5.
Technologies for Controlling Work-Related Illness

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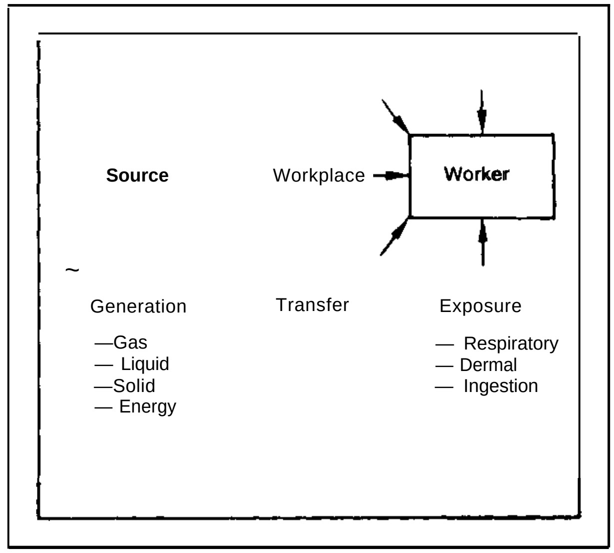
5.
Technologies for Controlling Work-Related Illness

This chapter describes the principles and technologies for controlling workplace health hazards—toxic substances and harmful physical agents found in the workplace. For clarity and since the control principles are similar for both toxic substances and harmful physical agents, discussion focuses on control of the former. Emphasis is given to technologies proven to be the most effective for protecting workers' health—those that prevent hazard generation or that prevent worker contact with the hazard. Three case studies commissioned by OTA illustrate these principles and technologies as applied in controlling work-related exposure to cotton dust, silica, and lead. In addition, the extent of the use of control technologies in United States workplaces is discussed.

Health hazards, as defined by public health science, cause disease by an agent (hazard source) transmitted through the environment by a vector (transmission of hazard) to a host or a receptor (worker) who is affected. This model includes workplace hazards to which workers are exposed (see fig. 5-1). For workplace hazards, the source–the point at which the hazard is generated—may be a gas, a liquid, or a solid if it is a substance, or a form of energy if it is a physical agent. Transmission or dispersion of the toxic substance or harmful physical agent is generally through workplace air or by direct contact. The worker at risk may receive (absorb) the hazard through ingestion, the skin, or by inhalation (see fig. 5-2).

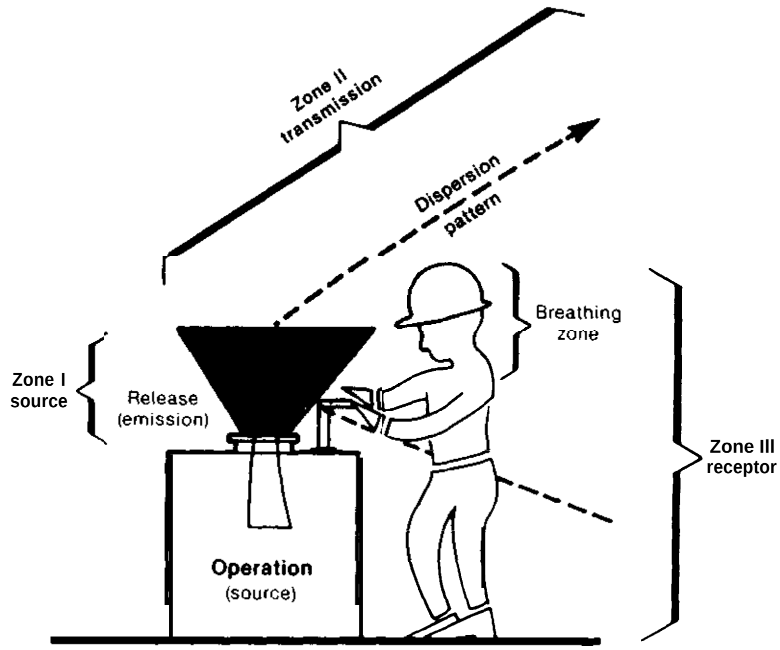
A control technology system can include hazard control at any or all of these three points—source, transmission, or worker. Hazard controls applied at the source, such as isolation of a process, or in the transmission or dispersion path, such as local exhaust ventilation, are generally called "engineering controls." Those worn by the worker, such as protective clothing or a respirator, are generally called "personal protective equipment."

Figure 5-1 .—Generalized Occupational Exposure



A hierarchy of control methods is commonly used. The first choice is control at the source, which can be done by design or modification of a process or equipment or by substitution of less hazardous materials. If the source is unalterable through design or substitution, the next choice is to control or contain the dispersion of the contaminant by isolation of the source, preventing the toxic substance from becoming airborne, or by removing the contaminant through local exhaust or general dilution ventilation. Finally, control at the worker may include administrative controls, personal protective equipment, and work practices. (Personal protective equipment is discussed in ch. 8, and the hierarchy of controls is discussed in ch. 9.)

Figure 5-2.—Generalized Model for Control of Workplace Hazards



CONTROL SYSTEMS

There have been many attempts to define control technology. Brandt (71) described it as a system designed to control contaminant emission and dispersion along the pathway to the worker. Bloomfield (61) cited ventilation to reduce levels of airborne contaminants as the primary means of engineering control. The International Labour Office (229) includes several techniques in control technology: ventilation; process changes; substitution of process, equipment, or material; isolation of stored material, equipment, process, and workers; and education of management, engineers, supervisors, and workers. Caplan (96) defined engineering controls for industrial hygiene purposes as "installation of equipment, or other physical facilities, including if necessary selection and arrangement of process equipment, that significantly reduces personal exposure to occupational hazards." Smith (450) defined control technology as substituting less dangerous substances, equipment, or processes; limiting releases or preventing buildup of environmental contamination; limiting contacts between worker and toxic materials by personal protective equipment; and introducing administrative changes.

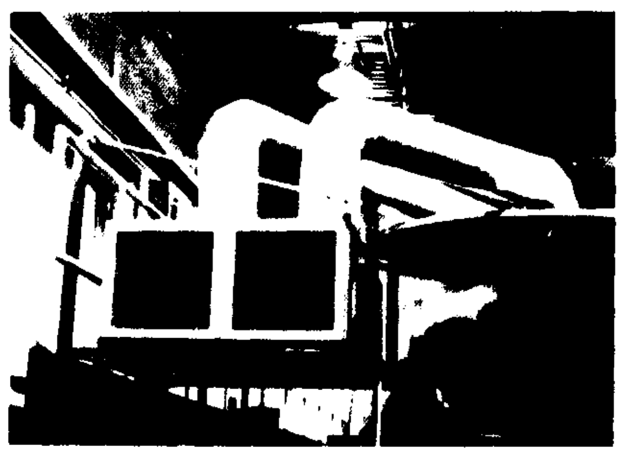


Photo credit: NIOSH

This electrostatic precipitator is used to remove oil mists from the atmosphere of a machine shop

For this assessment, a hazard control system includes:

1. control at the emission source by substitution of materials, change of process or equipment, or other engineering means,
2. control of the transmission or dispersion of the contaminant by isolation, enclosure, ventilation, or other engineering means, and
3. control at the worker by personal protective equipment, work practices, administrative control, training, or other means.

The controls in No, 1 and No. 2 are commonly called "engineering controls."

Training workers, supervisors, managers, engineers, and other concerned persons about a hazard and its control underlies the effectiveness of control solutions. Hazard-free operation requires rigorous maintenance of controls, and good housekeeping is essential to control secondary sources of contamination. Work practices (e.g., instructions that liquids should be poured away from the worker) and administrative procedures (e.g., that workers spend limited time in the presence of hazards) are also important parts of a control system. Table 5-1 is a compilation of hazard control principles and includes examples of control measures.

One tenet of effective hazard control is that a system should be designed in a way that the controls are automated or inherent in the operation of the system. Thus, hazard controls should function even in the absence of continuous worker and manager attention. For instance, enclosing a process to prevent emission of toxic substances to workplace air is a more reliable, and likely less expensive, control than respirators, where effectiveness is difficult to measure, protective fit is difficult to achieve. Although systematic design will consider **a** variety of control methods and combinations, engineering solutions are preferred because they depend less on routine human involvement for effectiveness. For example, grounding home electrical appliances provides greater protection against electrical shock than instructions to remember not to simultaneously touch an ungrounded appliance and a metal surface.

