depend on the physical configuration of the equipment and on the emission characteristics of the process, such as the type of contaminant and rate of generation, as well as on workroom conditions, such as crosswinds, position of workers, available space, and other operations in the vicinity. Hoods should be located as close as possible to the source, preferably enclosing it, totally or partially, and so designed that the air flow pattern ensures that the contaminant is captured and retained.

The most efficient hood is one which completely encloses the contaminant source thus preventing emission. The more the source is enclosed, the smaller the volume of airflow required for effective hazard control. A useful design guideline is to consider first an enclosure with only the minimum openings needed to operate the process. Hinged doors that
normally remain shut should be considered for operations requiring access to the process, such as cleaning.

The main types of hood are the following:

- **enclosing hoods** that surround the emission source so that air contaminants are prevented from being released into the work environment by a continuous inflow of air;
- **exterior hoods**, that are located at some distance from the source; air contaminants are drawn into the hood by an airflow that establishes an effective capture velocity;
- **receiving hoods**, that are exterior hoods utilizing the motion of an ejected air stream to carry contaminants from the source into the collection hood;
- **push-pull or jet assisted hoods**, which are a form of receiving hood utilizing a jet of clean air from a local supply duct to sweep the contaminants into the exhaust hood.

For the same airflow rate, the velocity at the open face of a hood can be increased by installing a **flange** around the face opening (Figure 7-7) to make sure that the air entering the hood comes mostly from the front. For flanged hoods with flange widths at least equal to the square root of the face area, the velocity at equal distances from the open hood face will be increased by 33%.

![Figure 7-7 – Example of a Flanged Hood](Image)

(From American Conference of Governmental Industrial Hygienists: Industrial Ventilation (ACGIH): A Manual of Recommended Practice, 22nd Ed., Copyright 1995, Cincinnati, OH. Reprinted with permission.)
Side baffles can also greatly improve the capture efficiency of a simple hood (Figure 7-8).

![Diagram of side baffles](image)

Air stream

Air stream

Figure 7-8 - Illustration of the influence of side baffles (INRS, 1996; by courtesy of INRS)

**Booth type hoods** are widely used for spray painting and welding operations. Where the parts to be treated are small, the booth will usually be mounted on a bench top whereas when the parts are large, the booth will be a walk-in type.

**Moveable hoods** are useful for many non-repetitive tasks such as welding, casting chipping, and grinding or sanding with a motorized hand tool. An open pipe end, round or rectangular, that is attached to the main exhaust duct with a section of flexible hose to provide some mobility serves the purpose very well inasmuch as it can be moved close to the emission source and oriented to take maximum advantage of the direction that the tool is ejecting contaminant-laden air.

*(There are two types of hood which are useful in some circumstances, but not for dusts. Canopy hoods are frequently used for hot processes to take advantage of the rising thermal currents that carry the contaminants upwards, and slot exhaust hoods are widely used alongside open surface tanks to extract vapour.)*

An example of a movable hood for a weighing operation is shown in Figure 7-9, and a form of movable ventilation system for outdoors application is shown in Figure 7-10.
Figure 7-9  Manual weighing at travelling ventilation booth (HSE, 1997; by courtesy of the Health and Safety Executive, UK)

Figure 7-10  Abrasive blasting of bridges painted with lead-based paint may require enclosure of the blasting area and exhaust of the dust-laden air to a mobile air cleaner. The blasting personnel must wear appropriate protective equipment. (Burgess, 1995; reprinted by permission of John Wiley & Sons, Inc.)
To sum up, important characteristics to be considered when designing hoods for local exhaust ventilation systems include:

**Source characteristics:**

- size, shape and the position of the dust source;
- nature of the operation which generates the dust;
- particle size;
- speed and direction of the contaminant as it moves away from the source (is it subject only to ambient air currents or is it projected in a high velocity stream of particles in one particular direction?);
- generation rate of the contaminant (how much is being produced?).

**Worker characteristics:**

- position and movements of the worker and equipment.

**Work environment characteristics:**

- local air movements due, for example, to general ventilation of the workroom, openings, operation of nearby machinery, passing persons, workers' movements, and so on.

### 7.4.4 Ducts

After the contaminated air has been collected into the hood, it must be transported through the duct system. The design of this is not always easy as it is often limited by space considerations. It is important to minimize pressure losses: the sharper the elbows and branch entries, the higher the pressure losses. For example, an entry of a branch at 20° to the main duct will cause a pressure loss of about 1/10 of the pressure loss caused by an entry at 90°. This is why layout is so important and retrofitting is difficult. Moreover, dusts may deposit at sharp bends due to impaction. Special attention must also be paid to the fact that bends and obstructions (such as air straightening vanes) inside the ductwork lead to additional turbulence and velocity changes that cause energy loss and hence dust deposition. Systems initially designed for gaseous contaminants will not be able to handle dust.

The ductwork should be so designed that the air velocity is high enough to keep the particles from settling. This applies particularly to long horizontal runs of ducting, where the build-up of settled dust particles could reduce the airflow in the duct and adversely affect control performance at the inlet to the system. Occasionally, vertical duct runs may be designed with a low air velocity so that the larger dust particles fall out of suspension into a collecting bin at the bottom of the duct (see Section 7.6.1). In addition to the deterioration of
the system and the inconvenience of frequent cleaning, certain dust accumulations may pose a fire hazard. Recommended carrying velocities for dusts are given in Table 7-II.

<table>
<thead>
<tr>
<th>Type of contaminant</th>
<th>Duct velocity: m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light/medium density dust (e.g., sawdust, plastic dust)</td>
<td>15</td>
</tr>
<tr>
<td>Average industrial dust (e.g., grinding dust, wood shavings, asbestos, silica)</td>
<td>20</td>
</tr>
<tr>
<td>Heavy dust (e.g., lead, metal turnings, damp dusts or those which tend to agglomerate)</td>
<td>25</td>
</tr>
</tbody>
</table>

Ductwork should be made of material which is sufficiently strong and well-supported to be rigid and to stand the wear and tear it is likely to receive; this is particularly important when handling hard dusts. The fixing of ducts to walls and ceilings requires rubber or another vibration absorbing material supports in order to avoid noise.

Important considerations in the choice of duct material are physical abrasion, corrosiveness of the air contaminant and temperature of the effluent. Stainless steel is recommended for food handling, pharmaceuticals and certain chemicals, but may be corroded by others. Rigid polyvinyl chloride (PVC) and glass-reinforced polyester resins (FRP) are widely used wherever corrosive effluents must be handled. For light duty and low temperature applications (less than 40°C), sheet aluminium or plastics such as PVC and polypropylene may be used. At temperatures >150°C, special stainless steel alloys must be used. For many applications galvanised sheet steel is a suitable material. The necessary thickness will vary, for example for galvanised steel from 0.8 mm for a 200 mm diameter duct carrying non-abrasive materials such as wood dust, to 2.5 mm for a 1500 mm diameter duct carrying sand or fly ash.

Corroded ducts will unbalance the system as air will then enter through entries (holes) other than the collecting hoods, thus wasting air flow; this either overburdens the fan or lowers capture velocities, or both.
As already mentioned in Section 7.4.1, in many industrial settings there are multiple dust-generating processes to be controlled and more than one hood will be needed. The system must be designed to balance, so that all hoods operate effectively at the same time, and this condition must be checked and maintained if a new hood is added or an old one blocked. Further details are given in the works referenced in Section 7.2.

7.4.5 Fans

The fan should be the last part of the exhaust ventilation system between the air cleaner and the exhaust stack. This arrangement makes it possible for almost the entire system to be maintained under negative pressure relative to the workplace so that if leaks occur anywhere in the system, air will leak from the workplace into the duct, instead of contaminated exhaust system air leaking in the other direction. Whenever the dust is hazardous, an air cleaner should be used to remove airborne contaminants from the exhaust air stream before discharge to the atmosphere, and it should be located immediately upstream of the fan to protect the fan from corrosion and erosion.

Centrifugal fans with a backwardly curved impeller are the most widely used fans in industry because they cannot overload the fan motor and cause stoppages and because they are rugged and give trouble-free service for decades with minimal service needs. If corrosive gases are present, centrifugal fans can be made of plastic, and, for service with potentially explosive gas concentrations, they can be constructed of non-sparking materials.

Axial flow industrial fans are mainly suitable for small systems containing little or no corrosive gases or erosive particulate material. They are easy to adapt to round-duct systems as the fans are mounted inside a tubular housing, whereas the centrifugal fan requires an inlet and outlet in planes that are perpendicular to each other. However, axial fans are inherently noisier than centrifugal fans.

Propeller-type fans are useless for industrial exhaust system use because they are unable to produce the static pressures required for the operation of these systems. Propeller fans are frequently installed in factory windows to provide some amount of general room exhaust capacity. When no provision has been made to provide adequate amounts of make-up air to these workplaces, propeller fans in windows can be observed to discharge air through one half of their face and to draw air in through the other half with no net room air exchange.

Important considerations in selecting fans are size and weight, energy consumption and fan noise. Fan selection is based on calculations of the total air volume the system has to handle and the required static pressure to overcome all pressure losses, usually with an allowance of 10-20% excess for future expansion needs.
7.4.6 Replacement air

It is important not to exhaust air from a workroom without providing for an equal quantity of replacement air supplied to the worker's breathing zone. There should always be an engineered make up air system. In cold climates, in order to save in heating costs, air is often recirculated, but cleaning of the recirculated air is then crucial, and, unless the cleaning is extremely efficient, recirculation can lead to a cumulative and possibly dangerous build-up of contaminant in the workplace air.

7.4.7 Downflow booths

In recent years downflow booths have been developed, which offer a different approach to traditional local exhaust ventilation in control at powder handling processes. The systems provide a clean laminar airflow from the ceiling, to control airborne dust within a contained work area. The contaminated air moves downwards and away from the operator breathing zone into a low level exhaust grille. A high quality filtration system captures any dust before the dust is recirculated to the overhead inlet. Most systems are self-contained with integral filters and fans.

Good levels of control have been demonstrated across a range of industries including pharmaceuticals, lead battery and rubber manufacturing and in the food industry. These systems have found greatest use at batch operations although some designs have been developed to accommodate continuous production work. The systems offer greatest benefit where the process machinery causes little disturbance to established airflows. The position of the operator and the effect of the operation must be carefully considered.

7.4.8 Summary of key elements of local exhaust ventilation

The key elements of an effective local exhaust ventilation system are therefore as follows.

- A **well-designed** hood, enclosure or other inlet to collect and remove the contaminant from its source, so it does not reach the breathing zone of the workers or disperse into the work environment. The hood should be suitable for all the jobs for which it is to be used, permitting them to be carried out without interference and without generating significant breathing-zone concentrations. The design will take into account airflow generated by tools, the process, or worker movement.

- **Properly designed and constructed** ductwork, to convey the contaminant away from the source. The duct will only have smooth bends and as few changes of direction as possible. Where the ducting serves several hoods, it will be designed to maintain adequate face velocity at all the hoods simultaneously, while using as little fan power as possible.
• Immediately upstream of the fan, an appropriate filter or other air-cleaning device to remove the contaminant from the extracted airstream (see Section 7.6).

• A correctly selected and rated fan or other air-moving device to provide the necessary airflow at the hoods, and also velocity in the ducts to keep the dust airborne.

• A properly designed and constructed discharge system.

• An effective checking and maintenance programme to ensure continued satisfactory performance.

• Properly designed arrangements for providing replacement air.

If a system fails to achieve the expected level of control, its failure can usually be traced to one of the above points.

Achievement of these points requires specialized and competent professionals. In an operation of any size, teamwork involving occupational hygienists, ventilation engineers and production personnel is indispensable.

In summary, what is required to effectively manage a ventilation system is:

• A system that works

• A system that is inspected to ensure it still works

• Procedures to remedy defects

• Knowledge of the system

Some details of ventilation for dusty operations are presented in Figures 7-11 to 7-17, as examples.
### Exhaust Volume, CFM

<table>
<thead>
<tr>
<th>Wheel diam. inches</th>
<th>Wheel width inches</th>
<th>Good enclosure*</th>
<th>Poor enclosure</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to 5</td>
<td>1</td>
<td>220</td>
<td>220</td>
</tr>
<tr>
<td>over 5 to 10</td>
<td>1/2</td>
<td>220</td>
<td>300</td>
</tr>
<tr>
<td>over 10 to 14</td>
<td>2</td>
<td>300</td>
<td>500</td>
</tr>
<tr>
<td>over 14 to 16</td>
<td>2</td>
<td>390</td>
<td>610</td>
</tr>
<tr>
<td>over 16 to 20</td>
<td>3</td>
<td>500</td>
<td>740</td>
</tr>
<tr>
<td>over 20 to 24</td>
<td>4</td>
<td>610</td>
<td>880</td>
</tr>
<tr>
<td>over 24 to 30</td>
<td>5</td>
<td>880</td>
<td>1200</td>
</tr>
<tr>
<td>over 30 to 36</td>
<td>6</td>
<td>1200</td>
<td>1570</td>
</tr>
</tbody>
</table>

*No more than 25% of wheel exposed.

Minimum duct velocity = 4500 fpm heavy grinding
3500 fpm light grinding

Entry loss = 0.65 VP for straight takeoff
0.40 VP for tapered takeoff

---

**American Conference of Governmental Industrial Hygienists**

**Grinder Wheel Hood**

**Speeds Below 6500 sfm**

**Date:** 1-82

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Figure 7-11 Grinding wheel (From American Conference of Governmental Industrial Hygienists: Industrial Ventilation (ACGIH): A Manual of Recommended Practice, 22nd Ed., Copyright 1995, Cincinnati, OH. Reprinted with permission.)
Figure 7-12 - Abrasive blasting room (Burgess, 1995; reprinted by permission of John Wiley & Sons, Inc.)
Figure 7-13 - Aspirating ring ("Anneau Aspirant") for Sieving Operations (INRS, 1993; by courtesy of INRS)
Table, rip, mitre and variety saws.

<table>
<thead>
<tr>
<th>Saw diameter, inches</th>
<th>Exhaust volume, cfm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 16 incl.</td>
<td>350</td>
</tr>
<tr>
<td>over 16 to 24 incl.</td>
<td>440</td>
</tr>
<tr>
<td>over 24</td>
<td>550</td>
</tr>
<tr>
<td>variety with dado</td>
<td>550</td>
</tr>
</tbody>
</table>

Duct velocity = 3500 fpm
Entry loss = 1.0 slot VP + 0.25 duct VP

Figure 7-14 Table Saw (From American Conference of Governmental Industrial Hygienists: Industrial Ventilation (ACGIH): A Manual of Recommended Practice, 22nd Ed., Copyright 1995, Cincinnati, OH. Reprinted with permission.)
Figure 7-15  Automatic Weighing Enclosure with Fresh Air Intake (HSE, 1997; by courtesy of HSE)

Figure 7-16 - Lateral Hood, with adjustable enclosure (INRS, 1985; by courtesy of INRS)
7.5 Examination and testing of ventilation systems

The fact that a system is installed does not necessarily mean that it is efficient. An initial check, followed by routine checks is essential. Parameters to be measured include air velocity, static pressure, and energy consumption.

