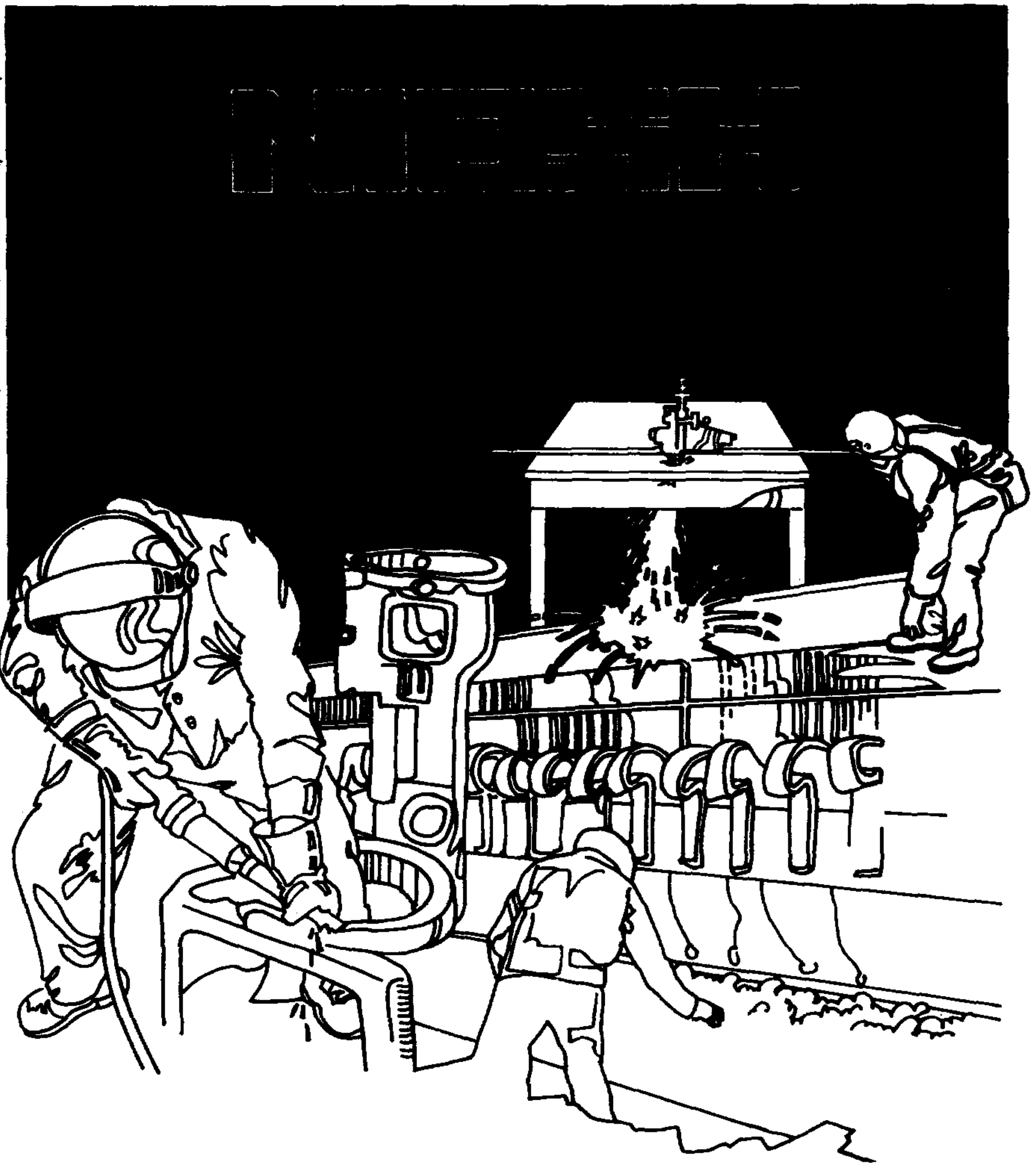
U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES ■ Public Health Service
Centers for Disease Control ■ National Institute for Occupational Safety and Health



Health Hazard Evaluation Report

MHETA 89-062-2004
DOWTY CORPORATION'S WELDING SHOP
WARRENDALE, PENNSYLVANIA

PREFACE

The Hazard Evaluations and Technical Assistance Branch of NIOSH conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

The Hazard Evaluations and Technical Assistance Branch also provides, upon request, medical, nursing, and industrial hygiene technical and consultative assistance (TA) to Federal, state, and local agencies; labor; industry and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

MHETA 89-062-2004
DOWTY CORPORATION'S WELDING SHOP
WARRENDALE, PENNSYLVANIA
OCTOBER 1989

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I. SUMMARY

In December 1988, the United Mine Workers of America (UMWA) requested the National Institute for Occupational Safety and Health (NIOSH) to investigate potential occupational health hazards from welding fume and solvent exposures at Dowty Corporation's welding shop, Warrendale, Pennsylvania. A preliminary walk-through evaluation was done on March 9, 1989. On March 27-29, 1989, NIOSH investigators conducted an industrial hygiene survey at Dowty Corporation's Warrendale welding shop.