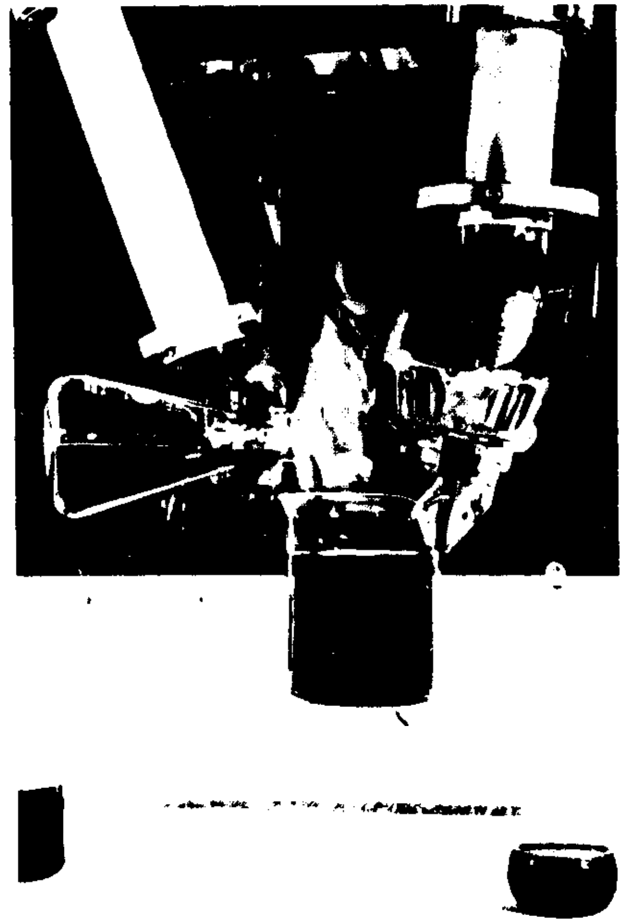


Photo credif: OSHA, Office of Informatlon and Consumer Affairs

Engineering controls include the enclosure of operations and using remote controls. This photo illustrates equipment designed to handle very toxic radioactive materials

Because of the continuing need for human intervention and attention in the use of personal protective equipment, practicing industrial hygienists employed by business, government, and unions have long recognized that such equipment should be turned to only after other means of protection have been exhausted (see ch. 9). Occupational Safety and Health Administration (OSHA) standards require the use of engineering and work practice controls except for the time period necessary to install such controls, when engineering and work practice controls are infeasible (including many repair and maintenance activities),

Table 5=1 .–Principles of Controlling the Occupational Environment

Point of application of the control measure	Control measure
At or near the hazard zone.	Substitution of nonhazardous or less hazardous material Process modification Equipment modification Isolation of the source Local exhaust ventilation Work practices (housekeeping)
To the general workplace environment	General dilution ventilation Local room air cleaning device Work practices (housekeeping)
At or near the worker	Work practices (housekeeping) Isolation of workers Personal protective equipment
Adjuncts to the above controls	Process monitoring systems Workplace monitoring systems Education of workers and management Surveillance and maintenance of controls Effective process-people interaction and feedback

SOURCE (576)

when they are insufficient, and in emergencies (see ch. 9). For instance, engineering solutions to reduce airborne lead concentrations to the OSHA standard are difficult to apply in lead smelters, and OSHA allows respirator programs while the solutions are engineered.

Of course, the nature of some jobs requires reliance on personal protective equipment. For instance, firefighters depend on self-contained breathing apparatus when fighting fires.

Control at the Source

Control at the source can be achieved by design of new or modification of existing processes or equipment, or by the substitution of less hazardous materials-all done, preferably, before the process or equipment is installed and operated. The industrial hygiene literature repeatedly points to source control as the most effective means of preventing work-related illness.

Designing Controls

Designing equipment to eliminate contact between hazard and worker is the most effective way to control exposure (71). The control of vinyl chloride monomer (VCM) provides an example of successful design eliminating a health hazard (see also box N in ch. 12). In the 1960s, before VCM was recognized as a carcinogen, it was identified as a cause of acro-osteolysis (bone deterioration, especially in the finger tips). This finding led the American Conference of Governmental Industrial Hygienists (ACGIH) to revise the Threshold Limit Value (TLV) exposure limit from 500 parts per million (ppm) to 200 ppm in 1970 (5).

Revision of the exposure limit meant that the firms that followed ACGIH recommendations had to find ways to reduce worker exposure. Analysis by design engineers identified two methods by which the high exposures associated with cleaning the VC reactor vessel could be reduced: elimination of reactor fouling or mechanical or chemical removal of the polymer buildup. Hydraulic reactor cleaning technology was adopted that reduced the frequency of worker cleaning from once per several reactor charges (loading the reactor) to once per 25 to 30 charges and thereby reduced worker exposure (256).

When VCM exposure was recognized in 1974 as strongly related to angiosarcoma of the liver (a rare and deadly cancer) by health professionals, OSHA mandated a permissible exposure limit of 1 ppm. Feasible engineering and work practice controls were required to reduce exposure below this level (617).

Again, industrial hygiene analysis determined that exposure to gases during reactor cleaning was a major problem. Re-investigation led the design engineers back to earlier considerations, of either eliminating the fouling or finding an automated cleaning method. But this time the design criterion was to reduce drastically exposure from over 200 ppm down to 1 ppm, and mechanical cleaning alone was found to be inadequate. However, spraying a simple coating solution on interior reactor walls before mixing each batch prevented polymer buildup, Automating and enclosing the reactor cleaning process by installing a permanently mounted nozzle inside the reactor (see fig. s-3) very effectively contained the VCM gases and greatly reduced worker exposure (256).

Commercial use of this design demonstrated that the new reaction vessels needed cleaning only once every 500+ polymerization batches, greatly improving the productivity of the process. The developer, B.F. Goodrich, now uses the innovative process in its vinyl chloride monomer plants both here and abroad and also licenses it worldwide to other chemical manufacturers. Table 5-2 shows the benefits of this control technology (256).

This example illustrates the advantages of applying engineering controls to the prevention of work-related illness. Engineers sought solutions to a recognized health problem by first considering methods that would eliminate exposure such as by automating cleaning or by preventing buildup of materials that require removal. This example also shows that production costs can be reduced and productivity increased, as Brandt postulated some 35 years ago in his book on occupational health engineering (71).

Health hazards can also be eliminated or controlled by changing an industrial process. For example, the National Institute for Occupational Safety and Health (NIOSH) recently conducted a study of dry cleaning machine operators exposed to perchloroethylene, a widely used solvent, known to cause contact dermatitis, central nervous system depression, liver damage, and anesthetic death. NIOSH investigators found higher exposure levels of perchloroethylene vapors in processes involving separate washing and drying machines than in processes that combined these two steps in one machine. The two-step process requires manual transfer of clothes, resulting in unnecessary worker exposure, which is avoided in the combined process.

Substitution

Substitution of a less toxic agent for a more toxic one is an important means of control, but care must be taken that the substitute does not

Figure 5-3.-Vinyl Chloride Reactor System

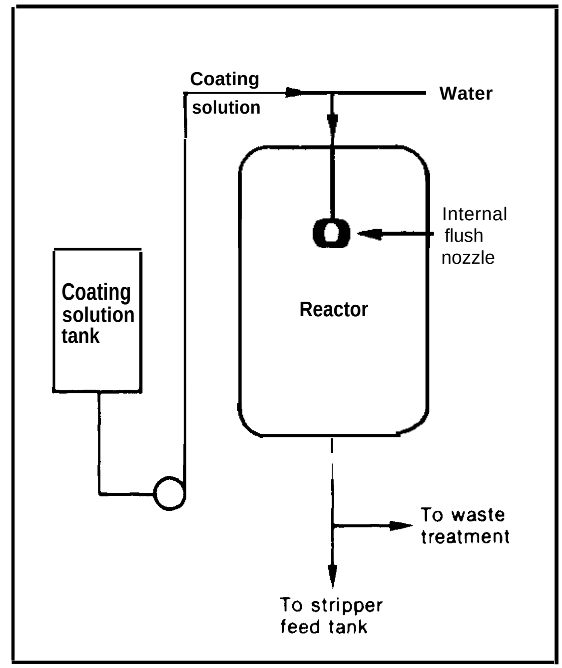


Table 5-2.—Benefits of New Technologies for Controlling Worker Exposure to Vinyl Chloride Monomer (VCM)

Reduction in worker exposure to VCM.
Reduction in VCM emissions to the atmosphere.
Closed reactor operation—entry only for normal maintenance.
Savings in labor.
Reduction in reactor downtime due to cleaning and, as a result, increase in productivity.
Polymer buildup lost as scrap is eliminated.
Reduction of rupture disc changes due to polymer buildup.
Constant and maximum process side heat transfer coefficient in the reactor.

SOURCE: (25S).

itself harbor toxic properties. For example, asbestos, an excellent insulator, is found widely in buildings, ships, and other places requiring thermal insulation. However, as its toxic properties, especially its carcinogenicity, were recognized, other materials were considered as a replacement. Several materials are suitable, depending on the application and the temperature range to be insulated. These include insulating concrete, vermiculite, fiberglass, and rockwool. While none of these is yet known to cause cancer, precautions should be taken to control exposure to these materials during installation (80).

Silica dust, which can cause lung disease, is one of the oldest known occupational health hazards, and its control well illustrates the principle of substitution (see case study, later in this chapter). Silica dust is a problem in "sand blasting," in cleaning and polishing moldings and metals, and in mining and quarrying, where it is generated by explosives and mining machinery.

In foundries, silica dust is generated during cleaning, during chipping and grinding of castings because some sand from the cores and molds remains on the castings, and during abrasive cleaning, which generates airborne silica dust. If abrasive cleaning is performed by sand blasting, silica dust may be generated from both the blast sand and the mold and core sand.

