V. WORK PRACTICES

Ideally, foundry processes should be designed to: (1) eliminate all chemical and physical hazards such as toxic chemicals, heat, noise, and vibration; (2) control fumes, dusts, vapors, and gases in the workroom atmosphere; (3) prevent physical contact with toxic substances; and, (4) control safety hazards. If the ideal process design cannot be achieved, engineering controls such as local exhaust ventilation, noise damping materials, machine guarding, molten metal splash barriers, and radiant heat shielding can be employed to provide a healthful and safe working environment. However, some processes, the batch-type processes and manual operations, for example, may limit the application of engineering control strategies to these hazards. In such cases, work practices are required in addition to engineering controls to protect the workers.

An effective work practices program encompasses many elements, including safe standard operating procedures, proper housekeeping and sanitation, use of protective clothing and equipment, good personal hygiene practices, provisions for dealing with emergencies, workplace monitoring, and medical monitoring. Work practices are supported by proper labeling and posting and training all of which will serve to inform personnel of foundry hazards and of the procedures to be used to guard against such hazards. Good supervision provides further support by ensuring that the work practices are followed and that they effectively protect workers from the hazards.

A. Standard Operating Procedures

The most frequent work-related injuries to foundry workers are the result of strains and overexertion, contact with hot objects or substances, and being struck by or striking against objects [48]. Safe-operating procedures, if followed, can decrease the risk of these worker injuries. An evaluation of foundry accidents has shown that one of the major contributing factors in foundry injuries was lack of, or violation of, safe-operating procedures [213].

In the 1977 California report of injuries in iron and steel foundries, burns accounted for 25% of the injuries in the melting and pouring operations. Strains and overexertion injuries accounted for 43% of the injuries in molding and coremaking operations. Being struck by or coming in contact with objects accounted for 31% of the injuries in the cleaning and finishing operations [228]. In the 1981 Ohio foundry injury data, of all lost-time injuries, burns accounted for 12%, strains and sprains for 34%, and struck by or contact with an object for 32% [50].

A significant reduction in the incidence of burns can be achieved by proper handling of molten metal. One of the major safety considerations in the handling of molten metal is the control of moisture in the ladles or near the pouring operations. If water is vaporized by molten metal and if the vapor is trapped below the metal surface, the high water vapor pressure can cause an explosion [181]. Therefore, ladles and other devices used for handling molten metal must be kept dry at all times. In addition, pits required for slag ladles must also be kept dry, and they should be checked periodically to ensure that there is no moisture under the refractory material.

Batch processes used in many foundries for melting and pouring require periodic opening of systems, and proper safety procedures and work practices are essential to protect workers against injury. For example, in iron foundries that use cupola furnaces, safe procedures for supporting and dropping the cupola bottom must be followed. The cupola bottom should be supported by metal props of sufficient structural strength. The metal prop bases should be supported by sound footings such as concrete. Props should be adjusted to proper height and should be positioned in a safe area that will not endanger the worker. When dropping the cupola bottom, workers should be in a protected area or a safe distance from the furnace. One recommended method for dropping the cupola bottom is to use a block and tackle with a wire rope and chain leader wrapped around the posts or props that support the bottom doors. Workers can then pull the props out with the block and tackle while standing at a safe distance from the drop area. Before the bottom is dropped, the drop area should be inspected to ensure that no water has seeped under the plates or sand and that audible and visual signals have been activated [214,215].

A great deal of material is moved in foundries, including transporting large quantities of sand and molten metal, molds and cores, and castings. Manual handling of molds, molding materials, and castings is more frequent in small foundries than in large foundries where cranes, conveyors, and other types of mechanical equipment are commonly used [175]. For efficient production and personal safety, manual and mechanized materials handling should be performed according to safe standard operating procedures to prevent musculoskeletal injuries, hernias, overexertion, and traumatic injuries. Workers should be instructed in and practice the proper lifting techniques and should be encouraged to ask for help in lifting heavy objects. The National Safety Council's (NSC) publication, <u>Accident Prevention Manual for Industrial Operations</u> [182], the American Foundrymen's Society booklet, <u>Safe Handling of Bulk Materials</u> [229], and the NIOSH <u>Work Practices Guide to Manual Lifting</u> [230] offer instructions in proper methods for lifting and carrying loads.

Mechanical handling involves the use of lifting and hoisting devices, such as cranes and chain hoists, and of forklifts and conveyors for transporting materials [229]. Impact injuries most often occur from mishandling or from using mechanical devices in which suspended objects or materials may slip off hooks or accidentally fall off cranes, hoists, conveyors, or forklifts onto workers [181]. To reduce injuries while using forklifts and other lifting devices the following principles should be adopted: (1) the mechanical devices should not be loaded beyond their rated capacity; (2) workers should stand clear of loads; (3) suspended loads should always be attended; (4) overhead materials handling equipment should never be used for transporting personnel during normal operating conditions; (5) where molten metal is being handled overhead, crane operators should be instructed in the proper handling of the load; (6) crane operators should never pass ladles carrying molten metal or any other load over workers; and, (7) a warning gong or bell should be sounded to warn of cranes or materials-handling equipment approaching or passing overhead with molten metal [231]. These principles have been included in safety standards for sand castings by the American National Standards Institute (ANSI), the American Foundrymen's Society (AFS), and other foundry employer, manufacturer, and worker groups. Recommendations for handling molten metal and other standard foundry operating procedures are included in ANSI Z241.1-1981, Safety Requirements for Sand Preparation, Molding and Coremaking in the Sand Foundry Industry [192], ANSI Z241.2-1981, Safety Requirements for Melting and Pouring of Metals in the Metalcasting Industry [214] and ANSI Z241.3-1981 Safety Requirements for Cleaning and Finishing of Castings [232].

B. Housekeeping

Clean, unobstructed aisles and gangways, well-defined working areas, and adequate storage areas contribute to safe and healthful working conditions. Ignoring these factors may undermine the safety and health program. Housekeeping can also have a marked effect on production efficiency. Special attention should be given to: (1) storing raw materials and scrap in bins, compartments, or other appropriate forms of containment or separation; (2) providing a constantly maintained means of access for operations such as metal pouring; (3) removing items not required for immediate use from the foundry working area; and (4) providing and encouraging the use of specified areas for tools, lubricants, and other equipment [233].