The industrial hygiene survey was done to evaluate occupational exposures to welding fumes and solvents generated during shop operation. Air samples were collected for a variety of environmental analytes including metal fumes, organic vapors, nitrogen dioxide and other oxides of nitrogen, carbon monoxide, and ozone. Eleven different metals and elements, including aluminum, arsenic, calcium, chromium, copper, iron, magnesium, manganese, phosphorus, sodium, and zinc were measured in air at detectable concentrations. Worker exposures to these metallic and elemental welding fumes were below existing Occupational Safety and Health Administration (OSHA) standards. One of the personal welding fume exposures from the "stools" welding area exceeded the NIOSH REL for arsenic, 0.002 mg/m^3 as a ceiling (C) exposure limit.

Worker exposures to nitrogen dioxide, carbon monoxide and ozone - gases commonly generated by some welding operations - were all below existing exposure standards and recommendations of the Occupational Safety and Health Administration (OSHA), the American Conference of Governmental Industrial Hygienists (ACGIH), and NIOSH.

Exposure to organic vapors (isobutanol, trichloroethane, toluene, perchloroethylene and xylene) were all below the OSHA permissible exposure limits (PELs) and ACGIH Threshold Limit Values (TLVs). Perchloroethylene, considered a potential human carcinogen by NIOSH, was detected in one sample from the stools area saw operator at 0.04 parts per million parts air (ppm) as a time-weighted average (TWA).

Some aspects of shop ventilation were suboptimal and, in conjunction with work practices, increased worker exposures to welding fumes and solvents.

Exposures to welding fumes and organic solvents at Dowty Corporation's Warrendale welding shop did not exceed the permissible exposure limits enforced by OSHA or recommended by ACGIH; although worker exposure to arsenic and perchloroethylene exceeded NIOSH recommendations for lowest feasible limit (LFL) exposures to potential carcinogens. Recommendations for reducing worker exposures to welding fumes and solvents are contained in Section VIII of this report.

KEYWORDS: (SIC 1211), welding fumes, arsenic, solvents, paint spraying.

II. INTRODUCTION

On December 13, 1988, NIOSH received a health hazard evaluation request (MHETA 89-062) from the UMWA to investigate potential health hazards from occupational exposures to welding fumes and solvents at Dowty Corporation's welding shop in Warrendale, Pennsylvania. A preliminary walk-through evaluation was done on March 9, 1989 to become familiar with the shop and welding operations. On March 27-29, 1989, NIOSH investigators conducted an industrial hygiene survey at Dowty Corporation to assess occupational exposure to welding fumes and solvents.

III. BACKGROUND

Dowty Corporation's Warrendale shop builds and repairs longwall coal mining equipment. Approximately 100 employees work in the shop over two work shifts as machinists, maintenance workers, painters, assembly workers, and welders. Shop welding operations are divided into structural and line belt welding areas. Structural welding operations involve construction of the conveyor belt support frame and components; welding operations in this area are metal inert gas (MIG) welding on carbon steel with carbon steel electrodes. In the structural welding area, three welders work at individual welding stations to construct the conveyor belt support frames (stools area); one worker operates a metal saw in this area. Two welders operate automatic welding equipment at individual welding stations to prepare conveyor frame components (rollers area). Other shop employees work in proximity to these welding operations in the structural welding area.

A variety of welding operations are done in the line belt area to repair roof support shields and mining face conveyor components. Welding operations in this area are less routine and commonly include arc gouging, cutting, shielded metal arc welding (SMA), and tungsten inert gas welding (TIG). One welder generally works in the line belt area at various work points; other line belt area employees work in the proximity of welding operations.

The shop has a large open-bay design and other shop activities are done in conjunction with welding operations. Two paint spray booths are operated adjacent to welding operations in the structural welding area. Two to three employees operate the paint spray booths. A solvent degreasing tank is operated adjacent to some of the welding operations in the line belt welding area; chlorinated solvents (trichloroethane, and perchloroethylene) are used in the degreasing operations.

Dilution ventilation is accomplished in the shop by ceiling exhaust and supply fans. During warmer weather, large shop doors are opened as an additional source of outside air intake and air mixing. The paint spray booths and the stools area welding operations have local exhaust ventilation systems. Other welding and shop operations depend on dilution ventilation for exposure control.

