SENTINAL EVENT NOTIFICATION SYSTEM FOR OCCUPATIONAL RISKS (SENSOR):

RECOMMENDATIONS FOR CONTROL OF SILICA EXPOSURE

AT

Ingersoll-Rand Company
Foundry Division
Phillipsburg, New Jersey

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PLANT SURVEYED:	Ingersoll-Rand Company Foundry Division Phillipsburg, New Jersey 08865
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SURVEY DATE:	November 27 to December 1, 1989
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SUMMARY

In 1987, NIOSH initiated the SENSOR (Sentinal Event Notification System for Occupational Risks) program, a cooperative state-federal effort designed to develop local capability for the recognition, reporting, follow-up, and prevention of selected occupational disorders. The New Jersey Department of Health is participating in the SENSOR program for occupational asthma and silicosis. The Engineering Control Technology Branch (ECTB) of NIOSH is assisting in the conduct of follow-back surveys to recommend improved controls in selected plants. This report describes an in-depth follow-back survey of exposure to silica dust and other airborne hazards at the Ingersoll-Rand Company, Foundry Division, Phillipsburg, New Jersey, as part of this effort. Environmental and engineering evaluations were conducted in November 1989.

The environmental evaluations included the collection of 57 personal and area air samples analyzed for respirable crystalline silica and respirable dust; 21 personal samples analyzed quantitatively for chromium, nickel, and lead; 9 personal and area samples analyzed for polynuclear aromatic hydrocarbons; 9 man-days of dosimetry for exposure to carbon monoxide; and 2 bulk/material samples analyzed for fiber size. Engineering evaluations included the determination of relative contribution of specific power tools to exposure in casting cleaning; the determination of particle removal efficiency in air recirculated by downdraft grinding benches; and airflow measurement of local exhaust hoods.

Sixteen of the 45 personal samples for respirable silica dust exceeded either the NIOSH Recommended Exposure Limit (REL) or the OSHA Permissible Exposure Limit (PEL) for quartz and cristobalite. The shakeout, casting cleaning (sawing and grinding), and molding operations had the greatest exposures. The 6-inch grinder and the 4-inch cutoff wheel appeared to be major sources of dust exposure.

Nine of 21 personal samples for the metals chromium, nickel, and lead exceeded either the NIOSH REL or the OSHA PEL for one or more of these metals. The torch cutting and casting repair (welding) operations had the greatest exposures.

Bulk analysis of fibrous material samples indicate that the majority of fibers are long (>5 μm) and thin (<1 μm).

Carbon monoxide dosimetry indicated that exposures were well below both the REL and PEL for carbon monoxide.

Deficiencies in the design and maintenance of equipment for the control of dust, particularly the shakeout system and the downdraft benches, were identified and recommendations for their modification or improvement are offered.

Keywords: SIC 3561/63; foundries; metal casting; chipping and grinding; silica; quartz; cristobalite; polynuclear aromatic hydrocarbons; carbon monoxide; chromium; lead; nickel; silicosis; respirable dust; real-time monitoring; aerosol photometers.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is the primary federal agency engaged in occupational safety and health research. Located in the Department of Health and Human Services (formerly the Department of Health, Education, and Welfare), it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions conducted by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards. The Engineering Control Technology Branch (ECTB) of the Division of Physical Sciences and Engineering has been given the lead within NIOSH to study the engineering aspects of hazard control.

Since 1976, ECTB has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques. The objective of each of these studies has been to document and evaluate effective techniques for the control of potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures.

In 1987, NIOSH initiated the SENSOR program (Sentinel Event Notification System for Occupational Risks), a cooperative state-federal effort designed to develop local capability for the recognition, reporting, and prevention of selected occupational disorders. Under this program, the state health department (or other agency) launches three types of actions upon notification of a case of occupational disease: first, disease management guidelines will be made available to the health care provider; second, medical evaluations of coworkers who may be at risk of developing similar disorders will be conducted; and finally, action directed to reduce work site exposures will be considered. To assist the states in developing intervention plans for exposure reduction, ECTB will conduct a pilot engineering assistance project with selected states participating in SENSOR. This assistance may include specific control recommendations for an individual plant identified and selected by the state, or for an industry that would be selected based on the state disease records, with the intent of developing guidelines for the elimination of occupational disease in the entire industry.

The New Jersey Department of Health (NJDH) is participating in the SENSOR program for occupational asthma and silicosis and has been recording physicians' reports of occupational silicosis for several years. Health department data indicate the largest number of silicosis cases in the state exists in the sand mining and processing, foundry, and pottery (sanitary ware) industries. This disease is caused by exposure to crystalline silica in these industries.

At least one study is being conducted by ECTB in a facility of each of these industries to develop specific control recommendations to eliminate future cases of disease; to train state personnel in the application of engineering control; and to develop a model protocol for the identification and control of exposure sources. This report describes an in-depth survey conducted as a part of this federal-state effort at the Ingersoll-Rand Company, Foundry Division, Phillipsburg, New Jersey.

The NJDH silicosis registry has shown the foundry industry to be a high silicosis risk industry; this plant was one of three foundries initially visited to select a site to demonstrate the feasibility of effective intervention in reducing the silicosis risk. The NJDH had identified cases of silicosis at the Ingersoll-Rand facility, and some of these cases had occurred among workers who also worked in a now-closed gray foundry operated by this company. The primary purpose of this survey was to determine if current workers are at risk of developing silicosis by identifying and evaluating worker exposures to silica-containing dusts; and as a consequence, to evaluate and recommend improvements in the effectiveness of current engineering controls, work practices, and administrative control programs in reducing dust exposures.

A second objective of this study was to develop improved dust controls for chipping and grinding operations. Ingersoll-Rand provides a unique intervention opportunity in this regard: in addition to using pneumatic-powered tools in their foundry, Ingersoll-Rand is a major producer of this equipment. In order to improve conditions in their facility, as well as to stimulate Ingersoll-Rand to incorporate dust controls in the equipment they produce, Brian McNeil, Ingersoll-Rand's product manager for grinders and sanders, was invited to observe the study. Guy Cusamano, a consultant, was hired by NIOSH to examine the feasibility of HVLV dust control for these operations and provide preliminary design recommendations.

The third and final objective of this survey was to provide hands-on training in conducting follow-back surveys to the staff of the NJDH. In addition, Nancy Clark of the Ohio Health Department accompanied the NIOSH and NJDH investigators on this study to better enable her to conduct follow-back visits on the Ohio SENSOR project, which is aimed specifically in preventing new cases of silicosis in foundries.

PLANT DESCRIPTION

The Ingersoll-Rand Company has operated both gray iron and steel foundries at this site. The gray iron foundry closed in 1978. The steel foundry is both newer (built in 1953) and smaller. The New Jersey Health Department identified several cases of silicosis at Ingersoll-Rand. The distribution of these cases between workers at the gray iron and steel foundries is unknown.

The plant employs 74 hourly and 13 salaried workers and operates on one shift (6:00 a.m. to 2:30 p.m.), except for melting and shakeout which begin at 5:00 a.m. Addition of a second shift is contemplated.

The main foundry is an L-shaped building consisting of a steel skeleton covered with steel siding. The floor is concrete covered with molding sand in the molding and melting department. Four air-handling units provide make-up air and space heating. Three units are located in the melting/molding area and the other located in the casting cleaning department; only one unit (in the core/mold area) was in use at the time of this study. A schematic layout of the plant is included as Figure 1.

PROCESS DESCRIPTION

Melting

The plant is a captive foundry producing steel and stainless steel castings for the parent company. Production is divided approximately 40 percent steel, 60 percent stainless steel. Five induction furnaces (1- to 1,000-pound capacity, 3- to 2,000-pound capacity, 1- to 2,500-pound capacity) are used to melt the scrap. In addition to the ferrous metals, approximately four heats per month of leaded bronze are poured. Normally, only two furnaces are in operation at any time. An annular-shaped exhaust hood surrounds the top of the melting vessel on the 2,500-pound capacity furnace (used for the leaded bronze). A 6,000-pound capacity electric arc furnace is also used. This furnace is equipped with a roof-mounted sidedraft hood to capture metal fumes escaping around electrode openings. Furnace refractories (alumina) are replaced about every 90 days, by the furnace operator. Disposable ladle liners are used as both a labor-saving and exposure-reducing measure.

Molding and Core Making

The foundry produces molds using an alkyd-oil (drying oil/isocyanate) molding system. Sand, binder, and catalyst are combined in one of three screw mixers. Some small cores are made with silica sand using a drying oil binder. The oil polymerizes on heating in an oven. Zircon and silica-based washes are used on molds and cores. In general, patterns are waxed to facilitate mold removal, although some nonsilica parting compounds are used.

The plant was originally designed to produce small- to medium-size castings on a semiautomatic line. These molds are poured on the open floor, moved to roller conveyors located in a ventilated cooling room, and mechanically dumped into a shot blast machine. This machine serves not only as a device to clean castings but as a sand reclaimer. This procedure would appear to effectively isolate the workers from both the smoke produced during the pouring and cooling, and the dust produced during shakeout. Larger molds (which represent the bulk of current production) will not fit on the conveyor. Shakeout and casting removal of the larger molds are performed manually. Sand from these molds is moved by front-end loader to a sand reclaimer (shot blast machine) connected to a baghouse.

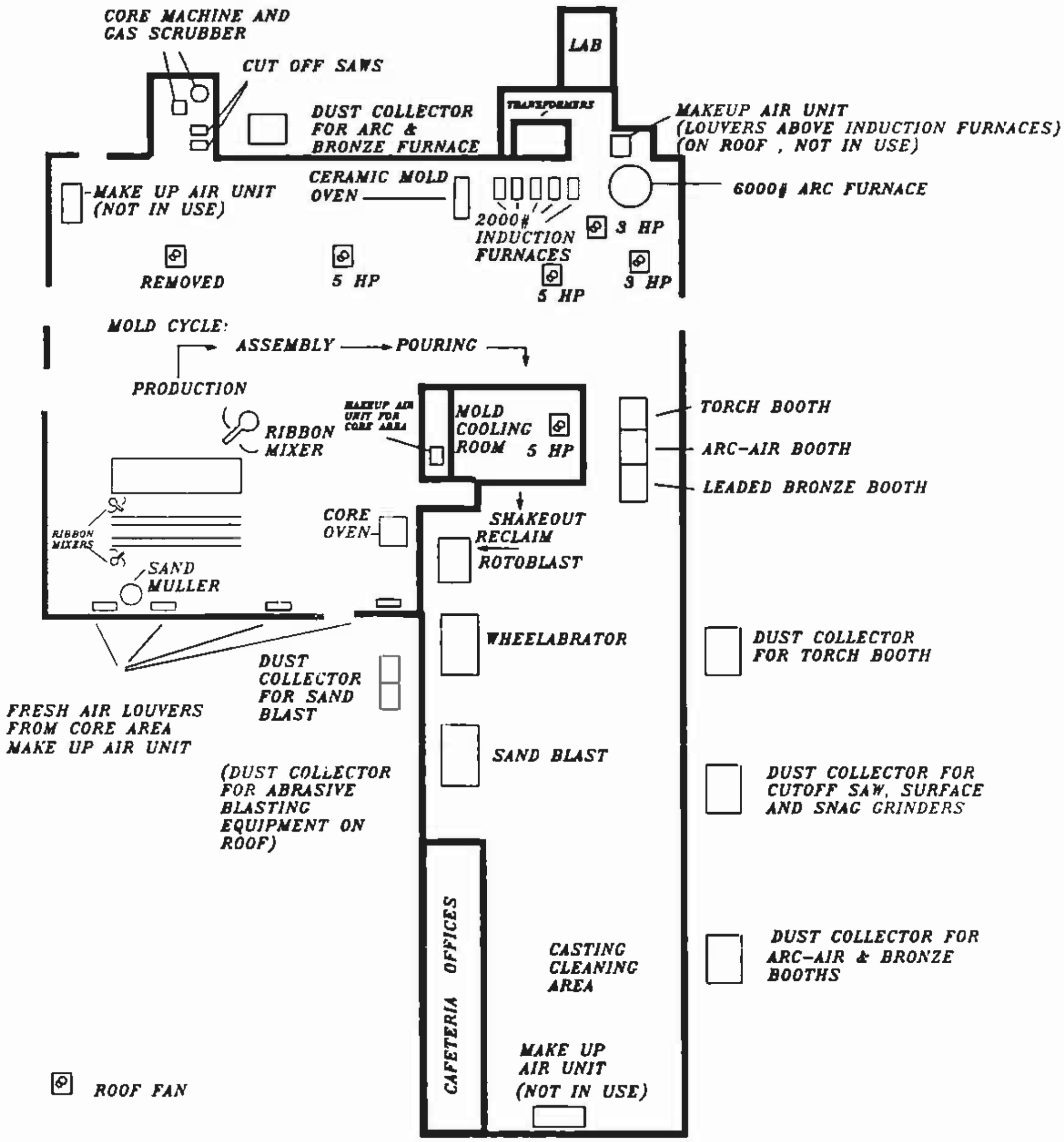

Figure 1. Schematic layout - Ingersoll-Rand steel foundry.

Casting Cleaning

After shakeout and cooling, casting appendages are removed by means of an oxygen torch in one of two ventilated booths; remaining extraneous material is removed by an arc-air torch in a second booth. Grinding of bronze castings is performed in an adjacent booth. Castings are cleaned automatically by steel shot in an abrasive blasting machine or manually by sand blasting in a walk-in cabinet. Additional material is removed from castings primarily by hand-held grinders used on downdraft benches. These benches recirculated filtered air back into the foundry. A swing frame grinder and cutoff saw were also used.

Inspection and Repair

Castings were inspected using dye penetrant (DP), magnetic-particle test (MT), and radiography. Imperfections are repaired in the main foundry building by arc or gas welding on downdraft benches similar to those used for grinding.

Ceramic Mold Foundry

Certain high-value stainless steel castings are produced using a ceramic molding process in an adjacent, older building. The metal is melted in one of two induction furnaces and poured into heated ceramic molds. A wall fan removes heat and metal fumes from the furnace area. The molds are made by mixing (in a small unventilated cement mixer) zircon/fused silica and potassium and ethyl silicates. After pouring, a hot topping compound (mixture of sodium nitrate, sodium fluosilicate, wood dust, perlite, alumina, aluminum, graphite, and magnesium chromate) is used to retard cooling of the casting. Castings are trimmed/cleaned by a water-jet cutter, a stand grinder, an abrasive saw, an abrasive blasting machine (steel shot), or hand-held grinders.