To help reduce the incidence of injuries, floors should be made of concrete, brick, steel, iron plate, or other suitable material except in areas where the nature of the work requires refractory floors. In foundries where pit molding is performed, a refractory floor and a guardrail are required, but proper gangways should still be provided and constructed of concrete, brick, steel, or iron plate [231].

Foundry work areas should be cleaned as required to prevent accumulation of hazardous and nuisance dust. The preferred cleaning method is a vacuum system that delivers the dust to a collector system with an outlet pipe leading to the open air. The filter of any mobile vacuum cleaner should be highly efficient to minimize the amount of fine free silica and other dust particles that are returned to the atmosphere. Wet systems are also applicable. It is important to clean overhead plant fixtures, roof trusses, and hoists. Movement of poorly cleaned overhead cranes and hoists and the vibration of machines can cause dust to fall on workers. Good housekeeping requires an easy and safe access to overhead structures; this is sometimes difficult in older foundry structures [184].

The amount of cleaning that must be done can often be reduced if the spillage of sand and other dusty materials is reduced, e.g., in mechanized foundries, sand spills from overloaded conveyor belts can be avoided with proper engineering enclosures. Proper containers can reduce the amount of cleaning that has to be performed. It is also important to keep the roof in good repair to avoid water leaks that may lead to unsafe conditions in molten metal handling areas [7].

Another important consideration is lighting. The lighting in any foundry must be adequate to perform the jobs safely [175]. Lighting fixtures have to withstand a somewhat corrosive atmosphere, operate well in dusty conditions, and withstand high temperatures and vibrations. The cost-benefit advantages of capital investment in lighting are achieved through increased safety, greater productivity, better quality work, and greater job satisfaction for the worker [233,234].

C. Personal Hygiene and Sanitation

Personal cleanliness can play a significant role in protecting foundry workers from exposure to hazardous substances. This is especially vital in the coreroom area where skin irritation and sensitization or dermatitis may be caused by prolonged or repeated skin contact with resinous binders. Workers should be encouraged to wash their hands or other contaminated parts of the body immediately after skin contact and before eating or smoking to reduce the risk of ingestion or inhalation of toxic materials, e.g., lead. Abrasive skin cleaners and strong alkalis or solvents that defat the skin should be avoided. Smoking and eating should be prohibited in foundry work areas because cigarettes and food can become contaminated with toxic chemicals. Washing and showering facilities should be designed to avoid recontamination or reexposure to hazardous agents. Workers should be encouraged to shower after each workshift whenever possible. This will not only decrease the potential for worker exposure to toxic substances but will also reduce the probability of carrying toxic substances home to expose the foundry worker's family.

D. Emergency Procedures

Emergencies within foundry operations can greatly increase the risks of serious or fatal injuries and acute inhalation exposures to toxic substances. When fires, explosions, collisions, and other accidents occur, the two immediate concerns are (1) protecting workers from exposure; and (2) treating injured workers. The potential for release of molten metal further aggravates the hazardous conditions during emergencies. A warning system is necessary to inform workers of an emergency and to trigger an emergency action plan that has been developed and practiced in advance. Warning systems should include: fire alarms, area monitors to detect excessive airborne contamination such as CO alarms in and around cupolas, and alarms to warn workers of dangerous spills and cupola bottom drop. Each worker should be trained to recognize the significance of the alarms and to know the procedures to follow when a warning is sounded [235].

Protective clothing and escape equipment for use during evacuation from hazardous areas should be located in or near areas where emergencies may occur and should be accessible to workers and supervisors. Self-contained breathing apparatus with full facepieces should be available to provide workers with adequate oxygen and respiratory protection. Escape equipment is intended for escape use only; it is not adequate for extended protection or rescue work. Escape equipment should be maintained and inspected on a regular basis to ensure that it will be functional when needed [235].

Burns, scalds, eye and face injuries, lacerations, and crushing injuries frequently occur in foundries [48,50,51,176,181,228]. At least one person on each workshift should be formally trained in first-aid procedures to care for an injured worker until professional medical emergency help arrives or until the worker can be taken to a doctor. The emergency plan should also include procedures for transporting injured workers to a proper medical facility [235].

E. Maintenance

Equipment failures due to inadequate inspection and maintenance in foundries are often the cause of fatal and nonfatal injuries and exposures to hazardous airborne contaminants. Constant vigilance to ensure that all equipment is in safe condition and that operations are proceeding normally is critical to safety and to accident prevention. Adequate maintenance and immediate replacement and repair of any worn or suspicious equipment or component parts are essential. Inadequate training and experience in how to cope with emergency maintenance situations is often a major contributing factor in foundry accidents. Equipment design, construction, use, inspection, and maintenance are key goals for foundry safety [236].

Inspection and maintenance of ventilating and other control equipment are also important. Regular inspections can detect abnormal conditions, and maintenance can then be performed. All maintenance work should include an examination of the local exhaust ventilating system at the emission source. This may require testing for airborne chemicals or measurement of capture velocity [237].

Records of equipment installation, maintenance schedules, failures, and repairs can assist in setting up inspection and preventive maintenance schedules. This is especially important for hoists, cranes, ladles, and other process equipment that are used to handle molten metal. If equipment is inspected, repaired, or replaced before failures occur, the risk of injury is greatly reduced. In addition, adherence to a preventive maintenance schedule reduces equipment downtime. Equipment failure records can be used by management in making decisions about which types or brands of equipment to purchase and which will operate safely for the longest time.

The introduction of mechanized equipment to replace the manual methods in foundry operations has increased the risk of injuries to maintenance and setup workers of process machinery. An analysis of accidents in foundries has shown that, in many cases, injuries were related to unexpected energy release within the equipment, although recommended lockout procedures were in use [192,238]. The Foundry Equipment Manufacturers Association (FEMA) developed the concept of Zero Mechanical State (ZMS) to alleviate this problem [238]. On any given machine or process, ZMS takes into account the total energy pattern of the equipment and institutes appropriate measures to keep all energies affecting the industrial work area either at rest or neutralized during maintenance and repairs.

In the typical ZMS routine, each worker who may be involved is assigned one or more of each of the following: a lock, a key, and a lockout device, with the worker's initials or clock number stamped on each lock or on a metal tag attached to each lock. Before de-energizing equipment, the equipment operator should be notified that repair work is to be done on the machine. Electrical power is then turned off, the lockout devices are placed through the holes in the power handle and through the flanges on the box, and an individual padlock is placed on the lockout device. Others who may be working on the same equipment should add their individual locks to the same device. A "Man-at-Work" tag is placed at the controls, and the controls are checked to ensure that all movable parts are at rest. If pneumatic, hydraulic, or other fluid lines affect the area under maintenance, they should be drained or purged to eliminate pressure and contents and the valves controlling these lines should be locked open or shut, depending upon their function and position in the lines. Air valves should be vented to the atmosphere, and surge tanks and reservoirs should be drained. If lines are not already equipped with lockout valves, they should be installed [192,238].