Tests are necessary to answer two important questions:

- Is the airflow through each hood equal to the design value?
- Is the hood capturing the contaminants given off by the process it is designed to control?

The answer to the first question involves making measurements of airflow and static pressure at various points to see if they match the design values. This tests whether the designer has successfully calculated the balance of the pressure losses in the system and specified the proper fan; and if the construction follows the design specifications. If these two conditions are met, the airflow at each hood will equal the design flow (Burgess et al.,
1989). Unfortunately, in practice such measurements are usually made on only a small number of new systems.

The second question, whether the hood is capturing the contaminants, concerns whether the design was effective for the control required, and therefore how well the hood is providing worker protection. A smoke tube, dust lamp, or direct-reading instrument will show whether the dust is captured (see Section 7.4.2), but a programme of personal sampling that measures the exposure of the workers using the new local exhaust ventilation system will be necessary to show if it is really effective. If the hoods appear to be functioning but the exposure is still too high, then a video imaging technique (Section 4.5.4) may help clarify the source of the exposure.

After the new local exhaust system has been tested and found to function adequately, it is important to prepare and follow a plan to monitor its performance periodically. Even well designed systems lose their effectiveness when maintenance is neglected. The abrasive effect of dusts may wear holes in the elbows, causing loss of suction at hoods and overloading of the fan. Air cleaning devices may become plugged, blocking passage of air, and accumulation of foreign material on fan blades may cause loss of fan efficiency and mechanical damage through imbalance.

Once a system is operating correctly, checks can be made in terms of the static pressure at different parts of the system. This is easier than velocity measurement. A small hole can be made in the duct a few centimetres downstream of the point where air leaves the hood, and connected to a simple U-tube glass manometer filled with water. The manometer should have a visible mark indicating the required pressure difference so at that point, so that deviations are obvious. Alternatively, the hole can be plugged, and a more sensitive type of manometer connected when a check is required. The correct pressure should of course be available for comparison, and it is important that the connection to the duct does not provide a leak into the duct or otherwise interfere with the airflow. One practical guide to the maintenance and testing of local exhaust ventilation systems has been published by HSE (1998).

7.6 Cleaning the exhaust ventilation

As discussed in Chapter 10, it is important that protection of the worker does not result in disproportionate pollution of the general environment, so where contaminants are removed from the workplace in ventilation air, the air should be cleaned before being discharged. This section outlines the main features of air-cleaning devices, with brief discussion of examples. Further information can be found in the specialized literature, such as Buonicore and Davis (1992).

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1 This section is based on a draft by Jiang Liu (Senior Engineer) and Prof. Guang-quan Liu, Institute of Environmental Health and Engineering, Chinese Academy of Preventive Medicine, Beijing, China.
Also to protect the wider environment, appropriate disposal of collected dust is indispensable. In some cases, it may be economical to recover materials. In the case of fabric filters, the disposal of the filters themselves is of concern, particularly if they have been used to collect toxic dusts. There was a case of intoxication of many people in a community where hand woven rugs were used which had been made of old fabric filters contaminated with a toxic metal. For wet scrubbers, the treatment and legal disposal of the waste water, including the space required for the liquid handling facilities, should be taken into consideration. Often, cleaning out and maintaining dust collectors is itself a very dusty job, and appropriate controls for the workers involved must be carefully considered.

Air cleaning devices for dust must be properly selected so that the airflow through the ventilation system is maintained and the emission standards met as the air cleaner accumulates dust.

7.6.1 Gravity settling chambers

A typical horizontal flow gravity settling chamber is constructed in the form of a long horizontal box with inlet, outlet, and dust collection hoppers. The dust-laden air stream enters the unit at the inlet, then enters the expansion section, which causes the air velocity to be reduced and particles to settle by gravity.

An improved type of settling chamber is the baffle chamber; the baffles cause sudden changes of the direction of the air stream thus enhancing particle separation and collection. The motion thus induced is superimposed on the motion due to gravity. Thus, particle collection is accomplished by a combination of gravity and an inertial effect. Particles as small as 10 to 20 μm can be collected. The settling chamber with baffle is more compact and requires less space then the simple gravity settling chamber.

Settling chambers are best used upstream of more efficient collectors. They can then reduce the load, improve the performance and extend the life of the more efficient and more expensive device, and the dust can be recovered more easily. Settling chambers have been used in many industries, including metal refining, foodstuffs, and power plants.

As an example, in China (Liu and Liu, 1997), settling chambers (with baffles) have been successfully used to treat the dust-laden gas from shaft kilns of cement plants. The settling chamber is installed on the top floor, utilizing the original building structure of the shaft kiln; it collects about 60% of the exhaust dust, which is then recycled into the process. The fractional collection efficiency is 70% for particles greater than 12 μm. Smaller particles are subsequently collected by an electrostatic precipitator or a high efficiency wet scrubber.
The advantages of settling chambers include: low cost of construction and maintenance; few maintenance problems; relatively low pressure drops; temperature and pressure limitations imposed only by the materials of construction used; dry disposal of solid particulates. The disadvantages include large space requirements and relatively low overall collection efficiency.

7.6.2 Cyclones

The most widely used mechanical collector is the cyclone. Air-cleaning cyclones are much larger versions of the sampling cyclones whose principles have already been described in Section 4.3.6. Like settling chambers, cyclones are frequently used as pre-treatment units to precede other, higher-efficiency air cleaning devices.

The advantages of settling chambers apply also to cyclones, and in addition cyclones can be used over a broad range of pressures and temperatures, from below ambient to above 1000°C. Their performance is insensitive to inlet dust concentration at the inlet; efficiency can increase with increasing particle concentration; and they can be used effectively for the removal of liquid droplets from gases, as in the discharge from absorption columns. The disadvantage is the low efficiency for airborne particles finer than 5 μm.

7.6.3 Electrostatic precipitators (ESPs)

Electrostatic precipitators are the most popular methods for efficient removal of fine solids and liquids from gas streams: they can have collecting efficiencies of over 99%.

A high potential electric field is established between discharge and collecting electrodes of opposite polarity. The discharge electrode is of small cross sectional area, such as a wire or piece of flat stock, and the collection electrode is large in surface area, such as a plate. The dust-laden gas to be cleaned passes through the field. At a critical voltage, the gas molecules are ionized at or near the surface of the discharge electrode. Ions of the same polarity as the discharge electrode attach themselves to neutral dust particles, which are then attracted to the collecting plate. On contact with the collecting surface, dust particles lose their charge and can then be easily removed by vibration, washing or by gravity.

The advantages of ESPs include: high collection efficiency for small particles; low operating pressure drops; temperature and pressure limitations imposed only by the construction materials used; dry disposal of solid particles. The disadvantages include large space requirements, high cost, and need for skilled operation and maintenance. The success of a precipitator depends not only on the quality of the system but also on adequate operation and maintenance, therefore well trained operators are required.
7.6.4 Fabric filters (baghouses)

Fabric filters remove particles from carrier gas streams by interception, impaction and diffusion. The fabric may be woven or non-woven. Initially the clean fabric serves as the porous filter through which the dusty gas is passed.

Once the filter has been in service any time, a cake of collected dust builds up and itself acts as a filter. This increases filtration efficiency, but also flow resistance. The filter must be cleaned or reconditioned before the loss of flow is critical. The accumulated cake is removed by fabric agitation or by reverse air jets or pulses, or some combination of these, but the fabric retains a residual dust cake and does not revert to the low efficiency and resistance of a clean filter.

Well designed, adequately sized and properly operated fabric collectors can be expected to operate at efficiencies in excess of 99%. Apparent inefficiency of fabric filters is frequently a result of by-pass due damaged fabric, faulty seals or leaks in the supporting structure.

The fabric is selected for its mechanical, chemical or thermal characteristics. Most are employed in either tube or envelop configuration.

The advantages of fabric filters include high efficiency for fine particles, ease of operation and maintenance, dry disposal of solid particles. The disadvantages include relatively high installation and operating costs, limitations for use in high temperatures and in handling sticky materials.

7.6.5 Wet scrubbers

Wet scrubbers are widely used in cleaning contaminated gas streams because of their ability to remove effectively both particulate and gaseous pollutants. They are designed to incorporate small dust particles into larger water droplets, which can then be removed by simple mechanisms such as gravity, impaction on baffles, or by centrifugal collectors. The droplets are produced for example by spray nozzles, by the shearing a liquid film with the gas stream, or by the motion of a mechanically driven rotor, and principles used to incorporate the dust into droplets include inertial impaction, direct interception, diffusion, gravity, condensation, electrostatic forces, and thermal gradients.

The advantages of wet scrubbers include: low initial cost; ability to collect particles (especially sticky materials) as well as gaseous pollutants; no secondary dust sources; ability to handle high temperature and high humidity gas streams; minimum fire and explosion hazards. The disadvantages include the need for adequate precautions for the disposal of the
scrubber waste liquid, corrosion problems, freezing in cold climates, and the high pressure drop and power consumption necessary to collect finer particles.

7.6.6 Selection of dust collectors

Previous sections have shown that a large choice of dust collectors is available, based on several collection principles, built in different sizes and materials, with a wide variation in effectiveness, initial cost, operational and maintenance requirements.

An ideal dust collector should:

- have high efficiency in removing dust from the air stream;
- allow the least possible amount of dust to escape;
- use minimal energy;
- reasonable initial, as well as in operating and maintenance costs;
- be simple to operate and maintain;
- meet all prevailing air and water regulations.

Consultation with manufacturers is recommended before selecting a suitable dust collector. Full understanding of the factors influencing the efficiency of dust collectors is the key for their adequate selection; these factors include:

- Concentration and particle size distributions of the airborne dust;
- Characteristics of air stream, including temperature, water vapour;
- Characteristics of dust: chemical composition, stickiness, abrasiveness;
- Disposal methods;
- Initial and operational and maintenance costs.

For some applications, concessions regarding reasonable cost and ease of maintenance may have to be made, in order to meet the emission standard for air pollution control. In some applications, in spite of their initial higher cost, ESPs are used instead of fabric filters because of the lower resistance offered to air movement (hence lower pressure drop or power requirement) and high temperature endurance.

Some useful information for the selection of dust collectors is presented in Tables 7-III to 7-VI (Vincent; 1995; reproduced by courtesy of J.H. Vincent).
### Table 7-III - Basic scientific factors for air cleaner selection

<table>
<thead>
<tr>
<th></th>
<th>Particle size to be collected</th>
<th>Gas temperature at inlet to collector</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Above 10 µm</td>
<td>1-10 µm</td>
</tr>
<tr>
<td>Cyclones</td>
<td>Yes</td>
<td>Care</td>
</tr>
<tr>
<td>Low energy</td>
<td>Yes</td>
<td>Care</td>
</tr>
<tr>
<td>Wet scrubbers</td>
<td>Yes</td>
<td>Care</td>
</tr>
<tr>
<td>High energy</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>wet scrubbers</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fibrous filters</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fabric filters</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Electrostatic</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Precipitators</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 7-IV - Practical technical factors for air cleaner selection

<table>
<thead>
<tr>
<th></th>
<th>Practical process requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low capital cost</td>
</tr>
<tr>
<td>Cyclones</td>
<td>Yes</td>
</tr>
<tr>
<td>Low energy</td>
<td>Yes</td>
</tr>
<tr>
<td>wet scrubbers</td>
<td></td>
</tr>
<tr>
<td>High energy</td>
<td>Care</td>
</tr>
<tr>
<td>wet Scrubbers</td>
<td></td>
</tr>
<tr>
<td>Fibrous filters</td>
<td>Yes</td>
</tr>
<tr>
<td>Fabric filters</td>
<td>Care</td>
</tr>
<tr>
<td>Dry electrostatic</td>
<td>Avoid</td>
</tr>
<tr>
<td>Precipitators</td>
<td></td>
</tr>
</tbody>
</table>
### Table 7-V - Aerosol property factors for air cleaner selection

<table>
<thead>
<tr>
<th></th>
<th>Dust properties</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High inlet burden</td>
<td>Erosive</td>
<td>Sticky</td>
<td>Light/Fluffy</td>
<td>Difficult to wet</td>
<td>High resistivity</td>
</tr>
<tr>
<td>Cyclones</td>
<td>Yes</td>
<td>Yes</td>
<td>Avoid</td>
<td>Avoid</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fabric filters</td>
<td>Care</td>
<td>Care</td>
<td>Avoid</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fibrous filters</td>
<td>Avoid</td>
<td>Yes</td>
<td>Care</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Wet scrubbers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low energy</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Care</td>
<td>Yes</td>
</tr>
<tr>
<td>Wet scrubbers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High energy</td>
<td>Yes</td>
<td>Care</td>
<td>Yes</td>
<td>Yes</td>
<td>Care</td>
<td>Yes</td>
</tr>
<tr>
<td>Electrostatic Precipitators</td>
<td>Care</td>
<td>Yes</td>
<td>Care</td>
<td>Care</td>
<td>Yes</td>
<td>Care</td>
</tr>
</tbody>
</table>

### Table 7-VI - Gas property factors for air cleaner selection

<table>
<thead>
<tr>
<th></th>
<th>Gas conditions</th>
<th>Other factors</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Constant pressure drop</td>
<td>Varying flow rate</td>
<td>Corrosive</td>
<td>High pressure</td>
<td>Minimum ancillary Equipment</td>
<td>On-line cleaning</td>
</tr>
<tr>
<td>Cyclones</td>
<td>Yes</td>
<td>Care</td>
<td>Care</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fabric filters</td>
<td>Care</td>
<td>Yes</td>
<td>Care</td>
<td>Care</td>
<td>Care</td>
<td>Care</td>
</tr>
<tr>
<td>Fibrous filters</td>
<td>Care</td>
<td>Care</td>
<td>Care</td>
<td>Yes</td>
<td>Yes</td>
<td>Avoid</td>
</tr>
<tr>
<td>Wet scrubbers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low energy</td>
<td>Yes</td>
<td>Care</td>
<td>Care</td>
<td>Yes</td>
<td>Care</td>
<td>Yes</td>
</tr>
<tr>
<td>Wet scrubbers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High energy</td>
<td>Yes</td>
<td>Care</td>
<td>Care</td>
<td>Yes</td>
<td>Care</td>
<td>Yes</td>
</tr>
<tr>
<td>Electrostatic Precipitators</td>
<td>Yes</td>
<td>Care</td>
<td>Care</td>
<td>Care</td>
<td>Care</td>
<td>Yes</td>
</tr>
</tbody>
</table>
References for Chapter 7.


