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SUMMARY

In February 1990, the management of Modern Materials Incorporated in Rochester, Indiana, requested a Health Hazard Evaluation (HHE) from the National Institute for Occupational Safety and Health (NIOSH). NIOSH was asked to evaluate chemical exposures associated with powder-coating operations in their Rochester facility and to evaluate the possibility that long standing health problems (some dating from 1984) experienced by management and employees may have been linked to exposures to isocyanates used in some powder coatings.

Between April 1990 and February 1991, NIOSH investigators made three visits to the plant to conduct environmental and medical evaluations. The medical evaluation included confidential interviews with workers who had experienced health problems that they felt might be associated with workplace exposures and a short questionnaire survey. The industrial hygiene evaluation included a review of Material Safety Data Sheets (MSDSs), a series of walk-through inspections, an evaluation of local exhaust ventilation systems, collection of bulk samples of powder coatings for laboratory analysis, and an air sampling survey. The air sampling survey evaluated exposures to several compounds including dust, epsilon-caprolactam (E-caprolactam), aldehydes, volatile organic compounds (VOCs), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and inorganic acids. Technical problems with sampling and analytical methodology made it impractical to measure isocyanate exposures in the workplace.

The NIOSH physician interviewed 15 current employees. Symptoms that employees described during interviews included shortness of breath, chest tightness, upper airway and eye irritation, musculoskeletal injuries, skin rash, and feelings of wooziness or nausea from use of spray paints. In some cases employees associated respiratory and skin problems with the use of coatings that contained isocyanates.

One group of interviewed employees described exposures in 1984, when their symptoms included a burning or itching sensation of the skin, eye irritation, fatigue, and nausea. By the time of the NIOSH evaluation, most remaining symptoms were primarily related to emotional problems and anxiety. Two of these interviewees described sensations of chest tightness and shortness of breath which were reportedly exacerbated by exposure to fumes at the factory or by nonspecific odors and smoke outside the workplace.

NIOSH investigators administered a symptoms questionnaire to the Modern Materials workforce. In contrast to the symptoms reported during medical interviews, analysis of responses to the NIOSH questionnaire did not reveal significant positive associations between exposures and respiratory diseases, or exposures and respiratory or mucosal symptoms. Because the questionnaire was administered only to current employees, former employees (who might have left the workplace because of health symptoms) were not included.

Air sampling indicated that the concentrations of most targeted chemicals were well below the Permissible Exposure Limits (PELs) and Recommended Exposure Limits (RELs) that have been established by OSHA and NIOSH, respectively. However, some exposures to E-caprolactam, formaldehyde, and SO_2 that exceeded NIOSH and OSHA criteria were documented.

Conditions which allow dermal exposures to corrosives, including potentially carcinogenic hexavalent chromium, were observed. In addition, a number of safety hazards including inoperative eye washes, inadequate personal protective equipment, and apparent failure to meet OSHA Hazard Communication requirements were noted. A number of ventilation malfunctions and design flaws were identified.

Recommendations were made to improve health and safety conditions by establishing a committee with responsibility and authority to establish and implement a written health and safety program. In addition, development of a written maintenance schedule for ventilation and other safety equipment was recommended. Specific recommendations were also made to improve the use of personal protective equipment, such as safety glasses, and to alter some work practices.

> Data collected during this HHE indicates that employees are exposed to potentially hazardous concentrations of aldehydes, epsilon-caprolactam, and sulfur dioxide. In addition, there is potential for hazardous exposures to other materials including carbon monoxide and dust from powder coatings. Workers are also exposed to unsafe conditions that result from inadequate use of safety devices, including eye washes and personal protective equipment. Investigators were not able to determine if workers are exposed to unsafe levels of isocyanates or if any cases of isocyanate sensitization have developed. Although workers suggested in medical interviews that exposures in the past had resulted in disease, a questionnaire survey of current employees did not find a significant association between current exposures and current symptoms or disease.

KEYWORDS: SIC 3479 (Coating, Engraving, and Allied Services, Not Elsewhere Classified), powder coating, epoxy, polyester, aldehyde, caprolactam, isocyanate.

PROCESS DESCRIPTION AND LITERATURE REVIEW

Powder coating is a dry, or solvent-free, painting process used to place a polymer coating on metal surfaces. Although it is less common than solvent-based coating, it is gaining popularity because it minimizes waste and provides a number of environmental advantages (Richart 1985). At this facility, most of the objects to be coated are relatively small and include outdoor furniture, automobile trim, lawn and garden equipment, and other products that are likely to be exposed to harsh environments.

The first step in the process is cleaning and surface preparation. The parts are placed in a steel frame wire basket approximately four feet long, three feet wide, and three feet deep. The basket is lifted by an overhead crane and sequentially dipped and soaked in a series of heated tanks containing water-based cleansers, degreasers, and surface treatment chemicals. A variety of cleaners and treatment chemicals may be used in the dip tanks. These include hydrochloric acid, chromic acid, phosphoric acid, hydrofluoric acid, zinc phosphate, potassium hydroxide, sodium hydroxide, ethylene glycol monobutyl ether (Butyl Cellosolve®), and a variety of phosphates and detergents. The treatment chemicals of greatest concern from the health and safety perspective are probably those containing chromic or dichromic acid. Chromic acid is a hexavalent form of chromium and has been classified as a carcinogen by the National Institute for Occupational Safety and Health (NIOSH) (NIOSH 1977). Chromic acid is also a powerful irritant, and repeated exposures can lead to respiratory and dermal sensitization reactions which are allergic reactions affecting either the skin or breathing (Proctor 1989).

After surface treatment and a final rinse stage, the basket of parts is moved into a small, gas-fired drying oven. When all the water has been evaporated, the basket is removed from the oven, allowed to cool, and then pushed across the floor into the coating area.

The parts to be coated are hung from racks on a continuously moving overhead conveyor and are carried through one or more ventilated spray booths. The coating is supplied as a finely divided dry powder which, according to literature reports, ranges in diameter from 5 to 100 micrometers (µm). There is currently some interest in the development of powder coatings with smaller particle sizes which would allow thinner coatings to be applied, but which might also present a greater inhalation hazard. At Modern Materials the powder coating is applied using two electrostatic spray guns, located on opposite sides of the booth. The guns produce an aerosol of electrically charged coating particles. In some cases the spray guns can be attached to a stand or reciprocating arm and no operator is required. However, if the items being coated are complex shapes, the guns must be aimed and moved by an operator. The powder is sprayed from the gun by compressed air, and particles are attracted to the metal objects by the electrical field that is developed between the charged gun and the electrically grounded conveyor.

After the objects to be coated are covered with a thin film of dry powder, they are carried into a gas or electrically-heated oven where the powder melts and flows to produce an even coating. With some coating formulations the elevated temperature in the oven also cures the paint by initiating a polymerization reaction. Depending on the type of coating being used, the oven temperature ranges from about 200 to 250^{o}C. Residence time in the oven is generally no more than a few minutes.

A wide variety of coating formulations is available, with the choice of coatings being dependent on the final properties required for that application. In general, the coatings used at Modern Materials can be placed in two categories, epoxies and polyurethanes.

Epoxy coatings are based on the polymerization of bisphenol-A with epichlorohydrin. Modern manufacturing techniques can be quite efficient and are believed to leave very little non-reacted material in the epoxy matrix (Lemon 1972). In general, the polymerized materials are considered to have low toxicities with the specific properties being dependent on the choice of catalysts, fillers, pigments, and other additives. The catalysts used in epoxy-based powder coatings are not usually listed on the MSDS, but some specify an organic amine. Other common additives include carbon black, calcium carbonate, and barium sulfate. In most cases, the manufacturers consider epoxy-based powder coatings to be a nuisance dust, but recommend that users minimize unnecessary exposure by using ventilation and personal protective equipment including gloves, respirators, and goggles.

Polyurethane coatings are based on a slightly different chemistry. The manufacturer's MSDSs do not reveal the specific compounds used in their production, but polyesters are generally made from a reaction of unsaturated organic acids with polyhydroxy alcohols (Mobay Chemical 1988, Streitwieser 1976). The resulting polymers are then cured or cross-linked with an isocyanate, polyisocyanate, or isocyanurate. In the uncured powders, the isocyanate group is prevented from polymerizing by a moderate volatility blocking agent which is usually epsilon-caprolactam (E-caprolactam). In these formulations, the E-caprolactam forms a weak bond with the isocyanate groups and prevents them from reacting together or with other materials. When heated, the isocyanate-caprolactam bond breaks and the E-caprolactam escapes as a vapor, leaving the isocyanate groups free to participate in a polymerization reaction. In addition to the isocyanates and E-caprolactam blocking agent, the polyester-based powders also contain other additives including calcium carbonate, carbon black, titanium dioxide, barium sulfate, acrylic oligomers, and chromium or cadmium based pigments. As with the epoxy-based coatings, the manufacturers generally regard the unheated powder coatings to be low toxicity materials which can be classified as nuisance dusts. However, at least one manufacturer warns that "... blocked polyisocyante resin may contain small levels of unreacted epsilon-caprolactam and isocyanate monomers. It is anticipated that additional levels of these monomers will be released when the polyisocyanate resin contained in the powder coating formulations are heated. Exposure to epsilon-caprolactam and isocyanate monomers causes irritation of the skin, eyes, nose, throat and may cause abdominal distress, nausea, vomiting and allergic skin and respiratory sensitization" (Evtech 1980).

Exposure to isocyanates can have both acute and long-term health effects. In sufficient concentrations, isocyanates can cause irritation of the eyes, nose, and throat, while higher concentrations can cause pulmonary irritation with bronchitis, chest tightness, and difficulty breathing (Proctor 1989, NIOSH 1977). Isocyanates can also cause allergic sensitization, producing an asthmatic reaction if the person is exposed later. Sensitization can occur at levels lower than those that cause irritation. Once sensitization has occurred, the asthmatic reaction can occur even at concentrations lower than the original sensitizing exposure. Cases of airway hyperreactivity and respiratory symptoms persisting years after exposure have also been reported. This suggests that exposure may cause generalized airway hyperreactivity in addition to a sensitization response that is specific to isocyanates.

Although there have not been many studies of powder coating, a few publications have described health and safety concerns in this industry, and there have been numerous reports of health concerns associated with other uses of epoxies. In general, the unheated powders are thought to have low toxicity. Although chemical pneumonitis has been reported following inhalation of epoxy powders (Rice 1973), the primary hazards appear to be associated with dermal contact, which can result in both direct irritation and in allergic sensitization (Bokelund 1980, Mathias 1988, Pedersen 1984). Epoxies in general have been associated with sensitization reactions, as have the isocyanate curing agents used in polyester-based coatings (Proctor).

Because the unheated powders are generally thought to have low acute toxicity, most concerns over chemical exposure focus on volatile materials that might be released during the heat-cure process or as a result of decomposition that could occur when powders contact the heating elements of an electric furnace.

In 1986, Peltonen et al. demonstrated that one of the major components of epoxies, Bisphenol-A, is released from epoxy-based powder coatings at temperatures between 180 and 250°C (350 to 480°F) with the rate of release being directly related to temperature (Peltonen 1986a). The same researchers (Peltonen 1986b) also demonstrated that even at temperatures below the normal cure temperature of 250°C, as many as 24 different organic vapors are released, including a variety of benzene derivatives, alcohols, phenols, and either melamine or an imidazole compound. Although the specific organics varied with the choice of powder, xylenes and isobutyl-methyl ketone were the most abundant compounds that were released by heating epoxies. A similar set of studies published by Pukkila et al. indicates that benzil can be used as an indicator of vapors released during the normal curing process of polyester paints, and that the presence of 1,4-dicyanobenzene is an indicator of their thermal decomposition (Pukkila 1989). Thermal decomposition was reported to begin at temperatures of about 350°C (650°F).

The potential chemical exposures associated with powder-coating operations appear to be diverse and have not been well documented. Although the studies referenced above do identify compounds that could be used as markers of potential exposure, there are no data available that describe exposure levels and, in most cases, there is no toxicological information on which to base exposure standards or criteria.

Although the number of studies is limited, currently available data do not indicate that unheated powder coatings represent a serious health threat. If proper protective equipment and ventilation are used, and if proper work practices are followed, exposures to unheated powder coatings can be controlled to low levels. Exposures to decomposition products and organics released during the curing process may represent more of a hazard than exposure to the uncured powders. The complexity of these exposures and the lack of available data make it difficult to estimate the true level of risk. However, these exposures should also be relatively easy to control.

Although exposure to potentially hazardous chemicals is a concern, the greatest risks in the powder-coating industry are likely to be associated with safety issues, such as fires or explosions and exposure to electrical shock. The electrostatic spray process requires the use of relatively high voltages and can produce significant static charges on non-grounded metal. Powder coatings are also flammable and can form explosive aerosols at moderate concentrations.

FACILITY DESCRIPTION AND BACKGROUND

The Modern Materials production facility is housed in a renovated three-story brick building, which was originally used as a dairy. The basic design of the building is not well suited for an industrial operation, especially one that involves the use of potentially hazardous chemicals. The production area is located on the first floor making it difficult to provide adequate local exhaust except near the outer walls. The operation includes three coating lines, two parts cleaning operations, and a "high-tech" area. The high-tech area is a coating operation where special orders are run. The process is similar to that used in the other three lines, except that it is batch oriented rather than continuous. A typical coating line is shown in Figure 1.

Offices are located on one side of the second floor and the other side is used for storage. The third floor is used only for storage. Locker rooms, a break room, and a small laboratory are located in the basement. A schematic diagram of the first floor production area is included as Figure 2.

Polyester coatings containing blocked isocyanates were first used at Modern Materials in 1984. While no health problems were reported during initial test runs, several employees started experiencing a variety of symptoms soon after the start of full production. Symptoms included eye and respiratory irritation, coughing, difficulty breathing, vomiting, fatigue, disorientation, depression, and anxiety. Management and employees believe that the symptoms were caused by exposure to fumes from the polyester coating. Although no air samples were taken at the time, employees who were present report that thick, blue smoke was released when the powder came in contact with the quartz heating elements that were being used in the oven. Analyses of the powder and of scrapings that were taken from the ventilation system, which were performed by an independent laboratory, indicated the presence of toluene-diisocyanate (TDI) and E-caprolactam.

Although the specific powder and the oven that caused the initial problem are no longer in use, some of the replacement coatings contain isocyanates or isocyanurates. Employees who were present at the time of the initial exposure have continued to experience a variety of health problems. Some of the symptoms are aggravated by exposure to emissions from the coating operations, while other employees report sensitivity to common irritants, such as cigarette smoke.

Based on information provided in the original request and in the opening conference, exposure to isocyanates, E-caprolactam, and unidentified decomposition products of over-heated polyester coatings appeared to be the most likely cause of the reported health problems. Because isocyanates are known to produce some of the symptoms reported by employees and management, and because they are the group of materials identified as having the greatest toxicity, initial investigations focused on those compounds.