IV. METHODS

An industrial hygiene survey was done at Dowty Corporation to evaluate occupational exposures to welding fumes and solvents. Three days of sampling were done, March 27-29, 1989. Sampling was done during the first (day) shift since this was reported to be the high production shift. The survey was scheduled for March in an attempt to sample worst-case winter exposure conditions when shop doors are kept closed. However, due to unseasonably warm weather, shop doors were opened during a large part of the industrial hygiene survey; consequently, we did not sample worse case conditions. Air samples were collected for a variety of environmental analytes including metal fumes, organic vapors, nitrogen dioxide and other oxides of nitrogen, carbon monoxide, and ozone. Both personal and area samples were taken. Personal exposure measurements were made by attaching the sampler to the worker and positioning the sampling orifice in the breathing zone. When sampling welders, the sampling orifice was positioned, as best possible, within the welding face shield.

Airborne total dust samples were collected to measure metal fume exposures. These samples were collected on 37 millimeter (mm) diameter cellulose ester filter media, 0.8 micron (μm) pore size, in a closed-faced filter cassette. Portable sampling pumps calibrated at 2.0 liters per minute (lpm) were used. Both consecutive, partial period (4-6 hours) and full period (7 hours or greater), time-weighted average samples were taken to measure personal exposures and area concentrations. Each sample was analyzed for approximately 30 different metals and elements using inductively coupled argon plasma, atomic emission spectroscopy (ICP-AES).[1]

The organic gas and vapor samples were collected on a solid charcoal media in a sorbent tube. These samples were collected using portable sampling pumps calibrated at 25 cubic centimeters per minute (cc/min). Personal and area samples were taken including both consecutive, partial period (3-4 hours) and full period (7 hours or longer) samples. Bulk airborne gas and vapor samples were also collected on charcoal tubes at a sampling rate of 100 cc/min. The bulk samples were analyzed qualitatively for organic compounds by gas chromatography (GC) in conjunction with mass spectrometry (MS). The charcoal tube samples were then analyzed quantitatively by GC for those organic gases and vapors detected in the bulk samples.[1]

Nitrogen dioxide and other oxides of nitrogen were sampled using the Palmes passive dosimeter.[2,3] The passive diffusion dosimeter requires no air moving device (sampling pump). The transportation of chemical analytes (e.g. nitrogen dioxide or other oxides of nitrogen) to the sampling media is accomplished by the diffusion of gas molecules. Personal and area samples were taken including both consecutive, partial period (3-4 hours) and full period (7-8 hour) samples.

Carbon monoxide samples were collected using passive detector tubes, long-term detector tubes, and short-term detector tubes. Detector tubes use direct reading, colormetric methods for carbon monoxide quantification.[4] Airborne carbon monoxide (CO) reacts with chemicals in the detector tube media to produce a color change proportional in length to the airborne CO concentration. The passive detector tube samples require no air moving device; CO is collected by the diffusion of gas molecules. The long-term detector tube samples were collected using a portable sampling pump calibrated to 25 cc/min. Both consecutive, partial period and full shift samples were collected with the passive and long-term detector tubes. The short-term detector tube samples for carbon monoxide were collected using a manual sampling pump calibrated to 100 cc per pump stroke. Samples were collected over a sampling period of approximately 4 minutes by drawing 1000 cc of air through the detector tube.[4]

The ozone samples were collected using short-term detector tubes by colormetric methods similar to those described for carbon monoxide.[4]

Ventilation measurements were taken to assess local exhaust ventilation systems with a pitot tube and inclined manometer, a heated wire anemometer, and a rotating vane anemometer. Air flow patterns were also evaluated using smoke tubes.[5]

V. EVALUATION CRITERIA

Evaluation criteria are used as guidelines to assess the potential health effects of occupational exposures to substances and conditions found in the work environment. These criteria consist of exposure levels for substances and conditions to which most workers can be exposed day after day for a working lifetime without adverse health effects. Because of variation in individual susceptibility, a small percentage of workers may experience health problems or discomfort at exposure levels below these existing criteria. Consequently, it is important to understand that these evaluation criteria are guidelines, not absolute limits between safe and dangerous levels of exposure.

Several sources of evaluation criteria exist and are commonly used by NIOSH investigators to assess occupational exposures. These include:

1. The U.S. Department of Labor, (OSHA) Federal Occupational Health Standards; Permissible Exposure Limits (PELs);[6]

2. The American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs);[7,8]

3. NIOSH criteria documents and recommendations. Recommended Exposure Limits (RELs).[9,10]

These criteria have been derived from industrial experience, from human and animal studies, and when possible, from a combination of the three. Consequently, due to differences in scientific interpretation of these data, there is some variability in exposure recommendations for certain substances. Additionally, OSHA considers economic feasibility in establishing occupational exposure standards; NIOSH and ACGIH place less emphasis on economic feasibility in development of their criteria.