Chapter 8 - The role of the worker: work practices and personal protection

The third component of the hazard classification in Table 5-1 in Section 5.3 is the receptor - the human operator who receives the exposure. However, a human receptor is far from passive, and the worker's activities affect the emission and transmission also. This must be taken into account in control.

8.1 Work practices

Work practices are particularly important whenever the manner in which tasks are performed influences the generation, release and dissemination of hazardous agents in the work environment, or the conditions of workers' exposure. Good work practices complement and enhance any engineering control measure.

Basic principles for good work practices include the following:

- minimizing the time during which a chemical agent is able to enter the workroom air;
- removal as soon as possible of products and wastes which may contaminate workplace air; for example, in foundries, pre-cleaning of castings right after shake-out, to reduce dust release during transport and handling of castings;
- care in closing containers immediately after use and in shutting doors to contaminated areas;
- careful handling of materials, such as transport of containers and transfer of powders from one to another;
- correct handling of empty containers and bags;
- prompt removal of spillages (see Section 9.1)
- suitable speed at performing certain tasks;
- allowing time for ventilation to clear the air, for example after shot-firing in a mine;
- avoiding where possible inhalation of visible dust;
- avoiding skin contact with chemicals which affect or penetrate the skin;
- not using chemicals from unmarked containers;
- not eating, drinking or smoking in the workplace;
- proper use of engineering controls and personal protective equipment.

An example of how work practices may contribute to, or may jeopardize the efficiency of an engineering control, is that of the disposal of empty bags (which have contained toxic powders) into a receptacle built for this purpose into the side wall of a ventilated booth (see Figure 7-17, in Chapter 7). The correct procedure, which ensures maximum control, is to place the bags into the receptacle immediately after dumping the powder and still within the controlling influence of the local exhaust system. If the worker goes about shaking and folding the empty bags outside the booth, dust will
be dispersed no matter how good the booth installation is. Engineering measures on their own do not guarantee control; a wrong procedure can counteract a carefully designed workstation.

Work processes and associated health hazards should be carefully studied with the objective of determining how exposure occurs and how it can be avoided or decreased by adequate procedural changes. Visualization techniques, such as video exposure monitoring, can be extremely valuable for such studies, as they demonstrate on the spot to all concerned how exposure changes when a worker performs the same operation in different ways, or, when a worker's breathing zone is located differently in relation to the task.

Workers are key actors, as they may not only contribute to the planning of safe work practices, but also are the ones who must accept and adhere to them.

Although work practices depend a great deal on workers' collaboration, the main responsibility should be with management, who are responsible for adequately training workers and for administrative provisions to allow workers to carry out their tasks in the safest possible way, which is not necessarily the fastest. The importance of management practice in shaping health and safety attitudes and practice has been discussed in Chapter 3. Amongst other things, job descriptions should include safe and healthy work practices.

It may occur that certain chemicals are absorbed through ingestion, particularly in situations of poor housekeeping, poor work practices and careless hygiene. Eating and drinking and storage of food or food containers in work areas should be forbidden wherever there is an ingestion hazard. Smoking should be forbidden in the workplace and strongly discouraged in general, because of the many health effects of dust which are made worse by smoking. Appropriate eating areas should be provided, and should always be kept clean. Workers should wash their hands and their faces before eating and drinking.

Figure 1-2 illustrated very well that air concentration itself is not the only parameter influencing uptake, and that even the way of breathing can affect exposure. Different persons breathe at different rates and in different ways and this affects the amount inhaled and the proportion deposited in each region of the lung.

8.2 Education, training and hazard communication

Information, education and training are key elements of preventive strategies. The importance of using safety-conscious professionals in the design of processes and workplaces has been mentioned in Section 5.5. When the workplace is operational, workers, management and production personnel should be made aware of the health
risks created by exposure to hazardous substances and educated and trained in how to prevent them.

Workers should be well informed on hazards and controls, and should know how to correctly and safely perform their tasks, operate processes and use equipment. There are many mechanisms for appropriate hazard communication, for example, courses, personal communications by supervisors and health personnel, and leaflets. In this respect, Material Safety Data Sheets (MSDS) constitute a very useful tool. In many countries, hazard communication and MSDS are the subject of national standards, enforced by law. The International Programme on Chemical Safety (IPCS) produces a series of International Chemical Safety Cards1.

In addition, the education and training of the workforce should provide adequate practical information on:

- safe work practices,
- good housekeeping,
- proper use and maintenance of protective equipment,
- personal hygiene,
- consequences of exposure to the materials they work with,
- early signs of over-exposure,
- procedures for maintenance and repair of Personal Protective Equipment (PPE), see Section 8.4,
- reasons and results of any monitoring programme.

Plant operators should be instructed on process operation, what precautions should be taken and when to take them. They should know about cleaning, storage and disposal procedures, and they should be shown why all of this is necessary. Instruction on disposal could relate to something as simple as putting waste in the correct container, which is supplied with a plastic liner and a lid.

Education and training are interlinked. Education relates to the transfer of information, but training adds the invaluable element of actually performing the task. The practical experience of going through the different aspects of control procedures reinforces the preventive message. For example, operators may need to make minor adjustments to ventilation arrangements depending on the task they are performing, or emissions may depend on process parameters over which they have some degree of control. Undeniably, training should be appropriate for the job, but it should be seen as a continuing requirement; periodic refresher training may be necessary. For

1Ten series of 70-80 Cards each have been published so far, and may be obtained from: Office for Official Publications of the European Commission, L-2985 Luxembourg Fax: +352 - 48 - 85 - 73/48 68 17
maximum benefit, managers and supervisors should appreciate why effective control is needed and they must know how best to achieve it.

Conscientious record keeping and readily accessible (and clear) records are important elements of many aspects of control. Records of training and education are part of this, and allow for adequate planning of refresher training.

8.3 Perception of dust problems

Workers' participation is indispensable in all steps of occupational hygiene practice, from the recognition to the control of hazards. In view of their experience with work processes, workers must be part of the teams planning control strategies. Their continual and close knowledge of the workplace will enable them to point out what is not obvious to the visiting professional.

However, the perception of those always in a workplace is likely to be incomplete. An occupational exposure may be overlooked, misunderstood, or ignored. For example, a study in Nigeria (Fatusi and Erbabor, 1996) demonstrated that, although 95% of the workers were aware of the potential hazards of exposure to sawdust, less than 20% wore protective masks. Some examples of commonly encountered shortcomings in perceiving dust problems will now be presented.

The fundamental toxic properties of the dust may not be appreciated.

The degree of hazard posed by different dusts varies enormously, but there may be a perception that all dusts are much the same. Particularly, but not exclusively, in the case of vegetable dusts, seemingly innocent dusts can be very harmful. Such misconceptions need to be countered by efficient hazard communication techniques, as outlined in the previous section.

Example 1: In mineral extraction, work on limestone presents a minor health hazard, but work on hard rock such as granite, grit-stones or sandstone may expose workers to very dangerous levels of respirable dust with high content of free crystalline silica. People may refuse to believe that one dust is toxicologically inert while another is very dangerous to health. It is sometimes also difficult to grasp that exposure to certain dusts will cause disease in perhaps twenty or thirty years time, particularly if no immediate consequences are seen. The fact that the most dangerous dust fraction may be largely invisible under normal light further aggravates the lack of awareness of the problem.

Example 2: In agricultural work and in the food industry there may be exposure to grain dusts and other materials which seem innocent but which may cause ill health. Repeated exposure may result in sensitization and onset of asthma or other
long-term lung damage. Very often, if this occurs, the only solution is to completely remove the sensitized worker from the source of exposure. Workers (and management) may have difficulties in grasping the notion that inhaling something like grain dust can be harmful and damage the lungs, because grain is a foodstuff perceived as completely harmless as it can be eaten with no ill effects.

**Example 3:** In woodworking, workers may be exposed to a wide variety of dusts, whose effects range from minor to carcinogenic. Sanding, for example, is a common process that exposes the worker to high concentrations of dust in the inhalable size range but this is often not perceived as a problem because wood is “natural”. Once again, there may be no immediate obvious effects, and the onset of the associated disease may occur many years after exposure started.

**Even when the toxic properties are known, the way in which exposure occurs is misunderstood.**

Because respirable dust is often invisible, there may be a false sense of security about the apparent lack of emissions from processes (see Section 2.1). Control measures may be in place, but these may in fact be ineffective without the workforce being aware of this.

### 8.4 Personal protective equipment (PPE)

All control possibilities should be explored before resorting to the use of personal protective equipment, as this is the least acceptable means for routine control of exposure, particularly to airborne contaminants. Reasons for this include the following. Some of these points are dealt with more fully later.

- PPE only protects the person wearing it, and sometimes a dust source can present a risk to other people in the same workplace, or in other places if the airborne material is spread through spillage or ventilation.
- Many studies have shown that PPE of all types usually provides less protection in the workplace that might be inferred from laboratory tests.
- PPE will not prevent environmental contamination.

In an ideal world, a selection of techniques involving plant and process design, good work practices, supported by administrative and management methods, would result in acceptable levels of dust exposure in the workplace. Unfortunately, in a real world all too often there is a need to deal with residual risk of personal exposure brought about by inadequacies in process design, constraints to prevention, or failure of control systems. The enlightened approach is to persevere with innovative solutions; however, a point is eventually reached where personal protective equipment begins to play an important part in the control strategy. For ease of presentation, this
section on PPE will be divided in respiratory protective equipment and in appropriate clothing to act as a barrier to dusty materials. Many of the elements regarding management of a respirator programme and of protective clothing programme are common.

8.4.1 Respiratory protective equipment (RPE)

Respirators are particularly difficult to wear and involve a physiological cost on the part of the wearer, particularly in hot climates and hot jobs. They should therefore only be used as a last resort, when other control methods are not feasible. The use of respiratory protective devices would be acceptable only under specific circumstances, for example:

- as a temporary solution, which environmental control measures are being designed and implemented;
- whenever environmental control measures are not technically feasible, e.g. painting a bridge, or insufficient for full protection, e.g. sand-blasting;
- for operations of very short duration, for example entering a closed polluted environment to check a gauge;
- wherever operators are overexposed to dust (high concentrations or high toxicity) for relatively short periods of time, for example sporadic abrasive blasting or weighing of toxic powders;
- maintenance and repair operations, such as replacing the refractory lining of a furnace; for operations which are technically and financially very difficult to control through environmental measures, and/or involve a very small number of workers.

Howie (1995) has reviewed practical aspects of setting up an effective PPE programme, presented under the following 18 headings. These apply equally to RPE, but of course, in practice, an RPE programme should be integrated into a general PPE programme according to need (Section 8.4.2).

1. **Assess risks and identify where control is required.**

2. **Implement all other reasonably practicable controls.**

Some examples of cases where RPE might be justified have been given above, but their necessity should always be under review, in order to reduce the number of workers wearing RPE and the time for which they must be worn. Ways of reducing dust generation or reducing the time of potential exposure of the workforce should always be sought.
The first step in the establishment of an RPE programme is to identify those areas where it is really needed. The establishment of well-defined mandatory respirator zones should be a priority. For instance, although dust levels inside the screening sheds, in a quarry, can be very high, it is not justifiable to implement costly environmental control measures, because operators do not enter the sheds on a regular basis. However, it is imperative that anyone who does enter these sheds be protected against the high short term dust exposures through appropriate respiratory protective equipment. It should be straightforward to ensure that anyone entering such areas is well informed of the problem and provided with the necessary equipment to protect against the dust. An assessment of the dust levels, along with a knowledge of the parent mineral will allow for a correct respirator selection. Careful use of respiratory protective equipment can result in appreciable reductions in personal exposure to dust.

3. Identify who needs residual protection.

It is important also to identify what level of protection is required (see heading 5 below).

4. Inform wearers of the consequences of exposure.

As discussed in Chapter 3, risk control should be integrated into management procedures. The proper use of RPE requires worker commitment, and it is therefore necessary for the wearer to understand its importance. Wearers must also understand the continuing importance of good work practice (Section 8.1), so that others are also protected. Incredible situations are sometimes observed, for example, a sandblaster may be wearing personal protective equipment, while there is no protection at all for other workers in the vicinity who may be performing completely non dusty operations, but who are nonetheless also exposed to the highly dangerous silica-containing dust. Therefore, the concern should be about “dusty zones”, rather than “dusty jobs”.

5. Select RPE adequate to control the exposure in question.

RPE should reduce the exposure of those wearing it to below acceptable levels, e.g. to below occupational exposure limits, taking into account the basis of such limits (Section 4.3.2). Various types of dust respirators are marketed. The least protection is afforded by disposable filtering face piece respirators and by half mask respirators acting under negative pressure. A higher level of protection may be provided by full-face respirators and by powered supply air respirators with helmets or hoods. Powered respirators with a supply of fresh filtered air to the face mask provide a relatively comfortable option. In some instances the best option might be to use a full-face mask or half mask supplied with clean air from a compressor system. Excessive breathing rates can reduce the effectiveness of respiratory protection. It
should be remembered that filtering respirators must not be used in atmospheres where the oxygen is depleted. Also, users of respirators frequently confuse particulate and vapour filters, with the disastrous result of wearing a completely ineffective filter against the hazard in question. Moreover, there are particulate contaminants that may subsequently vaporize through the filter element.

RPE may be tested according to an array of national or international standards. However, it has become increasingly apparent in recent years that the protection afforded by respirators in workplace use can be a factor of ten or worse less than might be expected from laboratory tests. It is essential to take this into account in considering what protection factor is required. Howie (1995) recommends that potential users should request workplace performance data from manufacturers, not just performance against standard laboratory tests, and should only purchase equipment where these data are provided.

Respirators should be selected for use only within their designed operating range. Selection criteria will include the comfort factor and the ease of use of the equipment. It is important that wearers are given a choice of equipment whenever possible. The proper use of respirators has been well discussed in the literature (HSE, 1998; ILO, 1997; NIOSH, 1987 and 1996; OSHA, 1998). As with other inadequate control equipment, inadequate RPE conveys a false sense of security and not only actually endangers workers but also wastes money.

6. Match RPE to the user.

The RPE should be a good fit for all who can be expected to use it, and this will usually mean that a range of sizes and types must be available, and where possible the wearer should be given a choice. RPE may be mainly tested on Caucasian males, but females and other racial types may well require a different range of sizes (Han, 2000). If the user has facial hair, including stubble, this may well prevent a good fit for half-mask types, and necessitate the use of powered respirators.

Some national authorities now require or recommend a system of measuring the goodness of fit of RPE to the wearer, particularly if used for very hazardous materials like asbestos (HSE, 1999).

7. Ensure that RPE does not create risk(s).

8. Ensure that different PPE’s are mutually compatible.

Poorly designed RPE may restrict the field of view of the wearer, and this must be considered in selection in relation to the job that must be done. Some designs
interfere with safety glasses or helmets, or these other types of PPE may affect the RPE so that fit is compromised.