Although exposures which reportedly occurred in the mid 1980s may be relevant to current health problems, it would be extremely difficult to reconstruct conditions that might have existed at that time, or to estimate exposure levels. Based on the descriptions given by management and employees, it seems likely that polyester-based coatings were overheated, resulting in the release of a complex mixture of organics. Because we could not accurately describe exposures that occurred in 1984, the objectives of this HHE were limited to the assessment of current working conditions, a determination of whether current health problems are the result of continuing exposures, and development of recommendations that would help improve occupational health and safety in the Modern Materials facility.

EVALUATION CRITERIA FOR CHEMICAL EXPOSURES

When conducting a health hazard evaluation at an industrial workplace, NIOSH investigators frequently perform sampling to measure the concentrations of various contaminants in the air. The air sampling results are then compared to various criteria, or exposure limits, which are believed to represent the maximum exposure concentration that could be considered safe for most workers. Exposure criteria have been developed by NIOSH, the Occupational Safety and Health Administration (OSHA), and other government or professional organizations, including the American Conference of Governmental Industrial Hygienists (ACGIH). Employers are required by law to meet the exposure limits developed by OSHA, which are called Permissible Exposure Limits (PELs). The exposure limits developed by NIOSH and ACGIH are called Recommended Exposure Limits (RELs) and Threshold Limit Values (TLVs) respectively. The RELs and the TLVs are not legally enforceable. However, they are sometimes based on newer or more complete research information than the OSHA PELs, and may be set at somewhat lower concentrations. If the REL or TLV for a given substance is lower than the PEL, employers are strongly encouraged to meet the more restrictive criteria.

Most exposure criteria are expressed as either eight-hour or ten-hour time-weighted average (TWA) concentrations. That is, they represent the maximum average concentration that is acceptable for a full workday. For example, the current PEL for carbon monoxide (CO) is 35 parts per million (ppm) expressed as an eight-hour TWA concentration. Within certain limits, it is considered acceptable for workers to be temporarily exposed to concentrations that are higher than 35 ppm, as long as the average concentration over the entire work day does not exceed this limit. Therefore, if the duration of the exposure is reduced by one-half, to four hours, the average CO concentration could double to 70 ppm without exceeding the PEL.

In addition to the eight-hour TWA limit, some exposure criteria also include a short-term exposure limit (STEL) or ceiling limit, which is a maximum concentration that would be considered acceptable at any time. Ceiling limits and STELs are not based on eight-hour average exposures. Instead they are maximum concentrations which should not be exceeded for even a short time. In general, it is permissible for the concentration of a contaminant to temporarily rise above the eight-hour TWA exposure limit, but it is not acceptable for the concentrations to exceed the STEL or ceiling. Following the earlier example, OSHA has set a ceiling limit of 200 ppm for CO, indicating that workers should never be exposed to CO concentrations above 200 ppm. Any exposure that exceeds 200 ppm constitutes a violation, even if the eight-hour TWA concentration is below the PEL of 35 ppm.

NIOSH and/or OSHA have established exposure criteria for many, but not all, of the chemicals measured in this survey. A summary of the exposure criteria used in this Health Hazard Evaluation (HHE) is presented in Table 1. In comparing the air sampling results to the exposure criteria, the reader should be aware that the exposure criteria are intended to be used as general guidelines and do not define an exact level of safety. It is also important to remember that air sampling was conducted over a relatively short period of time and that the actual concentrations of contaminants are likely to vary. The results obtained in a short-term evaluation of this type should not be considered definitive and may not allow a precise measurement of employee exposures. In summary, airborne concentrations of chemicals that approach or exceed exposure criteria indicate the need for improved industrial hygiene.

EVALUATION PROCEDURES

In order to evaluate reported health problems and potential occupational hazards, a series of medical, environmental, and laboratory evaluations of the powder-coating process was initiated. The medical evaluation included a series of medical interviews with selected employees, some of whom had been working at the site since the reported problems began in 1984, and a written questionnaire which was completed by all available employees. The environmental assessment included a series of air-monitoring surveys, an evaluation of local exhaust ventilation systems, and a walk-through assessment of industrial hygiene and safety conditions in the facility. The laboratory assessment was intended to identify the major organic compounds that employees might be exposed to. This was done by heating the various powder coatings under controlled laboratory conditions and analyzing the gases and vapors that were produced. The procedures used in each component of the HHE are described in detail in the following sections.

Medical Investigation

During the initial medical investigation, a NIOSH physician interviewed 15 of approximately 80 current employees. These employees represented both management and labor. Labor representatives generally had employment histories of less than one year and discussed current working conditions and symptoms, while management representatives had longer work histories and discussed symptoms which they attributed to their exposures that occurred in 1984. The company's OSHA 200 Injury and Illness logs of reportable diseases were also examined for illnesses that might be related to chemical exposures or for occupational injuries.

Although no occupational illnesses were recorded in the OSHA 200 log, some of the initial interviews suggested symptoms that would be consistent with exposures to isocyanates or other sensitizing agents. Therefore, a decision was made to distribute a questionnaire to all current employees. The questionnaire was completed by 53 employees. Ten respondents worked in the company's offices, which were located on a separate floor from the production area; the others worked at various locations in the plant.

Laboratory Investigation

The potential exposures associated with powder-coating operations have not been well established. Therefore, a laboratory investigation was initiated to determine, on a qualitative basis, what exposures might be expected in this work environment.

In order to determine what compounds were released during the heat-curing process, small samples of epoxy and polyester-coating powders were heated to 280°C in a laboratory tube furnace and held at that temperature for 30 minutes. The furnace temperature was slightly higher than the temperatures that are specified for most curing ovens. However, it was felt that this temperature could be reached on some surfaces of the ovens, and it is assumed that the organics released would be similar to those given off in the actual process. The volatile materials were collected in solid sorbent tubes containing activated charcoal, Orbo-23 resin or silica gel, and/or in toluene-filled impingers. The collected materials were then analyzed by gas chromatography-mass spectrometry (GC-MS).

In addition to the analysis of volatile compounds emitted from the paint, bulk samples of the surface cleaning and treatment chemicals were also collected for measurement of pH[1] and hexavalent chromium content.

Environmental Evaluation

The environmental evaluation focused primarily on air monitoring, but also included walk-through evaluations of industrial hygiene and safety conditions, and an evaluation of the local exhaust systems. Air monitoring included evaluation of exposures to dust from the unheated powder coatings, E-caprolactam, volatile organic compounds (VOCs), aldehydes, inorganic acids, nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and carbon monoxide (CO).

Although isocyanate exposures were initially thought to be the primary health hazard associated with the coating process used at Modern Materials, no attempt was made to measure isocyanates in the work environment. This decision was based on three considerations: first, there was no validated or NIOSH approved method for measurement of the specific isocyanate found in the coating being used at the time of the survey; second, the isocyanate methods that were available were unable to reliably detect isocyanate release during the laboratory portion of the investigation; and third, the use of coatings containing isocyanates was being phased out at this facility.

Dust

Airborne concentrations of total dust, which consisted primarily of unheated powders, were measured by a modification of NIOSH method #0500 (Eller 1989). Measurement involved collection on pre-weighed Zefluor® filters at a flow rate of 1.0 liter per minute (LPM) followed by gravimetric analysis. The total mass of dust collected was determined by measuring the increase in filter weight during the sampling period. A total of eight samples were collected for analysis of total dust, including four samples each on lines 1 and 3.

Epsilon-Caprolactam

In order to measure exposures to E-caprolactam, eight air samples were collected and analyzed. All samples were collected on line 1 at a time when a polyester coating was being applied. Samples were collected on Tenax® adsorbent tubes with Zefluor® prefilters and were analyzed by gas chromatography with flame ionization detection (GC-FID). Four of the samples were personal breathing zone air samples collected with the

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1 ph serves as an indicator of whether a liquid is an acid, a base, or neutral. Neutral liquids, such as distilled water have a pH of 7.0 while acids have a pH below 7.0 and bases have pH above 7.0. The strength of an acid or base is indicated by how far the pH is above or below 7.0.

cooperation of workers on line 1. Three of the remaining samples were area air samples collected near line 1, and the fourth was an area air sample collected near line 2. E-caprolactam was chosen as the target compound because it may be released by isocyanate-based powders and because it was identified in the laboratory simulation of the coating process. It should be noted that E-caprolactam is a moderate volatility compound and is found both as a dust and as a vapor at room temperature.

Aldehydes

Aldehydes were measured by collection on solid sorbent tubes followed by desorption in toluene with sonication, as described in NIOSH method #2541 (Eller 1989). Because concentrations were expected to be low, analysis was performed using gas chromatography-mass spectrometry (GC-MS). A total of approximately 32 personal and area samples were collected at lines 1, 2, and 3. Eight samples were qualitatively analyzed to allow various aldehydes to be identified. Based on the results of those analyses and on the results of the laboratory simulations, a decision was made to measure formaldehyde, acrolein, and acetaldehyde in the remaining samples.

VOCs

In order to measure total VOCs, 15 samples were collected on activated charcoal at a flow rate of 100 milliliters per minute (ml/min), and four samples were collected on XAD-2 resin at a flow rate of 1 LPM. All four XAD-2 tubes and four of the charcoal tubes were submitted to the NIOSH laboratory for qualitative analysis. Charcoal tubes were eluted in carbon disulfide and XAD-2 tubes were eluted in ethanol. All samples were analyzed by GC-MS and major components were identified. The remaining charcoal tubes were then eluted in carbon disulfide and analyzed by GC-FID using decane as a standard.

Combustion Products

Carbon monoxide, SO_2, and NO_2, which are common combustion products, were measured with passive, detector tubes. Most samples for these gases were collected in the parts washing and surface treatment area near the gas fired drying oven. A few additional samples were collected in other areas to serve as controls.

Inorganic Acids

Samples were collected for analysis of inorganic acids in the parts washing and surface treatment areas. Samples were collected on silica gel at a flow rate of 1 LPM and were analyzed by ion chromatography, as described in NIOSH method #7903 (Eller 1989).

Ventilation Assessment

Because most of the chemical hazards present in this facility could be controlled by local exhaust ventilation, a qualitative review of the ventilation system design and performance was included as part of the HHE. Exhaust hoods and ducts were inspected for design flaws or malfunctions, and capture efficiency was evaluated on a qualitative basis using smoke tubes. Flow rates were estimated by taking a series of velocity measurements at each hood opening with a hot-wire anemometer. Although these procedures do not provide a precise measure of ventilation performance, the data was judged to be sufficiently reliable for a qualitative evaluation of the systems.

RESULTS AND DISCUSSION

Laboratory Analysis Of Bulk Powders

In order to identify compounds that might be responsible for health problems at Modern Materials, bulk samples of 10 coating powders were collected for analysis. The actual coating process was simulated by heating a small sample of each powder to a temperature of 280°C for 30 minutes. The organic vapors produced were collected and analyzed by GC-MS and major components were identified. A summary of the results is presented in Table II.

These results indicate that a wide variety of organic compounds can be released during the curing process. The number of compounds released by each individual coating ranged from 5 to 12, with a total of 26 different compounds identified. As expected, many of the compounds were derivatives of benzene, which were probably released by the breakdown of the epoxy and/or polyester matrix. One of the most common compounds identified was benzil, which has previously been suggested as a marker of exposure to heat cured polyester coatings. The most significant finding was the presence of various aldehydes, including formaldehyde, acetaldehyde, acrolein, and benzaldehyde. Aldehydes are strong irritants and have been associated with various respiratory problems, including sensitization. In addition, NIOSH considers both formaldehyde and acetaldehyde to be potential human carcinogens.

As anticipated, E-caprolactam was released by polyester coatings that use blocked isocyanates. However, the expected isocyanates were not detected in the emissions from most of the blocked isocyanate powders. In fact, an isocyanate was detected in the emissions from only one powder, and even that was not the specific isocyanate that was anticipated. This failure to detect isocyanates in coatings known to contain them is difficult to explain. A flaw in the sampling and analytical method may have caused the failure, or it may be that the amount of free isocyanate released from these coatings was simply too low to be detected. Although it is difficult to draw conclusions from these limited data, we found no evidence to indicate that exposures to high concentrations of isocyanates are likely to result during normal coating operations. In addition, we found that E-caprolactam levels are not a good indicator of isocyanate concentrations.

Air Monitoring Results

Total Dust

The concentration of airborne dust was measured with a total of eight area air samplers located on lines 1 and 3. The results, presented in Table III, show that the TWA concentrations ranged from 2.4 milligrams per cubic meter (mg/m^3) to 58.4 mg/m^3. Seven of the eight samples measured average concentrations that were within applicable criteria, while the one remaining sample exceeded the OSHA PEL and the ACGIH TLV for inert dusts, or "particulates not otherwise classified (PNOC)." Currently the OSHA PEL is set at 15 mg/m^3 and the TLV is set at 10 mg/m^3. Although most of the measured dust concentrations fell within the criteria for PNOC, it should be noted that these criteria are intended for use with inert materials which have been shown to have little toxicity. The manufacturer's MSDSs generally indicate that powder coatings should be classified as PNOCs or as nuisance dusts. However, these recommendations appear to be based on relatively limited data obtained with similar but not identical materials. Although no specific health hazard can be cited, the dust levels reported here are high enough to indicate that current ventilation and control technologies are inadequate.

Epsilon-Caprolactam

As Table IV illustrates, concentrations of E-caprolactam vapor ranged from nondetectable (ND) to a maximum concentration equal to 1.8 mg/m^3 which was measured with an area sampler placed on the line 1 control panel. While even the maximum concentration measured was less than 10% of the current OSHA PEL, this one sample did exceed the NIOSH REL which is currently set at 1 mg/m^3.

In most cases the concentration of E-caprolactam dust was similar to, or slightly higher than, the concentration of vapor. Measured concentrations ranged from ND to 4.9 mg/m^3. The average concentration of dust measured with one personal breathing zone air sample was much higher than the others. In this one sample, the PEL was exceeded by almost five fold. This high concentration was measured on a worker who operated the spray gun for most of the shift, and who was involved with the end of shift clean up. Based on these results, it appears that employees who operate the spray guns or clean the booth without respiratory protection may be exposed to E-caprolactam dust at concentrations that are considered potentially hazardous. In addition, it appears that E-caprolactam vapor concentrations that exceed the NIOSH REL are possible in this operation.

Aldehydes

Qualitative analysis of materials collected on Orbo-23 resin indicated that the major aldehydes present in this work environment were formaldehyde, acetaldehyde, and acrolein. Results obtained from quantitative analysis for these three compounds are presented in Table V.

As shown in Table V, the airborne concentration of acetaldehyde ranged from ND to a maximum of 0.05 mg/m^3. The maximum concentration reported here is well below the OSHA PEL for acetaldehyde, which is currently set at 180 mg/m^3. However, it should be noted that NIOSH considers acetaldehyde to be a carcinogen and recommends that exposure be maintained at the lowest feasible concentration (LFC).