The exposure criteria described below are reported as time-weighted average (TWA) exposure recommendations (averaged over the full work shift); short-term exposure limits (STELs) recommendations for a 10-15 minute exposure period; and ceiling levels (C) not to be exceeded for any amount of time. These exposure criteria and standards are commonly reported as parts contaminant per million parts air (ppm), or milligrams of contaminant per cubic meter of air (mg/m^3). Occupational criteria for the contaminants evaluated in this study are as follows:

Substance	NIOSH (REL)	ACGIH (TLV)	OSHA (PEL)
Aluminum (welding fumes)	NO REL	5 mg/m^3	5 mg/m^3
Arsenic[1]	0.002 mg/m^3 - C	0.2 mg/m^3	0.01 mg/m^3
Calcium	NO REL	2 mg/m^3 (Calcium Oxide)	5 mg/m^3 (Calcium Oxide)
Chromium:			
Metal	NO REL	0.5 mg/m^3	1 mg/m^3
Chromium II Compounds	NO REL	0.5 mg/m^3	0.5 mg/m^3
Chromium III Compounds	NO REL	0.5 mg/m^3	0.5 mg/m^3
Chromium VI Compounds[1]	.001 mg/m^3	0.05 mg/m^3	NO PEL Other than above
Copper (Fume)	NO REL	0.2 mg/m^3	0.1 mg/m^3
Iron (Fume)	NO REL	5 mg/m^3	10 mg/m^3
Magnesium (Oxide Fume)	NO REL	10 mg/m^3	10 mg/m^3 Total 5 mg/m^3 Respirable
Manganese (Fume)	NO REL	1 mg/m^3	1 mg/m^3
Phosphorus	NO REL	0.1 mg/m^3	0.1 mg/m^3
Sodium	NO REL	NO TLV	NO PEL
Zinc (Fume)	5 mg/m^3 15 mg/m^3-15 min.-C	5 mg/m^3	5 mg/m^3 10 $mg/^3$ - STEL

SUBSTANCE	NIOSH (REL)	ACGIH (TLV)	OSHA (PEL)
Solvents:			
Isobutanol	NO REL	50 ppm	50 ppm
Perchloroethylene[1]	LFL	50 ppm 200 ppm - STEL	25 ppm
Toluene	100 ppm 200 ppm - 10 min. C	100 ppm 150 ppm - STEL	100 ppm 150 ppm - STEL
1,1,1,-Trichloroethane (Methyl Chloroform)	200 ppm 350 ppm - 15 min. C	350 ppm 450 ppm - STEL	350 ppm 450 ppm - STEL
Xylene	100 ppm 200 ppm - 10 min. C	100 ppm 150 ppm - STEL	100 ppm 150 ppm - STEL
Other Analytes:			
Nitrogen Dioxide	1 ppm - 15 min. C	3 ppm 5 ppm - STEL	1 ppm - STEL
Nitric Oxide	25 ppm	25 ppm	25 ppm
Total Oxides of Nitrogen	NO REL	NO TLV	NO PEL
Ozone[2]	NO REL	0.1 ppm 0.3 ppm - STEL	0.1 ppm 0.3 ppm - STEL
Carbon Monoxide	35 ppm 200 ppm - C	50 ppm 400 ppm - STEL	35 ppm 200 ppm - C

[1] Considered a potential human carcinogen by NIOSH.
[2] ACGIH has published a proposed notice of intended change for the ozone TLV to 0.1 ppm as a ceiling limit.
- These standards/exposure levels refer to time-weighted averages (TWA) unless otherwise specified as short-term exposure limits (STEL), or ceiling values (C).

PPM - Parts contaminant per million parts air.
MG/M^3 - Milligrams contaminant per cubic meter of air.
LFL - Lowest feasible limit.

VI. RESULTS/DISCUSSION:

Metal Fumes

Welding is a process for joining metals where coalescence is produced through heat. A range of gases, vapors, and metal fumes can be generated depending on the welding process. (note: metal welding fumes are comprised of agglomerated particles of vaporized metal approximately 0.01 to 0.1 microns in diameter).[11] The welding operations performed during this industrial hygiene survey were largely MIG welding of carbon steel with carbon steel electrodes and a Stargon shielding gas. A limited amount of SMA welding and cutting was done on the line belt side of the shop. A metal cutting and removal method called arc gouging was done for approximately 20 minutes (March 27, 1989). Compressed air and a gouging electrode (78% graphite and 22% copper) were used in this arc gouging operation.

Eleven different metals and elements were measured in air at detectable concentrations during this industrial hygiene survey; these included aluminum, arsenic, calcium, chromium, copper, iron, magnesium, manganese, phosphorus, sodium, and zinc. Appendix A lists the potential toxic effects from overexposure to these metals and elements as welding fumes.