9. **Involve wearers in the RPE selection process.**

10. **Provide RPE to workers, free of charge.**

11. **Train wearers in the proper use of their RPE.**

   As already mentioned under (4) above, dust control must be integrated into management process, and human aspects of this are particularly important in the PPE programme. Education and training on the proper use, cleaning and maintenance of personal protective equipment, as well as consideration of individual factors and cultural aspects, are very important. "Wearers and their supervisors should be thoroughly trained in how to fit the PPE correctly, how to assess whether the equipment is correctly fitted, how to inspect the PPE to ensure that it has been correctly manufactured and, for reusable equipment, whether it has been adequately cleaned and maintained." (Howie, 1995) Howie also emphasises that the greater the risk protected against, the more important is training in correct use.

12. **Minimize wear periods.**

   The importance of ongoing consideration of other methods of control has already been emphasised. If workers are required to wear restrictive, hot or uncomfortable RPE for extensive periods, they are likely to take any excuse to remove it.

13. **Supervise wearers to ensure the correct use of RPE.**

   Immediate supervisors should also be trained in the need, proper use and limitations of RPE.

14. **Maintain the RPE in efficient and hygienic condition.**

15. **Inspect RPE to ensure that it is correctly maintained.**

   Maintenance and a programme of inspecting the equipment ensure that the initial performance characteristics continue throughout its life. Respirators need to be looked after. Seals deteriorate, filters block up or lose their effectiveness, exhalation valves may stick in the open position. Powered respirators rely on a well-charged battery for extended use and to ensure that the airflow is adequate, so they need careful maintenance and recharging facilities if they are to remain effective. Obviously, the more complex the equipment, the greater the possibility that something goes wrong. Proper cleaning and storage are important aspects of maintenance, not only because
these are likely to affect the equipment’s efficiency, but also because users may well not wish to use dirty equipment.

16. *Provide suitable storage facilities for the RPE.*

Badly stored equipment may be stolen, or become dirty and damaged, therefore more likely to be ineffective and less likely to be properly used.

17. *Record usage, maintenance and inspection data.*

This will help ensure that these tasks are actually carried out, and that a RPE is not used beyond its effective lifetime.

18. *Monitor programme to ensure continuing effectiveness.*

This is another aspect of the integration of dust control measures into effective management procedures (Chapter 3).

It cannot be overemphasized that the use of respiratory protective equipment should never be considered as a substitute for proper dust control measures but as a last resort. Nevertheless, it can be an important part of the overall strategy to minimise personal exposure in dusty processes. Failure to recognise the need for a respirator programme and poor management of the implementation of that programme will result in unnecessary operator exposure, which will lead to greater incidence of occupational impairment and disease.

### 8.4.2 Protective clothing and control of exposure

For many dusty materials, the main concern is inhalation exposure. For materials that are also toxic by ingestion or where skin contact creates problems, there is a need for effective selection and use of working clothes. Effective programmes are linked with good systems for decontamination and prevention of spread.

The selection process for protective clothing has to take into account the conditions under which it is to be used. A completely effective barrier to dust penetration may lead to a situation where heat stress becomes a major factor. Very often clothing may be chosen to offer the best compromise solution. Fabrics are available that have a range of performance characteristics not only in terms of dust penetration resistance but also in terms of permeability to air and moisture. The more comfortable garments are those that display low resistance to air and moisture movement, thus helping to prevent conditions that lead to heat stress. Garments may be disposable, of limited
life, or designed for longer-term use with regular laundering. Protective clothing for dusty occupations often doubles as normal workwear.

Just as with respiratory protective equipment, there is a need to ensure that clothing fits properly. Factors to consider include the need to have garments sealed at the wrist and ankles and provided with a hood, resistance of the material and seams to withstand tough working conditions; etc. Personal protective clothing needs to be compatible with other items of personal protective equipment such as hearing protection, eye protection and respirators. Garments should be selected according to the required degree of protection. Information from manufacturers or suppliers should be helpful in this respect. Users need to know if garments can be satisfactorily cleaned for re-use or whether they must be regarded as disposable (single use).

Protection of the hands may be the most important part of a programme designed to prevent skin exposure. Correct selection of gloves is vital if they are to provide an adequate barrier. It should be kept in mind that dusts do not occur alone and other chemicals may affect the glove material; for example, certain substances (e.g., many organic solvents) are particularly penetrating and test information is vital for the correct selection of gloves. How often gloves are changed depends on the potential for degradation and the type of use. Some substances seriously degrade the glove material making it more prone to splitting or cracking, with resultant loss of barrier protection. Gloves may only provide an effective barrier against a hazardous substance for a limited period of time, and thereafter provide no protection even though they still appear to be sound. If the inside of a glove becomes contaminated, exposure may be increased rather than minimised. Perspiration increases the likelihood of skin absorption. Other problems associated with gloves include loss of dexterity and a false sense of security for the operator.

Effective procedures should ensure that gloves are carefully removed and properly cleaned after use, and prior to storage, which should be in a clean place, away from contaminated surfaces.

Any PPE programme has to be properly planned and managed if it is to be effective. Programme management goes much beyond the correct selection of equipment. It is a continuing battle to educate the workforce about why PPE is needed and how to ensure the greatest protection from its use. This includes correct methods of taking off PPE as well as putting it on. Problems may occur when workers remove protective clothing especially if gloves are taken off first and the hands become contaminated. Another problem is that, when workers leave a highly contaminated area and remove the respirators first, toxic dust collected on and in clothing may be breathed. Finally, an effective personal protection programme often is an expensive option when compared with innovative process change.
8.5 Personal and clothing hygiene

Personal and clothing hygiene is essential, for workers involved with hazardous chemical agents, particularly in the prevention of occupational skin diseases (dermatoses and cancer) and when dealing with substances which can be absorbed through skin.

Working clothes should be routinely changed and, when accidentally soiled with a toxic substance, should be changed immediately and never taken to the workers' home but laundered in special facilities (where adequate care is taken). A garment soaked with a chemical (with capacity to penetrate through intact skin), which remains in contact with the body long enough, can provide a condition of continued exposure that may eventually lead to a fatal dose. Dust also can be kept in clothing and later be re-entrained into the air in the breathing zone of the worker. Although easily preventable, many fatalities resulting from intoxication, due to lack of personal and clothing hygiene, have been reported.

Adequate facilities for washing and showering in the workplace must be provided by management. In addition to educating and motivating workers to take a shower after work, a sufficient number of showers must be available in the workplace and, in cold climates, hot water should be provided (at least in winter). After taking a shower, clean clothes must be donned.

Washing hands with adequate cleansing agents, whenever needed, is a good measure against occupational skin diseases. However, care must be taken with cleansing agents: some can be very abrasive to the point of even breaking the skin surface thus providing an entry point for infection and chemicals. Others can be allergenic; there have been cases of "epidemics" of allergic dermatitis in industry where, after thorough investigation, the "culprit" was found to be the cleansing agent.

Adequate locker rooms and, in the case of work with hazardous materials, adequate disposal and laundry facilities for used working garments are also essential.

8.6 Health surveillance

Health surveillance of workers includes pre-employment, periodic and special health examinations, including clinical observations, investigations of specific complaints, screening tests or investigations, biological monitoring and early detection of health impairment resulting from occupational exposure.

It should be remembered that exposure assessment through environmental data reflects only inhalation exposure. The real uptake is better assessed through biological monitoring which reflects total exposure (WHO, 1996a). However, biological
monitoring is not applicable in all situations, as it requires very good analytical laboratories not easily accessible everywhere. Moreover, biological exposure indices and methodology have been developed for only a limited number of substances (e.g., lead). Besides, whenever blood tests are involved, the required invasive techniques may introduce a risk of infection, for example with HIV or hepatitis B, if strict control of the medical material cannot be assured. Unfortunately this is the case in certain parts of the world.

Health surveillance is frequently required by regulatory authorities, as a component of a comprehensive standard. However, it should be considered as a complement of control strategies and never as a replacement for primary prevention. It contributes to the detection of problems or failures in control systems, and also to the identification of hyper-susceptible workers. If results from tests for the early detection of health impairment due to occupational hazards are used to prevent further exposure, this may help prevent further damage, and can therefore constitute an important secondary prevention tool. Health surveillance of workers exposed to mineral dusts is covered in a WHO publication (WHO, 1996b).

Health surveillance can also contribute to the recognition and evaluation of hazards. In fact, when dealing with certain “hidden hazards” (e.g. an agent which is unknown or has gone unrecognized in the work environment) this may be instrumental in disclosing exposure.

Specific alterations in health status, which may influence tolerance to work, should also be considered, particularly for workers assigned to jobs requiring adaptation, such as night shifts and hot jobs.

Workers should be informed of the reasons for medical examinations and tests so that they are motivated to participate actively. However, they should have the right to refuse invasive methods of examination. Whenever any skin-piercing technique is used, utmost care must be taken to prevent the transmission of communicable diseases, such as hepatitis B and C and AIDS. In the case of blood tests, disposable needles and syringes must be used. If such disposable items are not available, blood samples should not be taken.

A multidisciplinary approach is essential for the design, implementation and follow-up of any control strategy. Personnel responsible for health surveillance of workers should be kept informed about hazard evaluations conducted in the workplace and on exposures observed at specific processes or operations. On the other hand, occupational hygienists should be informed on abnormal conditions observed by health departments.
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Chapter 9 - Housekeeping and Related Matters

9.1 Good housekeeping

Control measures include everything, which stops contamination from being spread. One important complementary measure is good housekeeping, which involves keeping the workplace clean, controlling waste, cleaning up spillages and maintenance.

Poor housekeeping can lead to spread of contamination, and unnecessary exposure, which may be far from the hazard source, through inhalation of re-entrained dust. If the substance is deposited on surfaces, skin contact and ingestion can also be of concern. For example, in bag filling operations, personal dust exposure is closely related to work practices, including the level of cleanliness around the process. A well-designed operation will prevent the release of dust-contaminated air. However, if the system is worked beyond normal capacity there will be inevitable spillages and exposures will increase. Section 8.1 discussed the influence of work practice on dust exposure in bag opening.

Management and workers should give housekeeping a high priority, so that the workplace is kept as clean as possible, at all times. It should be kept in mind that:

- a dirty or untidy workplace demonstrates low priority given by management to careful work practices, and creates an attitude of carelessness in the workforce;
- leaks or spills, if not attended to promptly, may appreciably contribute to air contamination, including by re-entrainment of settled dust;
- surface contamination, visible or not, can be a major source of ingestion and skin contamination, leading possibly to absorption or skin disease (see Section 2.2.1).

The following practices should encourage good housekeeping.

- Clean-up tools, absorbents, etc., should be readily available, inspected, and replenished frequently.
- Clean-up of spills should have a high priority.
- Housekeeping tasks should be regarded as part of the job - a ‘clean as you go’ attitude - rather than as tasks to be done only when the work is finished. Workers should be responsible for keeping their own work area clean.
- As a back-up to the previous point, but not replacing it, maintenance procedures should also include a check on housekeeping.
- The cleanliness of work areas, and all the above practices, should be evaluated and encouraged by management during inspections of the workplace.
Dufort and Infante-Rivard (1999) give a checklist for inspecting housekeeping in manufacturing industry, illustrating how such a system can give a score which can be used for workforce incentives.

Spillages are often a source of exposure. Prevention should be a first priority, but adequate cleaning methods should be available in case a spillage occurs. Damp sweeping is often proposed to minimize raising dust and subsequent air contamination. Compressed air and dry sweeping should not be used to remove settled dust, because these practices make much of the dust airborne again. This is particularly dangerous if the dust contains hazardous constituents, such as free silica or lead.

Vacuum systems are better. Portable vacuum cleaners may be used, if the filtration efficiency of the filter element is adequate for the material to be cleaned up. If the bag is torn, or the filtration unit missing, the vacuum cleaner will become an aerosol generator, dispersing a dust cloud into the workplace atmosphere. If the filtration unit is not effective for very small particles (as is true for typical domestic vacuum cleaners), the situation may be even more dangerous since, although the cloud may not be as visible, the small particles released are more readily inhaled and usually contain a higher proportion of respirable particles.

Procedures to prevent spread of contamination may include decontamination at the end of the work period. In this way all contaminated clothing and work tools are left within clearly defined segregated areas. The workforce may have to transit through a properly constructed decontamination facility. Control features might include the need for a shower or comprehensive wash before the worker is allowed to put on normal clothing. Processes where particularly toxic dusts are handled may need this sort of arrangement.

9.2 Storage

It is a mistake to assume that storage rooms are hazard-free areas. Particularly if the ventilation is poor (which is often the case), there may be a build-up of airborne contaminants to dangerous concentrations. Depending on the materials or products stored, the resulting health risk may be high. It may happen that hazardous agents in gaseous form are released from dusty materials. For example, vinyl chloride (unpolymerised) may be released during the storage of granulated PVC; nitrogen oxides may occur in silos where grain is stored. This has relevance because a worker entering an area where only solid materials are stored might be wearing only a dust mask which is ineffective for gaseous contaminants. Unless the storage area is well ventilated, adequate precautions should be taken when entering, particularly if the chemicals likely to be released are fast acting and have ceiling values for permissible exposure levels.
Intermittent exhaust ventilation, to be turned on some time before entering the storage area, can be a solution. If personal protective equipment is used, it should be adequate for the gases that may be present.

Storage of raw materials, chemicals and products in appropriate places and in adequate containers is essential both for health and safety reasons. Containers should preferably be unbreakable, have no leaks and have well fitted lids, which should be kept closed except when materials are being used. Container design and work practice should be such as to avoid spillage when materials are being removed.

Whenever chemicals are stored, special attention should be paid to the possibility of accidental chemical reactions; for example, cyanides and acids should never be stored together.

9.3 Labelling

Adequate labelling of any container with a chemical agent is of the utmost importance. Many jurisdictions and agencies have requirements for labelling of materials supplied to the workplace, transported or produced. However, where this is not the case, management should ensure through a purchase policy that materials bought are adequately labelled.

Those responsible should be familiar with the provisions applying to their work site and understand the meaning of labels. Labels should indicate, clearly and in a language perfectly understandable by the users, the degree of toxicity of the chemical in question, possible routes of entry, main symptoms resulting from overexposure, safety and fire hazards, possible dangerous reactions, main precautions for use, and first-aid procedures in the case of overexposure or ingestion. Adequate symbols (e.g. fire, corrosive liquids, explosives, etc.) and other visual messages on labels are very important, particularly if there are illiterate workers.

Toxic or reactive materials should never be dispensed into, or from unlabelled containers, and in particular any containers formerly used for foodstuffs.