Mechanisms that are under spring tension or compression should be blocked, clamped, or chained in position. Suspended mechanisms or parts that normally cycle through a lower position should be moved to their lowest position or blocked, clamped, or chained in place [192,238].

When the maintenance or repair work has been completed, each worker should remove the padlocks; the last person removes all lockout devices. No worker should ever allow anyone else to remove the locks. If the key to a lock is lost, the owner should report it at once to the supervisor and get both a new lock and key. In some cases, equipment can be tagged out instead of locked out. However, tags are not as effective as locks because tags are easily removed, overlooked, or ignored [238].

F. Monitoring

1. Foundry Airborne Contaminant and Physical Hazard Monitoring

As described in Chapter III, foundry operations, especially those using silica sand and organic binders, may produce potentially hazardous materials, the nature and quantity of which may vary from one plant to another according to the type of foundry. Workplace monitoring is necessary to determine the existence and magnitude of possible hazards. Foundry work also presents various physical hazards, such as noise, heat, vibration, and radiation, that should be monitored to ensure safe and healthful working conditions.

An initial foundry plant survey should include an inventory of the substances present and their physical, chemical, and toxicologic properties. In addition to aiding management in the selection of protective measures, this information may be required by physicians treating exposed workers or by firemen fighting plant fires. Material safety data sheets, especially for resinous binder formulations, may not always contain adequate information [175]. Thus, the composition, properties, and hazards of the mixtures or materials may not be known or may not be available when needed.

The survey should follow the raw materials as they are processed throughout the plant and should identify locations of suspected hazards. Nonenclosed operations such as mulling, mixing, pouring, shakeout, and cleaning should be the primary environmental monitoring areas. Potential fire, explosion, and runout areas should be identified so that emergency procedures, including escape and rescue routes, can be determined. Noise, heat, and other physical hazards should also be evaluated. Melting, molding line, shakeout, and cleaning room operations should be the focus of an initial plant survey. Finally, any changes in processing methods, in plant equipment, in products, and in quantities and types of materials used and stored all affect foundrymen's potential exposure to chemical and physical hazards.

After the plant survey, areas where potentially significant exposures may occur should be sampled to determine the levels of chemical and physical hazards present in the working atmosphere. Personal sampling can provide a measure of engineering control effectiveness in containing foundry emissions and physical hazards and can indicate work practices and protective equipment that are necessary to control further exposures. NIOSH criteria documents on hazardous substances that may also be present in foundries have recommended the frequency of monitoring for contaminants or physical hazards. These documents should be consulted to establish a sampling schedule that will adequately describe the working environment. Sampling and analytical methods for foundry hazards are presented in Appendix D.

Workplace monitoring data should be recorded, maintained, and reviewed as necessary to improve engineering controls, to evaluate medical and training needs, and to determine the extent and frequency of use of personal protective devices. In addition, the correlation of airborne contaminant concentration and worker exposure data with medical examination reports may be very useful in identifying and assessing exposures.

2. Medical Surveillance

A foundry is a very complex working environment that is hot, noisy, dusty, and strenuous. The worker may be exposed to a wide range of chemical substances in various physical forms and to physical hazards which affect both health and safety. The potential synergism of co-existing hazards is not completely known. The object of medical surveillance of foundry workers is to ensure the workers' health and physical well-being, at work and away from work, both in the short- and the long-term. The preplacement medical examination allows the physician to assess the applicant's physical, mental, and emotional capabilities and as far as possible, match these with work requirements, responsibilities, and risks. Furthermore, it provides baseline medical findings against which subsequent changes can be compared. Medical and environmental monitoring data should be available to the worker as specified in 29 CFR 1910.20 [141].

a. Preplacement Examination

(1) History

The medical history should include medical, work, social, family, and smoking histories, with special attention to any history of previous occupational exposure to chemical and physical hazards.

(2) Clinical Examination

The preplacement examination should ascertain the worker's general fitness to engage in often strenuous and hot work, as well as ability to react quickly and rationally to any potentially dangerous situation that might arise. The physical examination should include a complete examination of the cardiovascular and respiratory systems with x rays, cardiovascular and pulmonary function tests, measurements of height and weight, a urinalysis, a complete blood count, and an estimate of physical fitness and work capacity.

Special attention should be given to the skin, including the ability to sweat freely, and sensitivity to irritants and sensitizers that may be encountered in the foundry. Old scars, in particular those which appear to have been caused by burns, should be noted. Workers who will use vibrating tools should be asked if they have symptoms of Raynaud's phenomenon, and their fingers should be examined.

Because of the heavy lifting and carrying requirements, special emphasis should be placed on the history of previous back and musculoskeletal problems, and the clinical examination for signs of lumbar spine abnormalities, restricted movement, or muscular spasm. The general consensus in the published literature is that preplacement lumbar x-ray screening has little, if any, value in predicting whether a worker will or will not develop back problems [230].

Because most foundry workers will be exposed to some fibrogenic dust, free nasal breathing is an important defense mechanism, and a normal functioning respiratory system is essential. Pulmonary sensitizers may be present in the work environment and their effect on a worker with an allergic susceptibility should be anticipated.

The eye hazards to which foundry workers are liable to be exposed include irritating dusts and fumes, foreign bodies of dust or metal particles, and UV radiation. Safety for most foundry workers depends upon good visual acuity and a full field of vision. Certain jobs may require full color vision. The safety of many may depend upon the visual distance judgment of crane drivers, slinger operators, and truck drivers.

(3) Special Examinations and Laboratory Tests

A full blood count and urinalysis may be indicated by the worker's history of past exposures or as the result of the clinical examination.

Pulmonary function tests of FVC and FEV_1 will provide an adequate baseline in most cases, but the physician may require additional measurements.

A posteroanterior, 14 x 17 in (36 x 43 cm) chest x ray should be taken and kept as part of the medical record.

Most foundry workers are liable to be exposed to noise intensities exceeding the present standards. A preplacement audiogram of all foundry workers is recommended.