Airborne welding fume concentrations from personal and area samples are presented in Table 1. Iron was the most abundant metal in air detected in every total dust sample at concentrations ranging from 0.09 mg/m^3 to 0.93 mg/m^3. Magnesium and manganese were also detected in all airborne metal fume samples. Arsenic was detected in only one sample, a personal exposure measurement from a stools welder, at a TWA personal exposure of 0.01 mg/m^3. This exposure level is equal to the OSHA-PEL for arsenic and exceeds the NIOSH-REL of 0.002 mg/m^3.[6,9,10] NIOSH considers arsenic to be a potential human carcinogen and recommends exposures be reduced to the lowest feasible limit (LFL).[9,10]

Chromium was detected in 2 of the 20 airborne fume samples at detectable concentrations of 0.001 mg/m^3. These concentrations of total chromium metal, comprising all oxidation states, were below the OSHA PEL for chromium (metal), 1 mg/m^3 - TWA, and the ACGIH TLV, 0.5 mg/m^3 - TWA.[6-8] NIOSH and ACGIH consider chromium in the 6^+ oxidation state to be a potential carcinogen and recommend reduced occupational exposures: NIOSH - 0.001 mg/m^3 - TWA and ACGIH 0.05 mg/m^3 - TWA.[8-10] The oxidation state of the chromium in these three samples is not known. (Additional analyses for chromium 6^+ were not done due to the low chromium content in these samples).

Personal exposures to all metals except arsenic were below existing exposure standards and criteria of OSHA, ACGIH, and NIOSH.[6-10]

The partial period, area metal fume sample collected from the arc gouging operation detected six metals at varying airborne concentrations:

Chromium	0.05 mg/m^3
Copper	0.1 mg/m^3
Iron	5.2 mg/m^3
Magnesium	0.25 mg/m^3
Sodium	0.5 mg/m^3
Zinc	0.07 mg/m^3

This welding operation (arc gouging) was done for approximately 20 minutes on an open bench in the center of the shop with no local exhaust ventilation. The welder doing the arc gouging used a powered air purifying respirator with a high efficiency, particulate filter. Welding fumes from this operation created a visible cloud of smoke and haze that migrated to other shop areas.

Oxides of Nitrogen

Nitrogen dioxide and other oxides of nitrogen can be generated from some types of welding operations including MIG welding.(11) Exposures to total oxides of nitrogen ranged from 0.38 ppm to 1.1 ppm (Table 2). Nitrogen dioxide exposures (TWA) ranged from 0.08 ppm to 0.39 ppm; while nitric oxide (NO) concentrations ranged from 0.23 ppm to 0.75 ppm. (Table 2). The 15 short-term detector tube samples for NO_2, collected from welding operations, ranged from 0.2 ppm to 0.3 ppm (Table 3).

Exposure to NO_2, NO, and other oxides of nitrogen (NO_x) can cause irritation of the mucous membrane, cough, headache, and dyspnea. At higher exposures (greater than 200 ppm NO_2), acute pulmonary edema may occur.(8,9,12,13) The OSHA-PEL for NO_2 is 1 ppm as a short-term exposure limit (STEL); NIOSH recommends a 15 minute ceiling concentration of 1 ppm for NO_2. The ACGIH-TLV for NO_2 is 3 ppm as a TWA and 5 ppm as a STEL.(6-10) The OSHA-PEL, ACGIH-TLV, and NIOSH-REL for nitric oxide are all 25 ppm as a TWA. The NO and NO_2 exposures at Dowty Corporation were below existing standards and recommendations of OSHA, ACGIH, and NIOSH. There are no OSHA, ACGIH, or NIOSH exposure standards or recommendations for total oxides of nitrogen.

Carbon Monoxide

Carbon monoxide can be generated from some welding operations when carbon dioxide is released from electrode coatings or used as a shielding gas.(11) The material safety data sheet for the Stargon gas used in MIG welding operations at Dowty Corporation's shop cited a carbon dioxide content of 10 percent or less. Carbon monoxide is also produced by the operation of gasoline engines (e.g. forklifts). Time-weighted average carbon monoxide exposures from welding shop operations ranged from 1.4 ppm to a high of 14 ppm (Table 4). Average carbon monoxide concentrations by area include: 7 ppm - stools, 7.8 ppm - rollers, and 4.4 ppm line belt area. Short-term carbon monoxide concentrations ranged from 4 ppm to a high of 28 ppm during fork lift operation (Table 5).