Labelling of personal protective equipment is one safeguard against its misuse; for example, labelling helps to prevent the use of a respiratory protective device designed to protect from dusts and fumes, in a work situation where there is exposure also to gases or vapours.
9.4 Warning signs and restricted areas

Warning and caution signs for work areas where potential hazards exist are indispensable. These should convey a clear message, be easily understood by the workers, including the illiterate, be as pictorial as possible, and be adequately located in visible and well illuminated areas. Workers' education and training are necessary (Section 8.2); visual signs should be considered as reminders.

Certain areas, for example, those where safety glasses or respirators must be used, require permanent signs; in other situations, such as when maintenance is being performed or when a spill of hazardous material has occurred, temporary signs are used.

There may be a need for restricted areas, for example, where highly toxic, radioactive or carcinogenic materials are handled. Such areas should be well defined, be kept under negative pressure, and should be very clearly indicated with adequate warning signs. Workers should only enter such areas if wearing highly efficient personal protection; moreover, they should previously receive adequate instruction in safe work practices and in the use of the required personal protection (Section 8.4). Strict medical surveillance is also necessary.

It may be that a process or a substance is particularly difficult to control at the source, but at the same time it may be that there is little need for an operator to be constantly in attendance. If it is too difficult to control contamination in certain areas of a workplace, one effective way of reducing workers' exposure is to isolate the highest concentration areas, and prevent workers from entering, unless strictly protected. Operators, who only need to ensure that a process is working normally, can be well protected just by remaining in a purposely-built refuge (with air access only from clean areas). Such refuges can also serve to protect against other workplace hazards, e.g., noise or extremes of temperature. Control rooms and refuges can even be built away from the main plant, with operations being monitored by closed-circuit television cameras.

Of course, if a control room is well-designed and comfortable, the operator is more likely to remain within its protective confines and not be tempted to enter areas of high exposure. In the event of plant breakdown, the operator should be provided with appropriate personal protective equipment and be thoroughly trained to use it. This approach has been shown to be effective in the quarry industry, refuse incineration and at mechanised grain terminals. Another example along the same lines is the development of clean air cabs on combine harvesters, although filtration efficiency needs to be monitored in this case.
Administrative and management elements are very important aspects of a control strategy, especially when there is the possibility of residual exposure after other control measures have been applied. Procedures should be adopted to segregate and indicate hazardous areas, enforce wearing of personal protective equipment, ensure that cleanliness and housekeeping are up to standard, and that engineering controls are used and working properly.

Reference for Chapter 9

Chapter 10 - Environmental Protection

10.1 General issues

Health protection from workplace hazards cannot be isolated from protection of the general environment. Strategies in the workplace should ensure that control is not attempted at the cost of wider pollution. This includes process emission to the air, any watercourse, and soil. Full consideration of this topic is beyond the scope of this report; some principles are outlined here, and some sources of further information are suggested in Section 10.3.

Adequate risk management requires that actions pertaining the workplace and the general environment be jointly planned and coordinated; not only are there overlapping areas, but, in most situations, the success of one is interlinked with the success of the other. For example, removing hazardous dust from the air will often result in dusty waste, which must be disposed of, and the consequences of this must be considered in the initial planning.

By its definition, environment encompasses “All factors (living and non-living) that actually affect an individual organism or population at any point in the life cycle” (Botkin and Edward, 1998). While protection of human health and wellbeing is one of the main foci of environmental protection, there is a need for a systems approach to environmental issues to ensure that any protective measures adopted would help to sustain the whole environmental system and not only its individual compartments. The aim of environmental protection is to minimise the impacts of contaminants on the environment as a whole.

In relation to airborne dust, the environmental effects caused by its presence include the following:

- **Health.** The health effects discussed in Chapter 2 may apply to a wider population, which will include more vulnerable groups such as those with chronic lung disease and children and the elderly.

- **Atmospheric properties.** Airborne dust can reduce visibility, and this effect of pollution sources can extend for hundreds of kilometres or more. Local climate can be affected through effects on radiation, cloud nucleation, and precipitation chemistry. The finer particles, such as those that pass through dust arrestment plant, are likely to be more important in these processes. (Willeke and Baron, 1993).

- **Effects on materials.** Dust deposition can discolour or streak buildings or structures making them look very unsightly. More important, their durability can
be affected by the chemical process caused by the dust, particularly acidic components. This deterioration is clear wherever ancient or medieval buildings survive in cities. For example, the exterior of the cathedral of Cologne, Germany, has been affected by air pollutants (Luckat, 1973).

- **Effects on vegetation and animals.** Dust effects on vegetation include direct effects caused by dust deposition on the plants, and indirect effects related to dust accumulation in soil and subsequent plant uptake. Cement-kiln dust, fluorides, lead particles, soot, magnesium oxide, iron oxide and foundry dusts are among those which are the most commonly quoted in relation to their damaging effects on vegetation, and in severe cases local effects can be obvious. The effects may include loss or pollutant accumulation in crops, loss of amenity, and damage to the ecosystem of other organisms that depend on the plants. Sometimes animals can be poisoned through grazing on polluted plants: an example is fluorosis in cattle near brick-works.

- **Effects through waste storage and disposal.** Dusty materials may be redispersed to the air during disposal, and disposal may result for example in exposure of waste-workers to the material, or pollution of the soil and water.

### 10.2 Strategies

Because control of workplace risks cannot be isolated from environmental problems, most of the management principles discussed in Chapter 3, and the considerations in Annex III also apply. The planning of processes and consideration of overall environmental impact are even more important than in the simple workplace context, because later ‘bolt-on’ control is even less likely to be effective where environmental considerations are taken into account. The classification of the hazard process in Table 5-1 may also be useful in considering strategies for environmental protection. Briefly, some important concepts are as follows.

**Source.** If all environmental compartments are considered, then moving hazardous materials to the outside air or water or to landfill sites are unsatisfactory measures. The final disposal of products that contain hazardous substances, perhaps years in the future, must also be considered. These considerations make it even more advantageous to control by changing the process or product so that hazardous materials are not used, or, if this is impossible, by substituting less hazardous materials. Process design to minimise waste is also important.

**Transmission path.** The problem of disposing of hazardous materials collected in filters or other arrestment plant has already been mentioned. The problem of water slurry from wet processes, and possible hazardous additives used with the water, must also be considered.
Receptor. The receptor to be considered is not only the worker, but also the rest of
the population and plants and animals, as has already been mentioned.

10.3 Further information

Apart from the texts already referred to, the following may be found useful:

General environmental science and technology: Manahan (1997)
Integrated Pollution Control: Welch (1998); Woodside and Kocurek (1997)
Waste disposal: Maltezou et al. (1989).

References for Chapter 10.

ISBN 0-471-157821

Luckat, S. (1973) “Über die Einwirkungen von Luftverunreinigungen auf die Bausubstanz
des Kölner Domes”. Teil I. Kölner Domblatt 36/37, S. 65/74.

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Raton, Florida, USA. ISBN 1566702135

integrated pollution prevention with ISO 14000, Lewis Publishers, Boca Raton, Florida, USA.
ISBN 1-56670-295-X.

Willeke, K. and Baron P.A. (Eds) (1993) Aerosol Measurement: principles, techniques and

Chapter 11 - Sources of Information

A wealth of information is available on potential hazards from work processes and operations, associated health effects, and, prevention and control techniques. It is important that those responsible for the control of health risks at work know where this information is and how to have continued access to it, since this is a dynamic field and new knowledge is constantly brought to light.

The objective of this chapter is to present examples of available sources of information related to dust exposure, its prevention and control.

11.1 International agencies

International collaboration can be very valuable in promoting, providing or facilitating access to pertinent information; international agencies have a very important role to play in this respect, as well as in technical cooperation for developing or strengthening national capacity in this field. This section presents examples of international agencies that may be able to provide information concerning occupational hazards, their prevention and control.

11.1.1 World Health Organization

The ultimate objective of the World Health Organization is “the attainment by all peoples of the highest possible level of health”. The WHO Occupational Health Unit has an occupational hygiene component, whose objectives include the worldwide promotion of hazard prevention and control in the work environment, through appropriate technologies, also accounting for environmental protection and sustainable development. The Unit promotes international collaboration and the sharing of technical and scientific knowledge on occupational hygiene, among countries around the world, with a view to decreasing the often wide inequalities in this field.

WHO collaborates closely with other relevant international organizations, as well as with a number of international and national professional associations, including the International Occupational Hygiene Association (IOHA) and the International Commission on Occupational Health (ICOH). These are Non-Governmental Organizations in Official Relations with WHO.

In order to better coordinate activities with the country level, WHO has six regional offices, covering the following regions: Africa (AFRO); Americas (PAHO/AMRO); Eastern Mediterranean (EMRO); Europe (EURO); South East Asia (SEARO), and Western Pacific (WPRO).

Web Site: http://www.who.ch
Address: 20, Avenue. Appia, 1211 Geneva 27, Switzerland
An important agency of WHO is the International Agency for Research on Cancer (IARC). Its publications include the IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, which cover different branches of industry (e.g., rubber, textile, wood) or specific industrial technologies (e.g., welding), or chemicals/groups of chemicals (e.g., silica, chromium, nickel).

Web site: http://www.iarc.fr/
Address: 150 Cours Albert Thomas, F-69372 Lyon Cédex 08, France;
Telephone: +33- 4-72.738.485 Fax: +33- 4-72. 738. 575

**11.1.2 International Labour Office (ILO)**

General information on the ILO can be found at the ILO Website (see below). Like the ILO’s main publications, this is available in English, French and Spanish.

One of the key functions of the ILO has been the development of international standards on labour and social matters, in order to establish the required action at the national level, as well as assisting and encouraging employers and workers to take their respective responsibilities. ILO standards are expressed in the form of Conventions and Recommendations, that define minimum standards in labour and social fields, and close to 50 per cent of these instruments relate directly or indirectly to occupational safety and health matters.

Conventions are comparable to multilateral international treaties, and once ratified by a country, become binding obligations. They require national laws and regulations to establish the measures required at national level, and also define the obligations of both employers and workers. Recommendations are intended to offer guidelines for action, and often a particular recommendation will elaborate on the provisions of a Convention on the same subject. For example, Convention № 155, *Occupational Safety and Health and the Working Environment* is accompanied by Recommendation № 164, providing for the adoption of a national occupational safety and health policy and describing the actions needed at the national and at the enterprise levels to promote occupational safety and health and to improve the working environment.

Further guidance is provided through the ILO Codes of Practice. They provide guidance to those engaged in the framing of occupational safety and health programmes. They either cover specific branches of economic activity (for example: mines, agriculture, forestry, shipbuilding, iron and steel, construction and public works), or particular risks (for example: ionizing radiation, airborne contaminants, asbestos). A Code of Practice on ambient factors is in preparation, which will replace
some of the single-topic codes relevant to occupational hygiene, and will cover not only chemical hazards but also physical hazards, including ionizing radiation.

Also relevant to occupational hygiene is the *Chemicals Convention 1990 (No. 170)*, which can provide a model for national measures, and is supported by a Code of Practice *Safety in the use of chemicals at work* (ISBN 9-2-108006).

Further information on these publications can be found in the *Catalogue of ILO publications on occupational safety and health*, 1998 (ISBN 92-2-109552-5).

**Web sites:**
General, in English, French and Spanish: http://www.ilo.org
Conventions and Recommendations:

**Address (occupational hygiene interest):**
Occupational Safety and Health Branch (SEC HYG), International Labour Office, 4 route des Morillons, 1211 Geneva 22, Switzerland.
Telephone: + 41 22 799 6716 Fax: + 41 22 799 6878
E-mail: sechyg@ilo.org
E-mail for general enquiries about publications: pubvente@ilo.org

**International Occupational Safety and Health Information Centre (CIS)**

The CIS is a service of the ILO in Geneva, dedicated to the collection and dissemination of information on occupational safety and health matters, with the main objective of preventing occupational accidents and diseases. It is assisted in its work by more than 120 national institutions (its National and Collaborating Centres) dealing with occupational safety and health matters in their own countries. The CIS database covers the following types of documents concerned with occupational safety and health:

- Legislation, regulations and directives
- Chemical Safety Data Sheets
- Training materials and methods; audiovisual aids
- Computer databases, Internet pages, multimedia training modules
- Articles in scientific, technical and medical journals
- Research reports, codes of practice, technical data sheets
- Textbooks; monographs aimed at specialised and popular audiences.

CIS issues bimonthly a summary of the world's literature *Safety and Health at Work: ILO-CIS Bulletin*. See Section 11.5.1 below.

**Website:** http://www.ilo.org/public/english/90travai/cis/
11.1.3 United Nations Environment Programme (UNEP)

The United Nations Environment Programme (UNEP) provides leadership and encourages partnerships to preserve the environment thus enabling nations and people to improve their quality of life without compromising that of future generations.

Web site: http://www.unep.org/
Address: UNEP, P O Box 30552, Nairobi, Kenya
Telephone +254 2 62 12 34; Fax: +254 2 22 68 86

The UNEP Division of Technology, Industry and Economics (UNEP/TIE) works with decision-makers in government, local authorities, and industry to develop and adopt policies and practices that are cleaner and safer, make efficient use of natural resources, ensure adequate management of chemicals, incorporate environmental costs, and reduce pollution and risks for humans and the environment.

UNEP/TIE has various units with responsibilities relevant to occupational hygiene. The Chemicals Unit promotes sustainable development by catalysing global actions and building national capacities for the sound management of chemicals and the improvement of chemical safety world-wide. The Economics and Trade Unit promotes the use and application of assessment and incentive tools for environmental policy and helps improve the understanding of linkages between trade and environment and the role of financial institutions in promoting sustainable development. The Production and Consumption Unit fosters the development of cleaner and safer production and consumption patterns for increased efficiency in the use of natural resources and pollution reduction; the Cleaner Production Programme promotes integrated preventive strategies for the control of industrial pollution and its information transfer activities include publications, training and technical assistance.

The *International Cleaner Production Information Clearinghouse (UNEP/ICPIC)* contains a database of case studies on cleaner production alternatives (also available on the Web).

UNEP/TIE Web sites: http://www.unep.org
and http://www.natural-resources.org/environment

Address: Tour Mirabeau, 39-43 quai André Citroën, F-75739 Paris Cedex 15, France
Fax: +33 1 44 37 14 74
Internet: unepie@unep.fr
Another UNEP programme is the Geneva-based *International Register of Potentially Toxic Chemicals (UNEP/IRPTC)*, which operates a worldwide network for the exchange of chemical safety information. It develops a series of data profiles on scientific information that are deemed important to conduct a chemical risk assessment, and on regulatory controls placed on chemicals.

Address: 15 Chemin des Anémones, 1219 Geneva, Switzerland
Fax: +41 22 797 34 6
E-mail: irptc@unep.ch

### 11.1.4 International Programme on Chemical Safety (IPCS)

The International Programme on Chemical Safety is an intersectorally coordinated and scientifically based programme. IPCS was established in 1980, as a joint programme of three Cooperating Organizations, ILO, UNEP and WHO (WHO is the Executing Agency). The two main roles of IPCS are to establish the scientific basis for the safe use of chemicals and to strengthen national capabilities and capacities for chemical safety.