Personal Protection and Hygiene

Safety shoes, safety glasses, and hard hats are required in all areas of the plant. NIOSH-approved disposable dust/fume/mist respirators are required in certain casting cleaning areas. The sand blast operator wears a supplied-air respirator (carbon monoxide was reported to be monitored at the compressor). The corporate industrial hygienist is responsible for respirator selection. Work clothing is provided to the operator who grinds leaded bronze castings.

POTENTIAL HEALTH HAZARDS AND ENVIRONMENTAL CRITERIA

POTENTIAL HAZARDS

The main purpose of the SENSOR program is to follow-up silicosis cases to prevent the development of new cases of this disease. Other major airborne hazards occurring in foundries are metal fumes and dusts, combustion and decomposition products of mold and core materials, and carbon monoxide. Information is also presented on these hazards, as attempts to control them may also cause a concomitant reduction in exposure to silica.

Crystalline Silica

Crystalline silica is contained in molding and core making sands, in clays used as bonding agents, in parting compounds, in some refractory materials, and as surface contamination on castings. Exposure can occur almost anywhere within the foundry. In most operations, workers may have exposure to other contaminants as well. The crystalline forms of silica can cause severe tissue damage when inhaled. Silicosis is a form of pulmonary fibrosis caused by the deposition of fine particles of crystalline silica in the lungs. Symptoms usually develop insidiously, with cough, shortness of breath, chest pain, weakness, wheezing, and nonspecific chest illnesses. Silicosis usually occurs after years of exposure, but may appear in a shorter time if exposure concentrations are very high. This latter form is referred to as rapidly-developing silicosis, and its etiology and pathology are not as well understood. Silicosis is usually diagnosed through chest X-rays, occupational exposure histories, and pulmonary function tests. The manner in which silica affects pulmonary tissue is not fully understood, and theories have been proposed based on the physical shape of the crystals, their solubility, toxicity to macrophages in the lungs, or their crystalline structure. There is evidence that cristobalite and tridymite, which have a different crystalline form from that of quartz, have a greater capacity to produce silicosis.[1]

Metals

The hazard of exposure to metals is dependent upon the type of metal cast. Some of the more hazardous metals used at this facility are lead, chromium, and nickel. Metal fumes can be encountered at melting, pouring, and various types of welding and brazing operations. Metal dusts produced during grinding operations are usually not as significant as the fume, because the dusts are of a larger particle size.[2]

Lead--

Inhalation (breathing) of lead dust and fume is the major route of lead exposure. A secondary source of exposure may be from ingestion (swallowing) of lead dust deposited on food, cigarettes, or other objects. Once absorbed, lead is excreted from the body very slowly. Absorbed lead can damage the kidneys, peripheral and central nervous systems, and the blood-forming organs (bone marrow). These effects may be felt as weakness, tiredness, irritability, digestive disturbances, high blood pressure, kidney damage, mental deficiency, or slowed reaction times. Chronic lead exposure is associated with infertility and with fetal damage in pregnant women.[3,4]

Nickel--
Inorganic nickel compounds are suspected of causing lung and nasal cancer, based on the mortality experience of nickel refinery workers. Nickel metal and its compounds can also produce a contact dermatitis known as "nickel itch."[5]

Chromium--
The dust from chromium metal is relatively nontoxic. However, chromium alloys can be oxidized to chromium trioxide (chromic acid anhydride), a soluble chromium (VI) compound. (Exposure in the operations sampled, metal melting, torch cutting, and welding, was assumed to be to chromium trioxide fume.) These compounds can produce health effects such as contact dermatitis, irritation and ulceration of the nasal mucosa, and perforation of the nasal septum. Certain insoluble chromium (VI) compounds are suspect carcinogens. Magnesium chromate, used as a component of the hot topping compound, is highly water soluble; however, it is not specifically identified by NIOSH as a noncarcinogenic chromium (VI) compound, requiring that it be handled as a carcinogen.[6]

Decomposition Products

Epidemiological studies suggest that workers in ferrous foundries are at a greater risk of dying from lung cancer than persons in the general population. The risk is a function of the job performed, with molders, metal pourers, and cleaning room personnel having the greatest rate of mortality from lung cancer.[7] There are strong suspicions that the agents responsible may be formed during the thermal decomposition of a wide variety of organic additives and binders used in foundry mold and core making processes.[2] These materials undergo thermal decomposition from the intense heat produced when the molten metal is poured. These decomposition products may be released during pouring, mold cooling, and shakeout. They may also remain in the sand or adhere to the surface of the casting.

The major hazardous degradation products which are expected to be present in most pouring and cooling operations are: carbon monoxide, carbon dioxide, aliphatic and aromatic hydrocarbons (most likely benzene, toluene, and xylenes), and smoke. The smoke may contain various polynuclear aromatic hydrocarbons with suspected carcinogenic properties. Depending on the specific core and mold materials used, numerous other substances may be present. Formaldehyde, hydrogen cyanide, and methylene bisphenyl isocyanate are additional substances that may be formed from the decomposition of alkyd-oil binder systems.[8]

Carbon Monoxide--
In the foundry, carbon monoxide is produced by melting processes based on combustion, from internal combustion engines, from other combustion sources,

and from the decomposition of organic molding materials during pouring and cooling. Carbon monoxide has typically been used as an index of the hazard in mold pouring and cooling areas in gray iron foundries. Carbon monoxide combines with hemoglobin in the blood reducing the oxygen-carrying capacity of the blood. Symptoms of CO poisoning are headache, dizziness, drowsiness, nausea, vomiting, collapse, coma, and death. Long-term, low-level exposure to CO can increase the risk of heart attack for some people.[9]

Formaldehyde--
Exposure to formaldehyde can occur in mold and core making processes using formaldehyde-based resins, and from the decomposition of other organic materials during pouring and cooling of castings. The primary health effects of exposure to formaldehyde are irritation of the respiratory tract, eyes, and skin. Eye and respiratory tract irritation has been reported in workers exposed to concentrations of less than 1 ppm.[10] Recent studies have found that formaldehyde induced nasal cancer in rats exposed to high levels (15 ppm) of formaldehyde over a long period of time.[11] These results have prompted NIOSH to recommend that formaldehyde be handled as a potential occupational carcinogen.

Hydrogen Cyanide--
Exposure to hydrogen cyanide can occur in pouring and cooling of castings when nitrogen-containing binders are used. Hydrogen cyanide is a chemical asphyxiant. It inactivates certain enzymes, the most important being cytochrome oxidase, which are used by the cells of the body for cellular respiration. Although the cells receive an adequate supply of oxygen through the blood stream, they are unable to use this oxygen because the metabolic process has been blocked by the presence of the -CN group. Inhalation, ingestion, or skin absorption of hydrogen cyanide may be rapidly fatal. Large doses may cause loss of consciousness, respiratory arrest, and death. Lower levels of exposure may cause weakness, headache, confusion, nausea, and vomiting.[9]

Isocyanates--
Diisocyanates such as methylene bisphenyl isocyanate are strong irritants of the eyes, mucous membranes, and skin, and also sensitizers of the respiratory tract. In sufficient concentrations, they cause irritation of the eyes, nose, and throat, a choking sensation, and a productive cough. Depending on the length of exposure and concentration, respiratory symptoms will develop with a latent period of 4 to 8 hours. Although the acute effects may be severe, a more important consideration is that respiratory sensitization can occur in susceptible individuals after repeated exposure to low levels of diisocyanates. Initial symptoms are often nighttime shortness of breath or cough with progression to asthmatic bronchitis. After symptoms subside, a return to work can cause an acute and severe asthmatic attack almost immediately or within a few hours.[12] A person who has become sensitized must avoid future exposure completely. Some decrease in lung function in the absence of symptoms has been observed in some workers exposed for long periods of time, even at low concentrations.[13] Exposures to diisocyanates (typically methylene bisphenyl isocyanate) are likely to occur in sand/resin mixing, in core/mold preparation, and at pouring and shakeout.

ENVIRONMENTAL CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a preexisting medical condition, and/or a hypersensitivity (allergy).

In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects, even if the occupational exposures are controlled at the level set by the evaluation criterion. These combined effects are often not considered in the evaluation criteria. For example, in the foundry, gases such as the oxides of nitrogen and sulfur dioxide may adsorb on dust particles and produce health effects at levels normally considered safe. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus potentially increase the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH RELs, (2) the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs®), and (3) the U.S. Department of Labor (OSHA) PELs.[14,15,16] Often, the NIOSH RELs and ACGIH TLVs are lower than the corresponding OSHA PELs. Both NIOSH RELs and ACGIH TLVs usually are based on more recent information than are the OSHA PELs. The OSHA PELs also may be required to take into account the feasibility of controlling exposures in various industries where the agents are used; the NIOSH RELs, by contrast, are based primarily on concerns relating to the prevention of occupational disease. In evaluating the exposure levels and the recommendations for reducing these levels found in this report, it should be noted that industry is legally required to meet only those levels specified by an OSHA PEL.

The environmental evaluation criteria for the air contaminants discussed in this report can be found in Table 1. The values reported in this table are time-weighted average (TWA) exposures. A time-weighted average exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have recommended short-term exposure limits (STEL) or ceiling (C) values which are intended to supplement the TWA where there are recognized toxic effects from high short-term exposures. Such limits are noted in the table.

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Table 1. Environmental Evaluation Criteria*

HAZARD	NIOSH REL	OSHA PEL	ACGIH TLV®
Crystalline silica (quartz) (cristobalite)	0.05 mg/m^3 0.05 mg/m^3	0.1 mg/m^3 0.05 mg/m^3	0.1 mg/m^3 0.05 mg/m^3
Chromium (metal, e.g. grinding dust, as Cr)	no REL	1 mg/m^3	0.5 mg/m^3
(chromic acid anhydride, e.g. welding fume)	25 ug/m^3 50 ug/m^3 (C) (as Cr)	100 ug/m^3 (C) (as CrO3)	50 ug/m^3 (as Cr)
Nickel (as Ni)	15 ug/m^3	1 mg/m^3	50 ug/m^3 #
Lead (as Pb)	<100 ug/m^3	50 ug/m^3	150 ug/m^3
Carbon monoxide	35 ppm 200 ppm (C)	35 ppm 200 ppm (C)	50 ppm 400 ppm (STEL)
Formaldehyde	0.016 ppm 0.1 ppm (STEL)	1 ppm 2 ppm (STEL)	1 ppm 2 ppm (STEL)
Hydrogen cyanide	4.7 ppm (C)	4.7 ppm (STEL)	10 ppm (C)

* All values are time-weighted averages unless noted as:
C - ceiling limit, or
STEL - short-term exposure limit.
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the TWA where there are recognized toxic effects from high short-term exposures.

STUDY PLAN/METHODOLOGY

NIOSH/NJDH investigators conducted environmental evaluations in the major work areas of both the steel and ceramic mold foundries including metal melting, mold and core making, mold pouring, torch and arc-air cutting, and casting cleaning.

Airborne exposures were evaluated in several ways:

1. Silica dust - Samples for the estimation of respirable dust and respirable quartz dust exposures, were collected on preweighed, 37 mm (diameter), 5 μm (pore size) PVC membrane filters (FWSB - Mine Safety Appliances, Inc., Pittsburgh, Pennsylvania), mounted in series with 10 mm nylon cyclones (Mine Safety Appliances, Inc., Pittsburgh, Pennsylvania). Air was drawn through the filter at an approximate flow rate of 1.7 liters per minute (lpm) using a battery-powered sampling pump (SKC Air Check Sampler, Model 224-PC X R7, SKC Inc., Eighty-Four, Pennsylvania). Time-integrated samples were collected in the breathing zone of workers for a full day shift, generally for about 7 hours (depending on individual work schedules). Workers were sampled for three (day) shifts. Job categories sampled included molders, core makers, core finishers, grinders, and shakeout, shot blast machine, and cutoff saw operators.

   All air samples were analyzed for respirable dust and respirable crystalline free silica dust content. Respirable dust content was analyzed gravimetrically according to NIOSH Method 0500 with the following modifications: (1) The filters were stored in an environmentally controlled room (21 ± 3°C and 40 ± 3% R.H.) and are subjected to the room conditions for a long duration for stabilization. Therefore, the method's 8- to 16-hour time for stabilization between tare weighings was reduced to 5 to 10 minutes. (2) The filters and backup pads were not vacuum desiccated.[8] The Limit of Detection (LOD) was determined to be 0.01 mg per sample. (The LOD is defined as the smallest amount of analyte which can be distinguished from background.[17])

   Respirable crystalline silica dust content (alpha quartz and cristobalite) was analyzed by NIOSH Method 7500, using X-ray diffraction with the following modifications: (1) Filters were dissolved in tetrahydrofuran rather than being ashed in a furnace. (2) Standards and samples were run concurrently and an external calibration curve was prepared from the integrated intensities rather than using the suggested normalization procedure.[17] The analysis of these samples for quartz and cristobalite required additional modifications due to interference problems in the primary quartz and primary cristobalite peak regions. These modifications were: (1) Quartz quantities were calculated by using secondary quartz standards and the samples secondary peak intensity. (2) Cristobalite quantities were calculated by measuring primary peak height values of the cristobalite standards and the samples rather than by using the integrated peak areas. Peak height measurements were used in this case because secondary cristobalite peaks showed even more interference than the primary peak. Unfortunately, the LOD for quartz corresponded to an airborne sample of approximately two times the NIOSH REL. Thus, all personal samples were subsequently reanalyzed at slower scan speeds to reduce the LOD. The LOD and the Limit of Quantification (LOQ) for the samples upon reanalysis at the slower speeds for quartz and cristobalite were determined to be 0.015 mg and 0.03 mg per sample, respectively. (The LOQ is defined as the mass of analyte equal to ten times the standard error of the calibration graph; or approximately the mass of analyte for which the relative standard error, s_r, equals 0.10.[17])

2. Metals - Samples for the estimation of exposures to chromium, nickel, and lead were collected on 37 mm (diameter), 0.8 μm (pore size) cellulose ester membrane filters (AA - Millipore, Inc., Bedford, Massachusetts), mounted in a closed-face cassette. Air was drawn through the filter at an approximate flow rate of 2.0 lpm using the same type battery-powered sampling pump used in the silica sampling. Time-integrated samples were collected in the breathing zone of workers for a full day shift, generally for about 7 hours (depending on individual work schedules). Workers were sampled for three (day) shifts. Job categories sampled included furnace operators, welders, torch and arc-air operators, and leaded bronze grinders. All air samples were digested according to NIOSH Method No. 7300 and analyzed for chromium, nickel, and lead using an inductively coupled plasma emission spectrometer. The LOD for these samples for chromium, nickel, and lead were determined to be 0.001 mg, 0.001 mg, and 0.002 mg per sample, respectively.