Carbon monoxide binds with hemoglobin in the blood reducing the ability of the blood to oxygenate the tissues. Symptoms of carbon monoxide exposure can include headache, nausea, dizziness, weakness, rapid breathing and, with very high exposures (> 4000 ppm), unconsciousness and death.[8,9,12,13] To prevent these health affects, NIOSH recommends a TWA carbon monoxide exposure limit of 35 ppm with a ceiling of 200 ppm; this NIOSH-REL for carbon monoxide is equal to the OSHA-PEL enforced in industry. The ACGIH-TLV for carbon monoxide is 50 ppm as a TWA with a STEL of 400 ppm.[6-10] The carbon monoxide exposures measured at Dowty Corporation were all below the standards and recommendations of OSHA, ACGIH, and NIOSH.

Ozone

Ozone (O_3) is an extremely irritating gas with a pungent odor detectable by smell at concentrations of 0.01 to 0.05 ppm.[9] Ozone can be generated by some welding operations including MIG welding; however, the nineteen, short-term indicator tube samples collected for ozone during the 3-day survey were all below detectable limits (< 0.05 ppm).[11]

Organic Vapors

Bulk samples of shop air indicated the presence of isobutanol, trichloroethane, toluene, perchloroethylene and xylene. These organic vapors are attributed to various shop operations, in addition to welding, including paint spraying operations (toluene, xylene, and isobutanol), solvent degreasing (trichloroethane and perchloroethylene), and the use of other shop cutting oils and solvents.

Isobutanol

Isobutanol concentrations were all below the limit of quantification (LOQ = 0.16 ppm) except for one sample collected from the paint sprayer, 0.82 ppm isobutanol (Table 6). Isobutanol is a mild skin irritant; irritation of the eyes and throat can occur at concentrations above 100 ppm. No chronic systemic effects have been reported in humans from isobutanol exposure.[9,12,13] The ACGIH-TLV and OSHA-PEL for isobutanol are both 50 ppm as a TWA. There is no NIOSH-REL for isobutanol.[6-10]

Trichloroethane

Trichloroethane (1,1,1-trichloroethane or TCE) was present at quantifiable levels (0.03 ppm or higher) in four samples from the stools welding area; the TCE concentrations in these three samples ranged from 0.06 to 0.48 ppm (Table 6). The two organic vapor samples, collected approximately two feet from the solvent degreasing tank where TCE and perchloroethylene were used, were below detectable levels for TCE (and perchloroethylene).

TCE is generally considered to be one of the least toxic of the chlorinated hydrocarbons. TCE, like the other chlorinated hydrocarbons, can cause central nervous system effects on overexposure with symptoms of dizziness, incoordination, drowsiness. Hypotension, liver damage, and cardiac arrhythmia have been reported from TCE exposure. Both liquid and vapor are irritating to the eyes and repeated skin contact often causes dermatitis. Exposure to TCE can occur from inhalation of vapors or by skin absorption.(8,9,12,13) NIOSH recommends a TWA exposure limit of 200 ppm with a ceiling REL of 350 ppm for TCE.(9,10) The ACGIH-TLV for TCE is 350 ppm as a TWA and 450 ppm as a STEL.(7,8) The OSHA-PEL for TCE is also 350 ppm as a TWA with a STEL of 450 ppm.(6)

Perchloroethylene

Perchloroethylene (PCE) was detected in two of the organic vapor samples from the stools welding area at concentrations of 0.04 ppm and 0.08 ppm (Table 6).

Perchloroethylene (PCE) is a central nervous system depressant and can cause symptoms of headache, dizziness, vertigo, tremors, nausea, irregular heartbeat, sleepiness, fatigue, blurred vision, and intoxication (similar to that from alcohol). PCE overexposure can cause both liver and kidney damage; it may also cause irritation of the eyes, nose, and throat, with flushing of the face and neck; repeated contact may cause dermatitis.(8,9,12,13) Exposure to PCE can occur from inhalation of vapors or by skin absorption.

NIOSH considers PCE to be a potential human carcinogen and recommends that exposures be reduced to the lowest feasible limit.(9,10) ACGIH recommends a TWA exposure limit of 50 ppm with a STEL of 200 ppm to prevent anesthetic effects; these levels are expected to provide a wide safety margin in preventing liver and kidney injury.(7,8) The OSHA-PEL for PCE exposure is 25 ppm as a TWA.(6)

Toluene

Toluene was detected in every organic vapor sample at concentrations ranging from 0.21 ppm to a high of 66 ppm in a personal sample from the painter operating the manual paint spray booth. Toluene concentrations were the highest during paint spraying operations in the paint spray booth. Many of the paints used in the spray booth contained toluene (and/or xylene) as solvents or pigment carriers. Employees operating the manual paint spray booth used respiratory protection (air purifying, negative pressure respirators with organic vapor cartridges), goggles, and coveralls.