Publications by IPCS include the *Environmental Health Criteria, Health and Safety Guides*, and *International Chemical Safety Cards*. Examples of Environmental Health Criteria on substances which may be found in the form of dusts, include:

- metals, e.g., Inorganic Lead (No. 165: 1995); Beryllium (No. 106, 1990); Platinum (No. 125, 1991); Cadmium (No. 134 and No. 135, 1992); Manganese (No. 17, 1981);
- fibres, e.g., Asbestos and Other Natural Mineral Fibres (No. 53, 1986); Man-Made Mineral Fibres (No. 77, 1988); Selected Synthetic Organic Fibres (No. 151, 1993);
- various chemicals, e.g., Tetrabromobisphenol A (a brominated flame retardant) (No. 172: 1995), as well as a large number of pesticides.

Web site (which includes much material on-line) http://www.who.int/PCS/
Address: World Health Organization, 1211 Geneva 27, Switzerland

### 11.2 National institutions

A few examples of national institutions (far from comprehensive) that can provide assistance concerning dust control problems are hereby provided. More can be found in the publication *WHO Collaborating Centres in Occupational Health*, giving details
of 52 institutions in 35 countries around the world. A list of these centres, with links to their Web sites, is available on http://www.ccohs.ca/who/ccnew.htm.

### 11.2.1 National Institute for Occupational Safety and Health (NIOSH), USA

NIOSH is the US Federal Agency responsible for conducting research and making recommendations for preventing work related illness and injuries. It produces a wide range of publications of international importance, including many relevant to dusts in the Hazard Control and Alert series. A complete list can be searched on the NIOSH Web site (see below). Many of the publications are available on-line, and contain practical information on control. Two that deserve particular mention are the NIOSH Pocket Guide to Chemical Hazards available on-line at: http://www.cdc.gov/niosh/npg/pgdstart.html and the document NIOSH/MSHA/OSHA (1997) Silica... It's Not Just Dust (NIOSH # 97-118).

The National Occupational Research Agenda (NORA) is an interagency agreement setting federal research priorities in the field. Details can be accessed through the NIOSH Web site.

**NIOSH Web site:** http://www.cdc.gov/niosh/homepage.html

**Addresses:**


NIOSH-Cincinnati: Robert A. Taft Laboratories, 4676 Columbia Parkway, Cincinnati, OH 45226, USA

Alice Hamilton Laboratories: 5555 Ridge Ave., Cincinnati, Ohio 45213

NIOSH-Morgantown: 1095 Willowdale Road, Morgantown, WV 26505-2888

### 11.2.2 Health and Safety Executive (HSE), UK

HSE is the British government organization responsible for health and safety at work (including mining). It produces a wide range of publications covering all aspects. A searchable list is available through the publications Web site (see below), and the publications catalogue, obtainable free of charge, is very useful. Consultative documents and news releases are available on-line, but in general texts of guidance documents are not available on the Web. There is a public information service with an enquiry line.

**Web sites:**

HSE: http://www.open.gov.uk/hse/hsehome.htm

Publications: http://www.hsebooks.co.uk/homepage.html
11.2.3 Institut National de Recherche et de Sécurité (INRS), France

The INRS has a number of activities and publications, as well as databases which are relevant to dust control. The transfer of new knowledge and of newly developed tools is one of its high priority tasks. A bulletin listing the publications of the Institute is issued every six months. The Web site gives details of many of its activities, and a searchable list of publications, with summaries of many of the publications. Some parts of the site are available in English, but most of course is in French, including the search facility.

Web site: http://www.inrs.fr/
Address: 30, rue Olivier Noyer, F-75680 Paris Cedex, France
Telephone: +33 1 40 44 30 00; Fax: +33 1 40 44 30 99

11.2.4 National Institute for Working Life, Sweden

The National Institute for Working Life has the official mission of “pursuing and fostering research and learning, as well as conducting development projects concerning work, the working environment and relations within the labour market,” so its remit extends well beyond traditional health and safety. It is concerned mainly with research, development and training. The NIWL Web site (fully available in English) gives access to searchable lists of publications. Summaries are on-line, many in English, and the more recent reports can be downloaded from the site.

Web site (English) http://www.niwl.se/default_en.asp
Address: National Institute for Working Life, S-171 84 Solna, Sweden
11.2.5 Canadian Centre for Occupational Health & Safety (CCOHS), Canada

An important task for CCOHS is providing advice. As well as giving information on CCOHS products and services, its Web page is an outstanding source of information on health and safety information available on the Internet. All facilities are available in French as well as English.

Web site: http://www.ccohs.ca
Address: 250 Main St. E., Hamilton, ON, Canada, L8N 1H6
Telephone: +1 905 570 8094; Fax +1 905 572 2206

11.3 Professional organisations

The major professional organizations in occupational hygiene are members of the International Occupational Hygiene Association (IOHA). A number of these are very active, and produce their own publications and hold national conferences. Some publish journals (see Section 11.5.2). Addresses of the member organizations are obtainable from the IOHA secretariat. Many of these organizations have their own Web sites, with links from the IOHA site.

IOHA Web page: http://www.bohs.org/ioha/index.html
Address: IOHA Secretariat, Georgian House, Great Northern Road, Derby DE1 1LT, UK.
Telephone: +44 1332 298101; Fax +44 1332 298099
E-mail: pblythe@compuserve.com

The CCOHS site http://www.ccohs.ca (see Section 11.2.5) provides links to many other professional organizations and other relevant bodies.

There are also a number of organizations concerned with aerosols. Their interests extend well beyond industrial dusts, but some of their publications and meetings are very relevant. The Web page of the Aerosol Society, which operates in Britain and Ireland, gives links to the major societies worldwide. Its Web site is http://www.aerosol-soc.org.uk/

11.4 Books, Reports and CD-ROMs

Any list of publications will rapidly become out of date. An important annotated list of major publications, updated quarterly, is the ACGIH publication catalogue, obtainable from American Conference of Governmental Industrial Hygienists, 1330 Kemper Meadow Drive, Cincinnati, Ohio 45240-1634, USA. North American publications and practice are of course prominent in this catalogue. A searchable Web version, with international ordering information, is available at:

http://www.acgih.org/catalog/index.htm
As already mentioned (Section 11.2), NIOSH and HSE publish important series of
guidance documents and reports. Lists, and, in the NIOSH case, many texts, can be
accessed through their Web sites, respectively:

http://www.cdc.gov/niosh/homepage.html
and
http://www.hsebooks.co.uk/homepage.html

See also Section 11.1 above for reports by international agencies.

A range of information on CD-ROM is obtainable from Silver Platter (see Sections
11.2.2 and 11.5.1) As well as the CD-ROMs mentioned elsewhere in this chapter,
Silver Platter produce MSDS, a compilation of 70 000 safety data sheets. Their
publications are listed on http://www.silverplatter.com/hlthsafe.htm.

Some particularly important books and other media are listed below. Most are
obtainable through the ACGIH catalogue. Internet bookshops are an alternative
source for many titles.

edition. American Conference of Governmental Industrial Hygienists, Cincinnati,
OH, USA. ISBN 1-882417-22-4. Also available in a metric units edition and on CD-
ROM.

ACGIH (updated annually) TLVs and BEIs. Threshold Limit Values for Chemical
Substances and Physical Agents; Biological Exposure Indices. American Conference
of Governmental Industrial Hygienists, Cincinnati, OH, USA. Also available (some
years) in Greek, Italian and Spanish, and on disk. The world’s leading list of
occupational exposure limits.

ACGIH (1999). TLVs and other occupational exposure values. American Conference
of Governmental Industrial Hygienists, Cincinnati, OH, USA. CD-ROM only.
(Includes ACGIH, NIOSH, OSHA, historical TLVs, British and German exposure
limits, NIOSH analytical methods, and other information.)

S. R. DiNardi, American Industrial Hygiene Association (AIHA) 2700 Prosperity
Avenue, Suite 250, Fairfax, VA 22031, USA. (Obtainable from AIHA
http://www.aiha.org)

91833-00-1. Vol. 2: Major Industries and Occupations. ISBN 82-91833-00-1. ILO-
CIS, Geneva, and Scandinavian Science Publisher as, Oslo. This work seeks to
integrate health and safety into good management, mainly in the context of European legislation and practice.


Burton, J. D. (1997) Industrial Ventilation Workbook*, 4th Ed. ACGIH, Cincinnati, Ohio, USA.

BOHS (1987) Controlling airborne contaminants in the workplace, Technical Guide No7, British Occupational Hygiene Society, Georgian House, Great Northern Road, Derby DE1 1LT, UK (Obtainable from BOHS http://www.bohs.org/)


11.5 Periodicals

Specialized journals and other periodicals are very important as a source of recent information. Some examples are given here.

11.5.1 Abstracts

Safety and Health at Work: ILO-CIS Bulletin. Abstracts of the world’s literature on the subject, taken from the CISDOC database (see also OSH-ROM below). Published 6 times a year by ILO-CIS, with a five-yearly index. See Section 11.1.2 above, and the ILO-CIS Web site http://www.ilo.org/public/english/90travai/cis/
OSH-ROM. This periodically-updated CD-ROM contains the NIOSHTIC, HSELINE and CISDOC databases, amongst others, and so provides searchable abstracts of much of the world’s literature on health and safety, including non-journal items such as government reports. Obtainable from Silver Platter, 100 River Ridge Drive, Norwood, MA 02062-5043, USA, or 20 Belmont Terrace Chiswick, London W4 5UG. See http://www.silverplatter.com/hlthsafe.htm.

PubMed. This is a searchable online database of the world’s medical literature, maintained by the US National Library of Medicine, which includes abstracts of some occupational hygiene publications. See http://www.ncbi.nlm.nih.gov/PubMed/

11.5.2 Journals

There are four specialist international occupational hygiene journals, carrying papers on research and development. All make their present and past contents lists freely available on-line. Their contents themselves are also usually available on-line to subscribers or members of the sponsoring organization.

American Industrial Hygiene Association Journal. American Industrial Hygiene Association (AIHA), 2700 Prosperity Avenue, Suite 250, Fairfax, VA 22031, USA. Free to AIHA members.
Web: http://www.aiha.org

Annals of Occupational Hygiene. British Occupational Hygiene Society (BOHS), Georgian House, Great Northern Road, Derby DE1 1LT, UK. Free to BOHS members. Published for BOHS by Elsevier Science.
Web (Elsevier; includes past contents):
http://www.elsevier.nl/inca/publications/store/2/0/1/
(BOHS; includes papers to be published): http://www.bohs.org/

Applied Occupational and Environmental Hygiene. American Conference of Governmental Industrial Hygienists (ACGIH), 1330 Kemper Meadow Dr., Cincinnati, Ohio 45240, USA. Free to ACGIH members. Contains extensive professional development material as well as research papers. Published for ACGIH by Taylor and Francis.
Web: http://www.acgih.org/applied/welcome.htm

Occupational Hygiene. Published by Gordon and Breach, e-mail: info@gbhap.com.
Web: http://www.gbhap-us.com/journals/225/index.htm

The following periodicals also include much relevant information:

Cahiers de Notes Documentaires (in French; summaries in English). Published by INRS - see Section 11.2.3 above. Also covers safety.
Gefahrstoffe: Reinhaltung der Luft (in German; summaries in English). Published by Springer-VDI-Verlag GmbH, Postfach 10 10 22, D-40001 Düsseldorf, Germany. Also covers emission controls and environmental measurements. Web: http://www.technikwissen.de/gest/index.htm

Scandinavian Journal of Work, Environment and Health. Published by the occupational health institutes of Denmark, Finland, Norway and Sweden. Scandinavian Journal of Work, Environment & Health, Topeliuksenkatu 41 a A, FIN-00250 Helsinki Finland. e-mail: Terja.Pehkonen@occuphealth.fi Web: http://www.occuphealth.fi/e/dept/sjweh/

There are two international journals in aerosol science, which cover the fundamental science of airborne particles.

Aerosol Science and Technology. Web: http://www.aaar.org/as&t.htm

Journal of Aerosol Science. 
Web: http://www.elsevier.nl/inca/publications/store/3/3/7/

11.6 Other Internet resources

Subscribers to an Internet mailing list receive all the e-mail messages posted to the list e-mail address, and can post messages themselves. A list brings together people interested in a particular subject, such as occupational hygiene in one country or region. It is therefore a simple, effective and cheap way of pooling experience, asking questions, or distributing information.

The CCOHS Web site:

http://www.ccohs.ca/resources/listserv.htm

gives brief information and subscription details for many mailing lists related to occupational health and safety.

The amount of information available on the Internet is vast and expanding, although some resources such as some online journals have become more restricted in access. As mentioned in Section 11.2.5, the site:

http://www.ccohs.ca

gives extensive links to health and safety resources worldwide.
There are also extensive links to sites in occupational and environmental health and related disciplines from sites at Duke University:

http://occ-env-med.mc.duke.edu/oem/index2.htm

and the University of Edinburgh

http://www.med.ed.ac.uk/hew/

Information on particular topics can be obtained by entering terms into search engines and related facilities. A review of these and their use in occupational hygiene has been published by Ennis (1999).

The use of Internet information can be expected to continue to develop rapidly, and professional associations (Section 11.3), established periodicals (Section 11.5.2), and the Web sites mentioned earlier in his section are likely to provide the best source of information on these topics for the immediate future.

Reference for Chapter 11

ANNEX I

List of Participants in the WHO Consultation on

“HAZARD PREVENTION AND CONTROL IN THE
WORK ENVIRONMENT: AIRBORNE DUST”

World Health Organization, Geneva
13 - 16 July 1998

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ANNEX II

Knowledge Gaps and Recommendations for Future Research

II.1 Background

Dust control has been the subject of wide-ranging research since the early 1900s, and there is an extensive literature in the form of books, manuals, journal articles and, more recently, electronic media such as CD-ROMs and the World-Wide-Web (see Chapter 11). Much of the available literature is scattered, appearing very often engineering journals, rarely read by occupational hygienists.

Meanwhile occupational hygiene literature often emphasizes exposure assessment and health effects, at the expense of prevention and control issues. One reason is that practitioners who develop innovative solutions to control problems often receive no incentive from their employers and little career advantage in publishing them. Partly as a result of this (it has been argued), the range of technical control options currently available to us is rooted in science which comes from the 1950s and earlier! But since this time, occupational hygiene itself has moved to the point where a structured multidisciplinary and broad-based approach to dust control problems can be identified, covering strategic, technical and managerial issues.