3. PNAs - Samples for the estimation of exposures to polynuclear aromatic hydrocarbons (PNAs), which are complex decomposition products of the core and mold constituents, were collected on 37 mm (diameter), 2 μm (pore size) polytetrafluoroethylene membrane filters (Zefluor - Gelman Sciences, Ann Arbor, Michigan), contained in a closed-face cassette mounted in series with a sorbent tube containing two sections (100 mg/50 mg) of washed XAD-2 resin (ORBO-43, Supelco, Inc., Bellefonte, Pennsylvania). Air was drawn through the filter and tube at an approximate flow rate of 1.7 lpm using the same type battery-powered sampling pump described above. Time-integrated samples were collected in the breathing zone of workers for a full day shift, generally for about 7 hours (depending on individual work schedules). Workers were sampled for three (day) shifts. Job categories sampled included metal pourers and crane operators. Both tubes and filters were desorbed in benzene and analyzed by gas chromatography according to NIOSH Method No. 7300 and analyzed for PNAs. The LOD and LOQ for these samples were determined to be 0.0005 mg and 0.0015 mg per sample, respectively, for each PNA.

4. Carbon monoxide - Exposure to carbon monoxide was determined using carbon monoxide dosimeters (Model 190 Data loggers, CO, National Draeger, Pittsburgh, Pennsylvania). These dosimeters employ an electrochemical sensor that produces an electrical signal proportional to the amount of

carbon monoxide present in the air. The instrument provides direct readout of the concentration, the time-weighted average concentration, and the maximum peak value. In addition, the stored values can be downloaded to a computer for examination of the time record of concentration. The accuracy of measurement claimed by the manufacturer is $\pm$2 ppm. Time-integrated samples were collected in the breathing zone of workers for a full day shift, generally for about 8 hours (depending on individual work schedules). Workers were sampled for three (day) shifts. Job categories sampled included metal pourers and crane operators.

A comparison of these monitors with that of a 2000 series Ecolyzer (Energetics Science, Inc., Elmsford, New York) was also conducted. Results of this comparison are reported in Appendix A.

5. Real-time sampling - Real-time dust exposure measurements and video recordings were made on workers performing chipping and grinding operations, to determine the relative exposure caused by different tools and operations, and to examine the possibility of control using high-velocity, low-volume (HVLV) exhaust hoods. The instrument used to measure dust concentration was a Hand-held Aerosol Monitor (HAM) manufactured by PPM, Inc., Knoxville, Tennessee. This instrument is a light-scattering device and its response is dependent upon the optical characteristics of the dust being measured. The HAM responds to respirable dust, but does not differentiate between crystalline silica and other dusts. For these reasons, concentrations are reported as relative concentrations (rather than absolute levels), as a result, this instrument was used only in comparisons between similar operations (i.e., chipping and grinding); and identification of a profile of concentration over a cycle of a given operation (i.e., shakeout). The analog output of the HAM was connected to a data logger (Rustrak Ranger, Gulton, Inc., East Greenwich, Rhode Island). When the collection was completed, the data logger was downloaded to a portable computer (Compaq Portable II, Compaq Computer Corporation, Houston, Texas) for analysis.

6. Formaldehyde and hydrogen cyanide - Exposure to formaldehyde and hydrogen cyanide were estimated through the use of detector tubes (National Draeger, Inc., Pittsburgh, Pennsylvania). These devices consist of a glass tube containing an inert carrier impregnated with a reagent. The ends of the tube are broken and the tube connected to a hand-operated air pump. Workplace air is pulled through the tube and the contaminant reacts with the reagent. The concentration is typically determined by the length of stain produced or by the number of pump strokes needed to produce a color change. Detector tubes are manufactured by several manufacturers and are available for a wide variety of airborne hazards. Detector tubes were used on the first day of the study during the pouring and cooling of molds to identify the presence of potential chemical hazards. These measurements were used to identify areas or operations causing potential exposure; they may not reflect actual exposures measured by long-term sampling techniques.

7. Ventilation rate evaluations were made to determine the effectiveness of the local exhaust hoods. Measured ventilation rates were compared to

recommended design values. Velocity measurements were made with a hot wire anemometer.

8. Recirculation of exhaust air - Performance of exhaust air recirculation systems was performed using a Royco (Royco Instruments, Menlo Park, California) portable optical particle counter. This instrument counts and sizes dust particles by measuring the amount of light scattered as individual particles enter a sensing volume. A single channel pulse analyzer allows all particles greater than a selected size to be counted. By repeated measurements at different minimum sizes, a particle size distribution can be obtained. Particle size distribution measurements were made at the inlet and outlet of two grinding booths using the room ambient dust as the challenge aerosol.

RESULTS AND DISCUSSION

MOLDING AND CORE MAKING

Nine samples for crystalline silica and respirable dust were collected to estimate the exposure to workers performing molding and core making operations. Personal samples were collected on three molders and one mold assembler; an area sample was also collected in the molding area on each of 3 days of the survey. Of the six personal samples, two exceeded both the REL and the PEL for quartz (one exceeded the REL by a factor of 7); all of the remaining air samples collected contained no detectable respirable quartz or cristobalite, corresponding to airborne concentrations of approximately <40 $\mu g/m^3$ and <20 $\mu g/m^3$, respectively. Table 2 summarizes the results of the crystalline silica and respirable dust measurements.

METAL MELTING

Personal air samples for metals (chromium, nickel, and lead) were collected for 3 days on each of two furnace operators Sample results are reported in Table 3. Of these six samples, none exceeded the REL or the PEL for any of the metals.

METAL POURING AND MOLD COOLING

Nine samples for polynuclear aromatic hydrocarbons were collected and 9 man-days of carbon monoxide dosimetry were performed to estimate the exposure to decomposition products from the pouring and cooling of molds. Personal samples were collected on the individuals assigned to metal pouring and an area sample was collected in the open crane cab, near the breathing zone of the operator.

PNAs are complex thermal decomposition products of organic materials. Results of screening measurements for 17 PNAs are presented in Table 4. With the exception of naphthalene (OSHA PEL 50 $\underline{m}g/m^3$), no specific environmental criteria are available. As a point of comparison, reference 18 classifies PNA exposure in various industries based on benzo(a)pyrene concentration (BaP). "Certain" jobs (e.g., casters) are listed as moderate exposures based on BaP levels of 0.1 to 1 $\mu g/m^3$. Exposures at this facility are at worst "moderate" - BaP levels are all below the limit of detection (<0.6 $\mu g/m^3$). Only the relatively volatile PNAs (naphthalene, acenaphthylene, acenaphthene, fluorene, and phenanthrene) were present in detectable quantities, and not all of these compounds were detected in all samples.

As indicated in Table 5, carbon monoxide measurements were all well below the NIOSH REL, OSHA PEL, and ACGIH TLV. All but one worker carried the dosimeter

Table 2. Worker exposure to crystalline silica and respirable dust.

JOB TITLE	DATE (da,mo,yr)	FILTER NO.	TIME (min)	RESP. MASS (mg/m3)	QUARTZ (ug/m3)	CRISTOBALITE (ug/m3)	TOTAL SILICA (ug/m3)
Cutoff Saw	28-Nov-89	OM-8273	403	1.0	149	< 22	149 - 171
Cutoff Saw	29-Nov-89	OM-8335	397	0.3	76	< 22	76 - 98
Cutoff Saw	30-Nov-89	OM-8306	246	1.6	81	48	129
		Average*		1.0	102	31	
	Std	deviation		0.5	33	12	
Grinder 0	28-Nov-89	OM-8285	424	0.9	47	< 21	47 - 68
Grinder 0	30-Nov-89	OM-8294	433	0.7	69	< 20	69 - 90
Grinder 1	29-Nov-89	OM-8333	410	0.2	< 37	< 22	< 58
Grinder 2	28-Nov-89	OM-8282	412	0.7	97	< 21	97 - 119
Grinder 2	30-Nov-89	OM-8315	438	0.8	< 34	< 20	< 54
Grinder 3	28-Nov-89	OM-8287	419	0.4	< 36	< 21	< 57
Grinder 3	30-Nov-89	OM-8297	438	2.2	91	94	185
Grinder 4	28-Nov-89	OM-8274	415	1.1	48	< 21	48 - 69
Grinder 4	30-Nov-89	OM-8313	435	1.0	46	< 20	46 - 66
Grinder 5	28-Nov-89	OM-8286	421	0.3	< 36	< 21	< 57
Grinder 5	30-Nov-89	OM-8296	435	0.7	69	27	96
Grinder 6	29-Nov-89	OM-8328	416	0.2	48	< 21	48 - 69
Grinder 7	29-Nov-89	OM-8334	433	0.5	46	< 20	46 - 67
Grinder 8	29-Nov-89	OM-8329	419	0.4	< 36	< 21	< 57
Grinder 9	29-Nov-89	OM-8339	420	0.2	< 36	< 21	< 57
		Average*		0.7	52	26	
	Std	deviation		0.5	20	18	
Grinder area	28-Nov-89	OM-8284	494	0.4	< 162	< 18	< 180
Grinder area	28-Nov-89	OM-8279	464	0.3	< 172	< 19	< 191
Grinder area	29-Nov-89	OM-8337	511	0.5	< 29	< 17	< 47
Grinder area	29-Nov-89	OM-8332	469	0.2	43	< 19	43 - 61
Grinder area	30-Nov-89	OM-8336	523	0.4	< 153	< 17	< 170
Grinder area	30-Nov-89	OM-8290	519	0.5	< 154	< 17	< 171
		Average*		0.4	119	18	
	Std	deviation		0.1	59	1	
Mold area	28-Nov-89	OM-8270	518	0.4	< 29	< 17	< 46
Mold area	29-Nov-89	OM-8309	511	0.1	< 29	< 17	< 47
Mold area	30-Nov-89	OM-8299	509	0.2	< 29	< 17	< 47
		Average*		0.2			
	Std	deviation		0.1			
Mold Assembly	30-Nov-89	OM-8312	401	0.3	< 37	< 22	< 59

* Averages calculated using the limit of detection
Values in excess of NIOSH REL: (shaded)

Table 2 (continued)

JOB TITLE	DATE (da,mo,yr)	FILTER NO.	TIME (min)	RESP. MASS (mg/m3)	QUARTZ (ug/m3)	CRISTO-BALITE (ug/m3)	TOTAL SILICA (ug/m3)
Molder 1	28-Nov-89	OM-8281	448	0.3	112	< 20	112 - 131
Molder 1	29-Nov-89	OM-8310	412	0.1	< 36	< 21	< 58
Molder 2	28-Nov-89	OM-8276	454	0.5	286	< 19	286 - 306
Molder 2	30-Nov-89	OM-8308	395	0.2	< 38	< 22	< 60
Molder 3	29-Nov-89	OM-8302	409	0.2	< 37	< 22	< 58
		Average*		0.3	102		
	Std	deviation		0.2	97		
Rotoblast	28-Nov-89	OM-8288	394	0.4	254	< 22	254 - 276
Rotoblast	29-Nov-89	OM-8330	376	0.2	53	< 23	53 - 77
Rotoblast	30-Nov-89	OM-8293	341	0.3	< 44	< 26	< 70
		Average*		0.3	117	24	
	Std	deviation		0.1	97	1	
Shake forklift	28-Nov-89	OM-8289	357	0.3	82	< 25	82 - 107
Shake forklift	29-Nov-89	OM-8275	388	0.3	77	< 23	77 - 100
Shake forklift	30-Nov-89	OM-8303	432	0.4	116	< 20	116 - 136
		Average*		0.3	92		
	Std	deviation		0.0	17		
Shakeout	28-Nov-89	OM-8269	348	0.5	230	< 25	230 - 255
Shakeout	29-Nov-89	OM-8272	373	0.4	134	< 24	134 - 158
Shakeout	30-Nov-89	OM-8305	402	0.4	75	< 22	75 - 97
		Average*		0.4	146		
	Std	deviation		0.1	64		
Shakeout area	28-Nov-89	OM-8280	486	0.4	206	< 18	206 - 224
Shakeout area	29-Nov-89	OM-8327	527	0.2	57	< 17	57 - 74
Shakeout area	30-Nov-89	OM-8323	534	0.3	< 150	< 17	< 166
		Average*		0.3	138		
	Std	deviation		0.1	61		

* Averages calculated using the limit of detection
Values in excess of NIOSH REL: (shaded)

Table 2 (continued)

JOB TITLE	DATE (da,mo,yr)	FILTER NO.	TIME (min)	RESP. MASS (mg/m3)	QUARTZ (ug/m3)	CRISTO-BALITE (ug/m3)	TOTAL SILICA (ug/m3)
Core Finisher#	28-Nov-89	OM-8277	390	0.2	< 205	< 23	< 228
Core Finisher#	29-Nov-89	OM-8266	405	0.1	< 37	< 22	< 59
Core Finisher#	30-Nov-89	OM-8322	409	0.2	< 196	< 22	< 217
		Average*		0.2			
	Std	deviation		0.0			
Grinder 11#	28-Nov-89	OM-8283	409	0.1	< 196	< 22	< 217
Grinder 11#	30-Nov-89	OM-8317	407	0.1	< 197	< 22	< 218
Grinder 12#	29-Nov-89	OM-8265	343	0.3	< 44	< 26	< 69
		Average*		0.2			
	Std	deviation		0.1			
Mold Assembler#	28-Nov-89	OM-8278	388	0.2	< 206	< 23	< 229
Mold Assembler#	29-Nov-89	OM-8267	303	0.3	< 50	< 29	< 79
Mold Assembler#	30-Nov-89	OM-8321	410	0.4	< 195	< 22	< 217
		Average*		0.3			
	Std	deviation		0.1			
Molder 4#	28-Nov-89	OM-8271	369	0.4	< 217	< 24	< 241
Molder 4#	29-Nov-89	OM-8268	356	0.5	< 42	< 25	< 67
Molder 4#	30-Nov-89	OM-8291	397	0.2	< 202	< 22	< 224
		Average*		0.4			
	Std	deviation		0.1			

* Averages calculated using the limit of detection
Values in excess of NIOSH REL:
Ceramic foundry

Table 3. Worker exposure to metals (chromium, nickel, and lead).