Toluene is a solvent for many inks, paints, and coatings. Exposure to toluene can be irritating to the eyes, respiratory tract, and skin. Prolonged or repeated skin contact with toluene can cause a dry, fissured dermatitis. Toluene is also a central nervous system (CNS) depressant producing symptoms of exhilaration, verbosity, inebriation, headache, and (in high concentrations around 7500 mg/m^3), collapse, coma, and death.(8,9,12,13) The NIOSH-REL for toluene is 100 ppm as a TWA with a 200 ppm - C. The ACGIH-TLV and the OSHA-PEL for toluene are 100 ppm - TWA with a 150 ppm - STEL.(6-10)

Xylene

Xylene, like toluene, was detected in every charcoal tube sample at concentrations from 0.3 ppm to 47 ppm (Table 6). The highest xylene concentrations were measured during paint spray operations at the paint spray booth. Xylene is also a common solvent for many paints, inks, lacquers, and varnishes. The toxic effects of xylene can include irritation of the eyes, nose and throat. Xylene exposure, like toluene, causes CNS depression; symptoms can include headache, feeling of inebriation, dizziness, gastric discomfort, and dryness of the throat. Repeated or prolonged exposure to xylene (above existing health standards) can cause a skin rash and damage to the kidneys and liver.(8,9,12,13) The NIOSH-REL for xylene is 100 ppm - TWA and 200 ppm as a 10 minute ceiling. The ACGIH-TLV and OSHA-PEL for xylene are 100 ppm with a STEL of 150 ppm.(6-10)

Ventilation and Work Practices

Work practices and ventilation practices observed at Dowty Corporation's welding shop influenced worker exposures. The shop uses general dilution ventilation for exposure control; ceiling supply and exhaust fans spaced throughout the shop are used to provide general dilution ventilation. During the winter months when ambient temperatures are cooler, only roof exhaust fans are operated; both supply and exhaust fans are operated during the warmer summer months. An additional source of outside air for contaminant dilution is provided by opening the large shop doors. These doors are generally open during warmer weather and closed on cold winter days; however, due to unseasonably warm weather, these shop doors were opened throughout most of this industrial hygiene survey.

Welding operations in the stools area used local exhaust ventilation to help reduce welding fume exposures. One local exhaust ventilation system, with branches to each of the three fixed welding stations, was used in the stools area. Two of the welding stations (stations 1 and 2) have plain, rectangular hood openings (46" x 15"). Welding operations are done approximately 12" in front of the hoods with the weld point between the exhaust hood and the welder. The third stools welding station uses a canopy hood suspended from the ceiling. Welding operations are done at waist to chest level; this configuration often places the welder's breathing zone between the weld point and the exhaust hood.

Volumetric air flow measurements from the stools local exhaust ventilation system are presented in Table 7. The average capture velocities, measured at the weld point, for exhaust hoods 1 and 2 were 90 feet per minute (fpm) and 58 fpm; the volumetric air flow was also higher in hood 1 (1710 cubic feet per minute - CFM) than hood 2 (1340 CFM). Smoke tube tests indicated that hood 1 was a more efficient collector of contaminants than hood 2. Some references suggest a capture velocity of 100 fpm at the weld point, although for some types of welding, insuring the integrity of the weld may be an issue at higher capture velocities.(14-16)

Average duct velocities in the exhaust lines serving hood 1 and 2 were 1920 fpm and 1510 fpm. Duct velocities of 2000-3000 fpm are recommended to prevent the settling of particulate and the occlusion of the ducts.[5, 14-16]

Welding work practices in the stools area also influenced exhaust ventilation efficiency. It was routine for welders using Stations 1 and 2 to stack welding parts on the bench in front of the hood; at times approximately 40%-50% of the hood opening was blocked by these materials. This reduced exhaust ventilation performance. Welders also positioned welding operations (the weld point) away from the exhaust hood. Moving the weld point closer to the exhaust hood would improve exhaust ventilation performance and reduce exposures.

The canopy hood had the highest volumetric air flow (4800 CFM); however, by design the capture velocity at the weld point was near 0 fpm. Canopy hoods are designed to use a general upward motion of the process-generated materials and contaminants (heated substances or evaporating solvents) to effect collection. This canopy hood design can be an effective design for some types of welding processes (e.g. automatic machine welding). However, as used in the stools area, with manual welding operations, this canopy hood was not as effective a form of exposure control since the welders breathing zone was often between the weld point and the exhaust hood.

MIG welding operations in the rollers area, all automatic, did not use local exhaust ventilation. One of the automated welders used forced air to direct welding fumes upward and away from workers in the immediate welding area.