The most direct method of eliminating silica dust is to make substitutions for silica-containing material. A number of silica-sand substitutes are available for abrasive blasting, including metallic shot and grit, garnet, nut shells, cereal husks, and sawdust, and have been widely used in abrasive blasting operations and to some extent in foundries *(560).*

In some cases, silica dust can be eliminated by substitution of a nonabrasive process—by cleaning castings by the salt bath process, acid pickling, or ultrasonic cleaning. Water jetting and laser cutting to remove excess metal from castings have been considered as alternatives to chipping and grinding (435).

Controlling Dispersion

If a source cannot be altered through design or substitution, the next choice is to control or contain the dispersion of the contaminant. This may be done by isolating the source, preventing the toxic material from becoming airborne, or by ventilation.

Isolation

Isolation of a process involves the placement of a barrier between the process and the worker. In dusty operations for example, there are three basic means of isolation: enclosure of an operation (to prevent dust, fumes, or vapors from escaping into occupied areas); *automation,* through the use of unattended machines; and distance, to place operations away from workers.

Isolation by enclosure has been used effectively to reduce silica exposure in foundries (359,569, 577). Abrasive blasting operations maybe located in enclosed, ventilated booths. Enclosure is also used to reduce worker exposure in the asbestos textile industry. Card machines, among the dustiest parts of the asbestos textile manufacture process, can be completely enclosed and asbestos dust filtered from the air exhausted (80). Enclosure has been applied successfully in containing contamination from radioisotopes since the beginning of the nuclear industry. A variation is to protect workers from physical and chemical hazards by locating their work stations in ventilated control booths.

Many jobs with risk of exposure to toxic substances can be automated. For instance shakeout (a method for removing foundry sand from molds or parts) in a foundry can be done by ventilated machines rather than by hand. Automobiles may be spray painted or welded by automated machines to remove workers from exposure to spray paint and solvent and welding fumes, respectively.

Finally, explosive or extremely toxic materials can be stored in remote and inaccessible areas and hazard-generating operations may be removed from areas where workers are concentrated. Open-air sand blasting can be done at a distance from other work sites to reduce the number of workers at potential risk. Persistently leaky pumps and piping for the transport of toxic substances can be isolated by placing them in areas remote from workers.

Wetting

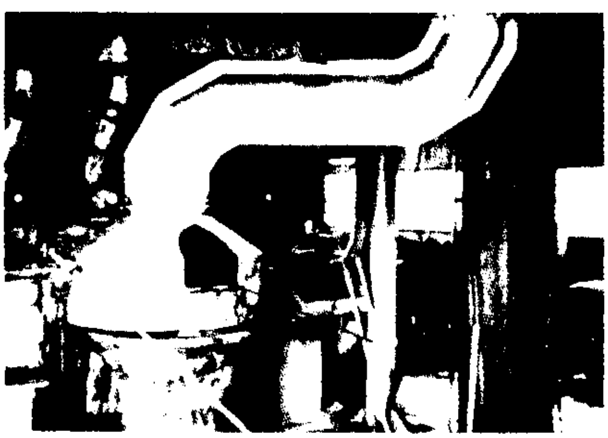
Wetting dust to prevent it from becoming airborne is used to reduce worker exposure. Spraying is a primary means of dust control in mining, but it is considered to be inadequate alone and is usually used in conjunction with ventilation (230,394). Substitution of wet processing and spraying for dry operations has been widely used to control silica dust. In foundries, adding moisture to sand has been found to reduce dust concentrations substantially (435,569). By contrast, wet processing in the manufacture of portland cement appeared to have no effect on respirable dust levels (419).

Local Exhaust Ventilation

Local exhaust ventilation is one of the most commonly used engineering controls. It aims to protect the worker by capturing generated gases, vapors, fumes, or particles in an exhaust air stream and discharging them away from workers. Examples are laboratory fume and kitchen-range hoods, both of which use fans to exhaust contaminated air, Industrial operations are often placed in hoods to obtain maximum contaminant control with minimal exhaust air volume.

For example, local exhaust can be applied in aluminum reduction operations to reduce worker exposure to carcinogenic particulate, in spray paint booths to control paint mist and solvent vapors, in garages to control carbon monoxide from auto exhaust, and in foundries to control silica exposure from abrasive blasting and grinding.

NIOSH is currently investigating "push-pull" ventilation. Generally, local exhaust ventilation depends on "pulling" air away from the operation and exhausting it at some distance from the worker, If the emission source is over two feet from the exhaust, a great quantity of room air must be pulled into the exhaust, significantly reducing control effectiveness. Furthermore, energy costs are increased to heat the air that replaces the exhausted air.



This hood in a secondary lead smelter illustrates the use of local exhaust ventilation

Using a jet of air "upwind" from the exhaust pushs the emissions toward the exhaust. This is commonly referred to as push-pull ventilation. NIOSH showed that push-pull ventilation controlled emissions from chrome plating tanks with just 25 percent of the exhaust needed if only pull was used. The system thus controlled emissions and reduced energy costs (582).

A successful local exhaust ventilation system.—As already indicated, controlling exposures is best done by considering design of the health hazard control at the time a process is established and carefully monitoring performance of the system. Anderson *(20)* describes the effective design of a control system in a large electronics plant.

The process begins when a manufacturing engineer asks to add or change a chemical process. The request is submitted to the facilities engineering department and an engineer is assigned responsibility for installing the equipment to satisfy process, safety, health, and other requirements. Part of the facilities engineer's responsibility is to review the need for local exhaust ventilation with the industrial hygienist, who is responsible for providing health protection information including details about hood design and air volume requirements. The preliminary design is then reviewed by the environmental engineering department to determine the need for air cleaning devices and emission permits. After the process design is completed, it is given a final review by the industrial hygiene, environmental engineering, safety, maintenance, and manufacturing engineering departments.

Installation is supervised by a coordinator who ensures that contract specifications are followed, Changes must be approved by the facilities engineer. The contract coordinator informs the facilities engineer when the job is done and puts a warning tag on each completed hood.

Before the hood can be used it must be adjusted to meet design specifications by the facilities engineer and the maintenance ventilation technician, who enters information about the system in a data base for scheduling preventive maintenance and who also tags the hood to indicate that this has been done. After this the hood is inspected by the industrial hygienist, who reviews its use with the workers and ensures that the proper chemical identification labels are placed at each station.

Hood effectiveness is measured periodically and data entered into a computer. Each week the computer system generates a card for each hood performing below specified levels for review by the industrial hygienist. If the hood is in need of attention, the card is forwarded to building maintenance. If that department is unable to fix the hood, the facilities engineering department treats the failure as a unique project, and then follows the same procedure that is used in designing a new hood,

If a hood is found to be dangerously deficient by the ventilation technician, it is tagged “Do Not Operate” and immediately reported to the department manager, facilities engineering department, and industrial hygiene department.

The main features of this well-thought-out system for designing and managing controls are:

- coordination among all concerned parties,
- integration of occupational health concerns at the beginning and throughout the design process,
- integration of occupational health concerns following installation, and
- execution of a well-planned preventive maintenance program.

The company has found that this approach greatly lowers costs by reducing the need to retrofit processes. Before this method was adopted, newly installed exhaust systems frequently failed because of improper design or installation. Post-installation approval guarantees all concerned parties that the system works from the start as it was designed. A well-planned, computer-based, preventive maintenance program assures continued effectiveness.

General Dilution Ventilation

While local exhaust systems are applied at a particular point to remove contaminants at relatively high rates, general dilution ventilation is the gradual introduction and mixing of fresh air with, and exhausting of, workplace air. Continuous air exchange in buildings reduces nontaminants that resist other control means while contributing to maintenance of a comfortable environment. General dilution ventilation is defined as “the process of supplying or removing air by natural or mechanical means, to or from any space” (71). The air circulation systems found in most buildings are examples of general dilution ventilation.

This technique requires careful planning, and it can fail if inadequate consideration is paid to contaminant generation rates. Furthermore, provision must by made for adequate fresh “makeup” or “replacement” air, for heating or cooling the makeup air, and for avoiding contamination of makeup air.

Recent interest in energy conservation has added new considerations. Increased building insulation has greatly reduced the flow of air from “leaks,” which requires more makeup air. Chapter 16 describes particular problems among office workers in new “tighter” buildings, Office workers report health effects from microorganisms, organic chemicals, asbestos, tobacco smoke, and other sources in buildings with inadequate ventilation (25).

Control by general ventilation is aided by removing sources, such as smoking, and by cleaning air. Since most building ventilation systems now recirculate air, cleaning the air becomes especially important. This is a relatively new problem; before energy conservation was given emphasis, accepted engineering practice was to completely exchange building air to avoid contamination buildup. Now, building air is often cleaned and then recirculated to reduce energy cost. Systems are available for cleaning both gas and particulate, but care must be taken to ensure that the system is reliable and the cleaning complete *(563).*

Neither local nor general ventilation acts to prevent generation of hazards; it can only capture or dilute contaminated air and take it to another location. The air may still have to be cleaned before discharge to the ambient environment, to meet Environmental Protection Agency or other ambient-air standards (6,562,563).

Control at the Worker

Control at the worker may include certain work practices, personal protective equipment, and administrative procedures. (Personal protective equipment is discussed in ch. 8.) For example, work practices important in preventing generation of airborne silica dust include using vacuum instead of compressed air cleaning, keeping enclosed operations tightly closed, and housekeeping to reduce dust accumulation.