Other medical examination recommendations are presented in the NIOSH documents listed in Appendix E.

b. Periodic Medical Examination

An annual periodic medical examination should be available to each worker. Its purpose should be to detect, as early as possible, any change in health which may or may not be due to occupation and which may or may not affect the worker's fitness to continue in a particular job. Through this examination, trends in health changes may be detected which may suggest a need for environmental control of a known hazard or of a previously unrecognized hazard or potential hazard.

An essential part of a periodic medical examination is the physician's interview with the worker. Confidence and good rapport must be established so that very early and even nonspecific symptoms may be elicited, which may then alert the physician to guide the subsequent clinical examination beyond the normal routine.

For the past 50 years, attention has been drawn to the presence of respiratory diseases in foundrymen throughout the industrial world. Despite the improvements in dust control methods in foundries that have become available, and generally applied, the problem of pneumoconiosis remains [34].

The chest x ray is the most specific means of diagnosing pneumoconiosis. The preplacement chest x ray may guide the physician in assessing fitness for foundry work; it may also reveal abnormalities that might later confuse or complicate the interpretation of any subsequent lung tissue changes [34]. The International Labour Office (ILO) stresses the importance of radiographic technique in the detection of early pneumoconiosis. High-speed and miniature films are not recommended. Films should be interpreted expertly according to the ILO U/C International Classification of 1980; although the "short" classification might be useful for clinical purposes, films that are used for epidemiologic or other studies should be read and recorded by the "complete" classification [102].

Although periodic chest x rays are routinely recommended for monitoring workers exposed to respiratory hazards, there is evidence, particularly with silicosis, that radiographic appearance does not necessarily correlate highly with ventilatory capacity [33,34,54,239]. There is a lower incidence of silicosis in younger foundry workers and in those who have been exposed fewer years [33,34,118]. Although presumably relatively short but massive free silica dust exposures can lead to severe disablement and death, such exposures are not likely to occur today. However, routine radiological chest monitoring of foundry workers is desirable [34]. Under reasonable foundry conditions, chest x rays at 3-5 year intervals should be adequate for young workers. Older workers, workers with 10 years or more of exposure, and those previously employed in dusty jobs should have chest x rays at more frequent intervals (1-3 years). Foundry workers with evidence of pneumoconiosis should have annual chest x rays. The physician may choose to change the frequency of chest x rays based on clinical impressions of individuals or on evidence of overexposure in particular foundry jobs, e.g., sandblasting.

Epidemiologic studies suggest an association between exposure to airborne hazards in foundries and an excess risk of lung cancer [30,31,40]. Other data, gathered from vital statistics, support the conclusion of an excess lung cancer mortality among foundry workers [31,42,43,127]. When taken individually, the data do not prove a causative relationship, but the overall evidence is strongly suggestive that working in a foundry is associated with an excess risk of developing lung cancer. Because routine chest x ray and sputum cytology do not readily detect bronchiogenic carcinoma at early stages, they are not currently recommended as part of regular medical surveillance for lung cancer in foundry workers.

During the periodic medical examination, the skin, eyes, and back should also be reexamined to note changes from the previous examination. The epidemiologic studies do not support an increased hazard of cardiovascular disease in foundry workers, and the standard 12-lead electrocardiogram is not of much practical value in screening or monitoring for nonsymptomatic cardiovascular disease. The symptoms elicited by the physician on interview, with respect to angina, breathlessness, and symptoms of chest illnesses, are likely to be of more value.

Similarly, with those handling vibrating tools, the physician's specific inquiries into cold, numb, blanched, or blue fingers are most useful in preventing substantial impairment from being suffered by even the vibration susceptible individual. Recommended engineering controls, medical surveillance, worker education, work practices, and personal protective equipment are contained in NIOSH current intelligence bulletin #38, Vibration Syndrome [240].

Where exposures for which NIOSH has already recommended occupational health standards occur in a foundry, physicians are referred to the medical examinations recommended in previous NIOSH documents (see Appendix E).

G. Other Work Practice Control Methods

Recommended work practices, such as proper materials handling procedures, housekeeping practices, and use of personal protective equipment, must be accepted and followed by the worker as an aid in preventing exposure to airborne contaminants and physical hazards in foundries. Employers can encourage acceptance of work practice controls by alerting and informing workers of the health and safety risks associated with the various melting, pouring, coremaking, and cleaning operations. In addition, employers should support these work practices by providing proper supervision, labeling, posting of hazardous situations, and effective administrative controls.

1. Posting and Labeling

Posting conspicuous safety and health warning signs in appropriate areas within the foundry will inform workers of hazardous operations, warn them about protective equipment that may be required for entry to certain areas, identify limited access areas and emergency equipment and exits, and instruct them about specific operating procedures, e.g., maintenance or repair of process equipment. When maintenance that increases the potential for exposure is in progress, signs should be posted to inform workers that such operations are taking place, for example, when the cupola bottom is being dropped, signs should be posted warning of potential spills of molten metal and that the operation is in progress.

Labels describing contents should be placed on containers of hazardous materials being used in the foundry. This is especially important in corerooms where new binding systems have recently been developed and the hazards associated with them are unfamiliar to the workers.

All labels and warning signs should be printed in English and where appropriate in the predominant language of non-English-reading workers. Workers unable to read the labels and signs provided should be informed of (and should understand) the instructions printed on labels and signs regarding hazardous areas of the worksite. All signs and labels should be kept clean and readily visible at all times.

2. Training

Training and behavior modification are important components of any program that is designed to reduce worker exposure to hazardous chemicals or physical agents and risk of accidental injuries. Training must emphasize the hazards present, the possible effects of those hazards, and the actions required to control the hazards. This is especially important in foundries where the recognition of hazards such as crystalline silica and noise is difficult because there are no immediate or sudden effects. Without special training on the long-term health effects of exposure to workplace materials, on the methods to avoid exposure, and on the symptoms of exposure, foundry workers may inadvertently allow themselves to be exposed to potential hazards.

In a 1974 California study, it was reported that 8.3 of the 14.9 injuries per 100 workers in ferrous foundries could have been prevented by adequate safety and health training [228]. The largest proportion of job disabilities that were preventable by safety and health training and behavior modification involved materials handling, i.e., 35% of the total for ferrous foundries. Although much of the materials handling in foundries is automated, a considerable amount of manual lifting and transporting of heavy materials is done. Manual lifting and handling of castings and molds produced the largest number of injuries and illnesses. The second most frequent type of injury or illness preventable by safety and health training and behavior modification was handtool handling, which accounted for 6% of the total number of injuries in ferrous foundries.