Formaldehyde concentrations were only slightly higher than those reported for acetaldehyde and ranged from ND to 0.09 mg/m^3. Although the highest concentration measured was less than 10% of the current OSHA PEL, almost all the samples exceeded the NIOSH REL which, because of formaldehyde's possible carcinogenic activity, is currently set at just under 0.02 mg/m^3. Of the three aldehydes measured in this HHE, acrolein concentrations were the lowest. Concentrations of acrolein ranged from ND to 0.03 mg/m3, which is about 10% of OSHA PEL or the NIOSH REL.

The data presented here indicate that low, but potentially significant, concentrations of aldehydes can be released during the curing process. The concentrations reported here are generally lower than those seen in some industrial settings where formaldehyde or other aldehydes are produced or used and are slightly below concentrations that have been reported to cause irritation. However, the concentrations were higher than would be expected in most non-industrial settings, and in 18 of 21 samples the NIOSH REL for formaldehyde was exceeded.

Volatile Organic Compounds

The concentration of VOCs was measured with a total of 14 personal breathing zone and area air samplers located at lines 1, 2, and 3. The results from these samples are presented in Table VI. Of the 14 samples collected, VOCs were detected in only two, and the concentrations on those two were very low. Although there are no established criteria for total VOCs, the concentrations reported here would not be expected to present a serious health risk.

Combustion Products

In order to determine whether the gas-fired drying oven in the parts cleaning area might be leaking combustion products into the atmosphere, CO, SO_2, and NO_2 were measured in that area. The results are presented in Table VII. Carbon monoxide concentrations near the drying oven ranged from 20 to 25 ppm. Although the measured concentrations fall below the OSHA PEL and NIOSH REL of 35 ppm (NIOSH 1984), they are high enough to indicate a potential problem with the drying oven exhaust system. This interpretation is confirmed by the fact that SO_2 concentrations were also elevated. Sulfur dioxide concentrations in the parts cleaning area ranged from 1.2 to 2.3 ppm. The measured concentrations of SO_2 were high enough to cause eye irritation, and exceeded the NIOSH REL of 0.5 ppm (NIOSH 1984). In some cases, concentrations also exceeded the OSHA PEL of 2 ppm.

Inorganic Acids

The airborne concentrations of inorganic acids, including hydrogen chloride, nitric acid, and phosphoric acid were measured in the parts cleaning area and the data is presented in Table VIII. Unfortunately, analytical problems that resulted in contamination of some samples compromised the validity of these results. However, the extremely low values that were reported seem to indicate that acid mists or vapors are not a significant concern. Analysis of bulk samples taken from the dip tanks are presented in Table IX. As shown, the pH readings ranged from 1.4 to 12.5 and the maximum concentration of hexavalent chromium was slightly over 1 milligram per milliliter (mg/ml). Although there are no criteria for pH or for hexavalent chromium content in a liquid, these readings indicate that personal protective equipment should be used to avoid skin or eye contact with these materials.

Medical Evaluation

Current Observations

The NIOSH physician interviewed 11 employees working in production areas; these included painters, maintenance workers, inspectors, cleaners, and workers in the "high-tech" and burn-off areas. Two workers described symptoms of chest tightness and shortness of breath which occurred in the production area; one of these workers indicated that the symptoms were worse with exposure to the orange paint. Orange paint, which was in use on the day of the interviews, is one of the polyester formulations that contains E-caprolactam blocked isocyanates. Another worker reported symptoms of shortness of breath on exertion.

Four workers (including both workers reporting chest tightness) described upper airway or eye irritation in the workplace. Three of the four said that these symptoms were either uniquely associated with, or made worse by, exposure to orange paint. Two workers reported skin rashes, and expressed concern that their rashes might be related to workplace exposures.

Workers also reported musculoskeletal injuries from heavy lifting. In addition, a worker complained of feeling "woozy" and nauseated while using canned spray paints for interior "touch-up" finishing. The spray was used at the end of the production line and not in a spray booth.

Past Observations

The symptoms expressed by the two management representatives and two long-term employees, which related to their exposures in 1984, were quite diverse. These interviewees reported that at the time of the exposure, they experienced symptoms including burning or itching sensation of the skin, eye irritation, fatigue, and nausea. By the time of the NIOSH evaluation, these respondents and their physicians primarily related their ongoing symptoms to emotional effects and anxiety which they attributed to the exposures. Two of the interviewees described sensations of chest tightness and shortness of breath, which could be exacerbated by exposure to fumes at the factory or by nonspecific odors and smoke outside the workplace.

Review of OSHA Form 200 Logs

Foreign body injuries of the eye were among the most commonly reported injuries. Several reports of foot injuries from falling objects were also noted.

Questionnaire Results

The questionnaire was completed by 53 employees of Modern Materials. Ten respondents worked in the company's offices, which were located on a separate floor from the production area; the others worked at various locations in the plant. The distribution of employees by production area is shown in Table X.

Of the 53 respondents, 47 (89%) were white, four (8%) were black, and two (4%) were Asian. Thirty-four (65%) were male. The age of the respondents ranged from 17 to 64 years old, with a mean of 32 years. The median age was 30 years. The mean duration of employment at Modern Materials was 2.5 years, with a range from one month to 15.3 years. The median duration of employment was ten months; 26 respondents (49%) had been employed for less than one year.

The concerns which prompted the hazard evaluation request pertained to possible exposures to isocyanates in the coating process. Because isocyanates are known to cause work-related irritation and allergic asthma, the questionnaire asked employees about respiratory irritation and asthmatic symptoms. The responding employees were divided into categories of those who were or were not exposed to emissions from the coating process. Because any chemicals released from the coating process would be expected to contaminate the entire production area, respondents who reported working on lines 1, 2, or 3, on the "high tech" line, or on maintenance were considered to have high-exposure jobs. Respondents working in the offices or in the dipping area were considered to have low potential for exposure and were placed in the non-exposed category. Employees who reported working in the burn-off or shipping areas, or who reported working "all over," were not included in this analysis because the level of their exposure could not be assessed as high or low. By this method, 44 workers could be classified as to exposure (32 exposed and 12 non-exposed) and were included in the analysis. Exposed workers were more likely to be male; 24 of 32 exposed workers (75%) were male, compared to 4 of 12 unexposed workers (33%) ($p = 0.02$, 2-tail Fisher's exact test). The mean age of the exposed group (32 years) and the non-exposed group (32 years), were not significantly different ($p = 0.89$, Student's t-test). Exposed workers tended to have been employed at Modern Materials for a significantly shorter period of time (mean = 1.5 years) than the unexposed workers (mean = 5.9 years; $p = 0.0004$, Student's t-test). Twenty-two of the 32 exposed workers (69%) reported smoking cigarettes at the time they completed the questionnaire, while only four of the 12 unexposed workers (33%) were current smokers; the difference was significant ($p = 0.04$, 2-tail Fisher's Exact test).

The prevalences of reported symptoms by exposure group are shown in Table XI. The symptoms studied were stuffy nose, runny nose, sneezing, eye irritation, wheezing, shortness of breath, and chest tightness. Because of the small size of the sample, the significance of the association was measured using a two-tailed Fisher's Exact test. The percentage of exposed employees reporting a symptom was lower than that of nonexposed employees for symptoms of runny nose, stuffy nose, eye irritation, wheezing, and shortness of breath but the difference was statistically significant at the level of $p < 0.05$ only for eye irritation ($p = 0.003$). The percentage of exposed workers reporting a symptom was higher than that of unexposed workers for symptoms of sneezing, and chest tightness, but the differences were not statistically significant.

It is possible that some workers reported symptoms that had their onset before the employee began working at Modern Materials. For each symptom, the employee was asked either the date when the symptom began, or whether it began before they started working at Modern Materials. Workers whose symptoms had a reported onset before the start of employment at Modern Materials were not included in this analysis because it was not possible to determine if their symptoms were related to workplace exposures. In order to maximize the sensitivity of the analysis, those who did not report the time of symptom onset were considered to have symptom onset after beginning employment; for most symptoms, 3 or fewer employees did not answer the question of when the symptom onset occurred (5 workers did not answer the question about sneezing onset). With these adjustments of the data, the association of reported symptoms with exposure was examined, and the results are shown in Table XII. These adjustments resulted in fewer positive reports of symptoms from employees in both exposed and nonexposed categories. As before, the only significant association between exposure and symptom occurred with reports of eye irritation ($p = 0.004$), and non-exposed workers were more likely to report this symptom than exposed workers.

In order to rule out the possibility that an association between exposure and a symptom was masked by a confounding variable such as age or smoking, each symptom was examined for association with smoking or with age. Only one significant association was found; employees who reported wheezing tended to be younger (mean age for those reporting wheezing was 25.1 years, while for those not reporting wheezing it was 35.8 years; $p = 0.0005$). Logistic regression was used to simultaneously examine the influence of exposure, age, gender and smoking on wheezing; only age showed a significant effect in this model, and was inversely related to reported wheezing.

In order to determine if exposures at Modern Materials were associated with pulmonary or allergic diseases, workers were also asked if they had ever been diagnosed with tuberculosis, pneumonia, pleurisy, bronchitis, emphysema, asthma, sinus disease, eczema, hay fever, or allergies, and the year of onset. In order to maximize the sensitivity of the analysis, diseases without specified date of onset were considered to have started after onset of employment. Table XIII shows the prevalence of each disease overall, and the prevalence when excluding workers who reported the onset of disease before they started working at Modern Materials. The association of exposure with reported disease (of onset after beginning work at Modern Materials) is shown in Table XIV. Unexposed employees report disease more frequently than exposed employees for all diseases studied with this questionnaire. Only the prevalence of bronchitis significantly differed between the two groups, and bronchitis was more frequently reported among unexposed workers. In order to rule out the possibility that an association between exposure and a disease was masked by a confounding variable such as age or smoking, each disease was examined for association with smoking or with age. Only one significant association was found; employees who currently smoked were less likely to report a history of bronchitis (2 of 26 smokers, or 8%, reported bronchitis, while seven of 16 nonsmokers, or 44% reported bronchitis; $p = 0.02$). Logistic regression was used to simultaneously examine the influence of exposure, gender and smoking on bronchitis; only exposure showed a significant effect in this model.

The analysis of responses to the NIOSH questionnaire did not reveal significant positive associations between current exposures and disease or current exposures and current symptoms. This was surprising in view of the symptoms which were reported in medical interviews. Interviewees were selected by management and labor representatives; because both parties were concerned about the possibility that workplace exposures caused these symptoms, workers with symptoms may have been more likely to be interviewed than those without symptoms.

It is possible that even if an association were present, this survey might not have detected the association because of a "healthy worker effect." In many workplaces, employees who become ill due to workplace exposures (or are more susceptible to illness) tend to seek other employment. The employees who remain in the workplace tend to be those who are healthy, and studies which examine only current workers (such as this one) might not detect an association between exposure and illness because the ill workers are not in the study or have moved to jobs not in the high-exposure category. The short duration of employment among workers at Modern Materials (median ten months) makes it very difficult to rule out this possibility, though it likewise cannot be proven from the available data. It is also possible that workers with low-exposure jobs at the time of the survey may have previously worked in jobs in higher exposures. Because the questionnaire asked only for current employment, this possibility could not be evaluated; if it were true, the investigation would have been less likely to detect an association between the exposure and symptoms or disease.

It is curious that the percentage of exposed employees reporting symptoms of runny nose, stuffy nose, eye irritation, and shortness of breath was lower than that of unexposed employees. The difference cannot be accounted for by differences in smoking prevalence or age in the two groups.

Ventilation Evaluation

Each coating line includes at least two major sources of contaminants that should be ventilated, the spray booth(s) and the curing oven. The high-tech area also includes walk-in spray booths and ovens which should be ventilated. In the parts cleaning area, the dip tanks and the drying oven were considered possible sources of contaminants and were evaluated for ventilation. In addition to evaluating each local exhaust system, general patterns of air flow were investigated with a smoke tube and a hot-wire anemometer.

Although most contaminant sources were equipped with local exhaust ventilation, the performance of these systems was highly variable, and in some cases was inadequate. In some areas, poor performance was caused by ventilation systems in need of design changes or improvements, while in other areas poor performance was caused by malfunctions or lack of adequate maintenance. Although a complete engineering evaluation was outside the scope of this HHE, some specific problems and recommendations for improvement are described here.

It should be noted that the requirements for ventilating a powder-coating operation may be slightly different than those seen in other industrial applications. The operation relies on weak electrostatic forces to carry the coating from the gun to the substrate. In order to allow an even coating to be applied, air currents in the booth must be kept relatively slow. Therefore, the spray booths rely on enclosure more than capture. That is, the spray gun must be located inside the booth, and the ventilation air flow should be just high enough to prevent the powder from escaping through the conveyor openings and the painter's access door. In contrast to the low air velocities required in the hood, the air velocity in the ducts must be relatively high to prevent the powder from settling. This is especially important because the powders are flammable and present a potential explosion hazard.

Although the ACGIH has not made specific recommendations for powder-coating operations, recommended duct velocities for dust collection equipment usually range from 2000 to 4000 feet per minute (FPM). The National Fire Prevention Association (NFPA) has also made recommendations concerning minimum duct velocities that are necessary to prevent potentially explosive concentrations of dust from developing. Unfortunately, the NFPA recommendations require a knowledge of the specific coating being used and the spray rate. A sample calculation presented in one publication indicates that total flow rates of around 1000 cubic feet per minute (CFM) per spray gun might be expected. The NFPA and the Powder Coating Institute (PCI) have also made recommendations concerning hood face velocities for spray booths used in powder-coating operations. The face velocity is defined as the average velocity of the air moving through the hood's openings. The NFPA recommends that the average face velocity should be no less than 60 FPM while the PCI recommends average face velocities of 90 FPM or greater.

While a complete engineering evaluation is beyond the scope of this HHE, there are some general ventilation guidelines that should be considered:

1. To the extent possible, the electrostatic spray guns should be completely enclosed in the spray booth.

2. The number of openings in each hood should be reduced to the minimum necessary, and the size of the openings should be reduced as much as possible.

3. Cross currents, or air movement across hood openings should be reduced or eliminated if possible. This will minimize the disruption of air flow patterns that are developed by the ventilation system and will increase the system efficiency.

4. Duct work should be designed to avoid turns and bends or changes in diameter. When turns are necessary, they should be as gradual as possible. Angles sharper than 45° tend to disrupt air flow and allow contaminants to accumulate and should be avoided.

5. Dented or damaged ductwork should be replaced.

6. Duct joints, turns, and elbows should not be made "in-house" by bending or folding straight sections of duct. In situations where odd angles are required, commercially available flexible ducts should be used.

7. Local exhaust ventilation systems require nearly constant supervision and maintenance. Inspections of all local exhaust systems should be performed on a monthly basis and a written record of any performance tests, malfunctions, and repairs should be maintained.