Other administrative procedures include rotation of workers in hazardous areas so that no one person is exposed full-time, and scheduling procedures such as cleaning or maintenance to take place on weekends or at other times when few workers are present.

An underlying factor in the success of administrative controls is the adoption and enforcement of exposure control policies. Company policies directed at control of chronic health hazards are often enforced less vigorously than are policies that require workers to wear hard hats or that prohibit tobacco smoking where flammable substances are used. This is probably because it is easier to relate cause and effect to an immediate explosion ignited by a burning cigarette than it is to relate severe respiratory problems to 10 years spent in a job with high exposure to a health hazard (210).

Integration of Health Hazard Controls into Workplace Management

Workplace decisionmakers—including managers, supervisors, workers, engineers, architects, equipment manufacturers, and installers—all contribute to effective disease prevention. For instance, Peterson (369) points out that engineers should know the concepts of hazard control and that they should

> . . . open their eyes to the consequences of decisions they may make in their professional capacity. Undergraduate engineers (and most graduate engineers for that matter) simply are not aware that it is perfectly possible to write noise specifications for much equipment: that carbon tetrachloride and benzene have excellent, much less hazardous, substitutes; that LPG fueled lift trucks generate much less carbon monoxide than do gasoline-powered lift trucks, that electric lift trucks are available and entirely suitable for most lift-truck tasks; or when and where to install fire doors.

Effective control programs need supervisors who are trained in hazard recognition and know about control systems. They must be responsible for maintenance of controls as part of the process and process equipment, and must understand the consequence of its failure (154,369).

Peterson (369) points out the direct benefits of workers being informed about and involved in controlling the hazards of their work. Since they are directly knowledgeable about the materials, equipment, and processes with which they are working, workers often spot health exposure problems in early stages and may have the best ideas about how to eliminate or control the hazard. (The need for training is discussed in greater detail in ch. 10.)

CASE STUDY: CONTROLLING WORKER EXPOSURE TO COTTON DUST

Byssinosis

> In many cases . . . the disease induced has appeared to me to differ from ordinary chronic bronchitis. In the commencement of the complaint, the patient suffers a distressing pulmonary irritation . . . . Entrance into the atmosphere of a mill immediately occasions a short, dry cough, which harasses him considerably in the day, but ceases immediately after he leaves the mill and inspires an atmosphere free from foreign molecules. These symptoms become generally more severe, the cough is at length very frequent during the day, and continuous . . ., disturbing the sleep, and exhausting the strength of the patient. . . . he seeks medical aid (Kay (241). Quoted in 124).

The quote was made in reference to a respiratory disease suffered by workers in English textile mills **150** years ago. That disease—byssinosis, or "brown lung''—was recognized in this country much later than in Europe. The reasons for the late recognition are complex. Many occupational health authorities suggest ignorance or refusal to recognize particular respiratory diseases that were common to mill workers to spare employers the costs of installing controls. In addition, social conditions inhibited workers from making their complaints known and prevented actions on those complaints. Also, local and State Governments were reluctant to act because they feared the loss of textile industry jobs as a result of requiring prevention of work-related injury and illness. Finally, a lack of scientific studies showing an association between cotton dust and illness in the United States contributed to the tardy recognition of the disease and inhibited action to prevent it until OSHA came into being **(124).**

The OSHA Cotton Dust Standard

Although the exact disease-causing agent within cotton dust has eluded identification, it is known that the dusts from the early stages of processing are more hazardous than those from later stages. Opening cotton bales and sorting, picking, and blending raw cotton present greater risks than do weaving and finishing.

In **1964,** the American Conference of Governmental Industrial Hygienists considered the evidence for establishing a recommended limit for cotton dust exposures. Two years later, the Conference agreed on a Threshold Limit Value of 1,000 micrograms/m3 as the maximum exposure that was consistent with maintaining workers' health. In 1969, the Secretary of Labor incorporated ACGIH's recommended TLV into Federal standards for employers with Government contracts (see ch. 11 for a discussion of the Walsh-Healey Act).

The Occupational Safety and Health Act of **1970** required that the newly established OSHA adopt the Walsh-Healey Act standards and apply them to all the Nation's workplaces. Thus, the cotton dust standard of 1,000 micrograms/m^3 was adopted as a startup standard by OSHA in 1971 (see Ch. 12).

In 1974, ACGIH revised its TLV downward to 200 micrograms/m^3 (the method of measurement changed also, and the "new" 200 micrograms/m^3 is not directly comparable to the ' old" 1,000 micrograms/m^3). That same year, the Director of NIOSH recommended that exposure to cotton dust should be reduced to the lowest feasible level, and that it should in no case exceed **200** micrograms/m^3.

In 1976 OSHA proposed a 200 micrograms/m^3 standard. The final standard, issued in 1978, set three different exposure limits—200 micrograms/m^3 for cotton yarn manufacturing, 750 micrograms/m^3 for "slashing and weaving" operations, and 500 micrograms/m^3 for exposures in other operations. This standard was contested by the textile industry through legal suits. While the Supreme Court upheld the standard for the textile industry in 1981, in the same year the current administration moved to reconsider it. This action is pending. Table 5-3 shows how the suggested and recommended levels for cotton dust came downward after the substance was regulated as a health hazard in the United States.

Changes in Cotton Dust Levels

Table 5-4 presents North Carolina Department of Labor measurements of the percentage of textile plant departments that were in compliance with the OSHA cotton dust standard i n **1981.** As can be seen, just two years after promulgation of the new standard and during the period the standard was being challenged in the courts, over half the departments complied with the standard. Some problems remain, as higher frequencies of noncompliance were found in the early stages of the process-opening, picking, carding, drawing, and combing. In these stages, workers are exposed to the more hazardous dusts associated with unprocessed cotton. overall, however, the cotton industry is coming into compliance with the new standard.

The industry trade association, the American Textile Manufacturers Institute, estimates that about 75 percent of the industry was in compli-

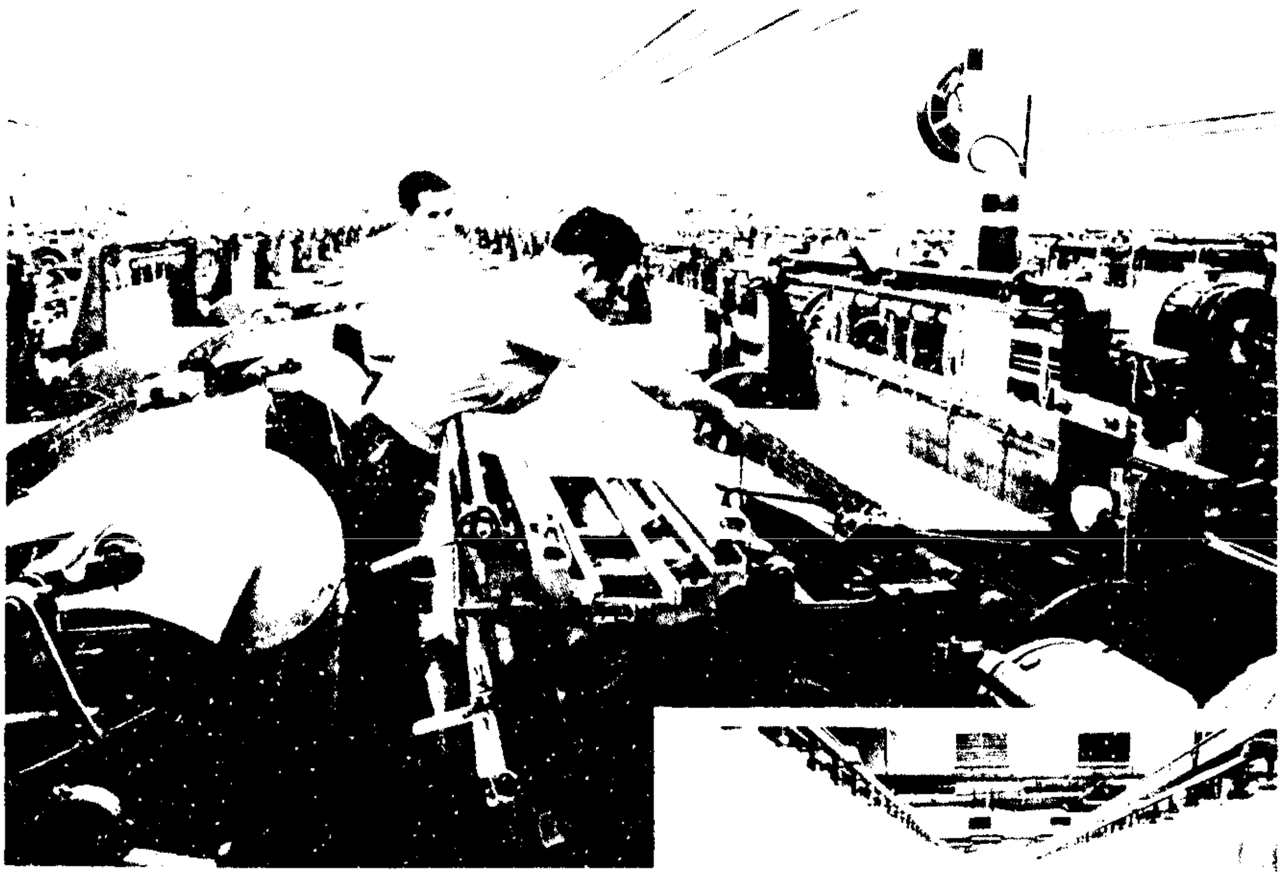


Photo credit O. SF/A, Office of Information and Consumer Affairs

The spinning of cotton fibers into yarn and weaving yarn into fabric are two of the operations regulated by the OSHA cotton dust standard. In recent years, the textile industry has invested heavily in modernized equipment in order to comply with the standard and to improve productivity

ance within two years of the standard being introduced. Some plants that have been completely modernized **are in full compliance** (413).