JOB TITLE	DATE (da,mo,yr)	FILTER NO.	TIME (min)	Cr CONC. (ug/m3)	Ni CONC. (ug/m3)	Pb CONC. (ug/m3)
Welder	28-Nov-89	102	404	21	7	<3
Welder	28-Nov-89	106	390	7	9	<3
Welder	29-Nov-89	110	399	18	6	<3
Welder	29-Nov-89	130	349	28	17	<3
Welder	30-Nov-89	114	428	804	72	<3
Welder	30-Nov-89	99	419	156	60	<3
		Average		172	29	
		Std deviation		287	27	
Torch Cutting	28-Nov-89	135	389	681	604	3
Torch Cutting	29-Nov-89	98	415	205	723	31
Torch Cutting	30-Nov-89	132	416	2524	1010	4
		Average		1137	779	13
		Std deviation		100	170	13
Torch Cut Brass	28-Nov-89	103	384	35	40	<3
Torch Cut Brass	29-Nov-89	133	417	35	41	115
Torch Cut Brass	30-Nov-89	107	420	27	39	298
		Average		32	40	138
		Std deviation		4	1	123
Power Cutting	28-Nov-89	119	230	4	<2	<4
Furnace (Ceramic)	28-Nov-89	109	150	23	7	<7
Furnace (Ceramic)	30-Nov-89	125	191	14	<2	<4
		Average		19		
		Std deviation		5		
Furnace operator	28-Nov-89	113	264	4	3	<3
Furnace operator	28-Nov-89	112	249	2	2	<3
Furnace operator	29-Nov-89	128	426	2	1	<3
Furnace operator	29-Nov-89	124	474	5	3	2
Furnace operator	30-Nov-89	115	479	7	4	<3
Furnace operator	30-Nov-89	134	465	4	2	<3
		Average		4	3	
		Std deviation		2	1	

Values in excess of NIOSH REL: (shaded)

Table 4. Worker exposure to polynuclear aromatic hydrocarbons (PNAs).

BREATHING ZONE/AREA:	BZ	BZ	AREA	BZ	BZ	AREA	BZ	BZ	AREA
JOB TITLE:	Pour	Pour	Crane	Pour	Pour	Crane	Pour	Pour	Crane
DATE:	28-Nov	28-Nov	28-Nov	29-Nov	29-Nov	29-Nov	30-Nov	30-Nov	30-Nov
COMPOUND									
Naphthalene (ug/m3)	58.0	116.6	82.0	57.2	67.3	53.0	57.5	49.9	62.7
Acenaphthylene (ug/m3)	0.7	<0.6	1.3	0.9	<0.6	0.7	<0.6	1.2	0.9
Acenaphthene (ug/m3)	1.8	<0.6	0.7	0.7	0.6	<0.6	<0.6	3.1	0.6
Fluorene (ug/m3)	<0.6	1.7	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Phenanthrene (ug/m3)	0.8	0.9	1.2	<0.6	<0.6	<0.6	<0.6	<0.6	0.9
all below are less than the limit of detection									
Anthracene (ug/m3)	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Fluoranthene (ug/m3)	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Pyrene (ug/m3)	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Benzo(a)anthracene (ug/m3)	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Chrysene (ug/m3)	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Benzo (b) fluoranthene (ug/m3)	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Benzo (k) fluoranthene (ug/m3)	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Benzo (e) pyrene (ug/m3)	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Benzo (a) pyrene (ug/m3)	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Indeno (1,2,3-cd) pyrene (ug/m3)	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Dibenz (a,h) anthracene (ug/m3)	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Benzo (ghi) perylene (ug/m3)	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6

Table 5. Worker exposure to carbon monoxide.

Worker/Location	Date	Carbon Monoxide Concentration (ppm) TWA	Peak (1 min)
Ladle/pourer	11/28/89	4	88
Molder/pourer	11/28/89	7	35
Crane cab	11/28/89	9	77
Clean up/pourer	11/29/89	8	202*
Molder/pourer	11/29/89	2	45
Crane cab	11/29/89	5	73
Furnace area	11/30/89	6	21
Molder/pourer	11/30/89	3	40
Crane cab	11/30/89	6	83

* Not inside worker's jacket - see text.

in their shirt pocket. On that worker, the dosimeter was affixed to his collar. Peak exposures may have been underestimated by the shirt-pocket location, as the workers wore aluminized jackets during pouring. This probably did not affect the TWA measurements, as the jackets were only worn for a total of 20 minutes, and the TWA measurements were similar. Real-time plots of the carbon monoxide exposures are presented in Figure 2. Inspection of these plots reveals that the peak carbon monoxide exposures correspond to mold pouring.

Eight detector tube samples for formaldehyde and eight detector tube samples for hydrogen cyanide were collected at breathing zone level in the pouring area, before, during, and 30 minutes after the pouring of molds on the first day of the study. All results were below the minimum indicated by the tubes, 0.2 ppm formaldehyde and 2.0 ppm hydrogen cyanide. A single reading of 0.2 ppm formaldehyde, not representative of a likely exposure, was obtained by a ninth set of samples near the surface of a mold that had been cooling for about 40 minutes. No hydrogen cyanide was indicated on the companion tube. It must be noted that these are grab samples used to identify areas or operations causing potential exposure; they may not reflect actual exposures measured by long-term sampling techniques.

Although all measurements of decomposition products were below established limits, it would be relatively easy to lower exposures still further. This could be accomplished by installing a large mold conveyor system to move molds into the cooling room as soon as they are poured. A system to handle small molds is already in place and needs to be better utilized. In addition, the crane operator could be removed from exposure by adapting the crane to radio control. This would also improve physical safety during mold pouring, as the operator would have a better field of vision.

TORCH AND ARC-AIR CUTTING

Personal air samples for metals (chromium, nickel, and lead) were collected for 3 days on the torch cutter. Sample results are reported in Table 3. All of these samples exceeded the NIOSH RELs for chromium (chromic acid anhydride) and nickel; none exceeded the REL or the OSHA PEL for lead. All of the samples exceeded the OSHA PEL for chromic acid anhydride. One exceeded the OSHA PEL for nickel.

CLEANING OF LEADED BRONZE CASTINGS

Personal air samples for metals (chromium, nickel, and lead) were collected for 3 days on the worker cleaning leaded bronze castings using a torch and an assortment of grinding tools. Sample results are reported in Table 3. All of these samples exceeded the NIOSH RELs for chromium (chromic acid anhydride) and nickel; two of the three exceeded the REL and the OSHA PEL for lead. All of the samples exceeded the OSHA PEL for chromic acid anhydride.

SHAKEOUT AND ABRASIVE BLASTING

Twelve samples for crystalline silica and respirable dust were collected to estimate the exposure to workers performing shakeout and abrasive blasting operations. Personal samples were collected on the shakeout area fork lift

CARBON MONOXIDE

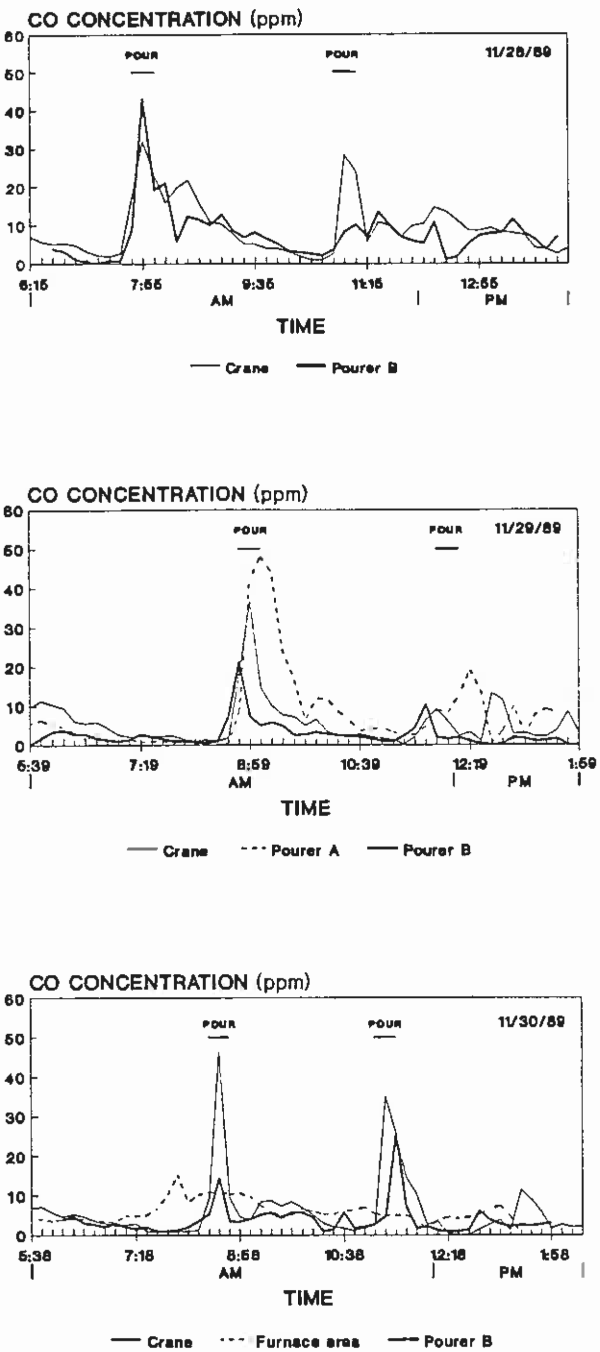


Figure 2. Real-time carbon monoxide exposures in metal melting and pouring.

operator, the shakeout (sand reclaim) operator, and the Rotoblast machine operator; an area sample was also collected in the general vicinity of the sand reclaim operation on each of 3 days of the survey. Of the nine personal samples, all but one exceeded the REL for quartz; four samples exceeded the PEL. Table 2 summarizes the results of the crystalline silica and respirable dust measurements.

CUTOFF SAW AND SURFACE GRINDING

Three samples for crystalline silica and respirable dust were collected to estimate the exposure to the worker using the cutoff saw and performing surface grinding operations. Of these three personal samples, all exceeded the REL for quartz; one exceeded the PEL for quartz. Table 2 summarizes the results of the crystalline silica and respirable dust measurements.

CHIPPING AND GRINDING OPERATIONS

Twenty-one samples for crystalline silica and respirable dust were collected to estimate the exposure to workers performing chipping and grinding operations. Personal samples were collected on the individuals assigned chipping and grinding using hand-held tools, and area samples were collected at both ends of the casting cleaning room. Of the 15 personal samples, four exceeded the REL for quartz; none exceeded the PEL for quartz. One sample exceeded both the REL and PEL for cristobalite by a factor of 2; all of the remaining air samples collected contained no detectable respirable quartz or cristobalite, corresponding to airborne concentrations of approximately <40 $\mu g/m^3$ and <20 $\mu g/m^3$, respectively. Respirable dust measurements indicated that the casting cleaning area was the dustiest area of the plant. Table 2 summarizes the results of the crystalline silica and respirable dust measurements.

Because the greatest number of workers are potentially overexposed to silica in the chipping and grinding operations, this area of the foundry received special attention. Real-time dust exposure measurements using the HAM and video recordings were made on two workers performing chipping and grinding operations, to determine the relative exposure caused by different tools and operations. Two workers volunteered to participate in this portion of the study. Each worker selected a casting that required use of a variety of tools. One selected a pump housing; the other selected an impeller. Each worker used a 6-inch horizontal radial wheel grinder (6,000 rpm), a 4-inch cutoff wheel (15,000 rpm), and a 3/8-inch diameter burr mounted on a 16-inch extension (18,000 rpm). The worker cleaning the impeller also used a cone wheel mounted to the same type of tool as the 4-inch cutoff wheel. Each tool was pneumatically operated with the tool exhausted unmuffled. Dust exposures and video recordings were made for a nominal 30 minutes on each worker. Dust exposures were recorded electronically using a data logger.

Dust exposure data were overlayed as a moving bar onto the video record and viewed to estimate activities that may affect exposure. This review indicated that the type of tool used, the direction of the grinding swarf (the stream of glowing metal particles), and the position of tool (inside or outside of the casting) caused noticeable exposure differences. To determine the extent to which these variables affected exposure, the real-time data were assembled into a commercial spreadsheet consisting of time, exposure, and activity for each 5-second time period. The exposure measurements were "slipped" 5 seconds with respect to the time and activities to allow for instrument delay. The average exposure, the time, and the "dust-dose" (the product of concentration and time) were calculated for each of the activity variables.

Summary data are presented in Table 6. The average dust concentration for each tool type and the percent of the time each tool was used are presented in Figure 3. During cleaning of the pump housing, dust concentrations were highest for the 6-inch grinder and the 4-inch cutoff wheel. For the case of the impeller, dust concentrations were highest for the 6-inch grinder and the cone grinder. Tool usage times were similar, except that the cone grinder was not used on the pump housing. The "dust-dose" is described graphically in Figure 4 as a function of tool type, tool location, and swarf direction. The "dust-dose" is almost an order of magnitude greater for the pump housing than for the impeller. The 4-inch cutoff wheel was the greatest contributor (57 percent) to "dust-dose" for the worker cleaning the pump housing, while the 6-inch grinder was the greatest contributor (54 percent) to the "dust-dose" for the worker cleaning the impeller. Cleaning inside of the casting appeared to have a beneficial effect on "dust-dose" for the case of the impeller: although the worker spends about five times as long cleaning the inside of the casting as the outside, inside cleaning only results in about 39 percent of the total "dust-dose" for this worker. This beneficial effect may be caused by the impeller diffusing the grinding swarf. Swarf direction appears to be a major exposure factor: for the pump housing, concentrations ranged from highest to lowest in the order of "toward," "up," "away," "down," and "undetermined." For the impeller, no or short periods were observed where the swarf was directed "toward," "up," or "away." A statistical analysis of the real-time data is included in Appendix B.

CASTING REPAIR

Personal air samples for metals (chromium, nickel, and lead) were collected for 3 days on each of two welders. Sample results are reported in Table 3. Of these six samples, three exceeded the NIOSH REL for chromium (chromic acid anhydride) and nickel; none exceeded the REL or the OSHA PEL for lead. Two of the six samples for chromium exceed the OSHA PEL.