Observations made during the inspection of each work area are presented in the following sections.

Parts Cleaning and Surface Preparation Area

The parts cleaning area is shown schematically in Figure 3. Employees working in the parts cleaning and surface preparation had complained of eye irritation, which seemed to be linked to emissions from the gas-fired drying oven. Air sampling conducted in the area confirmed that CO and SO_2 levels in the area were higher than expected.

While the NIOSH team was not able to make a quantitative evaluation of the oven exhaust system, simple tests with smoke tubes indicated that the drying chamber was under positive pressure relative to the room. Significant leaks were found around the oven doors and around the burner. Because the oven is designed to vent the burner exhaust gases through the drying chamber, the chamber should be maintained under negative pressure. In most cases negative pressure is be achieved through the use of a fan on the exhaust stack. In order to determine if a fan has been installed and is operating correctly, the manufacturer or the engineering company that installed the oven should be contacted.

In addition to exposures from the drying oven, there may also be some potential for adverse effects from exposure to acid and/or corrosive mists and vapors from the dip tanks. Currently there are two wall fans installed behind the row of smaller tanks (A-H in Figure 3). Although these fans, when operating, may help move air away from the work area, they do not provide an efficient system for capturing mist or vapor and would have little or no effect on the larger tanks (I-M in Figure 3). In order to properly ventilate the dip tanks, a ventilation system with local exhaust hoods is required. Two possible designs that could be utilized are included in Appendix A. These diagrams are taken from the ACGIH Industrial Ventilation Manual (ACGIH 1984) and provide general guidance in hood design. However, a ventilation engineer or experienced design professional should be contacted to develop appropriate plans for this specific operation.

Coating Line 1

Coating line 1 includes three possible sources of air contaminants; two spray booths and the gas-fired curing oven. The oven exhaust system would be difficult to evaluate. However, simple smoke tube tests seem to indicate that the oven chamber is under negative pressure relative to the room. Therefore, any combustion products or organics released by the curing process would probably not be released into the workplace.

Smoke tube tests indicate that the exhaust systems on the two spray booths are moderately effective, but may allow some contaminants to escape. Face velocity measured at the spray gun access door on hood 1 ranged from ND to 70 FPM. The average face velocity was below NFPA and PCI recommendations and was too low to provide complete control of contaminants. The distribution of air was also inadequate, with almost no movement around the top portion of the spray gun access port.

The booth is designed with two air intake slots, one at each end of the enclosure. The two slots are connected to one duct and would ideally have similar flow rates. Measurements made at the two slots indicated a flow rate of about 175 cfm at the slot closer to the main work area and a flow rate of 300 cfm on the opposite side. The total flow rate, based on these measurements is less than 500 cfm, which is probably inadequate to meet NFPA guidelines.

The relatively poor performance of booth 1 can be attributed to poor duct design and construction, and to inadequate maintenance. Specific problems that were noted with the system include the following:

1. The main duct is badly dented and in some areas has been closed to about half of the original diameter.

2. One connection between the booth and the ventilation duct was broken open.

3. There was a leak at the junction of the main duct and the cyclone dust collector.

4. There was a near 180^{o} bend in one duct just before the connection to the booth.

5. The main duct was allowed to form a "dead end" and was blocked with cardboard and tape which did not form a good seal.

Air flows and velocities measured on hood 2 of line 1 were somewhat higher than those recorded for hood 1. No major breakdowns or malfunctions were identified on hood 2. However, the basic design of the ducts could be improved. The major problems with the current system are the near 180^{o} turn where one branch joins the main duct and the 90^{o} angle used to connect the second branch to the main duct. As on booth 1, the dead-end on the main duct should be eliminated unless it is used for duct clean-out or is intended to provide additional flow and prevent powder from collecting in the main duct.

Coating Line 2

Coating line 2 uses an electrically heated oven, and, therefore, has no oven exhaust system. Although the use of electric heating coils eliminates problems with combustion products, the lack of an exhaust system may allow organics that are released by the coatings to enter the workplace. Although air sampling did not find high levels of contamination at the time of the survey, the buildup of residue on the walls, ceiling, and cooler parts of the oven indicates that low to moderate volatility organics are released. Unfortunately, the potential health significance of these releases is not known.

Inspection of the spray booth on line 2 found good capture efficiency at all openings with no major design problems or malfunctions. One minor leak was located at the junction of the main duct with the cyclone. It was also noted that the main duct is longer than is considered ideal, and might have allowed dust to settle and accumulate. Therefore, routine inspections should be conducted to make sure that the duct stays open and is not blocked by settled materials.

Coating Line 3

The curing oven on line 3 is gas fired, and is therefore equipped with an exhaust system. Tests with smoke tubes indicated that the oven chamber is at negative pressure relative to the work area, so emissions should not be a significant problem.

Line 3 has only one spray booth. However, it is larger than any of the other booths in this facility and incorporates two spray guns. The booth is designed to be used with two self-contained ventilation units which are available from the manufacturer and can be installed directly across from the guns. In this installation, only one ventilation system has been installed. The arrangement provides good capture efficiency for the gun opposite the ventilation unit, but allows significant coating to escape from the opposite end of the booth. Face velocity measurements taken at the ventilated end of the booth indicated uniform flow at velocities of 75 to 90 FPM, which is within NFPA recommendations. Face velocities at the opposite end of the booth were too low to measure.

In order to improve the system's overall performance, an extension was added at the end of the booth that is farthest from the ventilation system. This extension seems to have improved the situation, but has not resolved the problem entirely. One reason that the capture efficiency is relatively poor is because of strong cross drafts that move past line 3 from the shipping and receiving area. A wall, or a wind curtain, between the loading dock and the spray booth would probably help to improve the ventilation system performance. The performance might also be improved by moving the ventilation unit to the opposite end of the booth since the general room air currents would then carry contaminants toward the ventilation system rather than away from it.

Other Ventilation Systems

In addition to the local exhaust systems described above, ventilation in the high-tech area and piston-treating operation were also reviewed. In the high-tech area, the ventilation systems seemed to be working properly. However, at the time of the evaluation, one employee was observed spraying coatings outside of the booth. Employees should be trained in proper use of the spray booths and should be discouraged from working outside the booth. In the piston treatment area, the booth ventilation seemed to be functioning properly. However, both exhaust stacks from the gas-fired oven were broken and were allowing fumes to escape into the workplace.

General Dilution Ventilation

In addition to inspecting the ventilation system, the general patterns of air flow in the work area were also considered. Movement around line 1 was from the area of the curing ovens toward the workers who were placing parts on or removing parts from the conveyor. Air from the first floor production area was also found to move through the elevator shaft to the second floor storage room. It therefore seems possible that contaminants released from the curing process could affect people in the office area. Because some of the health concerns involve sensitization, and because some of the people who described the most problems work in the office area, this may be an important consideration.

The general layout of line 3 is also shown in Figure 1. At the time of the survey, the general direction of air movement was from the loading dock and spray booth toward the area where parts were placed on and removed from the conveyor. At times, the air currents were fast enough to interfere with the capture efficiency of the spray booth exhaust hood and, in general, they seemed to carry coating powders from the spray area toward workers who were hanging parts on, or removing parts from, the moving conveyor.

CONCLUSIONS AND RECOMMENDATIONS

The HHE described here was initiated as a result of management concerns over possible exposures to chemicals used in, or originating from, powder-coating operations. Initially, the major concerns focused on the possibility that workers were being exposed to isocyanates which are used in the polyester powder coatings.

While the initial interviews suggested the possibility of work-related respiratory problems and eye irritation, the analysis of responses to the NIOSH questionnaire did not reveal significant positive associations between exposures and disease or exposures and symptoms. It is possible that sporadic individual cases of work-related illness may have occurred; these would not be detected as a statistically significant event because the percentage of affected workers would have been too small. Laboratory investigations were unable to detect any significant isocyanate release when coating samples were heated. However, the environmental investigation did reveal potential exposures to several other compounds and identified numerous health and safety problems in the facility.

Although there was no clear evidence of any pattern of occupational disease, comparison of the air sampling results to established criteria indicate that employees may be over-exposed to a variety of compounds including the following:

1. Combustion products released from gas-fired ovens in the parts cleaning and piston treatment areas

2. Uncured powder coatings that escape from the spray booths

3. E-caprolactam, which is released by some polyester coatings

4. Aldehydes, which are released during the curing process

5. Hexavalent chromium, which is used in the surface treatment area

Although these exposures should be reduced through improved industrial hygiene, the greatest hazards are likely to result from the lack of a generally adequate industrial health and safety program. In particular, employees should be protected by engineering controls, should receive better training and should be required to wear safety shoes and eye protection. In some operations, chemical protective clothing, such as gloves and aprons should also be required. Safety equipment, such as fire extinguishers and eye washes, must be maintained in functional condition, and safety hazards, such as holes in the floor, should be quickly repaired.

Specific recommendations regarding general safety, chemical exposures, and ventilation improvements are presented in the following sections.

General Safety Recommendations

1. In order to address general health and safety issues, a safety committee, including both employer and employee representatives, should be established.

2. One employee should be given responsibility for ensuring that safety procedures established by the committee are being followed. This person should be provided with adequate training. Several organizations, including the National Safety Council and NIOSH, offer safety training programs that are appropriate for non-professionals who are responsible for plant safety.

3. Eye trauma from foreign bodies and foot injuries are preventable. Modern Materials should institute and enforce programs requiring the use of protective eye wear and footwear. Glasses should be required in all production areas and chemical splash goggles should be required in the parts cleaning and surface treatment area. Use of protective equipment supplements other aspects of a complete safety program, but does not reduce the need for engineering controls and proper work practices.

4. Safety equipment, including eye wash stations, safety showers, and fire extinguishers should be inspected on a routine basis and maintained in

good operating condition. Access paths to safety equipment must be kept clear so that employees can reach the equipment when it is needed.

5. Building upkeep and repair should be improved. A number of problems with the building were identified that could have safety significance. In particular, there were many blocked aisles which might present a tripping hazard or slow down evacuation in case of fire. There were also at least two holes in the floor that should be repaired. One was in the parts cleaning room and the other in the basement. Floor drains were also left uncovered and should be equipped with covers or gratings. The wooden steps going up to the spray platform on line 3 were broken and should be repaired.

6. Labeling of chemicals and other aspects of hazard communication, including worker training, should be improved. As a manufacturing facility, Modern Materials is required to meet all provisions of OSHA's hazard communication standard. The MSDS file meets one portion of that requirement. However, it is not clear that other regulations concerning worker training and chemical labeling have been met. Chemical containers, including dip tanks and storage bins should be labeled. Labels should identify the contents and any known hazards that are associated with that material. A number of commercial packages that include training materials and labels are available and can help meet the requirements of the hazard communication standard.

7. Electrical systems and wiring problems should be evaluated for safety and any potential hazards corrected. Although a careful inspection of the building's electrical system was not included as part of this evaluation, some of the wiring appeared to be in poor condition. In particular, there was an open electrical control box with exposed wires and unmarked controls in the high-tech area. This circuit may not have been in use, but if it was, it was a clear safety hazard. The wiring of lights in the back room also looked like it could present some problems. Coating powders do present a potential fire and explosion hazard, and spark proof or explosion proof equipment may be required in some areas. Use of household lighting fixtures should be avoided in areas where powder can become airborne.

8. A number of unsafe forklift operations were observed during the evaluation. Forklift trucks should be equipped with warning lights, horns, and a "reverse alarm" that sounds whenever the vehicle is moving backwards. Drivers should be sent to training classes to obtain operators' licenses, and untrained employees should be prohibited from operating lift trucks.

9. Baskets full of parts should be moved to and from the coating lines and parts cleaning operation on dollies, and not simply pushed across the floor.

10. Routine safety inspections should be performed on a monthly basis. These should include an inspection of ventilation ducts, and of burners and exhausts on gas-fired ovens, as well as an evaluation of general

housekeeping. Written records of all safety violations should be maintained so that persistent or unresolved problems can be identified.

Control of Chemical Exposures

1. Because sensitized individuals may react to extremely low levels of isocyanates, and because the investigation was not able to rule-out the possibility that exposures are occurring, non-isocyanate coatings should be substituted for isocyanate-based coatings whenever possible.

2. When the use of isocyanates is unavoidable, those employees who may be sensitized should continue to stay out of the building. If feasible, isocyanate-based coating operations should be shifted to the Louisiana facility where there are no reports of sensitization. This recommendation is based on an understanding that the Louisiana facility is designed for applications of this type and is equipped with better ventilation than the Indiana facility. If exposures are likely to occur in Louisiana, then operations should not be shifted because sensitization could also occur at that site.

3. Exposure to dust from uncured powders should be minimized. Improved ventilation design is the best method of achieving reductions in exposure level. However, changes in work practices and increased use of personal protective equipment may be suitable as temporary solutions. Based on the dust and E-caprolactam levels measured in this HHE, employees who control the spray guns and who perform cleanup at the end of the shift should use respiratory protection. A NIOSH approved quarter-mask or half-mask respirator with particulate filter is preferred. Users should be made aware that these respirators will only provide protection against the dust, but will not protect the wearer against gases such as aldehydes or isocyanates. To the extent possible, the cleanup should be conducted in a well-ventilated area, such as the large spray booth in the high-tech area. Use of compressed air to blow dust off parts and clothing should be discouraged because it produces an inhalation hazard and an eye injury hazard. A vacuum system with a high-efficiency particulate air (HEPA) filter should be utilized if technically feasible.

4. Touch-up spray painting should be conducted in well ventilated areas. Specially designed painting booths equipped with local exhaust ventilation and located in convenient areas would be ideal, but the booth available in the High Tech area may also be adequate for this application.

5. Exposure to combustion products should be reduced through improved maintenance of burners and exhausts on gas-fired ovens. Ovens should be checked for leaks by using smoke tubes on a routine basis.

6. Although many of the materials used for cleaning and surface treatment are not highly hazardous, some contain bases and acids, including chromic acid. These materials are caustic in the concentrated form, and chromic acid is considered by NIOSH to be a possible human carcinogen. Skin exposure should be minimized through the use of rubber gloves, and inhalation exposures should be minimized through the use of improved ventilation. Protective equipment, including a face shield, should be used when mixing a new tank of acid or base and when handling the

concentrated materials. When the tanks containing acids or bases are not in use, they should be covered. The potential for splashes and skin contact can also be reduced by using a deeper tank that will not overflow when the parts basket is lowered in.

Ventilation Improvements

While most of the operations do have local exhaust systems, the efficiency of those systems can be improved. Improved ventilation efficiency can have a number of advantages, including improved dust control, increased recovery of coating powder, and possible energy savings through reduced exhaust volumes. Some suggested improvements are the following:

1. During the walk-through, investigators identified numerous ventilation malfunctions. Breaks in the ducts on line 1 should be repaired as soon as possible. Breaks found in some exhaust ducts probably result from poor design that puts excessive stress on the connections. When those systems are repaired, it may be appropriate to insert a short section of flexible duct to relieve some of that tension.