In 1981, the U.S. textile industry purchased $1.6 billion worth of new machinery. About 70 percent of those purchases were for the purposes of modernization to increase productivity (413) in the face of increased foreign competition and, to some extent, to comply with the OSHA standard for reduced cotton dust levels.

Ruttenberg (413) concludes that it is impossible to decide the relative importance of increasing productivity and compliance with OSHA regulations in the modernization of the American textile industry', but that both have made a contribution.

> The U.S. Occupational Safety and Health Administration dust regulations have had a dramatic effect on . . . processing equipment design and purchasing. Machine suppliers modified equipment to comply with OSHA regulations and this equipment has been accepted on a worldwide basis as well as in the USA. The dust controls have also contributed to much better operating results. . . (U.S. Department of Commerce (551). Quoted in 413).

Table 5-3.-Suggested and Recommended Levels for Cotton Dust Exposure

Organization	Year	Level[a] (micrograms/m^3)	
American Conference of Governmental industrial Hygienists (ACGIH)	1964	1,000	tentative recommendation
ACGIH recommendation	1968	1,000	formal
Secretary of Labor	1968	1,000	Walsh-Healey Act standard
Occupational Safety and Health Administration (OSHA).	1971	1,000	OSHA standard
British Occupational Hygiene Society	1972	500	recommended standard for Britain
ACGIH recommendation	1974	00	formal
National Institute for Occupational Safety and Health (NIOSH)	1974	200	recommendation
OSHA	1976	200[b]	proposed standard
OSHA	1978	200	final standard

[a]The levels from 1964 through 1972 were based on techniques that measured the concentration of total dust in the workplace atmosphere. From 1974 on, the levels are based on the use of the vertical elutriator—a device that measures the quantity of small, respirable dust particles. Levels based on the these two methods are not directly comparable

[b]The 200 limit is for yard manufacturing, 750 for slashing and weaving, and 500 for all other processes The limit goes up as the cotton dust becomes cleaner

SOURCE Adapted from (413).

Table 5-4.—Cotton Dust Measurements Before Promulgation of the OSHA Cotton Dust Standard and Percentage of Companies Claiming Compliance with the Standard in North Carolina

Area of plant	Range of measurements before OSHA standard (micrograms/m^3)	Limit under OSHA standard (micrograms/m^3)	Companies claiming compliance in North Carolina (percent)
Opening	300-3,000	200	53
Picking.	700-1,700	200	61
Carding	300-1,800	200	52
Drawing	400-800	200	63
Combing	NA	200	61
Roving	NA	200	81
Spinning	200-300	200	83
Winding	1,200	200	76
Twisting.	1,200	200	80
Slashing.	NA	750	100
Weaving	400-1,000	750	96
Knitting	NA	500	100
Waste Processing	NA	500	85
Other	NA	500	97

SOURCE: (413).

> Tougher government regulations on workers' health **have,** unexpectedly, given the [U. S.] industry a leg up. Tighter dust-control rules for cotton **plants caused** firms to throw out tonnes of old in**efficient machinery and to replace it with the latest available from the world's leading textile machinery firms.** (The Economist (160). Quoted in 413).

Costs of Compliance with the Cotton Dust Standard

OSHA contracted for an economic analysis of the expected costs of compliance with the cotton dust standard, and the contractor assumed that compliance would be accomplished by "add-on"

ventilation equipment. However, the availability of newer production equipment, which increased productivity and reduced cotton dust exposures, resulted in much lower costs than those estimated at the time the standard was considered. As table s-5 indicates, the initial 1974 estimates of capital costs for compliance were nearly $2 billion **(in** 1982 dollars). At the time of promulgation in 1978, **OSHA estimated costs of just under $1 billion** (in 1982 dollars). Thus, while cost estimates plummeted more than 50 percent by the time the standard was issued, the reduced estimate was still almost four times higher than the actual costs reported in 1982 in a poststandard contract report.

Table 5-5.—Estimated and Realized Costs of Compliance with the OSHA Cotton Dust Standard

	Millions of 1982 dollars
Preregulatory estimates	
OSHA contractor, 1974	1,941
Revised OSHA contractor, 1974	1,388
ATMI[a] contractor, 1977	875
OSHA, 1978	970
Postregulatory estimate	
OSHA contractor, 1982	245

[a]American Textile Manufacturers Institute

SOURCE (413)

Although most of the more productive, less dusty machinery now in use in U.S. textile mills was available in the mid-1970s, its potential use was ignored in the early estimates of compliance costs. Even if purchase of new technology had been anticipated, it would have been difficult to assign the proper fraction of its costs to dust control. In the event, new technologies greatly reduced the costs.

CASE STUDY: CONTROLLING WORKER EXPOSURE TO SILICA DUST

Silica is a major component of the earth's crust; it is the sand covering the beaches, the sand sprinkled on icy winter streets, the grit in the dust on windy days—it is everywhere. It is also widely used in industry. Over 402 million tons of silica-containing sand were produced in the United States in 1980. Of this total, nearly 300 million tons were used for glassmaking, as molding sand in foundries, and as industrial abrasives. Since it is ubiquitous, silica is frequently found as an unwanted constituent of ores mined for other minerals. In those cases, it must be removed and discarded.

Silicosis is a disabling lung disease resulting from the inhalation, deposition, and retention in the lungs of respirable crystalline silica dust. Acute silicosis can occur within six months following exposure to extremely high silica dust concentrations. Silicosis victims appear to suffer more episodes of chest illness than workers without the disease. The mortality for nonmalignant respiratory disease is significantly higher among workers receiving compensation benefits for silicosis than in the general population. A complication of silicosis, progressive massive fibrosis, results in significant impairment in lung function and may result in respiratory failure and secondary heart disease. Tuberculosis and other pulmonary infections may complicate acute or chronic silicosis and significantly shorten life expectancy. Hickey, et al. (210) discuss these silica-related health problems and reported associations between worker exposure to silica dust and an increased risk of lung cancer.

Since diagnostic procedures do not detect silicosis at a reversible stage, and since medical treatment will not alter the course of the disease after it is found, emphasis on exposure control is imperative. Yet, even though the cause of the disease has been well understood and technologies for controlling exposure have been available for decades, silicosis continues to occur in the United States at an alarming rate. A minimum of 59,000 cases of silicosis may be expected based on knowledge about current exposure levels and numbers of exposed workers at risk in 1980 **in** U.S. **industry** (210).

Hickey, et al. (210) estimate that there are 1.3 million production workers with potential exposure to silica dust—40 percent of whom are in workplaces lacking exposure control. Historically the most severe exposures to silica have occurred in granite and stone working, foundries, mining, and abrasive blasting. Workers producing and using silica flour (silica ground so fine that it appears to be refined grain flour) have recently been recognized to be at high risk for silicosis, because of the extremely fine size of the particles produced.

Regulatory Activities for Silicosis Control

The current OSHA standard for silica is based on an equation that limits the total amount of free silica to 100 micrograms per cubic meter. This standard was adopted as a start-up standard in 1971 (see ch. 11). Evaluation of the silica standard shows that it may be inadequate at its present level. In 1974, NIOSH recommended limiting silica exposure to 50 micrograms per cubic meter—half the current level. The studies on which NIOSH based its recommendation used pulmonary function performance as the measure of health effect—a more sensitive indicator of silicosis than X-ray methods.

In certain circumstances, such as in abrasive blasting where alternatives to silica are available, substitution may be the most appropriate method of control. The United Kingdom banned the use of silica sand for abrasive blasting in 1948, and NIOSH has recommended a similar prohibition in this country (560). Sweden banned silica as an abrasive in manual abrasive blasting in 1981 (210). A California standard requires that prior to use, not more than 1 percent, by weight, of abrasive sand must pass a No. 70 U.S. standard sieve (0.3 mm). After use, the sand must have no more than 1.8 percent of its weight as particles 5 micrometers or less in diameter (211). These restrictions on size reduce the number of respirable particles.

In 1978, OSHA conducted a technological feasibility assessment and economic impact analysis for a specific standard addressing use of silica sand in abrasive blasting (211). The study considered three alternatives: banning use of silica sand in abrasive blasting, setting minimum criteria on size and hardness of blasting sand, and controlling exposure through work practices. To date no revised standard has been issued.