CERAMIC FOUNDRY OPERATIONS

Personal air samples for metals (chromium, nickel, and lead) were collected for 2 days on the furnace operator and for 1 day on the power (water-jet) cutter operator. Sample results are reported in Table 3. None of these samples exceeded the NIOSH REL or OSHA PEL for any of the metals.

Twelve samples for crystalline silica and respirable dust were collected to estimate the exposure to workers performing molding, mold assembly, core finishing, and casting grinding operations in the ceramic foundry. Of the 12 personal samples, all contained no detectable respirable quartz or cristobalite, corresponding to airborne concentrations of either $<40\ \mu g/m^3$ or $<110\ \mu g/m^3$ for silica (depending on scan times) and

Table 6. Summary of real-time dust exposure measurements.

CASTING: PUMP HOUSING			
TOOL	AVG CONC (mg/m^3)	TIME (sec)	DOSE (mg/m^3-min)
6 inch grinder	5.1	375	32
4 inch wheel	7.1	470	55
burr grinder	0.9	165	2
cone grinder	-	-	-
other activities	0.9	470	7
TOOL LOCATION			
inside casting	5.7	505	48
outside casting	4.9	505	41
other activities	0.9	470	7
SWARF DIRECTION			
up	8.6	340	49
down	1.4	175	4
away	4.9	230	19
toward	9.4	100	16
undetermined	0.9	635	10

CASTING: IMPELLER			
TOOL	AVG CONC (mg/m^3)	TIME (sec)	DOSE (mg/m^3-min)
6 inch grinder	1.5	270	7
4 inch wheel	0.1	270	1
burr grinder	0.2	375	1
cone grinder	0.5	395	3
other activities	0.2	215	1
TOOL LOCATION			
inside casting	0.3	1040	5
outside casting	1.5	270	7
other activities	0.2	215	1
SWARF DIRECTION			
up	0.2	20	0
down	0.9	240	3
away	0.0	0	0
toward	6.7	30	3
undetermined	0.3	1235	6

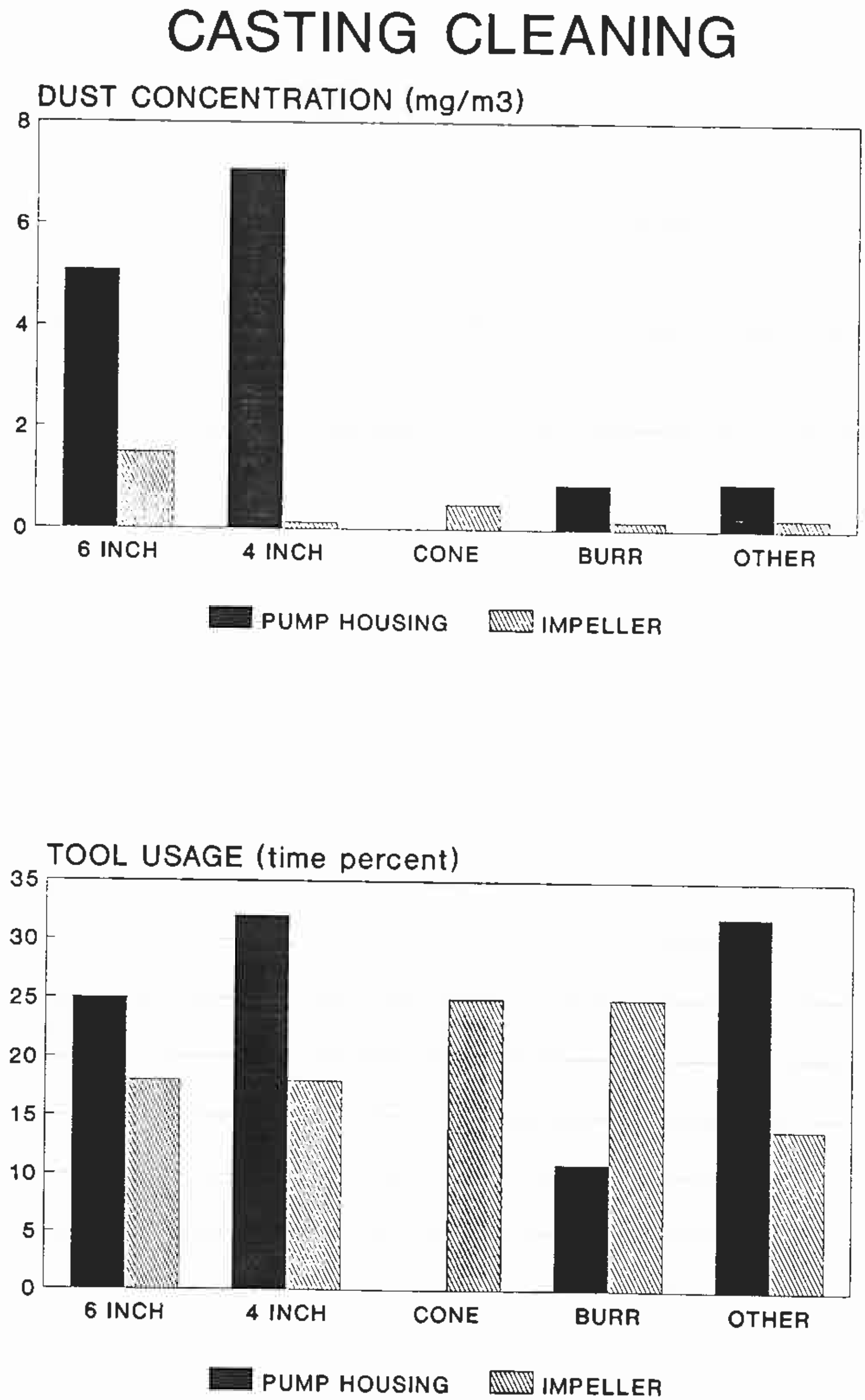


Figure 3. Average dust exposure and tool usage during the cleaning of the pump housing and impeller castings.

DUST EXPOSURE - GRINDING

PUMP HOUSING (97 mg/m3 - min) IMPELLER (12 mg/m3 - min)

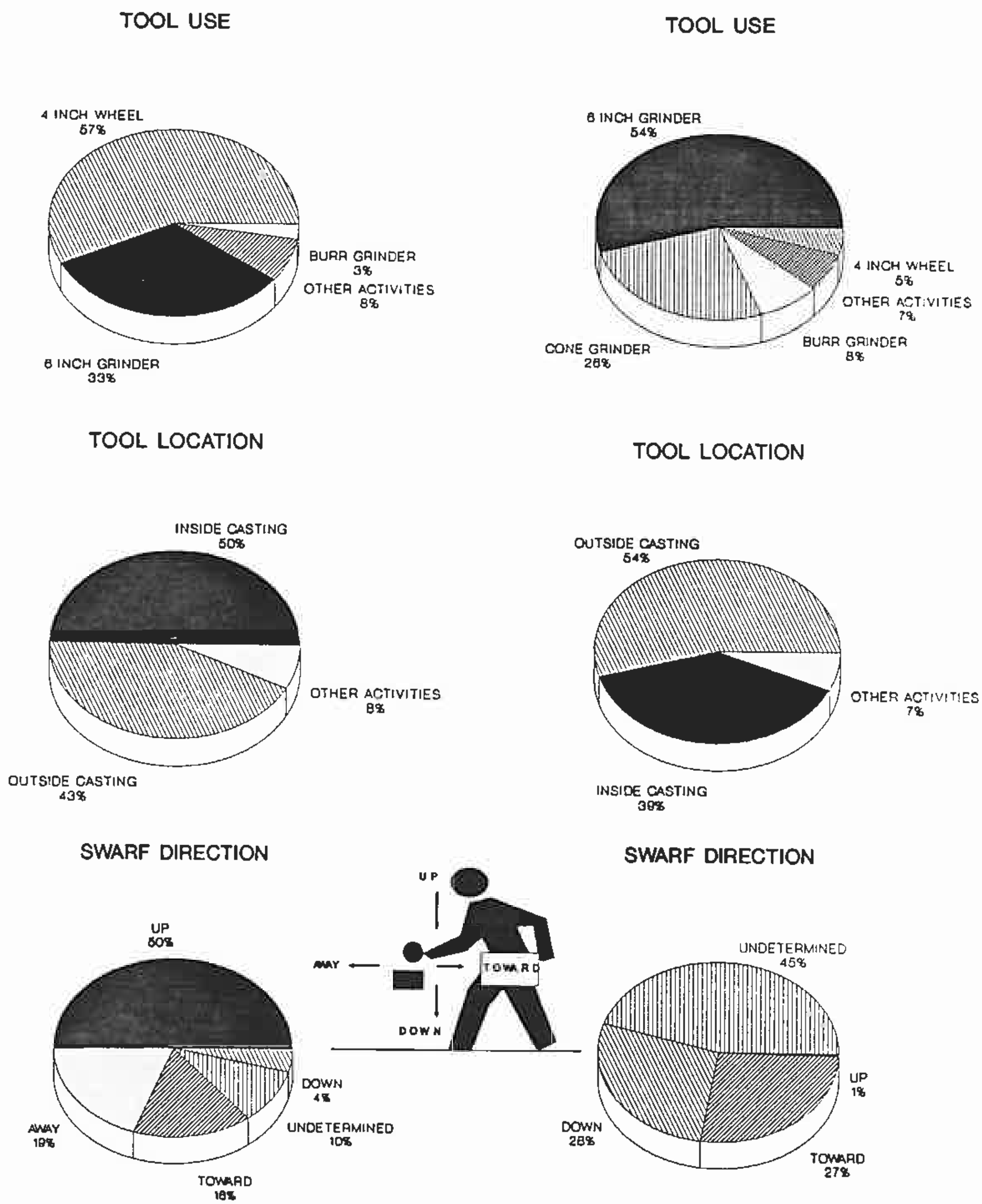


Figure 4. Analysis of dust exposure during the cleaning of the pump housing and impeller castings.

<20 $\mu g/m^3$ for cristobalite. Table 2 summarizes the results of the crystalline silica and respirable dust measurements.

RECIRCULATION OF EXHAUST AIR

Both weld repair and grinding operations are performed on downdraft benches which recirculate air back into the work environment. The booths consist of a metal grating on which the casting is placed and an L-shaped plenum chamber. The lower part of this plenum supports the grating and serves as a drop-out chamber for cleaning debris. The upper section contains primary and secondary sets of filters (efficiency rating unknown), followed by a propeller fan. Particle size distribution measurements were made at the inlet and outlet of two grinding booths (numbers 13 and 17) using the room ambient dust as the challenge aerosol. Booth number 13 was in use at the time of the test and visual inspection of the filters indicated that they were intact. Booth number 17 had secondary filters missing, and was switched on about 5 minutes before the test. Results of the particle size distribution measurements are reported in Figure 5.

Overall particle penetration of the filters in booth number 13 was 56 percent for particles greater in size than about 0.5 μm (size basis - optical equivalent to the Royco calibration aerosol). For booth number 17, the overall particle penetration was 113 percent. This increase in the number of particles may be due to errors in measurement, since simultaneous inlet and outlet measurements were not possible. It may also be due to the release of dust that had settled into the outlet of the booth, since the booth had been operating for only 5 minutes prior to the test.

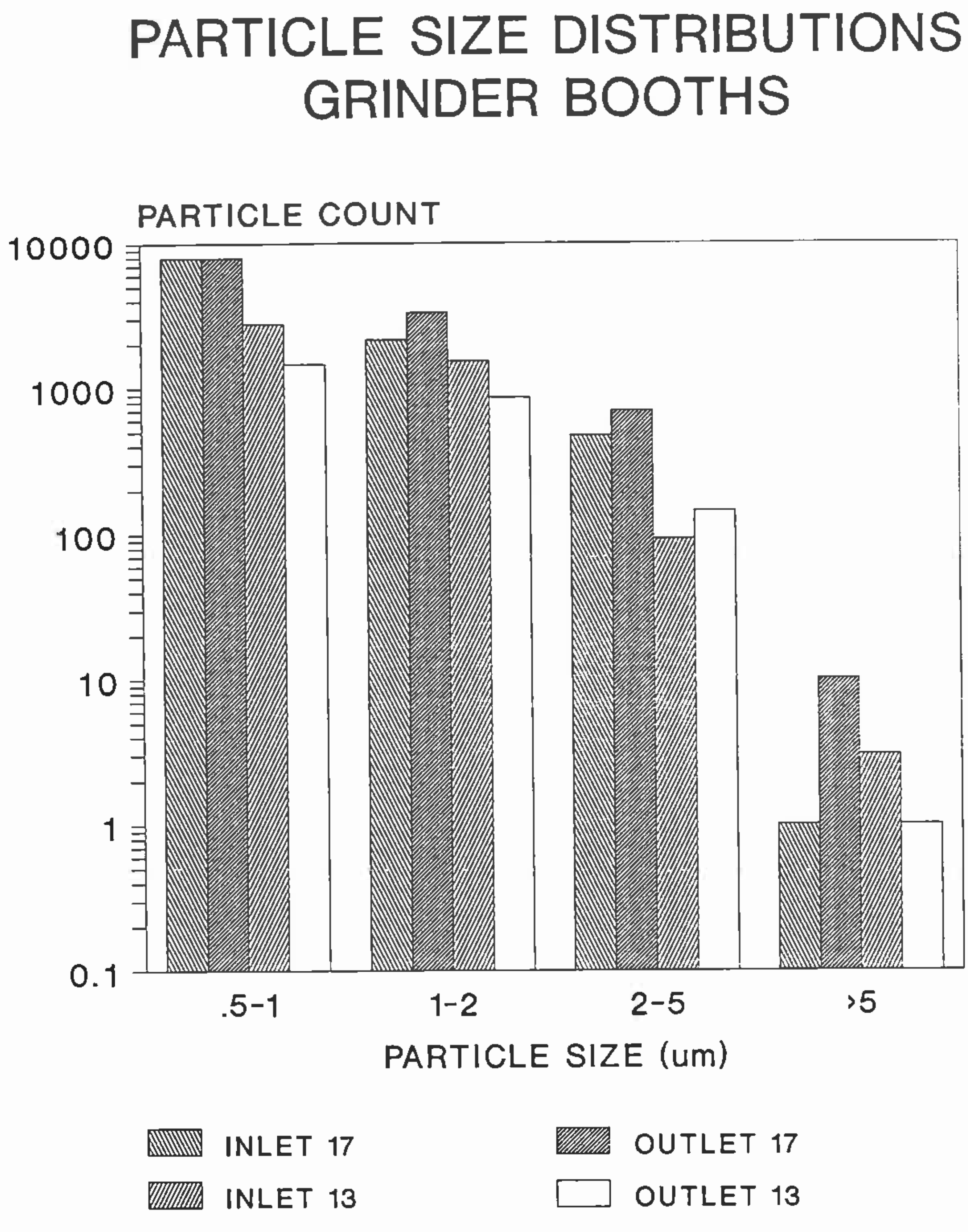
These measurements indicate that improperly maintained booths offer no protection, and that evenly properly maintained booths remove less than half of the fine dust that penetrates deep into the lung. The conclusion must be reached that the exhaust air from these booths must be removed from the work environment.