2. Breaks in the drying oven exhaust located in the piston treating area should be repaired as soon as possible. Flexible metal exhaust duct may be useful in that area. Duct tape should be avoided because the ducts are likely to get hot.

3. The exhaust system on the drying oven in the parts cleaning area should be inspected and repaired or modified so that the oven operates at negative pressure relative to the room.

4. The external exhaust stacks on most of the local exhaust systems should be extended away from, and if possible, above the building. Fumes released along the building walls are likely to reenter through windows, wall fans, and doors. The cone-style weather caps on exhaust stacks should also be replaced with double sleeve designs which are more efficient. ACGIH diagrams for proper design of weather caps are included in Appendix B.

5. The spray booth on line 3 should be equipped with a second ventilation unit. Until this is installed, the current ventilation system should be moved to the end of the booth that is closer to the oven. This should improve performance by taking advantage of room air currents which would then move the airborne dust toward the ventilation intake.

6. Wind curtains or walls should be used to block cross drafts that interfere with capture efficiency. It appears that line 3 is especially affected by cross drafts. A wind barrier should be placed between the shipping and receiving dock and the spray booth on line 3.

7. A system of local exhaust hoods should be installed behind the dip tanks in the parts cleaning operation. The tanks containing acids should be given highest priority for ventilation.

8. During the warmer months, general dilution ventilation should be improved by repairing all wall and window fans. Whenever possible, the wall fans should be oriented so that they draw contaminants from the ovens and booths away from the workers rather than across the work area.

9. To the extent possible, spray booth efficiency could be improved by reducing the size and number of openings.

10. The "dead-ends" on the main ventilation ducts on line 1 should be inspected and repaired. In some designs the end of a duct is intentionally left open to balance flow and to sweep out settled dust. However, in this case it appears that the end of the duct should be blocked with sheet metal. The design should be reviewed and the system repaired to the original state.

REFERENCES

ACGIH Committee on Industrial Ventilation [1984]. Industrial ventilation: a manual of recommended practice, 18th edition. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

Bokelund FS, Fregert, Trulsson L [1980]. Sensitization from epoxy resin powder of high molecular weight. Contact Dermatitis 6(2):144.

Evtech [1989]. Material Safety Data Sheet for Evlast polyester/polyurethane powder coatings, 100 series. MSDS-11, 152A-1 (06-89).

Eller PM, ed. [1989]. NIOSH manual of analytical methods. 3rd edition revised. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, the National Institute for Occupational Safety and Health.

Lemon RC [1972]. Epoxy resins in surface coatings. Ann Occup Hyg 15:131-136.

Mathias CGT [1988]. Allergic contact dermatitis from triglycidyl isocyanurate in polyester paint pigments. Contact Dermatitis 19(1):67-68.

Mobay Chemical Corporation [1976]. Chemistry for coatings. Mobay Chemical Corporation, Plastics and Coatings Division, p. 1-16.

NIOSH [1977]. Occupational diseases: a guide to their recognition. Revised Edition, Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health.

NIOSH [1984]. Congressional testimony: statement of J. Donald Millar, M.D., Director, National Institute for Occupational Safety and Health, Centers for Disease Control, Public Health Service, Department of Health and Human Services, before the Subcommittee on Health and Safety, Committee on Education and Labor, House of Representatives, May 15, 1984.

Pedersen NB [984]. Occupational dermatoses. In: Harrington JM, ed. Recent advances in occupational health, 2:73-86.

Peltonen K [1986a]. Gas chromatographic - mass spectrometric determination of volatile compounds arising from epoxy powder paints during the curing process. Analyst 111:819-822.

Peltonen KP, Pfaffli A, Itkonen, Kalliokoski P [1986b]. Determination of the presence of bisphenol-A and the absence of diglycidyl ether of bisphenol-A in the thermal degradation products of epoxy powder paint. Am Ind Hyg Assoc J 47(7):399-403.

Proctor NH, Hughes JP, Fischman ML [1988]. Chemical hazards of the workplace, second edition, J.P. Lippincott Company, Philadelphia.

Pukkila JH, Kokotti, Peltonen K [1989]. Thermal degradation of polyester coating powders: 1,4-dicyanobenzene as an occupational marker compound. Analyst 114(9):1009-1012.

Rice DL, Jenkins DE, Greenberg SD [1973]. Chemical pneumonitis secondary to inhalation of epoxy pipe coating. Archives of Environmental Health 32(4): 173-178.

Richart RS [1985]. Powder coatings in: Graber E, Klinsberg A, Siegeled PM eds. Kirk and Othmer: concise encyclopedia of chemical technology. New York, NY: John Wiley and Sons, pp. 944-945.

Streitwieser A, Heathcock CH [1976]. Introduction to organic chemistry. New York, NY: MacMillan Publishing Company, p. 943.

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Copies of this report have been sent to:

1. Modern Materials Incorporated
2. OSHA Region V
3. NIOSH, Cincinnati

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

Table I
Exposure Criteria for Chemicals Measured at Modern Materials Incorporated
HETA 90-174

CONTAMINANT	TWA	STEL or CEILING	SOURCE
Caprolactam dust	1 mg/m^3	3 mg/m^3	NIOSH
Caprolactam vapor	1 mg/m^3	3 mg/m^3	NIOSH
Total dust (PNOC)	10 mg/m^3	NA	ACGIH
Formaldehyde*	0.02 mg/m^3	0.12 mg/m^3	NIOSH
Acrolein	0.25 mg/m^3	0.8 mg/m^3	NIOSH/OSHA
Acetaldehyde*	LFC	LFC	NIOSH
VOCs	NA	NA	NA
Carbon monoxide	35 ppm	200 ppm	NIOSH/OSHA
Sulfur dioxide	0.5 ppm	NA	NIOSH/OSHA
Nitrogen dioxide	NA	1 ppm	NIOSH/OSHA

* NIOSH urges that exposures to carcinogens be reduced to the lowest feasible level because it is not possible to establish thresholds which will protect 100% of the population. NIOSH recommends that exposures to formaldehyde be controlled so that employees are not exposed to concentrations greater than 0.02 mg/m^3 measured as a TWA concentration for up to a 10-hour work day and a 40-hour workweek. NIOSH further recommends a 15-minute STEL of 0.12 mg/m^3. Although NIOSH has established these guidelines which should not be exceeded, the institute still urges that exposures be reduced to the lowest feasible concentration.

Abbreviations:

mg/m^3: milligrams per cubic meter
ppm: parts per million
OSHA: Occupational Safety and Health Administration
NIOSH: National Institute for Occupational Safety and Health
ACGIH: American Conference of Governmental Industrial Hygienists
TWA: Time-Weighted Average
STEL: Short-Term Exposure Limit
VOCs: Volatile Organic Compounds
LFC: Lowest Feasible Concentration
NA: Not Applicable
PNOC: Particulate Not Otherwise Classified

Table II
Results of Bulk Powder Analysis
HETA 90-174
Modern Materials Inc.

Compound	Coating Sample 1	2	3	4	5	6	7	8	9	10
Formaldehyde	x	x	x	x	x			x	x	x
Acetaldehyde	x	x	x	x	x			x	x	x
Acrolein	x		x	x					x	x
Benzaldehyde		x	x	x		x	x	x		
Caprolactam	x		x	x	x					
Methyl Butanal	x									
Butanal	x				x					
Toluenediamine	x									
Pentanal		x								
Benzene		x		x			x		x	x
Benzil		x		x		x	x	x	x	x
Toluene			x	x			x		x	
Acetone			x		x					
Pyridine			x			x				
Ethylhexanol			x	x		x				
Phenol				x						
Isobutanol	x					x				
Benzonitrile				x		x				
Allyl Isothiocyanurate										
Tolyl Isothiocyanate						x			x	
Benzene Isothiocyanate						x			x	
2-Ethyl-1-Hexanol						x				
Toluidine								x	x	
Benzene Isocyanate									x	
Aniline									x	
Methyl Pyridine									x	

All samples were heated to 280°C for 15 minutes.
Emissions were collected on solid adsorbent and eluted with carbon disulfide or collected in toluene for GC-MS analysis.

Table III
Results of Air Sampling For Total Dust
HETA 90-174
Modern Materials Inc.
November 1991

Location	Concentration (mg/m^3)
Area Sample	5.3
Top of control box, line 1	58.4*
Behind painters station	3.3
Inspection bench	6.2
Bag house, line 3	7.9
Desk near inspectors, line 3	2.4
Spray Booth, line 1	4.1
Cyclone, line 1	5.6

* Exceeds OSHA PEL and ACGIH TLV

EVALUATION CRITERIA

Exposure Standard	Dust (mg/m^3)
ACGIH TLV (8-hour TWA)	10
OSHA PEL (8-hour TWA)	15

ABBREVIATIONS

mg/m^3 : milligrams of contaminant per cubic meter of air
ACGIH : American Conference of Governmental Industrial Hygienists
OSHA : Occupational Safety and Health Administration
PEL : Permissible Exposure Limit (8-hour exposure)
TLV : Threshold Limit Value (8-hour exposure)

Table IV
Results of Air Sampling for E-Caprolactam
HETA 90-174
Modern Materials Inc.
November 1991

Job Description / Location	Average Concentration Dust (mg/m^3)	Vapor (mg/m^3)
Painter (personal sample)	0.73	0.12
Painter (personal sample)	4.86*	0.11
Inspector (personal sample)	ND	0.32
Inspector (personal sample)	0.28	0.08
Control Box, line 1	0.06	1.84**
Oven Door, line 1	0.10	0.10
Cyclone Collector, line 1	0.70	0.50
Oven Door, line 2	ND	ND

* A full shift exposure at this concentration would exceed the OSHA PEL and the NIOSH REL.
** A full shift exposure at this concentration would exceed the NIOSH REL.

EVALUATION CRITERIA

Exposure Standard	Dust (mg/m^3)	Vapor (mg/m^3)
NIOSH REL (10-hour TWA)	1	1
NIOSH STEL	3	3
OSHA PEL (8-hour TWA)	1	20
OSHA STEL	3	40

ABBREVIATIONS

mg/m^3 : milligrams of contaminant per cubic meter of air
NIOSH : National Institute for Occupational Safety and Health
OSHA : Occupational Safety and Health Administration
REL : Recommended Exposure Limit (10-hour exposure)
PEL : Permissible Exposure Limit (8-hour exposure)
STEL : Short Term Exposure Limit (15-minute exposure)

Table V
Results of Air Sampling for Aldehydes
HETA 90-174
Modern Materials Inc.
November 1991

Job Description / Location	Acetaldehyde (mg/m³)	Formaldehyde (mg/m³)	Acrolein (mg/m³)
Personal Samples			
Leader, line 1	0.01	0.02**	0.01
Painter	0.01	0.00	0.00
Hanger-inspector, line 3	0.01	0.04**	0.01
Hanger-inspector, line 1	0.02	0.04**	0.01
Painting and hanging	0.05	0.08**	0.00
Painting and hanging	0.01	0.04**	0.00
Hanging, line 3	0.01	0.02**	0.01
Hanger, line 2	0.00	0.02**	0.01
Area Samples			
Top of booth (line 1)	0.01	0.01	0.02
Oven outlet (line 1)	0.01	0.03**	0.01
Line 1	0.01	0.06**	0.03
Cyclone (line 1)	0.01	0.05**	0.02
Oven outlet (line 2)	0.01	0.03**	0.01
Side of spray booth (line 3)	0.01	0.04**	0.01
Bag house (line 3)	0.01	0.06**	0.01
Paint booth (line 3)	0.00	0.01	0.01
Line 3	0.01	0.03**	0.01
Burn-off area	0.01	0.06**	0.01
High-tech area	0.01	0.06**	0.01
High-tech area	0.01	0.06**	0.02
High-tech area	0.01	0.09**	0.01

** Exceeds NIOSH REL

EVALUATION CRITERIA

Exposure Standard	Acetaldehyde* (mg/m^3)	Formaldehyde* (mg/m^3)	Acrolein (mg/m^3)
NIOSH REL (10 hour TWA)	LFL	0.02	0.25
NIOSH STEL	LFL	0.12	0.80
OSHA PEL (8 hour TWA)	180	1.20	0.25
OSHA STEL	270	2.50	0.80

* Because these compounds may be carcinogens, NIOSH urges that exposures be limited to the lowest feasible concentration.

ABBREVIATIONS

mg/m^3 : milligrams of contaminant per cubic meter of air
NIOSH : National Institute for Occupational Safety and Health
OSHA : Occupational Safety and Health Administration
REL : Recommended Exposure Limit (10-hour exposure)
PEL : Permissible Exposure Limit (8-hour exposure)
STEL : Short Term Exposure Limit (15-minute exposure)
LFL : Lowest Feasible Concentration

Table VI
Results of Air Sampling for Volatile Organic Compounds
HETA 90-174
Modern Materials Inc.
November 1991

Job Description / Location	Concentration (mg/m^3)
Personal Samples	
Line leader, line 1	<2.8
Hanger - inspector & painter, line 1	<2.8
Line leader, line 2	<2.8
Hanger - inspector, line 3	<2.8
Line leader, line 3	<2.8
Operator, high-tech area	<2.8
Area Samples	
Oven outlet, line 1	<2.8
Spray booth, line 1	<2.8
Front of inspection bench, line 1	>2.8
Oven outlet, line 2	<2.8
Open end of oven, line 3	>2.8
Bag house behind sprayer, line 3	<2.8
Oven outlet, line 3	<2.8
Paint booth, line 3	<2.8

mg/m^3: milligrams of contaminant per cubic meter of air.
<2.8 mg/m^3 indicates that VOCs were not detected.
>2.8 mg/m^3 indicates that VOCs were detected but the concentration was too low to be measured accurately.

Table VII
Results of Air Sampling for Combustion Products
HETA 90-174
Modern Materials Inc.
November 1991

Location	Average Concentration (ppm) CO	NO_2	SO_2
Operator breathing zone	5	ND	1.2*
Operator breathing zone	NA	ND	1.2*
Beside drying oven	25	ND	1.7*
Beside drying oven	23	ND	2.3**
Right end of dip tanks	12	ND	1.6*
Spray booth, line 1	ND	NA	NA
Inspection area, line 1	ND	NA	NA

* A full shift exposure at this concentration would exceed the NIOSH REL.
** A full shift exposure at this concentration would exceed both the NIOSH REL and the OSHA PEL.