However, due to the serious silicosis problem, OSHA has made a special effort to enforce the existing silica standard. In 1972, silica was one of five major health hazards selected for special enforcement efforts in the 'Target Health Hazard Program" (414). Silica was again given priority in the 1975 National Emphasis Program, as one of the major worker health hazards in foundries (339). In both cases OSHA industrial hygienists focused health inspections on plants where silica was likely to be found.

Control Technologies: Engineering Methods

Silicosis is an entirely preventable disease. Exposure occurs whenever materials containing crystalline-free silica are processed and dust is generated. Processes include abrasion (sand blasting, grinding, milling, etc.) that creates dusts of particularly small particle size (less than 5 micrometers in diameter). These dusts are too small to be easily seen as a "cloud." Too small to settle, they remain airborne and "respirable"—that is, they may readily pass through the upper respiratory passages and be deposited in the alveolar spaces of the lung (the small air sacs deep in the lung where gas is exchanged with the blood).

The most direct method of eliminating silica dust is to substitute less hazardous materials for the silica-containing material. This control has been widely used in abrasive blasting operations and to some extent in foundries. Silica-sand substitutes include metallic shot and grit, garnet, nut shells, cereal husks, and sawdust. Olivine (magnesium iron silicate) has been used for mold making in foundries to reduce silica dust exposure, but it is not clear how effective this method will be *(210)*.

Process change may also be used to control silica dust exposure. For instance, water may be added to foundry molding sand or sprayed on at the point of dust generation in granite sawing and processing of portland cement. In some situations, dust-producing abrasive processes may be replaced by other types of cleaning such as salt baths, acid pickling, or ultrasonic cleaning. Water jetting and laser cutting for removal of excess metal from castings have been considered as alter-

substitutes that are suitable for replacing silica. Also, for those situations where engineering control maybe infeasible, further improvement in respirator effectiveness is **necessary.** Medical procedures for detection of the early stages of silicosis **should be refined to provide a better way of** worker protection. Information about the toxicity of silica and technologies for controlling exposure could be provided to workers and employers using it.

CASE STUDY: CONTROLLING WORKER EXPOSURE TO LEAD

Early efforts against industrial lead intoxication in this country were championed by Alice Hamilton. Her autobiography, *Exploring the Dangerous Trades (199),* presents many examples of terrible exposures that were corrected when managers and owners were convinced that lead was causing the "colic, " "lead fits, " and blindness that occurred in lead workers. Until they were convinced, owners and managers preferred to believe that the illnesses resulted from bad personal habits—drinking, smoking, or the consumption of coffee.

Some firms refused to act voluntarily, and states began passing "lead laws" in the 1910s that set limits on occupational exposures. These early efforts were the forerunners of the revised OSHA lead standard, which was issued in 1978.

The current standard regulates exposure to lead in over 40 different industries. With only few exceptions, most industries comply with the **sO** micrograms/m^3 permissible exposure limit for workplace air concentration. The exceptions include primary and secondary lead smelting and lead-acid battery manufacture, where controls are most difficult and economic conditions have been unfavorable. (Primary smelters purify lead from lead concentrate, which is lead ore enriched by milling. Secondary smelters recover lead from discarded lead-containing products—in particular, worn-out batteries. Battery plants make lead-acid batteries.) Although the standard was contested by both union and management and it is impossible to be certain of the future of these industries or of the burdens placed on them by the standard, it is clear that workers' health has been improved as measured by reduced lead levels in their blood.

Some Features of the OSHA Lead Standard

The lead standard sets limits on ambient concentrations of the metal in workplace air, requires engineering controls **and work practices to reach those limits, and requires that workers** be informed about lead, its effects, and the methods used to protect against them. Two features—Medical Removal Protection (MRP) and the extended time periods granted to selected industries before engineering controls are required—distinguish the lead standard from other OSHA health standards.

MRP requires employers to measure workers' blood lead levels regularly. If the measured concentration of lead in the blood exceeds certain limits, the worker must be removed from lead exposure until the level drops to an acceptable value. For up to 18 months, the employer must maintain the worker's wages and seniority status even if the person cannot perform his or her regular job.

OSHA requires that air lead levels be reduced to an effective concentration of **50** micrograms/m^3. Since reported exposures have ranged above 2,000 micrograms/m^3, reaching the regulatory limit poses many problems for employers. The regulation gives companies 3 to 10 years to attain the so micrograms/m^3 limit through engineering controls; in the meantime, employers can require the

natives to chipping and grinding in foundries. Vacuum cleaning may be substituted for dusty compressed air cleaning and screw conveyors used instead of dust-producing pneumatic conveyors. However, care must **be taken to assure that** such treatment, while suppressing visible dust, also controls the smaller, more hazardous, respirable silica dust particles.

Where silica remains in use and worker exposure is possible, local exhaust ventilation may be used to capture and carry dust away. Environmental Protection Agency or other ambient-air standard regulations may require that ventilated air be cleaned before discharge to the outside.

Control Technologies: Personal Protection and Administrative Controls

Respiratory protection and face, eye, and body protection against physical injury are also required by OSHA in specific regulations for abrasive blasting. NIOSH has specified the respirator types required for protection from various air concentrations of silica, but these often prove to be inadequate in practice *(210).* Employer-provided and -maintained protective clothing and facilities for changing at work plus training about personal hygiene prevent exposed workers from exposing family members to silica dust when taking work clothing home.

NIOSH (and others) recommend: administrative measures that help reduce risk of silicosis; training managers and workers about the hazards of silica dust; the effective use of personal protection equipment; and work practices that prevent the generation of silica dust, Dust-reducing practices include vacuum cleaning, regular maintenance of dust-producing and dust-controlling systems, and good housekeeping. Dusty work may be scheduled or located to reduce the number of workers at risk. However, Hickey, et al. **(210)** report that company dust-control policies are often unenforced.

Strategies for Silica Dust Control

One might ask why a well-recognized, entirely preventable, work-related illness, for which the etiology is understood and for which engineering and other controls are available, remains a problem. Hickey, et al. *(210)* note some possible reasons:

- the current OSHA standard is inadequate and based on outdated information,
- compliance with the inadequate standard is insufficiently monitored,
- accurately measuring silica concentrations in respirable dust samples is difficult and costly, and
- there is too much reliance on after-the-fact control methods that control the dust after it is generated rather than on methods that eliminate silica dust.

An underlying reason for failure of worker protection against silicosis is the cost of controlling exposures.

To attack this problem, Hickey, et al. *(210)* suggest promulgating a protective standard based on the latest medical knowledge and streamlining enforcement by developing an accurate, inexpensive, and rapid measurement method. These initial steps will provide the basis for developing more effective technology to prevent generation of silica dust. Greater emphasis should be placed on preventing generation than on refinement of measures for control after the dust is generated. Research should be conducted to find nontoxic

Photo credit OSHA, Office of Information and Consumer Affairs

Abrasive blasting workers are frequently exposed to high levels of silica dust

use of respirators to reduce workers' exposures to airborne lead.

Control Methods: Engineering and Respirators

Table 5-6 lists categories of control measures that can be employed to reduce lead exposures. In general, major changes in processes will be introduced only when a plant is rebuilt for other reasons. (An example of the costs involved in substituting a new process in primary smelters compared with adding on controls is presented inch. 16.) Add-on controls, in particular better ventilation, are probably the most common form of engineering controls, although far simpler controls—such as covering stockpiles and putting tops on reaction vessels—are an important part of engineering controls.

A number of process innovations are being made in the secondary smelting industry and in battery manufacture that reduce worker exposure to lead. A major source of lead exposure here has been the breaking open of old lead storage batteries. Goble, et al. (184) mention two new processes that significantly reduce the liberation of lead in that process. In addition, technological changes recently introduced in the manufacture of new lead storage batteries reduce worker exposure while increasing productivity.

Table *5-6* includes personal protective equipment as well as business cycle factors that influence the number of workers exposed. The role of respirators in providing protection until engineering controls are installed is clearly recognized in the OSHA standard. The standard does require that ultimately compliance shall be achieved through the use of feasible engineering controls.

Table 5-6.—Measures To Reduce Air Lead and Blood Lead Levels

A. Measures that affect air lead levels in the plant
   1. Changes in production processes (direct smelting processes, more automated battery production lines)
   2. Add-on controls (ventilation systems)
   3. Changes in operating practice (keeping floors cleaner)
   4. Greater or lesser use of lead-emitting equipment
B. Measures that do not affect air lead levels but limit times workers spend in lead-contaminated atmospheres
   1. Isolation booths with filtered air supply
   2. Changes in work practices to limit time in high lead areas
c. Measures that do not affect air lead levels but limit workers' lead absorption
   1. Respirators
   2. Showers, changing clothes before and after entering work areas
   3. Business cycle factors: layoffs, overtime
D. Measures that do not necessarily affect exposure of the work force as a whole but affect the distribution of exposures among the work force
   1. Monitoring of workers and removing those with biological indicators of exposure to areas with lower lead contamination
   2. Rotation of workers
   3. Firing of highly exposed workers
E. External measures that impact on lead exposure
   1. Changes of lead level in out-of-plant environment
   2. Changes of lead content in food and water

SOURCE (164)

Medical Removal Protection

The OSHA lead standard provides that when the amount of lead in a worker's blood exceeds a trigger level, he or she is to be removed from exposure or placed in an area of lower exposure until the blood lead level drops (see table 5-7). When the amount falls to a specified reinstatement level, the worker can return to his or her regular job.