With the preceding in mind, participants in the WHO Consultation (July 1998) proposed some guiding principles and new approaches for future research in this field. The following aspects should be emphasized:

- Control at the source, through adequate design of equipment and work processes; consideration of control measures as an integral part of any system, and not as an afterthought.

- Design of controls with the worker in mind (man-machine interface), having work practices, maintenance, hazard communication, education and training as essential considerations. (If maintenance is ergonomically difficult, control performance will deteriorate.)

- Design of control measures which are economically feasible and which also aim at conserving raw materials and other natural resources.

- Design of controls for low/no maintenance.

- Replacement of “end of pipe” solutions by source control, of expensive solutions by low-cost solutions, and of isolated solutions by an integrated approach to control.
Research on control measures needs to be interdisciplinary and should integrate all substance, machine and human aspects, also taking into account possible environmental impacts. There is a need for a holistic approach whenever considering hazard prevention and control.

II.2 Research topics

A. Control strategy and development

1. Quantitative models relating exposure to process parameters. Research in this area will help evaluate the reliability and economics of process changes under consideration to improve control, as well as provide guidance on the collection of the information necessary for field studies on exposure.

2. Economics and control strategies. What are the different engineering alternatives for minimizing hazards and what are the costs? How do we compare the economics of prevention to the economics of control?

3. Use of video exposure monitoring, computational fluid dynamics and other tools to investigate the behaviour of control systems. Use of visualization techniques to establish adequate work practices, to educate workers and to modify any unsafe behaviour.

4. Following from number 3., improvement of generic approaches to process-specific and engineering controls for a variety of common exposure scenarios, such as powder weighing and coating.

B. Exposure minimization

1. Fundamentals of dust generation by solids. How physical form of solid (granules, flakes, slurries, powder, size distribution etc.) affects aerosol generation, and how this can be applied at for example conveyor transfer points, in de-dusting treatments, and in more effective use of sprays. What throughput of material gives the least dust per kg of throughput?

2. Performance of seals and fittings on process equipment to minimize leakage

3. Application of Process Safety Management review techniques to the control of worker exposure. (In reviewing the design of equipment to prevent catastrophic losses, elaborate review processes have been devised. Perhaps, the same sort of review can be devised for contaminant generation so that designers are encouraged to think about process choices which affect generation rates and occupational exposure. Before process changes are made, occupational safety and health professionals need to know how to conduct a hazard assessment which is
predictive of exposure and how to conduct a technical options analysis so that process options are selected which truly minimize workers' exposure.)

4. Evaluation, with prospective studies, of the effect of hazard prevention and minimization efforts upon worker's exposure and cost. These are principally pre- and post-control implementation studies.

5. Relationships between process disruption and exposure.

C. Control measures development

1. Application of Computational Fluid Dynamics (CFD) to the design of local exhaust ventilation systems. This could be used as a part of an effort to develop mathematical model of workplaces, to predict the effect of workplace changes upon exposure. CFD models should be developed for various scenarios in the laboratory and then “field calibrated” for actual processes. Limitations of this analytical technique must also be identified and addressed.

2. The use of microprocessor-based process controllers that, in principle, could incorporate sensors and basic decision-making for the operation of ventilation systems and other controls.


4. Resource Conservation. Evaluate the benefits (conservation of energy, environment, economics) of various engineering control technologies. This must address the economics of resource conservation.

D. Management issues

1. Research into the effectiveness of various management systems at improving use of control measures, systems and procedures; including for example performance indicators for plant managers, incentive schemes for staff, and integration of workplace environment measures into product quality schemes.

2. Development of training programmes for occupational hygienists to provide an adequate level of understanding on managerial processes, aims and constraints.

3. Work by professional bodies and occupational hygiene educators with other educators to integrate occupational hygiene and safety into other curriculums, in fields such as management, chemical and production engineering, emphasising removal of hazard at source by design.
E. Respirator issues

1. Relationship between anthropometric measurements and respirator fit should be more fully investigated, over the full range of ethnic types.

2. Development of respirators should be developed which perform better under workplace conditions, so that they reproduce there the performance they achieve in the laboratory.

II.3 Communication and professional incentives

1. Professional societies should encourage publication of control solutions and case studies by:

   (1) giving strong incentive through their continuing professional development schemes to the publication of control solutions and case studies by their members, and,

   (2) seeking industrial sponsorship for periodic awards for control solutions by occupational hygienists.

2. Occupational hygiene journals should commission reviews of developments in prevention and control methods, their application and management, so that what is available becomes more widely known.

3. Educational institutions should collaborate with trade and industry associations in presenting seminars and short courses on prevention and control issues.
ANNEX III

The Production Process as Hazard Source for Control Purposes

III.1. Process

A systematic approach to control solutions requires a classification of processes or activities from which hazards may arise. The classification herein proposed is derived from a descriptive analysis of the structure of a production process - a design analysis which provides answers basically to the following questions: what has to be produced? by which method?

The material flow of the production process is used, as a point of reference, to investigate the possibility that another method, hopefully less hazardous, can be used to achieve the same production results (Kroonenberg and Siers, 1983; Eekels, 1987; Swuste et al., 1993). According to design analysis, a production process comprises three levels, namely production function, production principle and production form, which are interrelated and organised hierarchically (Table III-1).

<table>
<thead>
<tr>
<th>Table III-1 Design analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>what:</strong></td>
</tr>
<tr>
<td>PRODUCTION FUNCTION</td>
</tr>
<tr>
<td>core activity</td>
</tr>
<tr>
<td><strong>how:</strong></td>
</tr>
<tr>
<td>PRODUCTION PRINCIPLE</td>
</tr>
<tr>
<td>general process</td>
</tr>
<tr>
<td>energy source</td>
</tr>
<tr>
<td>operational control methods</td>
</tr>
<tr>
<td><strong>by use of:</strong></td>
</tr>
<tr>
<td>PRODUCTION FORM</td>
</tr>
<tr>
<td>detailed design, machines</td>
</tr>
<tr>
<td>preventive measures</td>
</tr>
</tbody>
</table>

The *production function* is the highest level and divides the production process into its core activities.

The *production principle*, the second in order, specifies the general process (e.g. bulk feed through pipes vs. sacks opened and poured into the process), motive power

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(energy source) and operational control methods by which the function is, or can be achieved.

The motive power relates to the energy source utilized. The operational control methods determine the distance of the worker from the exposure source, and can be classified as: direct manual, direct mechanically driven, and indirect (remote controlled or automated method). For the manual and mechanically driven operations, the worker is close to the machine or equipment. The remote controlled and automated operations increase the distance between the machine and the operator, but not for maintenance workers.

The lowest level is represented by the production form, which determines how the production principle is carried out; it describes the materials, tools and machines in use and the eventual measures applied to prevent accidents or exposure.

The concept of production functions is closely related to the classification introduced in 1936 in the chemical industry, dividing a production process into the so-called unit operations, as is shown in Table III-2 (Badger and McCabe, 1936). The assumption behind unit operations is that, although the number of individual processes is great, each one can be broken down into a series of steps which appear in process after process.

Table III-2 Unit operations

<table>
<thead>
<tr>
<th>material receipt</th>
</tr>
</thead>
<tbody>
<tr>
<td>material storage</td>
</tr>
<tr>
<td>transport and feed</td>
</tr>
<tr>
<td>processing</td>
</tr>
<tr>
<td>packaging</td>
</tr>
<tr>
<td>waste disposal</td>
</tr>
</tbody>
</table>

These operations have common techniques and are based on the same scientific principles. The concept of unit operations is not restricted to the chemical industry, but has been used in industry in general. A classification according to unit operations is helpful and is incorporated in the proposed classification of production processes (Shreve, 1956; Blackadder and Nedderman, 1971; Geankoplis, 1978; Hovinga and Deurloo, 1984; Ghosh and Mallik, 1986).

III.2 Production Functions

In the following sections, the manufacture of products is subdivided into three production functions: processing operations, materials handling and supporting
operations. Waste disposal is an operation which contains elements of materials handling and of processing and is linked with both.

**Processing operations**

Processing includes all activities where materials change their form, state, composition or assembly. It takes place through a whole range of scales from micrograms to tonnes, in unit, batch and mass/bulk production and in departments ranging from laboratories through workshops, canteens, building sites to production departments and automated chemical reactors. A broad classification of sub-functions (Hovinga and Deurloo, 1984; Moore and Kibbey, 1982), is hereby presented, under four headings:

- shaping: changing of shape and/or state with no volume change;
- separating: changing of shape or composition with reduction in volume or division into several parts;
- combining: uniting or coalescing into one body or one substance with increase of mass;
- surface treatment: influencing the micro-geometric shape and quality of the surface layer.

**Handling of materials**

Handling of materials - which covers transport, storage and packaging, as well as the processes of feeding materials into, and removing products from, manufacturing processes (Bolz and Hagemann, 1958; Caenegem, 1979), can be sub-divided as follows:

- transport: continuous and discontinuous;
- feeding/emptying: the interface between transport and processing;
- loading and unloading, storage and packaging: sub-divided according to the physical form of the product.

**Supporting operations (e.g. repair and maintenance)**

Supporting operations consist of repair, maintenance, replacement and adjustment, setting and cleaning. Under each of these types of operations, alternative means of achieving the same result (or production function) can be grouped together, thus allowing, in principle, a choice to be made between the different alternatives, on the basis of the associated hazards and of the ease with which they could be controlled.

Combining the classifications of hazards and processes provides the basic tool for embarking on risk management.
III.3 From Hazard to Process

For example, in a few branches of industry in the Netherlands, agreements with a view to reducing occupational hazards have been made between social partners. Toxic substances, as well as noise and physical workload play an important role in these agreements. In general, the approach taken for reducing the emission or exposure to toxic substances has been *substance-oriented*. Therefore, the possibilities of replacing toxic substances with less toxic ones, or of reducing the transmission, or of reducing the exposure, are well documented. For some of these solutions, like local exhaust ventilation systems or personal protective equipment, much commercial information is available. Various formats of material safety data sheets have also been introduced for toxic substances.

However, other *source-oriented* control measures, like adaptations and alterations of production lines, machines and installations, have not yet been sufficiently worked out and have been only briefly mentioned both in the literature and in agreements between stakeholders.

Problems related to occupational accidents or exposure to occupational hazards become manifest at the level of the production form. But the accident or exposure scenarios are determined by the production principle. Expertise in the fields of safety science or occupational hygiene is specifically focused on the production principle. This expertise, possibly complemented with quantitative exposure assessment results, allows the assessment of the types of hazards and the magnitude of the risks related to a certain production principle. In this way, a translation can be made from a given occupational hazard, or to be more precise from an accident or an exposure scenario, to various process indicators.

The above description provides a generic description of the design analysis, particularly in terms of occupational hygiene hazards. An added difficulty arises with new designs when there is no previous experience to indicate the type of associated potential hazards, and of safety hazards likely to arise in unusual situations. In order to find ways of overcoming this problem, an experimental study was undertaken, involving a combination of the design analysis and a safety analysis technique entitled HAZOP (hazard and operability) study. A HAZOP study is a proven and well established technique in the chemical industry for identifying possible process deviations. The technique is applied during plant design or during the design of complex installations, and consists of a systematic search for deviations that may have harmful consequences.

In general, the technique is used during the detailed engineering design of a process or installation, when process flow diagrams (PFD), piping and instrumentation diagrams (P&ID) and operation manuals are prepared. Process flow diagrams depict
the major process equipment together with the principal process flows and process controls involved. Normal operating temperatures and pressures, as well as mass flows and compositions of the main flows are indicated. The piping and instrumentation diagram is a schematic representation of all equipment, piping and instrumentation of a plant; this is a basic working document in engineering and construction and serves as the principal reference when operation manuals are prepared.

During the detailed engineering phase, changes in the design are possible, but are limited to possibilities that do not alter the choices made during the phase of the basic engineering design of the process or installation. The results of a HAZOP study usually lead to the introduction of extra devices such as valves, reference points, or other control devices.

In a survey in the Dutch Steel Industry, a HAZOP study was applied to an installation of steel works, using the basic material flow instead of PFD's and P&ID's (Swuste et al., 1997a). In contrast to classical HAZOP studies, the safety analysis was not used directly to generate design adaptations, but to determine possible accident scenarios. These accident scenarios were evaluated and validated from subsequent incident records. The results of the study showed a high predictive value for the accident scenarios and also identified and indicated directions in which the results of the study could be improved.

The HAZOP technique focuses on the disturbed process flow, and has been proven useful in the generation of accident scenarios. This technique is suitable when studying highly automated and complex installations, such as steel works, where operations are remote-controlled, hence workers do not come into the vicinity of hazard sources during normal conditions (the undisturbed process flow). However, if the process flow is somehow disturbed (e.g., workers have to investigate a failure in the process), the source-worker distance may be appreciably reduced thus introducing safety and occupational risks. Although this study was limited to foreseeing safety hazards (accidents), the same methodology could be used in relation to health hazards, e.g. exposure to toxic materials.

III.4. From Hazards via Process to Solutions

When accident and exposure scenarios per production principle are formulated using the results from the design analysis, the analysis (as used in the described projects) also guides the search for solutions.

The research in the building industry gives an example of solutions following from systematic variations in either production functions or production principles (Swuste et al., 1997b). Here too expertise from the fields of safety science and occupational
hygiene is used to indicate the consequences of each variation in terms of accident and exposure scenarios, leading to a mutual comparison of different solutions to the same problem.

The comparison of solutions can also include other criteria, such as the costs of the solution, maintenance requirements, training needs for workers, and other criteria, which influence the acceptance of the solution by the different parties within companies. In the study in the building industry, the production principle contains the greatest possibilities of variation leading to solutions.

Changing or eliminating production functions can have even more far reaching consequences. When a certain production function is eliminated, all hazards and risks associated with it automatically disappear. However, there are limited opportunities to change production functions in existing installations or processes.

During the design of an installation, a production line or a plant, the possibilities for modifying the production functions are much more extensive. Both the production function and the production principle are generic descriptions of a production process and can, by their nature, be applied during the phase of basic engineering design, in contrast to the production form (which greatly resembles the stage of PFDs and P&IDs). Basic engineering design is a phase where the design analysis, in combination with expertise from the safety science and occupational hygiene fields and the principles found in the HAZOP technique, can potentially bypass initial support on the expected accident and exposure scenarios and propose different solutions and design variations to eliminate or control them. Instead of applying these techniques during detailed engineering design when change is costly, the consequences of a given design, in terms of accident and exposure scenarios can be predicted in advance during basic engineering design and dealt with long before the actual construction starts.