EVALUATION CRITERIA

Exposure Standard	CO (ppm)	NO_2 (ppm)	SO_2 (ppm)
NIOSH REL (10-hour TWA)	35	NA	0.5
NIOSH STEL (15-min.)	NA	1.0	NA
NIOSH CEILING	200	NA	NA
OSHA PEL (8-hour TWA)	35	NA	2.0
OSHA STEL (15-min.)	NA	1.0	NA
OSHA CEILING	200	NA	5.0

ABBREVIATIONS

ppm : Parts Per Million
NIOSH : National Institute for Occupational Safety and Health
OSHA : Occupational Safety and Health Administration
REL : Recommended Exposure Limit (10-hour exposure)
PEL : Permissible Exposure Limit (8-hour exposure)
STEL : Short-Term Exposure Limit (15-minute exposure)
CEILING : Maximum Allowable Concentration At Any Time
NA : Not Applicable
ND : Not Detected
CO : Carbon Monoxide
$N0_2$: Nitrogen Dioxide
SO_2 : Sulfur Dioxide

Table VIII
Results of Air Sampling for Inorganic Acids
HETA 90-174
Modern Materials Inc.
November 1991

Location	Concentration (mg/m^3) Phosphoric Acid	Nitric Acid	Hydrogen-Chloride
Left end of dip tanks	0.00	0.04	0.03
Beside drying oven	0.00	0.00	0.02
Right side of dip tanks	0.00	0.04	0.04
Behind dip tanks	0.00	0.02	0.02

mg/m^3 : milligrams of contaminant per cubic meter of air.

EVALUATION CRITERIA

Exposure Standard	Phosphoric Acid (mg/m^3)	Nitric Acid (mg/m^3)	Hydrogen-Chloride (mg/m^3)
NIOSH REL (10-hour TWA)	1	5	NA
NIOSH STEL	3	10	NA
NIOSH CEILING	NA	NA	7
OSHA PEL (8-hour TWA)	1	5	NA
OSHA STEL	3	10	NA
OSHA CEILING	NA	NA	7

Table IX
Analysis of Bulk Samples from
Parts Cleaning Dip Tanks
HETA 90-174
Modern Materials Inc.
November, 1991

Sample	ph	Hexavalent Chrome Concentration (mg/ml)
1	12.5	<0.001
2	6.1	0.39
3	3.0	1.14
4	1.4	<0.001

mg/ml: milligrams of hexavalent chromium per milliliter of cleaning solution.

Table X
Distribution of Employees Within the Plant
Modern Materials Incorporated
HETA 90-174

Location	Number	Percent
Line 1	11	21
Line 2	3	6
Line 3	13	25
High-tech	4	8
Dipping area	2	4
Maintenance	1	2
Burn off	3	6
Shipping	2	4
Office	10	19
All over	3	6
Not specified	1	2
TOTAL	53	103%*

*Total is more than 100% due to rounding of percentages.

Table XI
Association of Symptoms with
Exposure to the Powder Coating Process
Modern Materials Incorporated
HETA 90-174

Symptom	Exposed Employees Reporting Symptom	Nonexposed Employees Reporting Symptom	P*
Stuffy nose	12 (38%)	6 (50%)	0.51
Runny nose	13 (41%)	6 (50%)	0.74
Sneezing	13 (41%)	4 (33%)	0.74
Eye irritation	5 (17%)	8 (67%)	0.003
Wheezing	13 (41%)	5 (42%)	1.00
Shortness of breath	9 (28%)	4 (33%)	0.73
Chest tightness	13 (41%)	3 (25%)	0.49

*Two-tailed Fisher's Exact test

The first column lists the symptom studied. The second column lists the number and percentage of workers with exposure who reported the symptom; the third column lists the number and percentage of workers without exposure who reported the symptom. The fourth column lists the result of a Fishers' two-tailed exact test; p is the probability that the results could have occurred by chance.

Table XII
Association of Symptoms with Exposure to the Powder Coating Process, Excluding Workers Whose Reported Symptoms Began Before Employment
Modern Materials Incorporated
HETA 90-174

Symptom	Exposed Employees Reporting Symptom	Nonexposed Employees Reporting Symptom	P*
Stuffy nose	10 (37%)	5 (45%)	0.720
Runny nose	11 (42%)	5 (45%)	1.000
Sneezing	10 (34%)	2 (20%)	0.693
Eye irritation	4 (14%)	7 (64%)	0.004
Wheezing	11 (37%)	4 (36%)	1.000
Shortness of breath	4 (15%)	4 (33%)	0.221
Chest tightness	12 (39%)	3 (25%)	0.492

*Two-tailed Fisher's Exact test

The first column lists the symptom studied. The second column lists the number and percentage of workers with exposure who reported the symptom; the third column lists the number and percentage of workers without exposure who reported the symptom. The fourth column lists the result of a Fishers' two-tailed exact test; p is the probability that the results could have occurred by chance symptoms.

Table XIII
Frequency of Reports of Disease
Modern Materials Incorporated
HETA 90-174

	Total Diagnoses		Diagnoses Since Starting Employment	
Disease	Frequency	Percent	Frequency	Percent
Tuberculosis	0/51	0%	0/51	0%
Pneumonia	10/51	20%	3/51	6%
Pleurisy	0/51	0%	0/51	0%
Bronchitis	18/51	35%	9/51	17%
Emphysema	0/51	0%	0/51	0%
Asthma	4/51	8%	2/51	4%
Sinus problems	19/51	37%	6/51	12%
Eczema	0/51	0%	0/51	0%
Hay fever	7/51	14%	5/51	10%
Allergies	11/51	22%	4/51	8%

See text for discussion of how diseases were classified by time of reported onset.

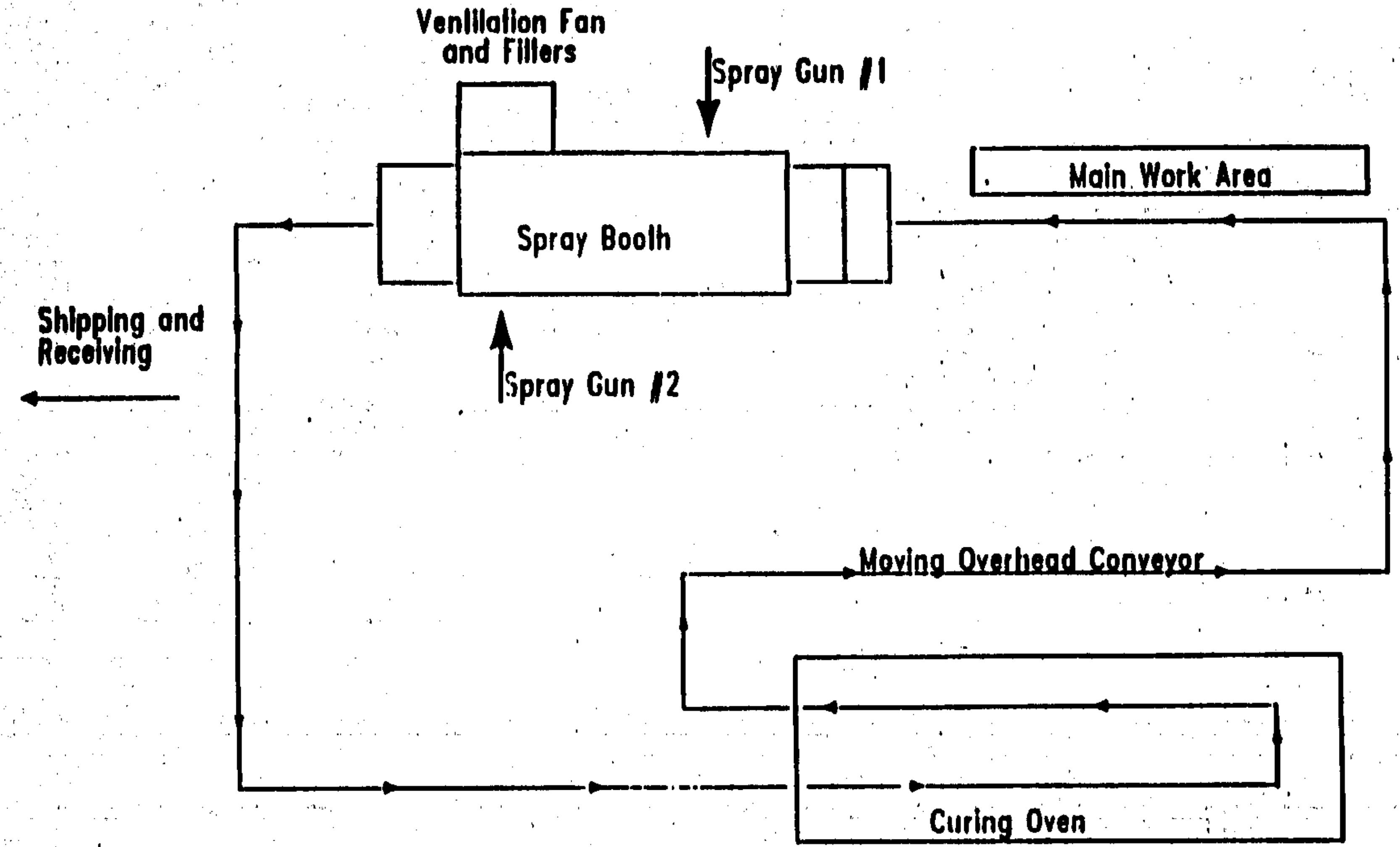
Table XIV
Association of Disease with Exposure.
Modern Materials Incorporated
HETA 90-174

Disease	Exposed Employees Reporting Disease*	Nonexposed Employees Reporting Disease*	P**
Tuberculosis	0/31 (0%)	0/11 (0%)	---
Pneumonia	1/28 (4%)	2/ 9 (22%)	0.14
Pleurisy	0/31 (0%)	0/11 (0%)	---
Bronchitis	3/28 (11%)	5/ 7 (71%)	0.003
Emphysema	0/31 (0%)	0/11 (0%)	---
Asthma	0/31 (0%)	2/11 (18%)	0.06
Sinus problem	2/24 (8%)	3/ 8 (38%)	0.09
Eczema	0/31 (0%)	0/11 (0%)	---
Hay fever	0/29 (0%)	2/11 (18%)	0.07
Allergies	2/28 (7%)	2/ 9 (22%)	0.24

* Denominators differ between diseases because different numbers of respondents reported having the disease before beginning work at Modern Materials; these were not included in the analysis.
**Two-tailed Fisher's Exact test

See text for discussion of how diseases were classified by time of reported onset.

Figure 1
Schematic Diagram of a Typical Coating Line



Objects to be painted are placed on the overhead conveyor at the main work area. The conveyor, which is electrically grounded, carries the objects into the spray booth where two electrostatic guns are used to create a charged aerosol of powdered coating. The electric field developed between the guns and the conveyor carries the coating to the substrate. The coated parts then move into an electric or gas-fired curing oven where the coating melts and flows to form a smooth, chemically bonded surface. As the parts move back to the main work area, they are inspected and either removed or allowed to run through the cycle again.

Figure 2
Schematic Diagram of the First Floor Production Area

A) Cleaning and surface-treatment area; B) High-tech area; C) Coating lin 1; D) Coating line 2; E) Coating line 3; F) Shipping and receiving; G) Loading dock; H) Production offices; I) Piston-treatment area.