When the OSHA standard was being considered, employers pointed at MRP as a source of high costs. They argued that older, more experienced workers who were paid a premium for their knowledge would be removed to less skilled jobs, causing losses in productivity. In addition, since MRP requires that the worker's wages be main-

Table 5-7.—Blood Lead Levels That Trigger Medical Removal From and Return to Lead-Contaminated Atmospheres

	Blood lead levels[a] (micrograms/100g blood) for	
Date	Removal	Return
March 1979	80	60
March 1980	70	50
September 1981[b]	60	40
March 1983[b]	50	40

[a]Workers' blood levels are to be monitored quarterly except workers with levels greater than *40* micrograms/100g are to be monitored monthly.
[b]Many firms have been given extensions of the time for the 60/40 and 50/40 triggers

SOURCE (164)

tained, experienced workers doing less skilled jobs would still receive the pay associated with their previous positions.

Table 5-8 summarizes three years' data about medical removal from companies seeking relief from the lead standard. These data represent a worst-case group and may not be representative of the industry. In both the primary smelter and the battery industries reported, the percentage of workers on MRP transfer and the share of worktime spent on transfer peaked in the second year. The data for primary smelters is reasonably complete, based on 5 of 7 smelters and about 2,120 workers each year, compared with a total of about 2,500 workers; it is less complete for the battery industry, based on only *8* plants and about 1,300 workers in an industry that employs about 30,000 people. In the secondary smelting industry, the percentage of workers on MRP and the proportion of worktime on MRP transfer increased each year. The data in this case are certainly incomplete, and the facilities reported may not be representative of the entire industry; the data in table 5-8 are based on about 640 workers out of a total of some 3,000 workers in the industry. If the data are representative, the secondary smelters are encountering greater problems complying with the OSHA standard.

Goble, et al. (184) compared the percentage of total worktime on MRP transfer to projections of transfers that had been made based on assumptions of *so* or 100 micrograms/m^3 air lead levels in the industries. They found that the reported percentages of transfer worktime agree reasonably well with achievement of 100 micro~grams/m^3 air lead levels, supporting the conclusion that effective air lead levels are between 50 and 100 micrograms/m^3. Given that blood lead levels are related to worker health, these changes are evidence that lead-related diseases and disorders should be declining.

The number of terminations of workers because blood lead levels remained above the reinstatement values even after removal to lower exposure situations is apparently small. An examination of the new-hire and termination rates before and after imposition of the OSHA lead standard did not show an increase. That observation is inconsistent with the idea that employers would terminate "leaded-up" workers and replace them with new hires.

Changes in Air Lead Levels

Although some data about air arid blood lead levels are available, they are often unsuitable for making precise estimates of levels, of high exposure. For instance, although 67 percent of secondary smelter workers in 1977 were exposed to greater than 200 micrograms/m^3 airborne lead, neither the maximum exposure level nor the average exposures of the highly exposed workers in this group were reported. Goble, et al. (184) made a number of assumptions and then calculated approximate average air lead exposure levels in the three industries in *1977-78* and in 1981-82 (see table s-9). Air lead levels dropped by about one-quarter in primary and secondary smelting and

Table 5-8.—Medical Removal Protection Transfers in a Sample of Lead Industry Plants

Industry	Year	Plants: In survey	Plants: In industry	Average number per plant: Lead exposed workers	Average number per plant: Workers on MRP[a] transfer	Percent worktime on MRP
Primary lead smelting	1979	5	7	465	21	1.0
	1980	5	7	419	31	2.1
	1981	5	7	492	18	1.3
Secondary lead smelting	1979	6	36	120	4	1.0
	1980	6	36	104	9	4.6
	1981	6	36	96	11	6.9
Battery manufacture	1979	8	136	176	2	0.4
	1980	8	136	140	8	1.9
	1981	8	136	162	6	1.5

[a]MRP, Medical Removal Protection.

SOURCE: (1S4 from data available in 103).

Table 5-9.— Reductions in Average Air Lead Levels, 1977-78 and 1981-82

Industry	Average air lead levels (micrograms/m') 1977-78	1981-82	Percent reduction
Primary lead smelting.	740	565	24
Secondary lead smelting . .	285	205	28
Battery manufacture . . .	160	80	50
Seven battery plants	160	90	50

SOURCE (184)

by half in battery plants. Confidence about the validity of these estimates, especially for battery plants, is increased by the access Goble, et al. had to detailed, company-collected exposure data from seven battery plants. The percentage reduction observed in those plants is the same as the calculated reduction for the industry overall.

The data in table 5-9 show what are probably minimal estimates of reductions in air lead levels because of systematic errors in the calculations. Clearly, however, levels are coming down. Equally clearly, there is some distance to go before the eventual goal of *50* micrograms/m^3 is reached. OSHA recognized that engineering control of air lead levels would take time, up to **10** years in some industries. The decreases shown in table *s-9* were achieved in less than 5 years and during the period when the standard was still being challenged in the courts.

Changes in Blood Lead Levels

Data on blood lead levels for the period before promulgation of the lead standard are not so plentiful as air lead data. The estimates shown in table 5-10 for 1977-78 are from information presented in OSHA hearings. The data shown for 1981-82 are from measurements reported in a Charles River Associates *(103)* report prepared for OSHA, and those are probably more reliable.

Table 5-10.—Average Blood Levels Before and After Promulgation of the OSHA Lead Standard

Industry	Approximate average blood lead levels (micrograms/100g blood) 1977-78	1981-82	Difference
Primary lead smelting.	49.4	41.6	7.8
Secondary lead smelting . .	56.5	44.2	12.3
Battery manufacture	53.2	42.4	10.8
Seven battery plants	53.0	38.3	14.7

SOURCE (184)

A satisfying drop in blood lead levels was seen in less than **5** years between 1977 and 1982. Not shown on the table is the finding that the number of workers with blood lead levels greater than 80 micrograms/100g blood dropped from l,553 (2 percent of 2,200 primary smelter workers plus 16 percent of 3,170 secondary smelter workers plus 6 percent of 16,700 battery workers) to about 20 (0.1 percent of 2,470 primary smelter workers plus 0.6 percent of 3,000 secondary smelter workers and no battery workers).

Furthermore, the number of workers with blood lead levels above 40 micrograms/100g dropped from 17,217 to 6,738. This significant decrease is especially important because that is the lowest action level required at any stage of MRP. In other words, the almost 9,000 workers who have moved from the over-40 to under-40 micrograms/100g category are now at a level that means they would not have to be removed from their current jobs even as the threshold level for medical removal drops.

In 1978, OSHA had estimates prepared of the blood lead levels to be expected if the statutory limits for lead were set and realized at 50, 100, or 200 micrograms/m^3. The levels were expected to fall as exposures decreased and workers eliminated some of the lead accumulated during their previous high exposures.

Measured blood lead levels two-and-a-half years after the introduction of the standard were consistent with projections made on the basis of achieving a level near so micrograms/m^3 in the battery industry and 100 micrograms/m^3 in the other two industries **(184). These measurements are somewhat surprising because the air lead levels** in the industries **are above so or 100** micrograms/m^3. Effective respirator programs and attention to personal hygiene **have** probably contributed to the lowering of blood lead levels.

Although no blood lead level has been established below which symptoms are never found, and there is no level at which symptoms will necessarily occur, there is agreement that lower blood lead levels are associated with lower risks (174).

OSHA has established 40 micrograms/100g as an action level; when the lead standard is fully implemented, workers with blood levels above 50 micrograms/100g must be removed from lead exposure until their blood lead levels drop below 40. The Centers for Disease Control (558) have concentrated on 30 micrograms/100g as a level at which concern should be raised.

costs

Capital expenditures for current controls run at about $1,000 to $1,500 per worker each year. To that must be added the expense of respirators, clothing, and facilities for personal hygiene (showers, changing rooms, etc.)–between $1,000 and $1,700 per worker per year. Monitoring and medical surveillance cost about $500 per worker annually, and the tranfer costs under MRP are expected to run between $300 and $600 per worker yearly. Taken altogether, complying with the lead standard is estimated by Goble, et al. to cost between $2,800 and $4,300 per worker yearly.

In addition to the current costs, Goble, et al. (184) project that future conventional industrial hygiene controls will cost between $8,000 and $9,000 per worker per year in secondary smelters and battery plants. Future costs in primary smelters are expected to be lower, about $5,200.

Table 5-11 presents estimates of the engineering cost of reducing air lead levels to 50 or 150 micrograms/m^3. The costs are quite close. One reason is that (according to engineers employed by Charles River Associates (184)) the best conventional engineering controls will not reduce exposure to 150 micrograms/m^3. Another reason is that isolation booths, if installed, could reduce exposures to less than 50 micrograms/^{3} for about the same as it would cost to reach 150 micrograms/m^3.

Table 5-1 I.—Projected Industry-Wide Annual Costs of Compliance With Air Lead Levels of 50 and 150 micrograms/m^3

Industry	Millions of 1962 dollars: 50 micrograms/m^3	150 micrograms/m^3
Primary lead smelting . .	15.5	16.0
Secondary lead smelting	24.5	26.4
Battery manufacture . . .	97.4	not done

SOURCE: (1S4).