VENTILATION MEASUREMENTS

Booth face velocities were measured using a hot wire anemometer for the torch, arc-air, and leaded bronze booths, the cutoff saw booth, and the downdraft benches used for grinding and weld repair. Measurements are reported in Table 7. Air volumes were calculated from the product of the face (bench) area and the average air velocity. Flow rates for the benches were generally above those recommended in the ACGIH publication Industrial Ventilation.[19] Several booths were noted to be not operable. Flow rates for the torch, arc-air, and surface (cup) grinder booths were below recommended values.

BULK MATERIAL ANALYSES - FIBERS

Bulk samples of the ceramic blanket and refractory debris (from the sawing of ceramic fiber sleeves) were obtained for subsequent analysis for fiber size and the presence of asbestos. The refractory dust was first ashed to remove any organic fibers. Both samples were ultrasonicated in isopropyl alcohol and deposited onto 25 mm cellulose ester filters. A section of each filter was



13 - INTACT FILTERS
14 - MISSING FILTERS

Figure 5. Particle size distributions for the inlet and outlet of two downdraft grinding benches recirculating exhaust air.

Table 7. Ventilation measurements.

Equipment	Existing flow rate (cfm/sqft)	Recommended minimum flow (cfm/sqft)	Reference[19]
Weld repair -			
welding bench #1	300		NR
welding bench #2	256		NR
welding bench #3	421		NR
welding bench #4	426		NR
welding bench #5	180		NR
welding bench #6	197		NR
welding bench #7	577		NR
Refractory cutoff saw	not in use	250	VS-401
Hand grinders -			
downdraft grinding bench #1	212	150-250	VS-412
downdraft grinding bench #2	301	150-250	"
downdraft grinding bench #3	283	150-250	"
downdraft grinding bench #4	not in use	150-250	"
downdraft grinding bench #5	299	150-250	"
downdraft grinding bench #6	315	150-250	"
downdraft grinding bench #7-15	not in use	150-250	"
downdraft grinding bench #16	154	150-250	"
Cutoff saw booth	105	100-150	VS-414
Surface (cup) grinder booth	63	100-150	VS-414
Torch booth	173	200	VS-415*
Arc-air booth	147	200	VS-415*
Lead grinding booth	283	200	VS-415*

NR - no recommendation

* No specific recommendation exists in Industrial Ventilation[19]; operation is judged by the authors to be similar to metal spraying, therefore, VS-415 is referenced.

prepared for transmission electron microscopy using NIOSH Method 7402. No asbestos was detected. X-ray spectra indicated that the fibers were composed of aluminum silicate. Fiber size distributions are shown in Figure 6. Only one end of the fiber was visible in the field of view for approximately 60 percent of the fibers from the ceramic blanket and 30 percent of the fibers from the refractory debris. Therefore, the fiber length indicated in Figure 6 is biased toward shorter fibers. Superimposed on this figure is an indication of the relative tumorgenicity of these fibers in animals.[20] For both materials, the majority of fibers are of a size that caused cancer in experimental animals. Thus, substitutes of larger fiber diameter and ventilation of the refractory saw should be seriously considered.

BULK MATERIAL ANALYSES - QUARTZ

As noted earlier, interfering compounds were present in the personal samples for silica. To attempt to resolve these difficulties, the company industrial hygienist provided (after the survey) bulk "rafter" samples from the molding, shakeout, and casting cleaning areas. The bulk samples were submitted for a Talvitie[21] preparation prior to analysis by X-ray diffraction, in an attempt to remove the interfering compounds. (This preparation also removes any cristobalite present in the samples.) Unfortunately, the interfering compounds were not removed and the samples were analyzed using the secondary quartz peak. The sample from the molding area contained 9.4 percent quartz; the sample from the molding area contained 7.9 percent quartz; no quartz was detected in the sample from the cleaning area (limit of detection 2.5 percent). Estimates of airborne quartz, determined by applying these percentages to the airborne respirable mass, grossly underestimated actual respirable quartz measurements.

FIBER SIZE DISTRIBUTION
CERAMIC BLANKET

FIBER LENGTH (um)

DIAMETER (um)	›0.2 - 1	›1 - 4	›4 - 8	›8 - 64	›64
‹0.1	0	1	0	2	0
›0.1 - 0.25	0	1	4	2	0
›0.25 - 0.5	0	1	0	5	0
›0.5 - 1.5	0	0	1	15	7
›1.5 - 2.5	0	0	0	8	1

LOW TUMOR RATE IN ANIMALS *
MODERATE TUMOR RATE IN ANIMALS
HIGH TUMOR RATE IN ANIMALS

* (from Stanton)

FIBER SIZE DISTRIBUTION
REFRACTORY DUST

FIBER LENGTH (um)

DIAMETER (um)	›0.2 - 1	›1 - 4	›4 - 8	›8 - 64	›64
‹0.1	0	3	6	1	0
›0.1 - 0.25	0	4	6	0	0
›0.25 - 0.5	0	3	6	12	0
›0.5 - 1.5	0	0	1	11	0
›1.5 - 2.5	0	0	0	3	0

LOW TUMOR RATE IN ANIMALS *
MODERATE TUMOR RATE IN ANIMALS
HIGH TUMOR RATE IN ANIMALS

* (from Stanton)

Figure 6. Fiber size distributions obtained from the analysis of bulk samples of the ceramic blanket and the refractory dust. See the note in the text regarding bias of the analyses towards shorter fibers.

RECOMMENDATIONS AND CONCLUSIONS

GENERAL CONCLUSIONS

1. Overexposure to crystalline silica does not appear consistently throughout the plant. Present methods of shakeout and sand reclamation are responsible for the overexposure to quartz of the shakeout operator. In the cleaning of castings, silica exposure appears to be first a function of the degree of sand burn-in (and subsequent conversion to cristobalite) of the individual casting and, second, a function of the tools required to clean it. Further investigation on the part of the plant is required to identify the cause of the gross overexposure of one worker to quartz in the molding operation. This exposure may have originated from the molding sand mixer, the injudicious use of compressed air for cleaning, or the use of a poorly ventilated saw to cut refractory materials.

2. Hazardous exposures in this plant are not limited to silica, but include the metals lead, chromium, and nickel for the torch operators and welders, and potentially mineral fibers for the molders and all others in the plant (as a result of contamination of the sand).

RECOMMENDATIONS WARRANTING IMMEDIATE ATTENTION WITH RELATIVELY LOW COST

1. A list of resource materials, and where they may be obtained, is presented in Appendix C. In order to develop the in-house expertise needed to implement a good health and safety program, it is strongly recommended that <u>all</u> of these materials be purchased and read. While the availability of a corporate industrial hygienist is a valuable resource, it is important that responsibility for health and safety be assigned to one individual within the <u>foundry</u> management.

2. Substitution of olivine sand has been shown to reduce the incidence of silicosis.[22] Silica sand is used in this foundry as their molding aggregate and in sand blasting. Olivine could be substituted with little or no change in operations, as it is compatible with the alkyd-oil binder system currently used. It would involve increased cost of molding aggregate when compared to silica sand, but may reduce dust control costs.

3. Aluminum silicate fibers from both the ceramic blanket and refractory sleeves are of a size that cause cancer in experimental animals. Exposure to these materials can occur to the molders when they are cut during the assembly of molds, and later to all in the foundry when the fibers contaminate the sand when it is reclaimed. Thus, substitutes of larger fiber diameter and ventilation of the refractory saw (used to cut the ceramic sleeves) should be seriously considered.

4. As noted earlier, the hand grinding operators are potentially exposed to excessive levels of silica, particularly the more biologically active form, cristobalite. To minimize this hazard, the castings should be as clean as possible before grinding. The use of various mold surface coatings should be investigated to reduce the amount of sand that is burned into the surface of the casting.

5. Magnesium chromate is a constituent of the hot topping compound used in the ceramic foundry. Since the pouring is performed in a relatively small building without the benefit of any local exhaust ventilation, and because of its potential carcinogenicity, prudence would indicate that a substitute be sought and used.

6. Torch, arc-air operators, and welders should be furnished with supplied-air respirators, due to the toxicity of the metals with which they work and the high exposures measured.

7. The exhaust from the compressed air-operated tools should be ducted away from the tool via a hose to avoid blowing dust from the casting. Mufflers should be installed at the end of this hose for noise reduction. Although noise was not addressed in this study, the metal grates of the grinding benches can amplify the noise from grinding. Replacing the metal grates with a wooden lattice can reduce noise levels at a relatively low cost.

8. Several booths were noted to be not operable. Flow rates for the torch, arc-air, and surface (cup) grinder booths were below recommended values. In addition, operations on some booths were taking place in front of rather than within the booth, due to the difficulty in moving heavy castings. Figure 7 illustrates a movable platform to facilitate casting handling in booths.

9. Ventilation rates on all equipment should be periodically measured and be upgraded where necessary to those recommended in Industrial Ventilation. A standard pitot tube and inclined tube manometer should be obtained for measuring volumetric flow rates. An inexpensive swinging vane anemometer is also suggested for purchase to measure air velocities into hoods. A log of these measurements should be maintained.

10. The refractory cutoff saw used in the molding department was not adequately exhausted. In addition, the saw was not being used with water as it had been originally designed. Detailed ventilation recommendations for this operation are contained in the ACGIH publication Industrial Ventilation, VS-401.

RECOMMENDATIONS WARRANTING IMMEDIATE ATTENTION WITH GREATER COST INVOLVED

1. The plant uses downdraft tables to control dust from hand grinding and metal fumes from welding. These benches recirculate filtered air back into the foundry. Detailed recommendations for air recirculation and downdraft bench airflow requirements are contained in the ACGIH publication Industrial Ventilation. Measurements indicate that the improperly maintained booths offer no protection, and that evenly properly

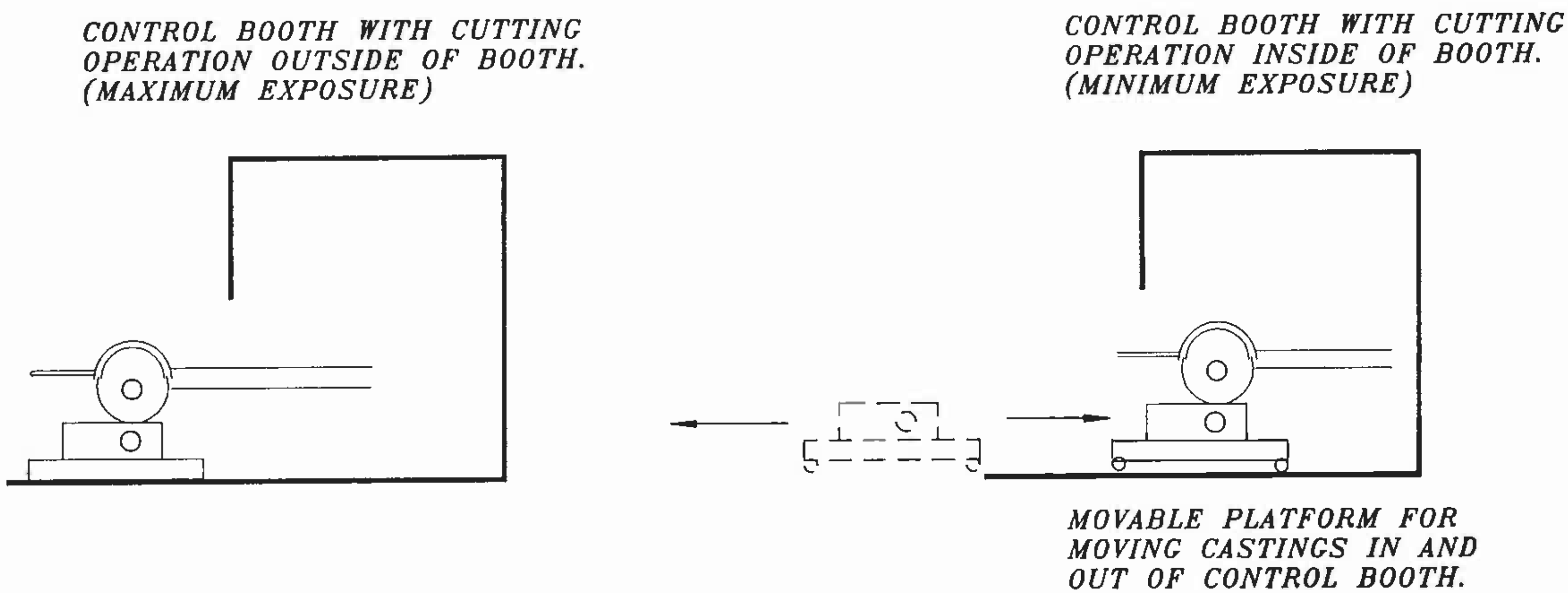


Figure 7. A movable platform to facilitate casting movement into enclosures.

maintained booths remove less than half of the fine dust that penetrates deep into the lung. The conclusion must be reached that the exhaust air from these booths must be removed from the work environment. One option would be to remove the filters and fans and then connect the benches into a duct system discharging out-of-doors through a single, larger dust collection unit. The removal of the individual fans should result in a significant noise reduction.

2. The cleaning of the large castings presents difficult problems. The size of the casting precludes work at a distance near enough to the grates of the downdraft booths for efficient capture. A review of the grinding operations indicated that the type of tool used, the direction of the grinding swarf (the stream of glowing metal particles), and the position of tool (inside or outside of the casting) caused noticeable exposure differences. The 6-inch grinder and the 4-inch cutoff wheel are the tools which contribute most heavily to dust exposure. Fortunately, these are also the tools that may most easily be controlled through the use of high-velocity, low-volume exhaust hoods. Detailed recommendations are contained in the ACGIH publication Industrial Ventilation, VS-801 through VS-807 and in reference 23. Since Ingersoll-Rand is a producer of these tools, the foundry should work closely with the power tool division to develop tools with integral dust control.