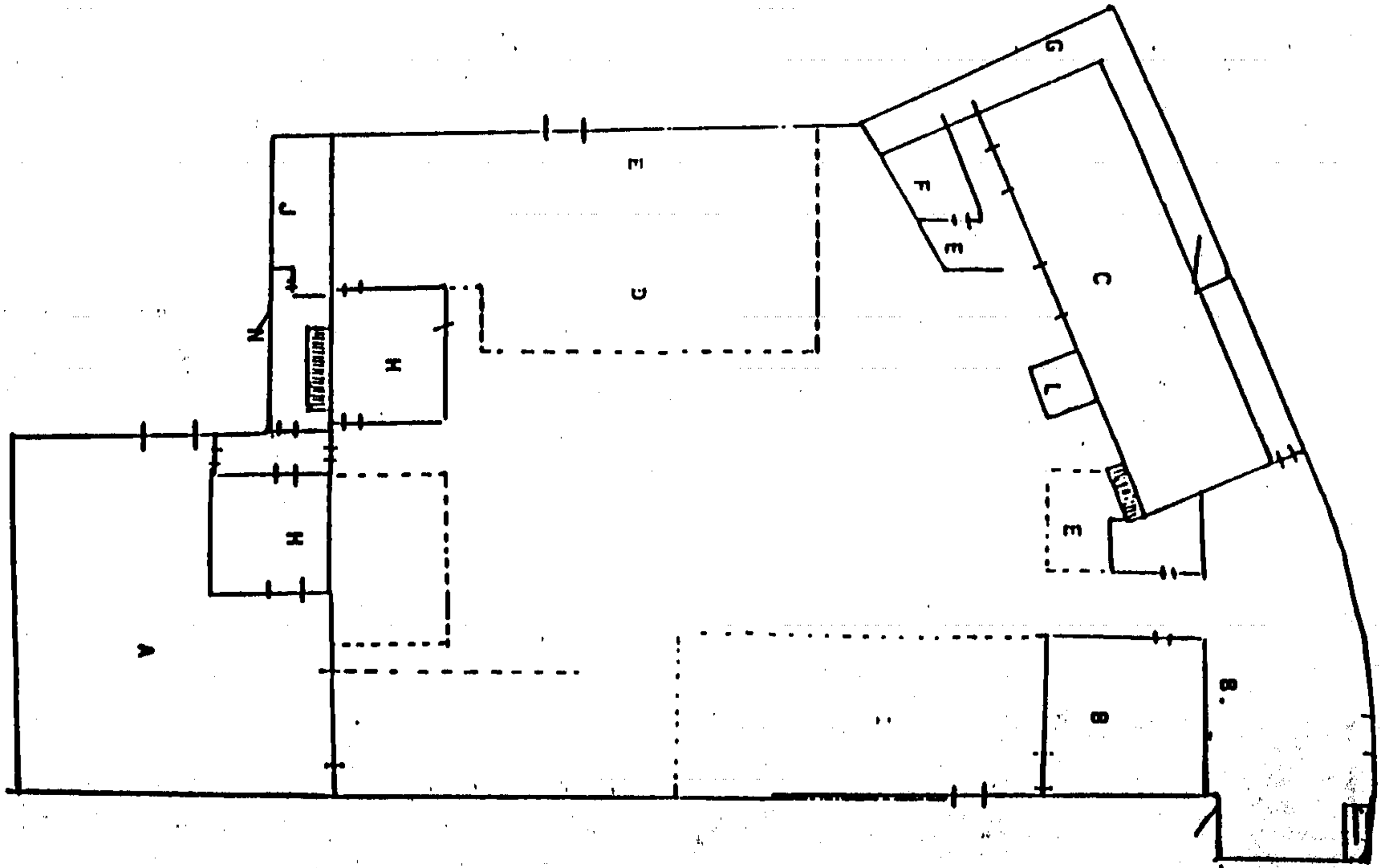
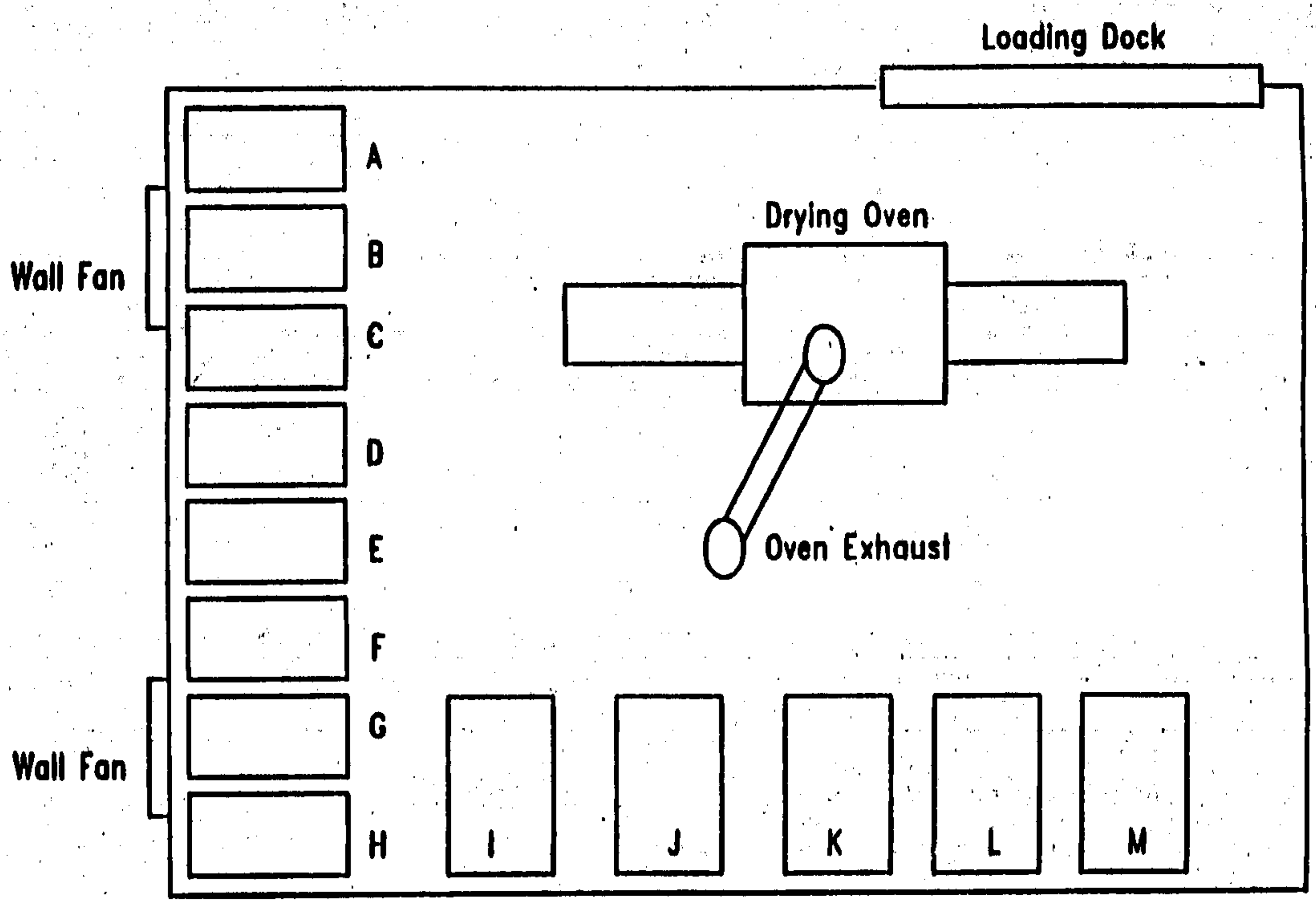
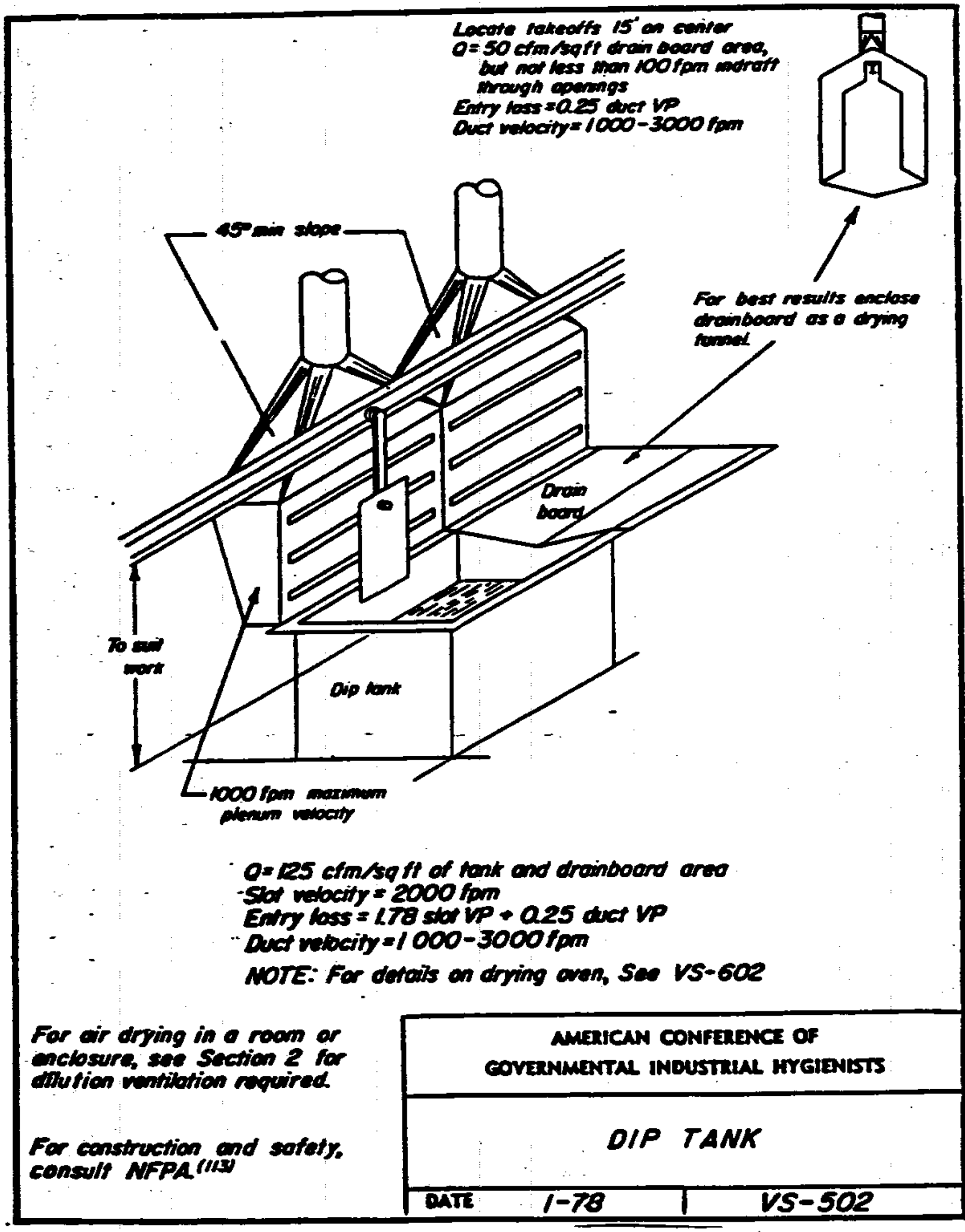


Figure 3
Parts Cleaning and Surface Treatment Area

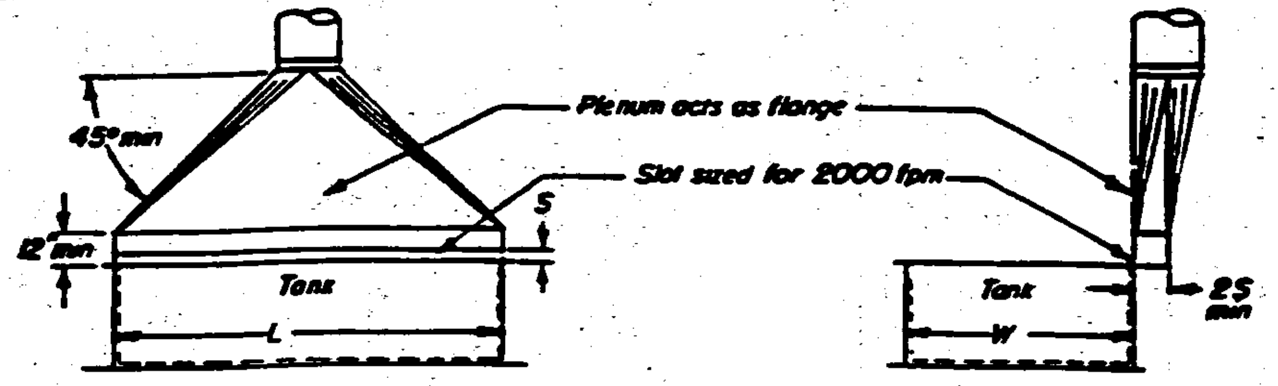


APPENDIX A

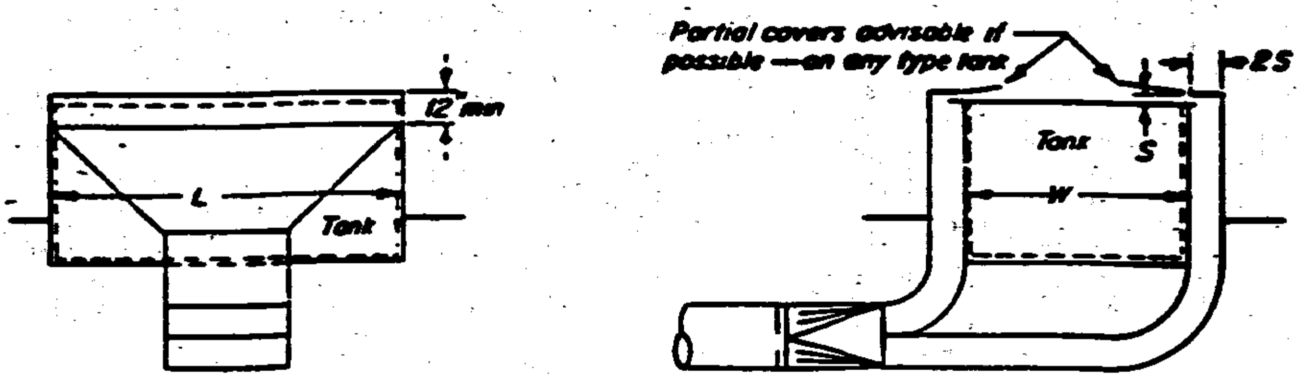
Ventilation Design Drawings and Specifications for Dip Tanks [2]



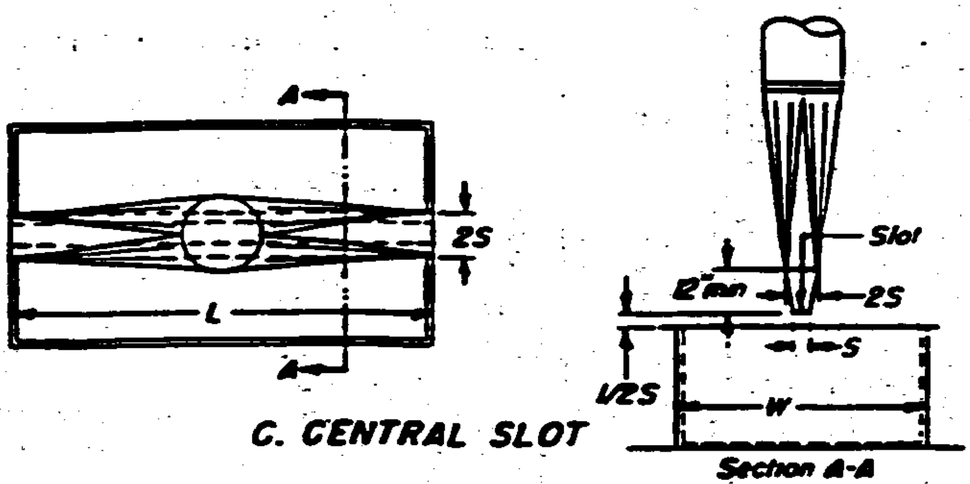
[2] All drawings and specifications are adapted from "Industrial Ventilation: A Manual of Recommended Practice", 18th edition, American Conference of Governmental Industrial Hygienists, 1984.



A. UPWARD PLENUM



B. DOWNWARD PLENUM



C. CENTRAL SLOT

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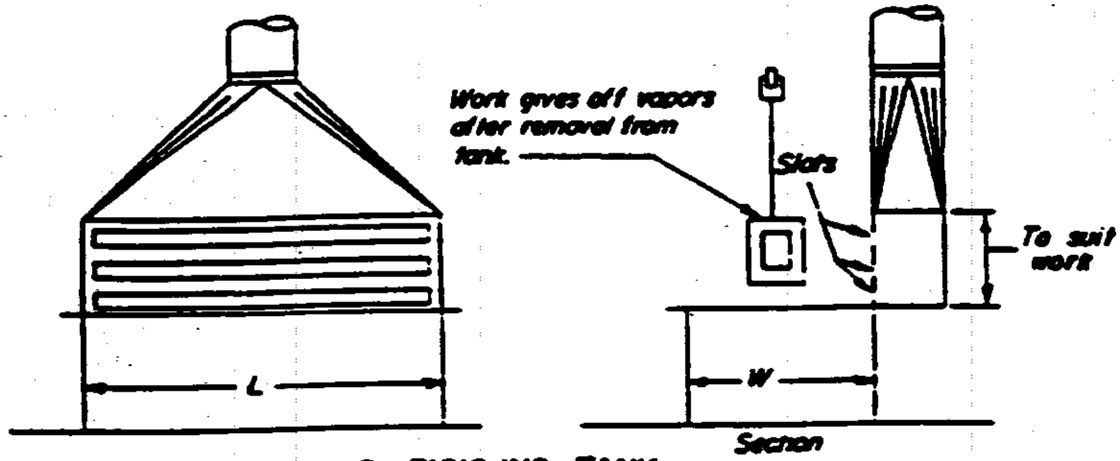
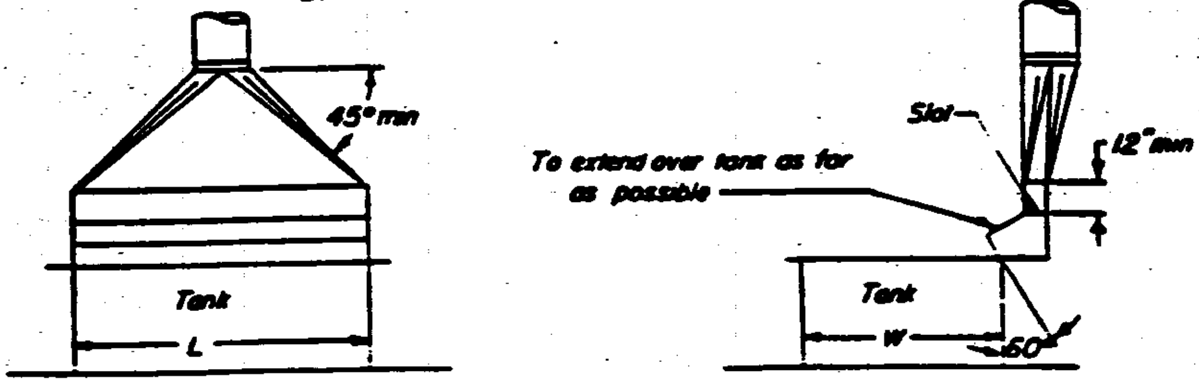
OPEN SURFACE TANKS