A training program should describe how a task is properly done, how each work practice reduces potential exposure, and how it benefits the worker to use such a practice. The worker who is able to recognize hazards and who knows how to control them is better equipped to protect himself from exposure. Frequent reinforcement of the training and supervision of work practices are essential.

3. Supervision

To protect workers' health and safety in a foundry, it is essential for supervisory personnel to be aware of the potential risks to workers when proper work practices are not followed. Supervisors should be present to assure that proper procedures are followed during operations such as furnace charging and bottom dropping. Supervisors should also be prepared to direct other workers during emergency situations. Occasional checks should be made to verify that personal protective equipment and clothing are used properly. Supervisors should also be able to recognize exposures to hazardous materials and emissions, e.g., phenol and formaldehyde in the coreroom or CO around cupolas. One positive strategy for concerned management is to rate supervisory personnel on their understanding and implementation of safe and healthful work practices, in addition to other factors such as productivity.

4. Administrative Controls

Administrative controls are actions taken by the employer to schedule operations and work assignments in a way that minimizes the extent, severity, and variety of potential hazardous exposures. For example, only necessary personnel should be permitted to work in areas where there is a high risk of exposure. The duration of exposures may also be reduced by rotating workers between assignments that involve exposure and those that do not. Management and workers must be fully committed to the safety and health programs.

VI. PERSONAL PROTECTIVE EQUIPMENT AND CLOTHING

Where the engineering controls and work practices discussed in Chapters IV and V are inadequate to prevent illnesses and injuries, other protective methods must be considered. Personal protective equipment and clothing provide a means for reducing exposures to occupational hazards by isolating the worker from the physical hazards and airborne contaminants in foundries. Personal protective clothing and equipment, however, have their limitations and workers must be adequately trained in the proper use and maintenance of such items.

The use of appropriate, properly maintained personal protective equipment and clothing is essential to the safety and health of all foundry workers. The protective equipment and clothing used must be relevant to the hazard against which the worker is to be protected [7,226,241,242]. Improperly designed, maintained, and used equipment, in fact, can increase worker exposure to foundry hazards.

A. Protective Clothing

Protective clothing is essential in foundry operations where molten metal is used. In the 1973-74 State of California study [228], most of the burns and scalds which accounted for 27% of the "orders-preventable" disabilities could have been prevented if adequate protective clothing and equipment, especially for the hands and feet, had been in use. Of the burns, 58% resulted from contact with hot or molten metal or slag.

Protective clothing worn in foundries includes such items as gloves, shirts, trousers, and coveralls made of flame-retardant cotton or synthetic fabric; leather aprons, gloves, sleeves, and spats; aluminized suits or aprons used during melting and pouring operations for radiant heat protection; and air-supplied abrasive blasting suits for wear during cleaning operations. Because of the many types of protective clothing and equipment available, selection of proper protection should be carefully considered. Probably the most important criteria for selection are the degree of protection that a particular piece of clothing or equipment affords against a potential hazard and the degree to which the clothing and equipment may interfere with working safety and effectiveness. This should take into account the physical form of the hazard and, especially, the temperature of the material being handled [7,226].

B. Face, Eye, and Head Protection

Of the 520 "orders-preventable" injuries and illnesses in the California study [228], 28% were eye injuries other than those from welding flash. Most of the eye injuries could have been prevented had adequate eye and face protection been used by workers where the eye hazards were present. Half of these injuries occurred while workers were using machines or portable grinders that threw off metal fragments. Because eye injuries can occur in all foundry work areas, all workers should wear appropriate eye protection.

The Practices for Occupational Eye and Face Protection (ANSI Z27.1) provides guidelines and performance standards for a broad range of face and eye protectors [243]. Eye protection devices must be carefully selected, fitted, and used. If corrective lenses are required, the correction should be ground into a goggle lens. Goggles may be worn over ordinary spectacles, but they require cups that are deep and wide enough to completely cover the spectacles.

The three general types of equipment available to protect eyes from flying particles that may be encountered in operations such as chipping and grinding are: (1) spectacles with impact-resistant lenses; (2) flexible or cushion-fitted goggles; and, (3) chipping goggles. Where both side and frontal protection is needed, spectacles should have sideshields. Both flexible and cushion-fitted goggles are designed to provide frontal and side protection from flying particles. Most models will fit over ordinary ophthalmic spectacles. Chipping goggles, which have contour-shaped, rigid plastic eyecups, should be required in all grinding and cleaning rooms. Two styles are available: one for individuals who do not wear spectacles and one to be worn over corrective spectacles [182,243].

Eye protectors having mild filter shade lenses or polarizing lenses and opaque sideshields are adequate for protection against glare only. For conditions where hot metal may spatter and where visible glare must be reduced, a faceshield worn over mild shade spectacles with opaque sideshields should be specified [182,243].

Various types of faceshields are available to protect the face and neck from flying particles, sprays of hazardous liquids, and splashes of molten metal. In addition, they may be used to provide antiglare protection where required. Faceshields are not recommended by ANSI Z27.1 [243] for basic eye protection against impact. For impact protection, faceshields must be used in conjunction with other eye protection. For foundry furnace tenders and pourers, faceshield protection is necessary to guard against molten metal splashes and IR and UV radiation from hot metal and furnace areas. A metalized plastic shield that reflects a substantial percentage of heat has been developed for use where there is exposure to radiant heat [182].

Hardhats should be required to protect the head from possible impact injuries. In foundries, it is essential that head protection be worn when making furnace repairs or when entering vessels, especially cupolas. In addition to protecting workers against impact and flying particles, hardhats should be flame resistant and provide protection against electric shock [182,215].

C. Respiratory Protection

Respiratory protective devices vary in design, application, and protective capability. The user, supervisor, and employer must, therefore, be supplied with relevant information on the possible inhalation hazards present and other chemical and physical properties of the contaminants to understand the specific use and limitations of available equipment in order to assure proper selection [182,244,245,246,247].

Respiratory protective devices are tested and approved by NIOSH and the Mine Safety and Health Administration (MSHA) for protection against a wide range of inhalation hazards, including highly toxic atmospheres and those containing nuisance dusts. OSHA requires the use of NIOSH/MSHA-approved respirators. Testing and approval of these respirators are subject to conditions in 30 CFR 11 [248].