During the survey in the rubber manufacturing industry, the design analysis was applied to an existing process and technology and showed itself able to subdivide different production processes into comparable parts (Kromhout et al., 1994; Swuste et al., 1993). This division is a necessary step in a study design, which is extended over a whole branch of industry and where the variation in production processes is extensive and dependent on the type of product produced. In the rubber manufacturing industry, the design analysis was not used to generate solutions for observed occupational hazards. The survey was focused on an inventory of existing solutions and control measures. The state of the art of control measures was determined and the effectiveness of these control measures was established. The control measures concerned were local exhaust ventilation, the replacement of powdered and toxic raw materials and the use of personal protective equipment.
The results of this survey were not encouraging. The almost complete absence of source-related solutions, the low efficiency of the solutions applied and the restricted replacement of powdered, toxic raw materials showed a rather ill developed risk management approach in this branch of industry. In a follow-up survey, five years after the original survey, the state of the art on control measures was determined again (Swuste and Kromhout, 1996) The results were more encouraging. A growing number of source-related solutions had been introduced in the companies. To a great extent this was the result of increasing pressure from the Ministry of Social Affairs and Employment and the Factory Inspectorate after the first survey, finally leading to an industrial agreement on working conditions and prevention of occupational hazards between social partners in the rubber manufacturing industry.

The two surveys in the rubber manufacturing industry showed the need for support to companies in the generation of possible solutions and control measures. Solutions are mostly chosen on the basis of available, commercial information, or on the basis of information supplied by a branch organisation of the Factory Inspectorate. There is a clear need for information on solutions that have stood the test of experience. This need is not restricted to the rubber manufacturing industry. Recent initiatives have been taken to expand the 'company memory' on prevention to a national and even an international level, using solution databanks. These initiatives have been supported by developments in legal requirements. To ensure the success of these databanks, which potentially can become 'the state of the art of prevention', a classification not only of production processes, but also of hazard generation and solutions needs to be applied to the structure of this databank. These classifications provide the basis for a navigation system by which a user of the databank is guided to preferred solutions. The principles for these classifications have been partly worked out in projects conducted for the Ministry of Social Affairs and Employment of the Netherlands (Swuste et al., 1997c), the European Commission (Hale et al., 1994) and the construction industry.

References for Annex III.


ANNEX IV

Case Studies

IV.1 Objective

The collection of case studies has two objectives, namely:

• to motivate occupational health professionals to search for solutions, by applying available knowledge on dust control to actual problems at the workplace level;

• to disseminate useful experience on control solutions, thus promoting exchanges of experiences in this important field.

A format for case studies is proposed in this Annex. Format is important because it systematises the collection of information. It also serves as a checklist of aspects involved in planning, implementing and evaluating a control system, from the decision-making process, to workers’ perception and participation, to technical issues and cost benefit.

Two examples of case studies are also presented in this Annex. (These examples were prepared before the formulation of this Annex, therefore they do not follow the proposed format.) The aim is to trigger the preparation of such case studies to be collected and eventually disseminated by WHO, duly acknowledged, in a future series of booklets. Solutions not considered “sophisticated” enough to be published in the specialized literature, but efficient, are particularly welcome.

It is hoped that this Annex may encourage ingenious and dedicated occupational hygienists, in different parts of the world, who often design simple cost-effective solutions for dust control, and do not always get the deserved recognition. Whenever the environmental impact is important, which is often the case, the examples prepared may also be proposed to the UNEP Cleaner Production Data Base.

IV.2 Recommended Format for Case Studies

A. Workplace Characteristics:

A.1 Name and Address (Optional)
A.2 Type: (e.g., foundry, pesticide packing, rubber manufacturing, and construction)
A.3 Products:
A.4 Number of Workers:

B. Operation: e.g., shakeout, cast cleaning, bag filling, sawing, etc.
B.1 Description:

B.2 Source Characteristics

B.2.1 Dust Source:
B.2.2 Mechanisms of Dust Production and/or Dissemination: break-up of larger pieces, dust fall and air currents, bad work practices, etc.

C. Description of Adopted Control Measures, by Category:

For example:

- *changing the process to achieve the same result by other means*: e.g., buying material already in the desired size to avoid sawing at this workplace.

- *work practices*: see Section 3.1 for an example.

- *ventilation*: e.g., a semi-enclosed work station with local exhaust (down-draft) was installed ...

- *wet methods*:
  and so on.

D. Implementation of Measures

D.1 Decision-making process:

Action triggered by: (for example) workers’ complaints, medical reports, labour inspection.

Team involved:
Establishment of Priorities:

D.2 Main difficulties encountered:

Cost:
Specialists with know-how on dust control:
Availability of control equipment:

E. Evaluation of the Efficiency of Measures

E.1 Environmental Evaluations (measurements)

*Before:*

*After*: upon installation, and later (e.g., after 6 months). (The sustainability of a programme is important, and this is rare to find). Such measurements should be carried out at the same point, with the same instrumentation and procedure.
E.2 Workers’ Perception

Although very subjective, enquiries on the workers’ perception of improvements may give precious insight on the control strategy.

E.3 Medical and Personnel Service Feed-back

Effects on Health conditions:
Effects on Absenteeism:

F. Cost-benefit Analysis

Number of workers protected:
Initial investments:
Operational costs:
Savings in raw material, materials recovered, etc.:
Decrease in health expenditures:
Decrease in environmental costs:
Visible effects on productivity:

IV.3 Examples of Case Studies

IV.3.1 Example from the Literature

This is an example from a publication by the British Occupational Hygiene Society (BOHS, 1996) of a summarized case study for the purpose of providing ideas for persons with similar problems.

Keeping it Simple (BOHS, 1996)

The importance of looking at every stage in the processes carried out in the workplace cannot be overemphasized. Even when you think the job is done and dusted, there could be hazards that need to be addressed.

THE PROBLEM

A ceramics producer kept its dust well under control during the actual production process, but the problem arose when disposing of the empty bags, which had contained harmful raw materials. These bags were just thrown on the ground, where the operators stood on them, rolled them up, and threw them away. And the result - clouds of dust billowed into the air, affecting the operators and coating the working area, which ultimately had to be cleaned.
THE SOLUTION

Because the hoppers where the dust was mixed already had dust extraction systems fitted, the company adapted the canopy, attaching a polythene bag to a flanged hole. The empty dust bags were then rolled up above the hopper and pushed through the hole, directly into the polythene bag.

THE COST

Negligible! All that this method required was for a hole to be cut in the existing canopy, and the purchase of a supply of polythene bags. Nothing could be simpler!

THE BENEFITS

No more escaped dust to pose health risks to operators or mess up the working environment. A simple solution to the problem means no need to fit special exhaust ventilation.

_A dust-free environment means a happier and more productive workforce - and at negligible cost!_

IV.3.2 Dust Control Measures for a Small Tungsten Mine¹

IV.3.2.1 Introduction

In tungsten ore mining, large amounts of dust are generated in the process of tunnel and stope drilling, blasting, and mucking operations. The silica content of dust may be over 70%.

In the mine studied here as an example, production increased rapidly in the past, especially in the years 1956-1958, due to the introduction of dry pneumatic drills and mechanization to replace the old manual methods. However, due to the lack of the necessary dust control measures, dust concentrations at workplaces were as high as several hundred mg/m³, which resulted in a disastrous incidence in the rate of silicosis among workers (the prevalence of silicosis in the tungsten mine was over 50% in 1956).

Several years later most of the workers involved died. Disasters of this sort focused the attention of the government, managers of mines, workers and institutions responsible for occupational health and safety to cooperate in investigating effective methods for controlling dust in mines. Comprehensive measures for controlling dust were put into place in every mine in 1958.

¹ Principal investigator: Prof. Shao Qiang and Eng. Shi Jin, Institute of Environmental Health & Engineering, Chinese Academy of Preventive Medicine, Beijing
This is the case of a small tungsten mine where comprehensive dust control measures have been applied with good management since 1959, as described below. Dust concentrations at workplaces were decreased from the original several hundreds mg/m³ to around 2 mg/m³ (which is the hygienic standard of dust containing silica at a workplace). Over 80% of the dust concentrations at workplaces were less than 2 mg/m³. After 1960, there were no new cases of silicosis among new workers performing dusty jobs.

**IV.3.2.2 Control Measures**

**During drilling**

In the process of tunnel and stope drilling, wet drilling was adopted, including the following.

- The rock wall was washed with a water jet (or spray) as cleanly as possible, in order to remove the dust which settled on the wall during blasting (Figure IV-1²).

- Wet type pneumatic drills were used instead of dry pneumatic drills. Much less dust was produced during rock drilling when water was applied through the hollow drill steel to the cutting bit, so that the point of dust production was constantly flooded. In the early stage, the dry drills were converted to wet by the machine shop of the mine itself; which sometimes produced uncertain results. Today there are different kinds of well-designed wet drills on the market which are equipped with air-water locked valves to guarantee that water is applied first through the hollow drill steel to the cutting bit during operation, with water pressure kept 0.1–0.2MPa below compressed air pressure in practice.

**During blasting**

In order to confine and minimize the dust produced in the blasting process, the following measures were adopted.

- A plugging water bag was added between the explosive and plugging sand in the drilling hole (Figure IV-2 and Figure IV-3);

- There were water spray facilities, composed of several nozzles, 10-30 m from the working surface; these could produce water spray curtains (Figure IV-4) during blasting. The sprays were controlled manually or automatically, and lasted for 15–30 minutes after blasting.

- The dust-laden air could be removed immediately after blasting by a local exhaust ventilation system, as mentioned below.

²Figures are placed at the end of this Annex.
• After blasting, the rock wall was washed, as mentioned above.

**During mucking operations**

In this process the broken rock or ore was loaded into cars for removal, or was transferred to chutes by means of a muck shifter or other mechanical means. Implemented measures included the following.

*Generous use of water.* This was the main dust control measure in this process, but incomplete wetting limited the efficiency. As the rock was handled, new, unwetted surfaces were constantly being formed and dry dust escaped. Continuous application of water to the muck pile was therefore necessary.

Equipping the muck drifter with *spray nozzles*, which could spray water during shovelling and loading operations by means of an automatic controlled valve.

*General dilution ventilation,* which was applied to take care of the residual dust still airborne in spite of the local exhaust ventilation system.

**Comments on ventilation**

The specific methods described above were effective in reducing dustiness, but rarely accomplished full control. Ventilation was required to take care of the residual dust. As well as the general mine ventilation, local ventilation systems could be used, consisting of an axial fan and a connecting pipe line, including a scrubber if necessary. The scrubbers had efficiencies of 80-95%. Three arrangements were generally available and the most appropriate could be selected according to the requirements.

*Blow type* (Figure IV-5) - Fresh air was drawn from the main tunnel by the fan, conveyed by the pipeline (made of rubber, steel or reinforced plastic), and blown out at a point about 10 m from the working face. The air velocity at the working site had to be not less than 0.25 m/s. If the air quality in the main tunnel was not good enough, a scrubber was added before the fan.

*Exhaust type* (Figure IV-6) - Contaminated air from the working site was drawn through the exhaust pipeline, located about 5 m from the working face, and discharged into the returning air tunnel at a point about 10 m downstream of the working face tunnel. If the discharged exhaust air might pollute another inlet air source, the exhaust air had to be treated by a scrubber before discharge.

*Combined type* (Figure IV-7) - Whenever the distance of the working face tunnel was greater than 200 m, a combined type was needed. The arrangement of blow pipe line and exhaust pipe line of the combined type local exhaust ventilation system is shown in Figure IV-7.
IV.3.2.3 Effectiveness of Single and Comprehensive Dust Control Measures

Effectiveness of single and comprehensive dust control measures are shown respectively in Tables IV-1 and IV-2.

IV.3.2.4 Complementary Measures

Respirators: Workers insisted on wearing dust respirators during working hours; this was helpful and safer especially when there were weak points in dust control measures of which workers were not aware.

Supervision: Dust concentrations at the work sites were periodically tested by the health and safety department, in order to detect any failures or weak points in dust control.

Health education: Health education of the manager and workers was very important, so that they were made aware of the severe effects of dust exposure and therefore implemented or collaborated with the dust control measures.

<table>
<thead>
<tr>
<th>Process</th>
<th>Dust control measure</th>
<th>Dust concentration before control measure mg/m³</th>
<th>Dust concentration after control measure</th>
<th>Efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock drilling</td>
<td>Using wet drill</td>
<td>368</td>
<td>3.6</td>
<td>99</td>
</tr>
<tr>
<td>Blasting</td>
<td>Water spray and ventilation</td>
<td>122</td>
<td>5.2</td>
<td>96</td>
</tr>
<tr>
<td>Mucking</td>
<td>Wetting with water perfectly and continuously</td>
<td>66</td>
<td>4.9</td>
<td>92</td>
</tr>
<tr>
<td>Cleaning the tunnel wall</td>
<td>Washing down with water perfectly</td>
<td>11</td>
<td>1.5</td>
<td>87</td>
</tr>
<tr>
<td>Cleaning the air from the main tunnel</td>
<td>Using scrubber</td>
<td>6</td>
<td>1.1</td>
<td>81</td>
</tr>
</tbody>
</table>
### Table IV-2 - Effectiveness of Comprehensive Dust Control Measures

<table>
<thead>
<tr>
<th>Process</th>
<th>Dust control measures</th>
<th>Dust concentration after applying dust control measures mg/m³</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock drilling</td>
<td>wet pneumatic drills</td>
<td>1.5 (average of 12 samples)</td>
<td>2 drills working simultaneously</td>
</tr>
<tr>
<td>Rock drilling</td>
<td>washing down wall perfectly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rock drilling</td>
<td>blow type local fan ventilation</td>
<td></td>
<td>air velocity at working area 0.35-0.54 m/s</td>
</tr>
<tr>
<td>Mucking</td>
<td>wetting the muck pile perfectly and continuously</td>
<td>1.5 (average of 8 samples)</td>
<td></td>
</tr>
<tr>
<td>Mucking</td>
<td>washing down the wall perfectly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mucking</td>
<td>applying blow type local fan ventilation</td>
<td></td>
<td>air velocity at working area 0.35-0.54 m/s</td>
</tr>
</tbody>
</table>

### FIGURES

Figure IV-1 - Washing down the wall with water jet: 1. Water pipe line  
2. Flat type jet nozzle  
3. Ventilation pipe line
Figure IV-2  Structure of water bag: 1. Position *before* filled with water; 2. *after*

Figure IV-3 - Water bag in drill hole: 1. Plugging sand; 2. Water bag; 3. Explosive

Figure IV-4  Water spray curtain for blasting: 1. Water spray curtain; 2. Forward water spray curtain; 3. Water pipe line; 4. Exhaust ventilation pipe line; 5. Trench for waste water
Figure IV-5  Blow type local fan ventilation system: 1. Fan; 2. Ventilation pipe line

Figure IV-6  Exhaust type of local fan ventilation system: (a) Using steel pipe line  
(b) Using rubber pipe line 
1. Steel pipe line  2. Rubber pipe line  3. Fan

Figure IV-7  Combined type of local fan ventilation system  
(a) Using steel pipe line  (b) Using rubber pipe line

Reference for Annex IV