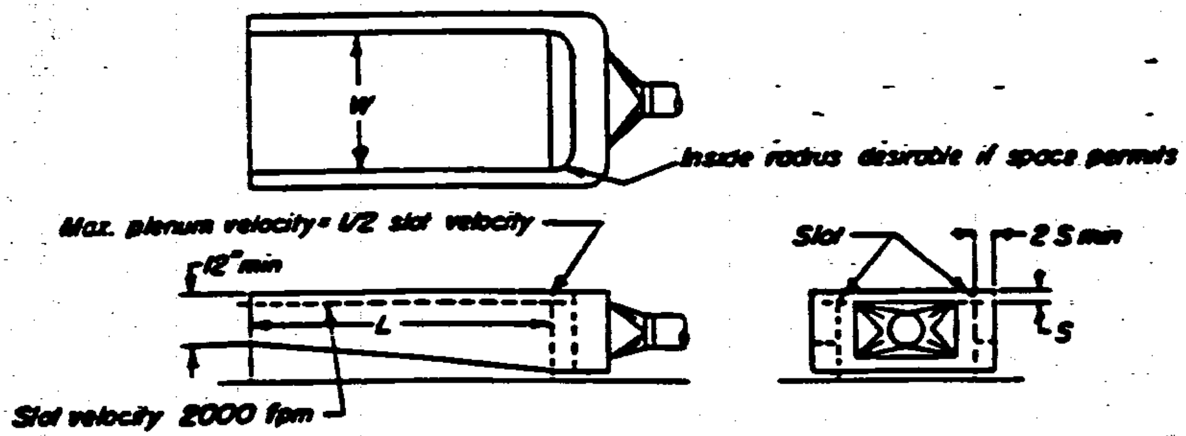
DATE	1-64	VS-503



D. PICKLING TANK



E. SEMI-LATERAL



F. END TAKE-OFF

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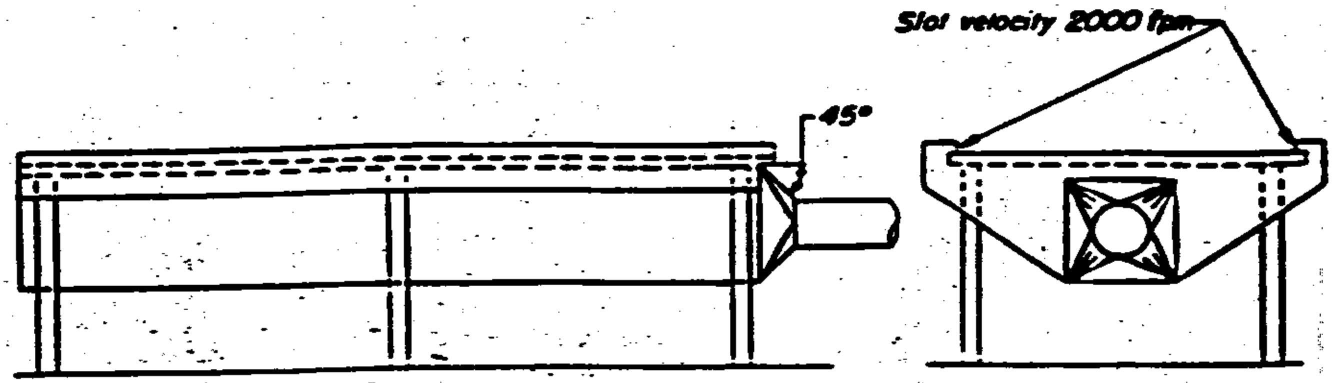
OPEN SURFACE TANKS

DATE	1-66	VS-504



Q = 50-100 cfm/sq ft of table top.
Duct velocity = 2500-3000 fpm
Entry loss = 1.78 slot VP + 0.25 duct VP

Note: See "Open Surface Tanks", VS-503 and VS-504 for other suitable slot types. Air quantities may be calculated on dilution basis if data is available. Maximum plenum velocity = 1/2 slot velocity. Large plenum essential for good distribution.

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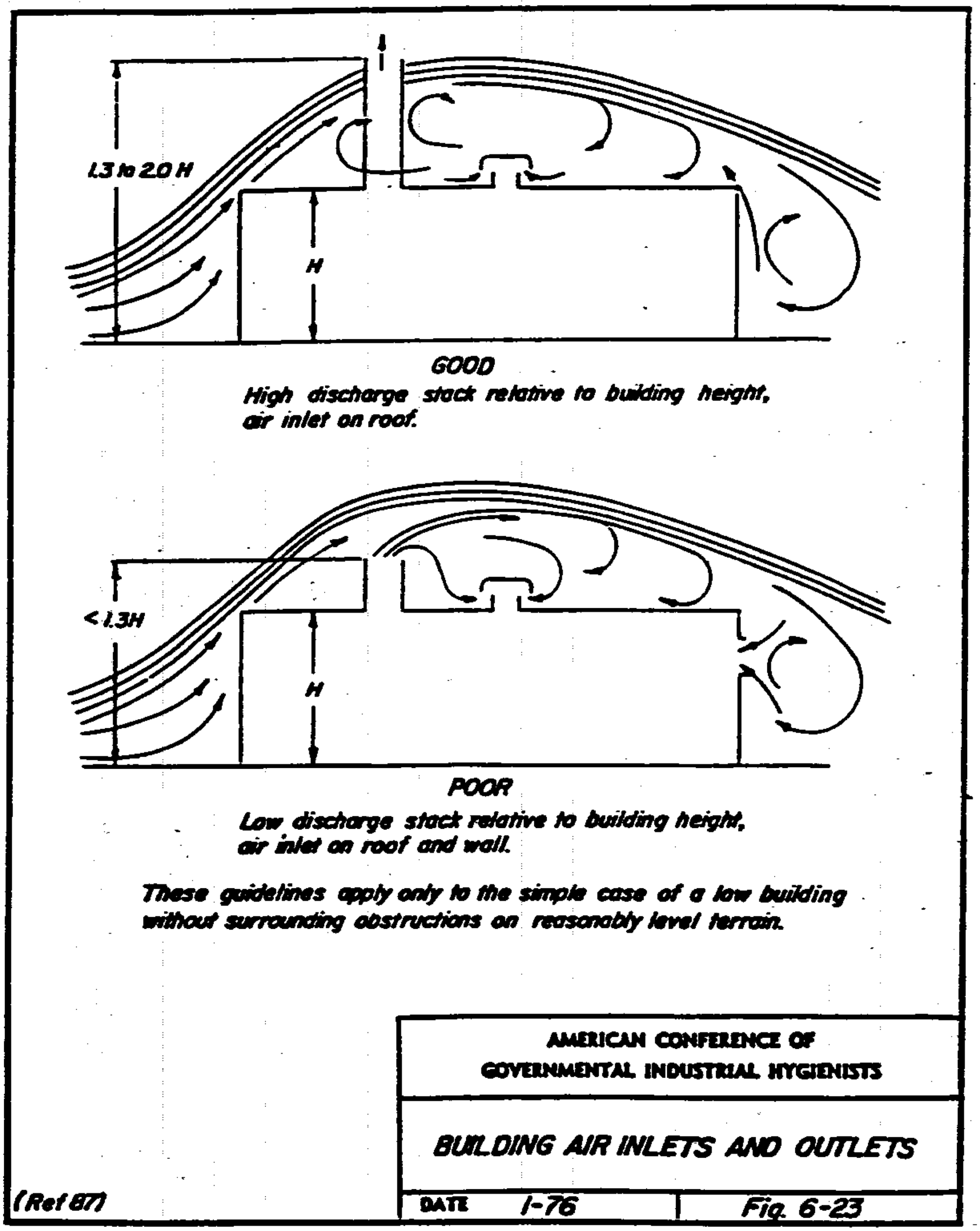
TABLE SLOT

DATE 1-70 | VS-505

APPENDIX B
Ventilation Design Drawings for External Exhaust Stacks [3]



GOOD

High discharge stack relative to building height, air inlet on roof.

POOR

Low discharge stack relative to building height, air inlet on roof and wall.

These guidelines apply only to the simple case of a low building without surrounding obstructions on reasonably level terrain.

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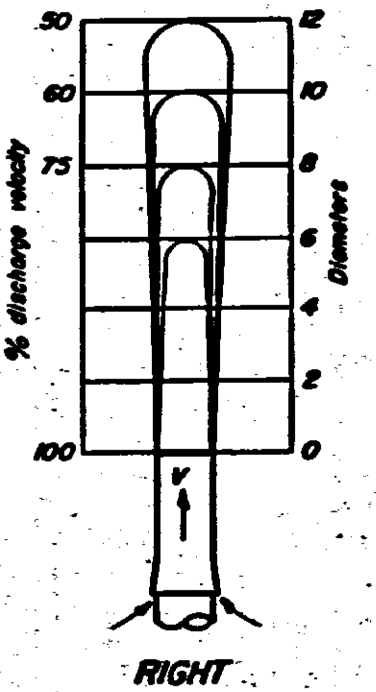
[3] All drawings and specifications are adapted from "Industrial Ventilation: A Manual of Recommended Practice", 18th edition, American Conference of Governmental Industrial Hygienists, 1984.

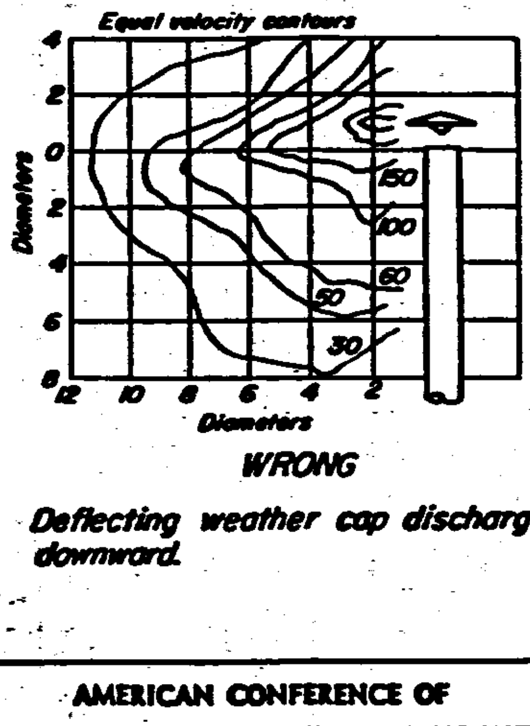
STACKHEAD



RIGHT

Vertical discharge cap throws upward where dilution will take place.

WEATHER CAP



WRONG

Deflecting weather cap discharges downward.

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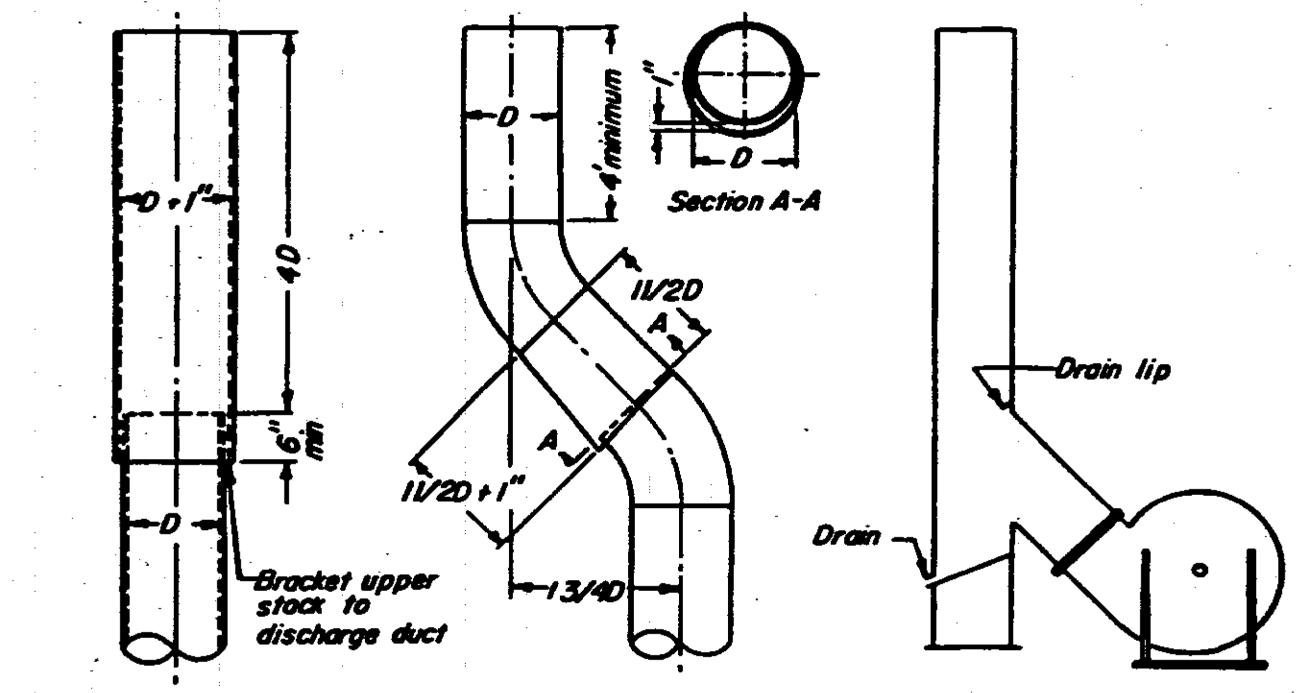
PRINCIPLES OF DUCT DESIGN

DATE 1-82 | Fig. 6-22



VERTICAL DISCHARGE [87][116]
No loss

OFFSET ELBOWS [106]

OFFSET STACK [106]

Calculate losses due to elbows

1. Rain protection characteristics of these caps are superior to a deflecting cap located 0.75D from top of stack.

2. The length of upper stack is related to rain protection. Excessive additional distance may cause "Blowout" of effluent at the gap between upper and lower sections. [86]

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STACKHEAD DESIGNS

DATE 1-76	Fig. 6-24