In addition, 29 CFR 1910.134 states that respirators shall be selected on the basis of the hazards to which workers are exposed [141]. The revised NIOSH respirator decision logic should be used for guidance in the selection of respirators [141]. The criteria for selecting respirators depends on a safe exposure limit and other chemical and physical properties of the contaminant. If sufficient information regarding the properties of the contaminants and the specific use conditions cannot be obtained, the selection of a suitable respirator may not be possible [182,245,247,249].

Because of the inherent airflow resistance in respirators, pulmonary function capability must be assessed in evaluating whether a worker can use a respirator. Respirators approved under 30 CFR Part 11 have inhalation resistances varying from 12 to 102 millimeters of water and exhalation resistances varying from 15 to 25 mm of water; these respirator performance specifications are for normal, healthy men. In the case of a self-contained breathing apparatus, the weight of the equipment also makes the respirator difficult to use. If a worker's cardiovascular or pulmonary function is impaired, wearing a respirator may constitute an unacceptable risk due to breathing resistance or the weight of the respirator apparatus itself [245]. Air-supplied respirators, still causing breathing resistance, are lightweight and widely and effectively used under conditions where the operator is not required to move beyond a limited range.

For the respirator to remain effective, a respirator maintenance program should be established in all foundries. Respirators should be sanitized daily and should be cleaned, inspected, and repaired as needed. In addition, OSHA requires, as part of 29 CFR 1910.134, proper maintenance and storage of respirators. Proper care will help to protect against dust, sunlight, extreme cold, excessive moisture, and damaging chemicals. The OSHA regulations include limited specifications as to the manner in which maintenance, cleaning, and storage requirements should be accomplished [245].

Adequate time should be devoted to servicing and inspecting respiratory protective equipment so that the filters, cartridges, valves, and the respirators themselves can provide the protection for which they were designed and certified. If practical and feasible, it is preferable to have a central respirator servicing facility, operated by a worker who has been thoroughly trained to service and inspect respirators [244,246]. A central respirator servicing facility can reduce the amount of management surveillance required and provide uniform respirator servicing. However, if only a few respirators are used, each worker can maintain their own respirator, and time should be allotted for servicing. If workers service their own respirators, an inspection program operated by a supervisor should be instituted [245].

It should not be assumed that wearing a respirator affords total protection against all contaminants. Workers should be informed about respirator limitations, such as the difficulty in obtaining a proper skin-respirator seal and that air-purifying type respirators for dust and solvents do not provide oxygen. Providing training in the proper fitting, care, use, and limitations of respirators should be considered as important as providing the respirator itself [245]. The workers should be informed that respirators should not be used in lieu of appropriate industrial hygiene practices and engineering controls.

Misuse can be minimized by establishing written procedures for respirator selection, cleaning, and use and by properly supervising all aspects of a respirator program. The written procedures as required by 29 CFR 1910.134 should contain all information necessary to ensure proper respiratory protection. A description of the limitations of each device in protecting against different materials or concentrations helps the user or employer select the proper respiratory protection [245].

D. Hearing Protection

Prolonged worker exposure to excessive noise in foundry operations, as in any industry, can result in permanent hearing loss unless protective measures are instituted. Engineering controls should be implemented to reduce noise to acceptable levels, these were discussed in Chapter IV. When engineering controls are not feasible, it may be necessary to provide protection by the use of ear protectors. Noise control and hearing conservation programs should conform to 29 CFR 1910.95 [141].

The types of ear protectors available for foundry workers are earmuffs that fit over the ear, earplugs that are inserted into the ear, or combinations of the two. The acoustical effectiveness of ear protectors ranges from about 20 to 45 decibels with greater attenuation at the higher frequencies. Usually, ear plugs give better attenuation at the lower frequencies and ear muffs better protection in the middle to upper frequencies [250]. The combination of ear muffs and ear plugs provides greater noise reduction than either one alone (about 5 decibels) [250,251]. The need for proper fit and seal of any type of ear protector cannot be over-emphasized.

Acoustically, there is not much difference between the types of earmuffs available, except for the very lightweight versions which may not provide sufficient protection against low frequency sounds. Selection of a particular type of earmuff can be safely left to the workers themselves, provided the manufacturer's instructions are followed [246,247,251,252]. Where earmuffs are worn for entire shifts, comfort, durability, and effectiveness are important considerations. For example, prolonged exposure to intense heat may lead to earmuff distortion. In addition, perspiration and dust accumulation between the earmuff and the worker's face can cause skin irritation.

Earmuffs may not always be compatible with other personal protective equipment. For example, the temples of safety glasses may lift the earmuffs away from the head, permitting sound to reach the ear through the broken seal. When respirators are worn, their straps may make it difficult or impossible for a worker to wear earmuffs. The brims of safety hats must have adequate clearance above the earmuffs; otherwise, the protective action of the helmet is jeopardized. Besides the interference with safety glasses and hard hats, ear muffs may increase heat discomfort; they are bulky and harder to carry and store, and they have more parts to keep clean. On the other hand, ear plugs require careful fitting in order for rated attenuation to be obtained. Ear muffs are relatively simple to fit; whereas workers may insert the ear plugs carelessly and thus not receive full protection from the plugs [250,253].

Some nondisposable earplugs are less acoustically effective than earmuffs. Semirigid earplugs give a reasonable degree of protection provided they are the correct size and are fitted properly. Cleanliness of plugs is also important to avoid external ear canal infection; handling earplugs in the dusty foundries environment can present a hygiene problem [247,250].

Disposable earplugs reduce the risk of ear infection. Provided the manufacturer's instructions are followed carefully, disposable earplugs may give more protection than semirigid plugs because they mold themselves to the shape of the ear canal. Disposable earplugs are usually made of polyurethane foam or glass down, which has the texture of cotton wool. Dry cotton plugs, although easy to insert, provide little protection [250]. Under foundry noise conditions ear plugs have been reported not to provide their rated noise attenuation levels [168].

When selecting proper hearing protection, the need to communicate with other workers and to hear warning signals in many high noise environments must be considered. Communication is most significantly affected when the noise has high intensities in the speech frequency range. Hearing protection devices interfere with speech communication in relatively quiet environments where the noise does not raise the open-air speech threshold by 80 dB or more [254]. However, in noisy environments, earplugs or earmuffs should not interfere with, but may even improve, speech intelligibility because speech-to-noise ratios are kept nearly constant. The protected ear does not distort speech by the overloading caused by the high speech and noise levels [250,254].