RECOMMENDATIONS INVOLVING LARGER EXPENSE

1. The foundry was originally designed to produce small- and medium-size castings. The bulk of the current production is large castings, which does not permit use of the semiautomatic mold handling system already in place. This system should be modified/replaced so that all molds could be isolated once they are poured. In addition to increased exposure to decomposition products from the open floor cooling of large molds (inspection of the carbon monoxide exposure plots reveal that the peak carbon monoxide exposures correspond to mold pouring), high silica exposures occur during the front-end loader handling of the molding sands. Substitution of front-end loader sand handling with an automated mold handling system should result in lower exposures.

2. Provisions are made for the introduction of fresh make-up air into the foundry through several make-up air units. Only one of these units was operating. Ideally, all air exhausted from the building should be replaced by tempered air from an uncontaminated location. By providing a slight excess of make-up air in relatively clean areas, and a slight deficit of make-up air in dirty areas (e.g., around abrasive blasting and sand handling areas), cross contamination can be reduced. Unfortunately, the make-up air units discharge directly into the plant, mixing with contaminated plant air before arriving at individual workstations. It is recommended that the tempered air be ducted directly to operator work areas, providing the cleanest possible work environment. For those individuals working at relatively fixed workstations (e.g., grinders), this fresh air could be supplied in the form of a low velocity air shower (<100 fpm to prevent interference with the exhaust hoods), located directly above the worker.

3. The exposure of the crane operators to decomposition products could be reduced in one of two ways: the crane cab(s) could be enclosed and fresh air be introduced into the cab from outside of the plant through a "zipper" duct system running parallel to crane rails; or the crane could be equipped with a remote control (either a pendant or radio unit) and operated from the floor. The latter option may also serve to reduce the likelihood of burns from hot metal, if the plunger of the bottom pour ladles can be rigged to operate by the crane's smaller hook.

4. Consideration should be given to the installation of a central vacuum system. Such a system could be used to eliminate broom and shovel housekeeping, to minimize the use of compressed air for cleanup, and to ventilate casting interiors during internal grinding.

5. Contaminants in the scrap occasionally generate sufficient smoke to degrade visibility. Consideration should be given to equipping all furnaces with hoods like that used on the leaded bronze furnace, or with hoods similar to that shown in Industrial Ventilation, VS-106. If a system of dampers were installed to shut off furnaces not being used (i.e., the arc furnace), no additional dust collection would need to be acquired. These hoods should also be installed in the ceramic mold foundry.

6. A hood similar to that used for barrel filling (Industrial Ventilation, VS-303) could be used for the filling and operation of the mixer used for mold materials in the ceramic mold foundry.

7. If further study indicates that silica dust escapes at the feed point to the ribbon mixers in the molding area, the feed point can be enclosed and exhausted as is depicted in Figure 8.

8. Smoke was observed to be escaping around openings in the back of the arc-air booth. The exhaust take-off did not appear to be in a position to "receive" the high velocity contaminant stream. The operation is judged to be similar to metal spraying, therefore, a hood like that depicted in Industrial Ventilation, VS-415 is recommended for this, the torch, and the lead operations.

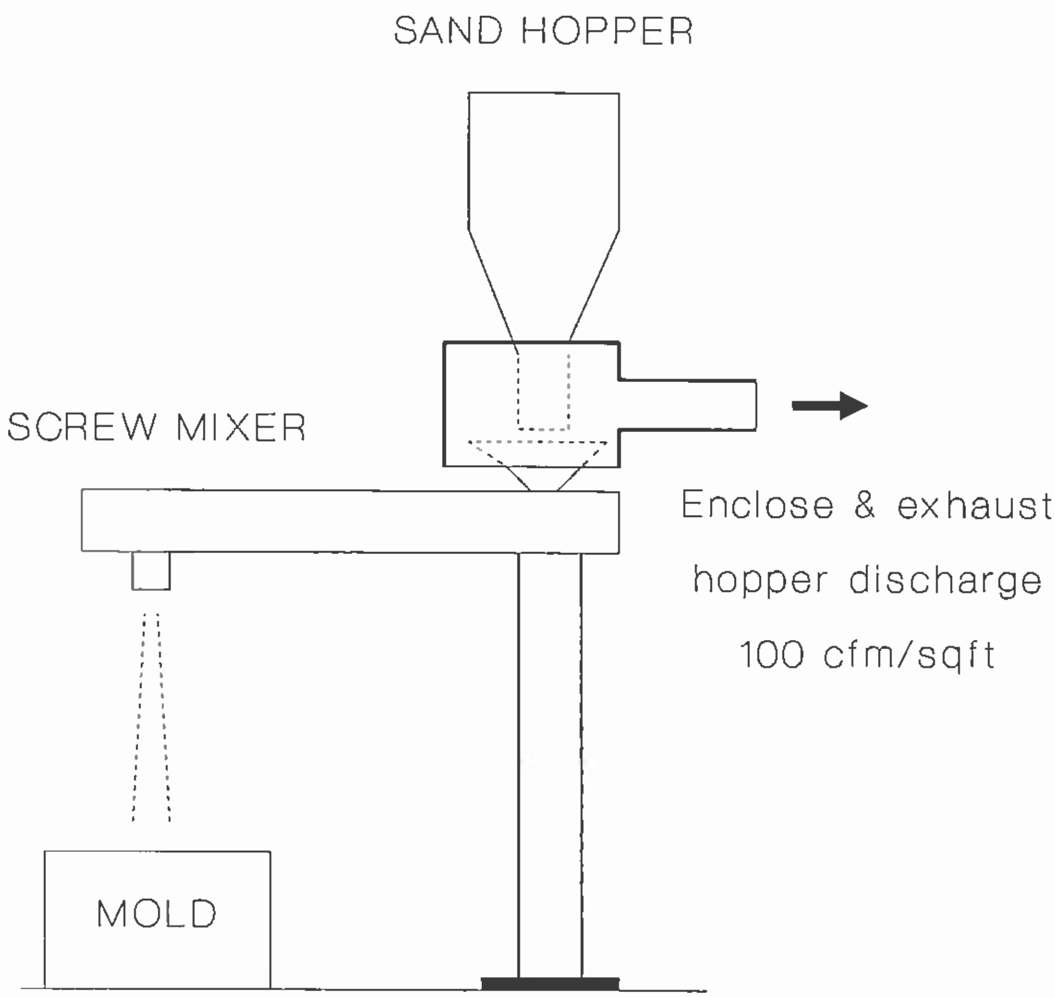


Figure 8. Ventilation of the feed-in point of a molding sand mixer.

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APPENDIX A

COMPARISON OF CARBON MONOXIDE MONITORS

Introduction

Side-by-side area measurements of carbon monoxide were made using one 2000 series Ecolyzer (Energetics Science, Inc., Elmsford, New York) and two Model 190 Data loggers, CO (National Draeger, Pittsburgh, Pennsylvania). Both types of units employ an electrochemical sensor that produces an electrical signal proportional to the amount of carbon monoxide present in the air. The Ecolyzer is an active sampling device, employing a vacuum pump to deliver the sample sensor, while the Model 190 Data loggers are passive devices, relying on diffusion to present the sample to the sensor.

Procedure

All instruments were placed in the metal melting/molding areas of the steel foundry. Side-by-side measurements were conducted for an 8-hour shift. Both instrument types were used with the interference filters supplied by the factory. The Ecolyzer also employed the factory-supplied sample humidifier. The Model 190 data loggers were zeroed and calibrated in the NIOSH Cincinnati laboratory. The Ecolyzer was zeroed and calibrated on-site. The analog voltage output of the Ecolyzer (0 to 1 volt, operated on the 0 to 100 ppm range) was connected to a data logger (Rustrak Ranger, Gulton, Inc., East Greenwich, Rhode Island). When the approximately 8-hour sample collection was completed, the data logger was downloaded to a portable computer (Compaq Portable II, Compaq Computer Corporation, Houston, Texas) for analysis. Stored data values from the Model 190 Data loggers were also downloaded to the computer.

Results

Plots of the 10-minute average measurement from each instrument are presented in Figure A-1. The units seem to agree within the limits claimed by the manufacturer (National Draeger claims an accuracy of ± 2 ppm).

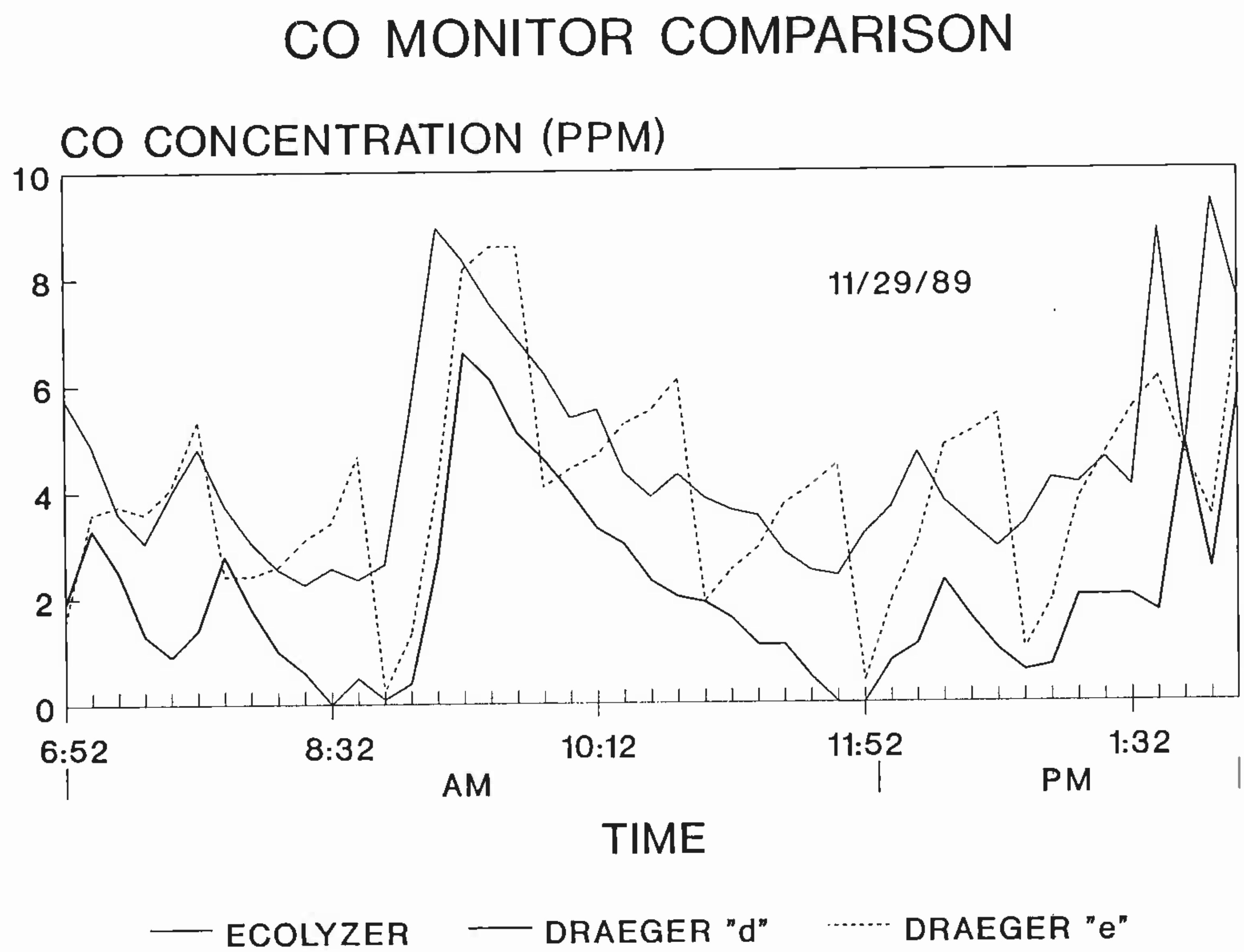
CO MONITOR COMPARISON
CO CONCENTRATION (PPM)
10
8
6
4
2
0
11/29/89
6:52
8:32
10:12
11:52
1:32
AM
PM
TIME
ECOLYZER
DRAEGER "d"
DRAEGER "e"

Figure A-1

APPENDIX B

STATISTICAL ANALYSIS OF REAL-TIME DATA

The preliminary data analysis indicated that the type of tool used, the direction of the grinding swarf (the stream of glowing metal particles), and the position of tool (inside or outside of the casting) caused noticeable exposure differences. Because not all combinations of variables were present, each existing combination was assigned as individual independent variables. The logarithm of the exposure was the dependent variable. The SAS General Linear Models Procedure was used to fit the data. The Ryan-Einot-Gabriel-Welsch (REGW) Multiple Range Test was used determine if significant differences (alpha = 0.05) existed between the log mean exposure means for each independent variable. The analysis is presented in Table B-1. The combinations of tool, grinding location, and swarf direction are listed in order of exposure from highest (top) to lowest (bottom). Those combinations with the same letter for (REGW) are not significantly different.

Table B-1 Ryan-Einot-Gabriel-Welsch (REGW) multiple range test for cleaning the pump housing and impeller. Means with the same letter are not significantly different.