Major process changes, although costing more in capital expenditures, are expected to result in operating savings. In general, the capital costs of process change may be appropriate if a new plant is to be built, but they outweigh the costs of add-ons in an existing plant unless significant tax savings or credits accompany installation of the new process.

Summary of Improvements

The data about workplace air lead and blood lead levels show that both have decreased since the issuance of the OSHA lead standard. While the air lead levels have dropped about 25 percent in primary and secondary smelters and about so percent in battery plants, they still remain much higher than 50 micrograms/m^3 that is the goal of the standard. At the same time, however, blood lead levels have dropped appreciably, and in general are close to the levels predicted for reaching air lead levels between 50 and 100 micrograms/m^3. A number of factors—including decreases in lead uptake from the environment in general, changes in the methods for measuring lead, errors in the model that is used to project blood leads based on air leads, and greater-than-expected impacts of respirator programs and hygiene practices—have contributed to the apparent better realization of reductions in blood levels than was predicted. Whatever combination of factors is responsible, the falls in blood lead levels are gratifying and bode well for better health among lead workers.

EXTENT OF CONTROL TECHNOLOGY USAGE IN THE UNITED STATES

The National Occupational Exposure Survey (NOES) (see chs. 2 and 12) includes data that describe the extent of the usage of control technologies for the prevention of work-related illness. NOES, conducted from 1980-82, estimates the extent of worker exposure to potentially hazardous workplace agents. This survey was conducted as a followup to a similar survey, the National Occupational Hazard Survey, conducted in 1972-74.

The sample of businesses in the NOES survey consists of approximately 4,000 establishments in 67 metropolitan areas throughout the United States. The sample represents all nonagricultural businesses covered under the Occupational Safety and Health Act. Data were collected onsite by teams of engineers and industrial hygienists specially trained for the survey.

NOES was conceived for the purpose of recording specific worker exposures to potential workplace health hazards. Among the questions that the survey attempted to answer were:

- What occupational groups are exposed to what types of potential health hazards in the United States?
- In what types of industries are these hazards found?
- What control technologies are present to prevent work-related disease in terms of plant operation and occupational safety and health practice?
- What are the exposures by intensity, duration, type of control?
- What trade name products were present?

Both surveys included questions about demography and occupational safety and health practice, followed by a walk-through survey of the plant work area to inventory potential exposures. A series of questions specifically aimed at the practice of using controls was asked in NOES.

With the control questions asked in NOES it is possible to analyze the extent of engineering control usage in the manufacturing sector of the country. Areas include practices of material substitution, process change, and the management of personal protective equipment programs. These data are unique in that there are no other comprehensive assessments of work-related exposure control practice. Control technology usage may be classified by plant size and by industry, allowing distributions to be done for comparison.

These data may be used to pinpoint patterns of control technology use within and among industry groupings, giving insight about areas where improvement is needed. This analysis may also be used to assist in setting priorities for control technology research.

Information About Controls and Areas for Research

The vinyl chloride, industrial solvent, lead, cotton dust, and silica examples show that control technologies for workplace exposures can be engineered once commitment to control is made. Commitment, however, is often difficult to achieve. For example, in the regulatory proceedings concerning new health standards, arguments are often raised about the harmful health effects of existing exposure levels, and the costs and feasibility of controls (see ch. 14 and box 12-1 in ch. 12). In addition, opposition to some governmental regulation may result simply from employers' concern that an outside authority is telling them what they must do to protect workers.

However, as shown by the vinyl chloride and cotton dust examples, the installation of technologies to control workplace hazards can be accompanied by greater productivity. As seen in the case of the ventilation control system in the electronics industry, there are advantages to planning, installing, and maintaining control technologies in a systematic way. Anticipation of work-related health problems very often reduces the cost of their control.

Access to information about control technologies for workplace health and safety could be improved. Perhaps the greatest current need is for published information about controls in the occupational safety and health literature. While there are journals dedicated to toxicology and epidemiology, there are none specific to industrial hygiene engineering. Industrial hygiene journals infrequently and engineering technical journals only rarely include articles about technologies for controlling worker exposure to hazardous materials. Yet it has been suggested that such information should be part of every engineer's training and be readily available as reference material to the practicing engineer *(587).*

Published information about specifics of workplace control is sparse for several reasons. First, and probably most significantly, companies that develop controls simply do not take the time to publish details since it is not their business. On the other hand, it is likely that some consider the information proprietary and keep it unpublished for competitive reasons.

In some cases, such as for the control of exposures to vinyl chloride, a few companies market new technology for preventing work-related injury and illness. This, however, appears to be infrequent and be limited to very large companies such as B.F. Goodrich and Dupont. Probably most companies that have found and use innovative control technologies in their plants simply have yet to explore workplace control technologies as a market.

University and government researchers have published some practical information that can be used by design engineers but the volume of this material is limited. One widely used handbook specific to ventilation is the ACGIH Ventilation Manual that is published annually *(6).* Programs such as the NIOSH Control Technology Assessments have produced useful information for hazard control in some specific and some generic manufacturing processes (see ch. 12).

There is also a dearth of new approaches in this area. For instance, First (173) pointed out that little has been added to the theory of ventilation since two Ph.D. theses done at Harvard in the 1930s. The tendency has been to retrofit control solutions after problems appear rather than to anticipate them. Yet there is promise of new methods on the horizon.

Brief and colleagues (74), recognizing the limitations of retrofit solutions in preventing work-related injury and illness, have explored techniques for designing new plants with new control systems built in. They have found that in the past

> retrofit control procedures were recommended without being able to judge the effectiveness of controls, until after installation and operation. This retrofit approach is probably not as cost effective as designed-in controls, although cost effectiveness was rarely tested. In many cases additional administrative and personal protective programs were used to achieve desired worker protection.
>
> We have embarked on a new era involving some major companies and government agencies investigating the impact of engineering design on the workplace environment. The objective is simple. It states that we will attempt to design into our plants and operating facilities the necessary engineered controls to meet occupational health standards. Intuitively, we believe that it is more cost-effective to install engineering controls in new plant designs than to retrofit later. Equally as important is the practicality of having an environmentally sound plant at the start, rather than one which requires modifications later. Retrofitting controls may be difficult to implement due to physical factors and the time to implement the changes after the plant is running.

In this innovative approach, design is based on selection of process equipment controls appropriate to the process. The key is to determine emission rates of contaminants from each type of process equipment used. These data may then be used to build a near-field dispersion model (a mathematical expression of the release and buildup of contaminant in workers' breathing zones) to calculate collective concentrations to which workers could be exposed. By trying various combinations of equipment and controls in the model and testing them against recommended health standards, engineers can predict potential worker exposure and thus design processes with optimum worker protection *and* production. These investigators stress the need for interaction between engineers and occupational safety and health professionals at the design stage for this to succeed.

Thus, control technology for work-related illness prevention is possible but insufficiently applied, particularly in plant design stages. Technologies are available but information about specific solutions is difficult to find because it is seldom published. Retrofit is the dominant mode even though there is recognition that solutions should be designed into new processes.

SUMMARY

Workplace exposures to toxic substances can be controlled at their source, during transmission, and at the worker. Control at the source includes changes in the design of a process and substitution of nontoxic or less toxic materials. Controlling the transmission of a toxic substance can be done by isolating or enclosing hazard sources, wetting toxic dusts to prevent dispersion, installing local exhaust ventilation to capture and carry toxic substances away, or reducing toxic concentration through the use of general dilution ventilation. Control at the worker includes the use of personal protective equipment (see ch. 8), work practices, and administrative procedures. Engineering controls that can be designed into a work process to control hazard sources and dispersion of contaminants are preferred to other measures that may provide less reliable protection. Training (see ch. 10) of supervisors and workers is required to make sure control programs are effective.

Three case studies prepared for this assessment provide information on controls for health hazards. Exposures to cotton dust cause a debilitating respiratory disease known as byssinosis. In the years following the issuance of a revised OSHA health standard concerning cotton dust, the U.S. textile industry has invested heavily in modernizzing its operations. The new equipment has led to improved productivity in this industry, as well as reduced worker exposures.

Data about workplace air lead and blood lead levels show that both have decreased since the issuance of the revised OSHA lead standard in 1978. The possible factors to explain the improvements in blood lead levels include changes in exposures to lead in the workplace air, the use of medical removal protection, decreases in the amount of lead absorbed from the environment, changes in lead measuring methods, and improvements in respirator programs and hygiene practices.

Silicosis—a disabling lung disease-is caused by silica dust. Control measures include substitution with safe abrasives, ventilation, wetting, as well as the use of respirators, work practices, maintenance of ventilation systems, and good housekeeping practices.

A considerable amount of information about how to design and implement control technology for worker protection is available but is not widely disseminated. Research on improved control technology design and implementation is also needed. For example, little has been added to the basic theory about ventilation since the 1930s. The National Occupational Exposure Survey conducted by NIOSH collected information which will give estimates of the extent of worker exposure to potential hazards and the current practice of control technology use. These data can potentially assist in setting priorities for research on improved controls.