The concept of blocking the ear to improve hearing in a noisy environment can be a difficult one for a worker to accept, and some workers may resist wearing protectors because of anticipated difficulties in communication, especially if the protector is first tried in a quiet environment. Hearing protectors with a filter, which allows the lower frequencies in the speech range to pass through while blocking the higher frequencies of foundry noise, may appear to have advantages. Some of these filter-type devices may provide better communication in quiet environments although their reliability has been questioned. However, the conventional insert- or muff-type protectors provide acceptable communication; in addition, they provide protection against high noise levels [250,254].

The assignment of responsibility for maintenance and supervision of hearing protective devices will depend on the number of workers using them; however, if possible, one individual or section should have responsibility for supplying and inspecting hearing protective devices. Usually, the same person or section in charge of all other personal protective equipment should be selected. However, the enforcement of the program should be the responsibility of the line supervisor in each working group. Selecting and fitting ear protectors, especially nondisposable earplugs, should be performed by a qualified medical person. Cleanliness of molded earplugs is very important. The user should wash them with water and mild soap whenever they are removed, at least once a day. Disposable earplugs should be formed and inserted only with clean hands to reduce potential for ear infections and should always be discarded after each day's use. Both disposable and nondisposable earplugs are small and may become misplaced or lost; therefore, replacements should be readily available.

In addition to ensuring the proper use of and providing maintenance for hearing protection devices, foundry employers should inform their workers of the benefits to be derived from hearing conservation. Workers should understand the purpose of ear protection, how to recognize (both occupational and nonoccupational) high noise sources, and how to correctly use ear protectors.

VII. OCCUPATIONAL HEALTH AND SAFETY STANDARDS FOR FOUNDRIES

A. U.S. Standards

The OSHA-promulgated general regulations that apply to all industries were adopted from consensus standards developed by a variety of private organizations, including the American National Standards Institute (ANSI). Although the general regulations are not directed specifically toward foundries, many of them are applicable to foundry operations. These standards cover walking and working surfaces, handling of flammable and combustible materials, means of egress, vehicle-mounted work platforms, medical and first-aid stations, fire protection, compressed-gas cylinders, guarding of portable and powered tools, electrical hazards, personal protective equipment, medical and first-aid requirements, and occupational and environmental controls. Specific standards in 29 CFR 1910 that apply to foundries are listed in Appendix F.

The OSHA PEL's covering airborne contaminants (29 CFR 1910.1000) prescribe exposure limits in terms of 8-hour TWA concentrations for a number of the chemical agents present in foundries [141]. These regulations were adopted from the 1968 TLV's developed by the American Conference of Governmental Industrial Hygienists (ACGIH). Exposure limits have also been recommended by NIOSH in various criteria documents. Exposure limits applicable to foundries, including OSHA PEL's, ACGIH TLV's, and NIOSH REL's, are presented in Appendix B.

In addition to exposure limits, other requirements have been used in standards for controlling hazardous chemicals in foundries. OSHA standards (29 CFR 1910) define requirements for environmental and medical monitoring, labeling, and recordkeeping, as well as exposure limits for many toxic chemicals [141].

Safety standards for sand casting have been developed by ANSI, under the sponsorship of the AFS and other foundry organizations. The standards were based on recommendations by a committee of foundry safety officers with broad experience in the types of accidents that have occurred in foundries. ANSI Z241.1-1981, American National Standard for Safety Requirements for Sand Preparation, Molding, and Coremaking in the Sand Foundry Industry [255]; ANSI Z241.2-1981, American National Standard for Safety Requirements for Melting and Pouring of Metals in the Metalcasting Industry [256]; and ANSI Z241.3-1981, American National Standard for Safety Requirements for Cleaning and Finishing of Castings [257] have been published. These consensus standards are limited to those safety aspects of the metal casting industry for which other general industry standards do not exist or are inadequate. Although the standards are primarily concerned with minimizing injuries of personnel working around equipment, they require that air contaminant concentrations in the operators' breathing zone do not exceed the TLV's and that controls be provided to reduce airborne contaminants below the TLV. Personal protective equipment and medical and environmental monitoring are not addressed by the standard.

The Foundry Health and Safety Guide series, published by the AFS [69], discusses potential foundry hazards by substance, OSHA PEL, and hazard and control procedures.

Under the Occupational Safety and Health Act of 1970, states may elect to have their own occupational safety and health compliance programs, provided they meet Federal approval. Michigan has developed a comprehensive safety standard for both ferrous and nonferrous foundries [258]. The standard incorporates general industry standards to the extent that they are relevant to foundry equipment or processes. The standard also covers personal protective clothing and equipment, control of toxic fumes and dusts, working surfaces, and the safe handling of scrap, molten materials, sand, lead, and caustic chemicals. Worker training, recordkeeping, and medical and environmental monitoring are not addressed. Some states having a large number of foundries, including Pennsylvania, Ohio, and New York, do not have standards that address foundry hazards separately.

The National Fire Protection Association (NFPA) has also developed recommendations relevant to the foundry industry [259]. In particular, NFPA Standards 86A, B and C, covering all industrial ovens and furnaces, present guidelines, rules, and methods applicable to safe operation of such equipment. These regulations do not cover toxic vapors, noise levels, heat stress, or furnace operation. Information is presented on safety control applications, such as lockout, fire protection for furnace areas, and maintenance procedures. The rationale for the entire standard indicates that most furnace or oven failures are due to inadequate operator training, lack of proper equipment maintenance, and improper application of equipment.

B. Standards in Other Countries

The United Kingdom (UK) has a series of regulations that are directly applicable to foundry operations. The Factories Act of 1961 [260], which consolidated many previous regulations, deals with hazards in many industries in addition to foundry-specific hazards, e.g., regarding lifting of castings and other heavy loads. Other regulations retained in the Act are applicable to foundries, including the Grinding of Metals (Miscellaneous Industries), Special Regulation 1950, the Blasting (Casting and Other Articles) Special Regulation 1949, The Iron and Steel Foundries Regulation 1953, and the Foundries (Parting Materials) Special Regulation 1950. The blasting, grinding, iron and steel foundry, and parting powder regulations were enacted because of the silicosis problem found in earlier studies. The regulation on parting powders bans the use of silica flour as a parting material for use on molds and cores.

Special UK regulations pertinent to foundries included the Nonferrous Metal (Metal and Founding) Regulations of 1972 [260]. These regulations cover sand and die-casting of nonferrous metals.