PUMP HOUSING REGW Group	Log Mean	N	Combination
A	2.673	2	SOT
A	2.294	2	GOU
B A	2.080	3	GIU
B A	1.7429	5	SOU
B A	1.682	58	SIU
B A	1.669	17	GOA
B A	1.612	18	GOT
B C	1.130	7	SIA
D C	0.597	22	SOA
D E	-0.119	35	GOD
E	-0.455	33	BIN
E	-0.617	94	NNN
IMPELLER REGW Group	**Log Mean**	**N**	**Combination**
A	1.816	6	GOT
B	-0.643	48	GOD
C	-1.024	75	CIN
D	-1.622	4	CIU
D	-1.847	43	NNN
D	-1.918	75	BIN
E	-2.267	54	SIN

Key to combinations:

1st letter
tool

G - 6-inch grinder
S - 4-inch cutoff saw
C - cone grinder
B - burr grinder
N - other activity

2nd letter
grinding location

I - inside casting
O - outside casting
N - other activity

3rd letter
swarf direction

T - towards worker
A - away from worker
D - down
U - up
N - undetermined or other activity

APPENDIX C

RECOMMENDED PUBLICATIONS

American Conference of Governmental Industrial Hygienists - (513) 661-7881

- Industrial Ventilation, A Manual of Recommended Practice, 20th edition (1988)
- Industrial Ventilation Workbook (1989)
- "Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1988-1989"

American Foundrymen's Society - (800) 537-4237

- Health and Safety Guides (1985)
- Foundry Ventilation Manual (1985)

National Institute for Occupational Safety and Health - (513) 533-8287

- NIOSH Publications Catalog
- An Evaluation of Occupational Health Hazard Control Technology for the Foundry Industry, 1978. DHEW Publication no. (NIOSH) 79-114
- Recommendations for Control of Occupational Safety and Health Hazards... Foundries DHHS (NIOSH) Publication No. 85-116
- NIOSH/OSHA Occupational Health Guidelines for Chemical Hazards, DHHS (NIOSH) Publication No. 81-123

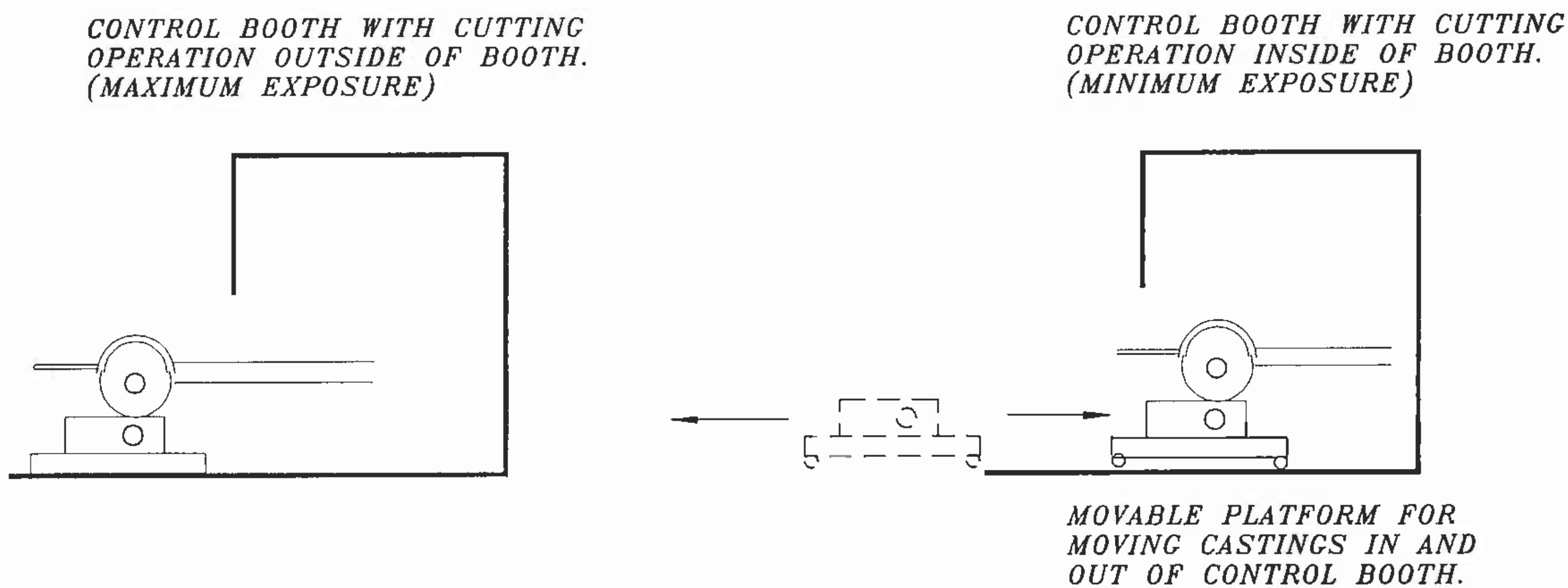

Figure 7. A movable platform to facilitate casting movement into enclosures.

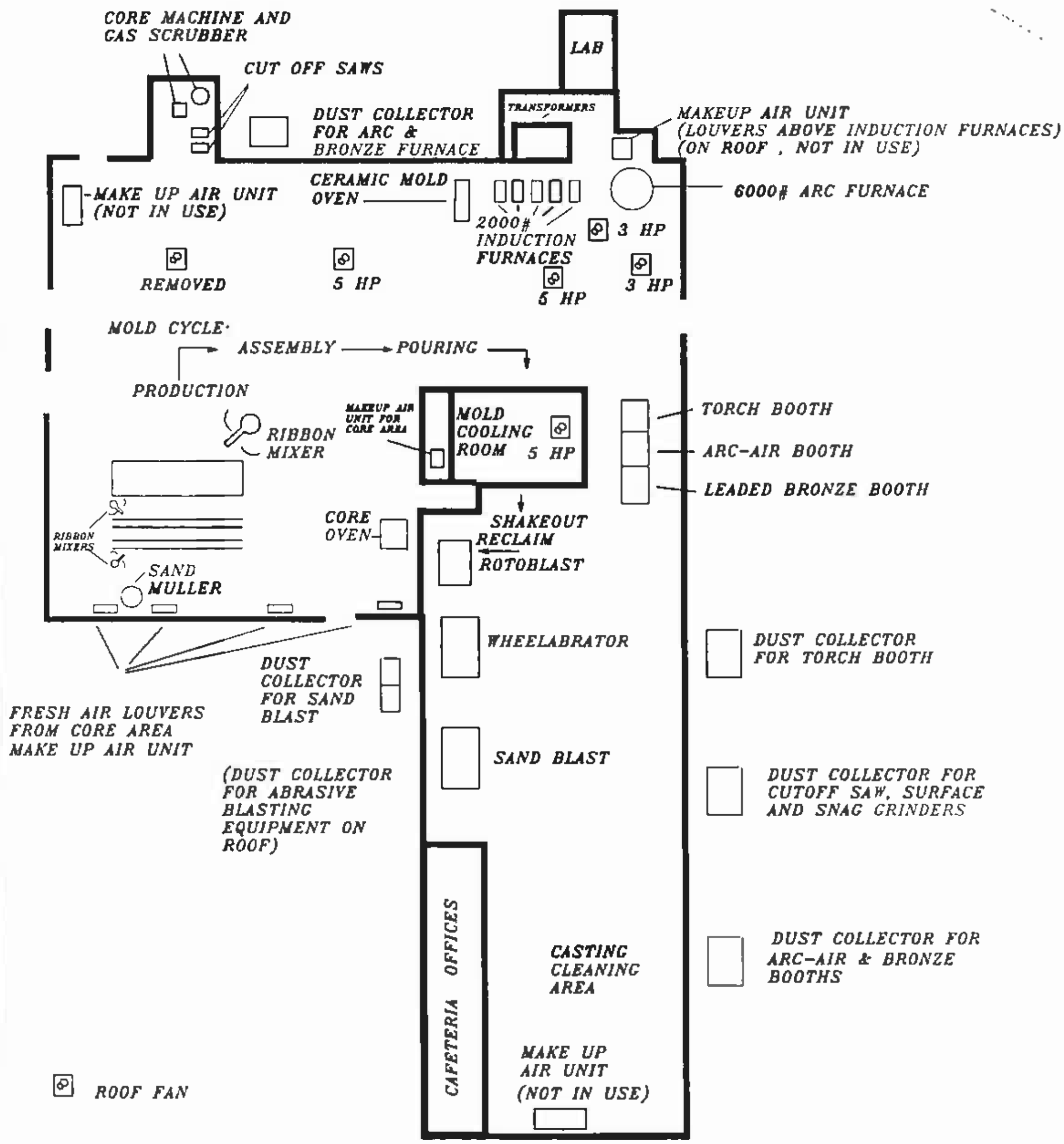

Figure 1. Schematic layout - Ingersoll-Rand steel foundry.

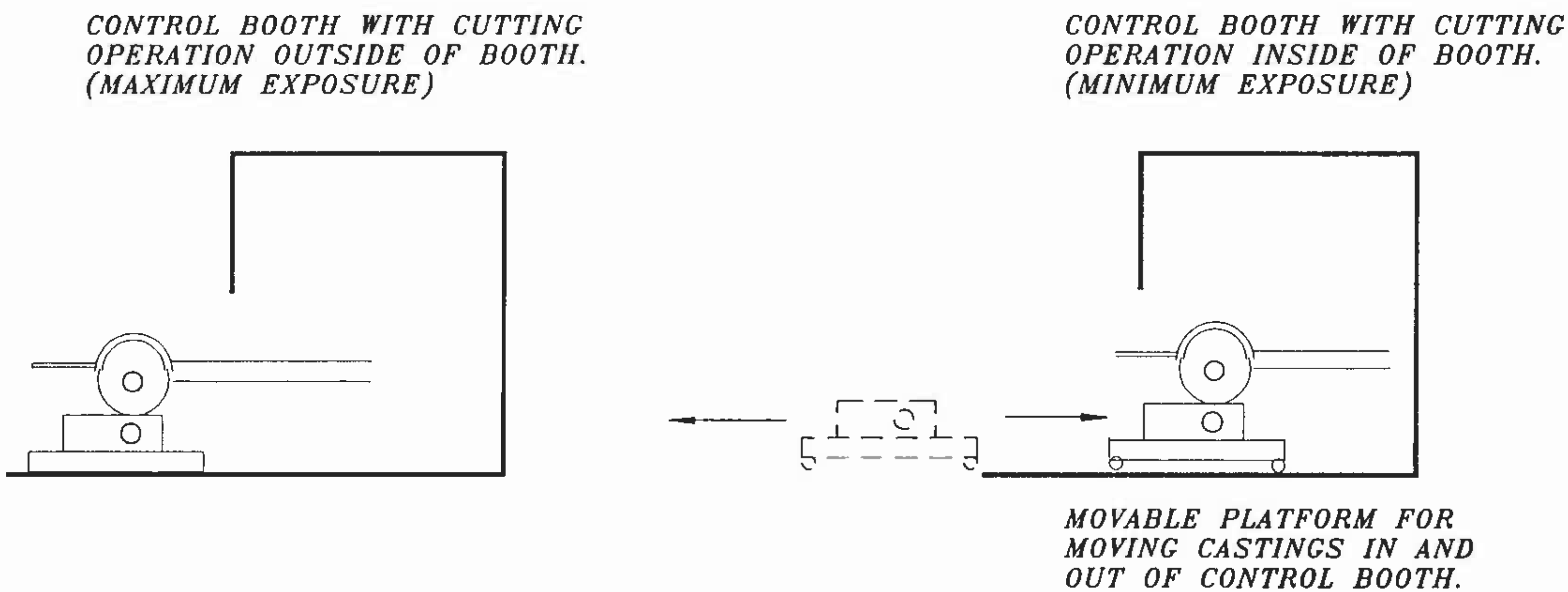

Figure 7. A movable platform to facilitate casting movement into enclosures.

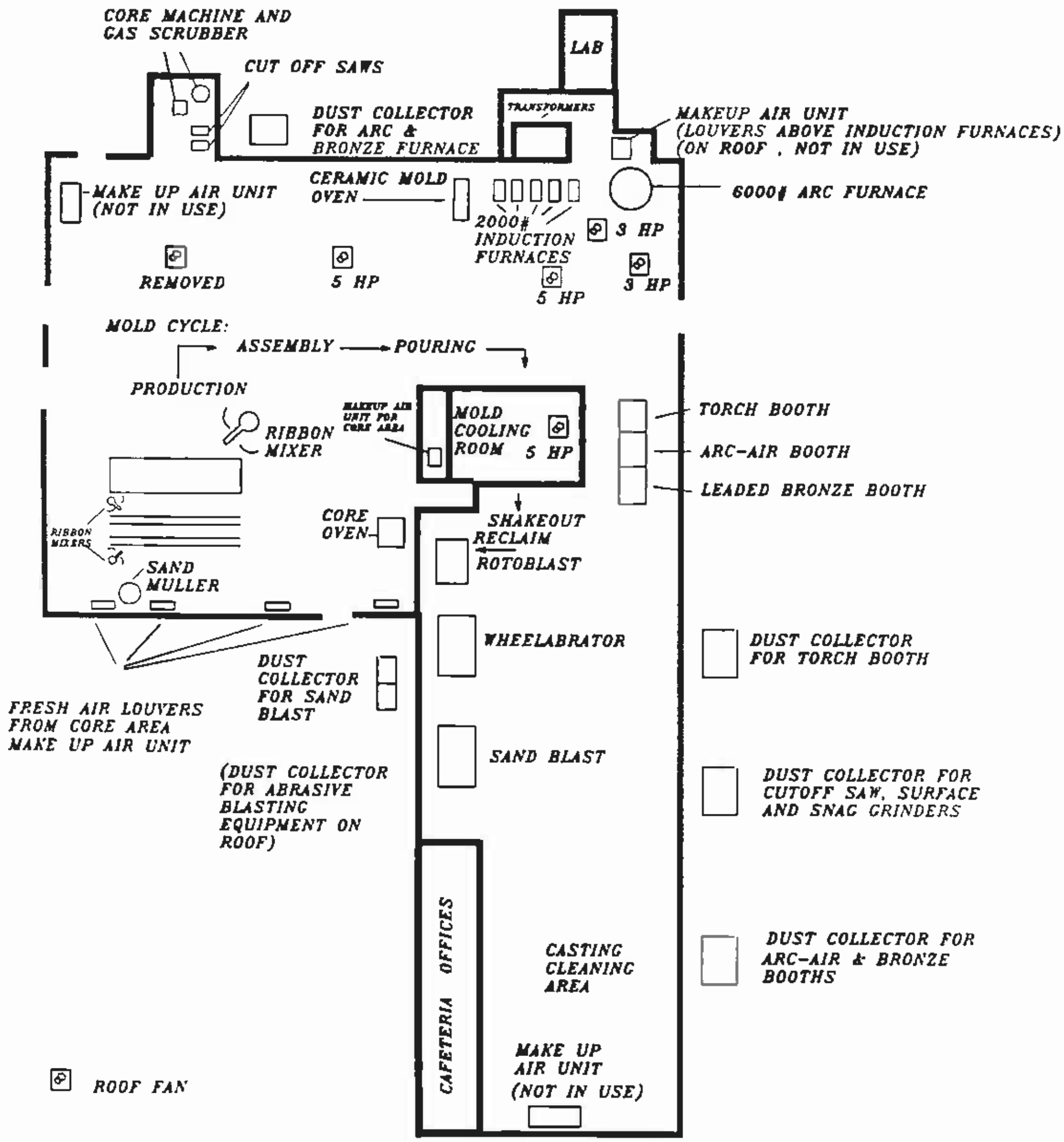

Figure 1. Schematic layout - Ingersoll-Rand steel foundry.