The most recent general standard adopted in the UK that has jurisdiction over foundries is the Health and Safety at Work Act of 1974 [261]. Specific parts of the regulation define employer's duties with respect to safety equipment, workplace cleanliness, emergency procedures, protection against dust and fume, and personal protective equipment. The Health and Safety at Work Act further includes worker training, notice and provision of proper supervision, and environmental limits applicable to the workplaces.

Additional recommendations for control of foundry hazards in the UK are made by the British Cast Iron Research Association (BCIRA). The BCIRA functions as a technical review organization for iron foundries and reviews and recommends practices in the industry based on literature and reports of injuries and illnesses from their member companies. The BCIRA publishes "Broadsheets" describing hazards in foundries, their sources, existing TLV's, and recommended means of control. These "Broadsheets" cover safety and health hazards such as binders, catalysts, CO, and molten metal handling.

Europe has few national regulations relating specifically to foundries [261]. General regulations concerning places of employment protect workers by applying maximum workplace concentration (MAC) values to chemical and physical hazards. The regulations for labeling serve to identify potential workplace hazards. Requirements specify that certain hazardous industries and facilities which have a large number of workers must employ a physician to care for personnel and a safety expert to monitor the environment.

In Germany, the Association of German Foundrymen (AGF) issues leaflets or guidelines on foundry hazards, which are equivalent to regulations [261]. The content is similar to the British "Broadsheets," but the BCIRA guidelines are voluntary. Subjects discussed in the AGF leaflets include design and operation of compressed-air supply for foundries, design of cupola dust-arrester systems, the handling of binders and mold coatings, and exposure limits for foundry noise [261].

The Province of Ontario, Canada, has adopted foundry regulations as part of the Industrial Safety Act of 1971 [262]. These regulations encompass performance criteria for foundry operations, e.g., minimum width of gangways for transporting molten metal and minimum ventilation requirements for local exhaust on grinding wheels. The use of personal protective equipment, general and local ventilation requirements, and building restrictions are specified for foundry subprocesses. Environmental and medical monitoring, worker training, recordkeeping, and TLV's are not included in the regulations.

The Province of Quebec, Canada, also has a regulation that specifically addresses foundries [263]. The regulation details work practices associated with processes and equipment, as well as the minimum requirements for safe equipment and work areas. ACGIH TLV's are included in the requirements. Requirements for worker training and medical and environmental monitoring are not included.

VIII. RESEARCH NEEDS

Proper assessment of health and safety hazards in foundries requires that further research be conducted to determine the health effects of the total foundry environment on the foundry worker and that more injury data be compiled and analyzed on the causes of accidents in foundries. Research in control and process technology is needed to reduce the risk of illness and injury to foundry workers.

A. Epidemiologic and Health Effects Studies

In recent years, most of the foundry epidemiologic studies have been conducted in Finland, Yugoslavia, and Great Britain. In the United States, however, a comprehensive epidemiologic study of foundry workers' health was conducted by Renes et al. in 1948-49 [115], and in 1978 a retrospective mortality study reviewed the death records of International Molders and Allied Workers Union (IMAWU) workers who had been members for at least 11 years [31]. Both of these studies reflect past foundry practices, such as the use of silica parting powders. To accurately assess the status of foundry workers' health, prospective and retrospective epidemiologic studies that examine a representative cross section of U.S. foundries and foundry workers are needed. Because of the respiratory hazards in foundries, any epidemiologic studies must also consider the effects of smoking habits and their relationship to occupational hazards and risks.

Many of the epidemiologic studies either reported only the health effects in ferrous foundry workers or did not distinguish between the health effects in ferrous and nonferrous foundry workers. Studies should be undertaken to determine whether the higher melting temperatures needed for ferrous alloys, which allow for the production of tridymite and cristobalite in core molds, result in a higher incidence of respiratory illness. Epidemiologic studies should be performed to determine whether a significant difference exists in the health of ferrous and nonferrous foundry workers.

The causes of injuries and the prevalence of these injuries in foundry worker populations have been cited in numerous studies. However, comparison of the studies is difficult because different criteria and terminology are used in reporting injuries. Research is required to develop a comprehensive foundry injury information and reporting system, with a consistent terminology, to analyze trends in the causes of injuries to foundry workers. Studies are needed to determine why injuries and accidents are so prevalent among foundry workers. Such studies should utilize a comprehensive ergonomic approach including behavioral, motivational, and socioeconomic factors. Definitive studies are needed to determine the effects of the interaction of foundry air contaminants, physical hazards, and work procedures on all aspects of worker health and safety.

In recent years, a number of non-silica sands, including olivine, zircon, and chromite, have been introduced as mold materials in casting processes. Even though some studies have been performed on these materials, further research is needed to determine their toxicity.

B. Engineering and Process Controls

The improvement of engineering controls and the development of process technologies to reduce worker exposures to hazards should have a positive impact on the health and safety of foundry workers. The control of casting and cleaning operations is difficult to achieve with the currently available ventilation controls. Further research, preferably on a controlled experimental basis, should be performed to determine whether a combination of existing and new or improved ventilation methods might be sufficient to achieve control of air contaminants in chipping and grinding operations and in shakeout. The high-velocity, low-volume ventilation control method should be further studied for foundry application because it has the potential for providing breathing-zone protection for cleaning room workers. Further research should also be undertaken to evaluate existing floorstand grinder hood techniques and to establish conditions under which controls can be achieved.

Metal penetration, which occurs during the pouring and cooling of castings, is a major source of silica dust exposure for workers removing excess metal and mold materials from the castings. Consequently, control of burn-on would reduce the amount of cleaning and finishing of castings and would, therefore; reduce worker exposure. Recommendations for further research on burn-on control should include the systematic examination of the factors that cause metal penetration, with special emphasis on the influence of the different base-sand compositions and the impurities in mold and core constituents and washes. Further research should be performed to develop mold coatings that resist metal penetration.

Controlling noise below 90 dBA in chipping and grinding operations is not possible with present methods. Further research should be initiated to investigate and document control solutions for all foundry noise problems.

The development and use of new foundry control and process technology, including new binder compositions, need to be closely monitored and assessed to determine possible human hazards. Processes, such as the Schumacher process used for sand handling, electrostatic fog techniques, and the molding unbonded sand with vacuum (the V-process), should be studied to decide their effectiveness in controlling exposures and to evaluate their economic feasibility. Alternatives, such as the use of olivine sand and other non-silica sand mold materials, should be investigated to determine whether they can be adapted to both ferrous and nonferrous foundries and whether a system for separating olivine and silica sand can be developed.