The welding and cutting operations on the line belt side had no local exhaust ventilation. These welding operations are often done at various points along an equipment repair roller line. Arc gouging operations were done in the center of the shop on an open table with no local exhaust ventilation.

Both of the paint spraying booths had local exhaust ventilation. One of the paint spraying booths was automated (Booth 1), the second paint spraying booth was a manual operation (Booth 2). Smoke released near openings in the automated paint spraying booth (Booth 1) was drawn into the booth indicating the booth was operating under negative pressure. Smoke tube tests near the opening to the manual paint spray booth (March 28, 1989) indicated no air movement into the booth. Inspection of booth air filters indicated they were occluded with paint. Additional smoke tube tests on March 29, 1989, after the filters were changed, showed booth 2 was operating under negative pressure. Rotating vane anemometer measurements taken at the opening to paint spray booth 2, after the filters were changed, averaged approximately 50 fpm into the booth.

Paint spray in the automatic paint spray booth (Booth 1) was directed away from any booth openings. Painters operating the manual paint spray booth often directed paint spray towards the booth opening. This contributed to the release of organic solvents and paint pigments into the general shop air. After painting operations, painted parts and materials were dried in the general shop area; this work practice also contributed to a release of organic vapors into general shop areas.

VII. CONCLUSIONS

1. Worker exposure to metal welding fumes were below existing OSHA standards and ACGIH-TLVs. One of the personal, welding fume exposure measurements collected from a stools area welder exceeded the NIOSH-REL for arsenic; this exposure measurement also exceeded the OSHA action level (50% of the PEL) for arsenic.[6-10] Welding operations in the line belt area were reduced during this industrial hygiene survey and we were not able to fully assess shop exposures resulting from extended, full shift welding, cutting or arc gouging in this shop area.

2. Worker exposures to nitrogen dioxide, carbon monoxide, and ozone - gases commonly generated by some welding operations - were all below existing exposure standards/recommendations of OSHA, ACGIH, and NIOSH.[6-10]

3. Exposures to organic vapors were all below the OSHA-PEL and ACGIH-TLV. One of the personal organic vapor samples exceeded the OSHA-PEL and ACGIH-TLV for toluene and xylene, as calculated to reflect the additive exposure effects of these solvents; this sample was collected from a painter (paint spray booth #2) using a negative pressure, air-purifying respirator with organic vapor cartridges. Perchloroethylene exposure, detected in a personal sample from the saw operator in the stools area was 0.04 ppm - TWA. NIOSH considers perchloroethylene to be a potential human carcinogen and recommends that exposures be reduced to the lowest feasible limit (LFL). Worker exposures to isobutanol, 1,1,1-trichloroethane, toluene and xylene were all below NIOSH-RELs.[6-10]

4. Due to warm ambient conditions, the large shop doors were opened throughout most of the industrial hygiene survey; consequently, we did not sample worse case, winter operating conditions.

5. Some aspects of shop ventilation were suboptimal and, in conjunction with work practices, increased worker exposures.

   A. The capture velocity for the stools area exhaust ventilation hood (#2) was insufficient to capture all welding fumes at the weld point, approximately 12 inches from the hood.

   B. The canopy hood, as used for manual welding operations in the stools area, was not as effective a form of exposure control since the welders breathing zone was often between the weld point and the exhaust hood.

C. General dilution ventilation, used for welding operations in the rollers and line belt areas, is not as effective a form of exposure control as local exhaust ventilation.(14-17)

D. The exhaust ventilation system used in the manual paint spray booth was inoperative during part of this survey due to dirty filters occluded by paint. This, in conjunction with manual painting practices of directing paint spray towards the booth opening, increased organic vapor concentrations in this shop area.

VIII. RECOMMENDATIONS

1. Modify the stools area ventilation system and some welding work practices to reduce worker exposures to welding fumes:

   - Move the welding point closer (as close as possible) to the exhaust hood opening.
   - Enclose the sides, top, and bottom of local exhaust ventilation hoods 1 and 2, as suitable to welding operations, to increase exhaust hood collection efficiency.
   - Check local exhaust ventilation unit 2 to insure that all ducts are clean and that the damper is fully opened.
   - Restructure the canopy exhaust hood in the stools welding area into a larger bench welding hood, or instruct welders using this hood to avoid working directly over the weld point, placing their breathing zone between the weld point and exhaust hood.

2. Consider adding local exhaust ventilation to other shop welding operations as a more effective engineering exposure control.

3. Balance volumetric air flow between supply and exhaust fans (local exhaust and general dilution) so that exhaust air volumes are equal to intake air volumes during all seasons.

4. Change the filters in the paint spray booths with sufficient frequency to insure proper exhaust ventilation system operation. Instruct the painters operating the manual paint spray booth to direct paint spray away from the booth opening.

5. Develop a more formal respiratory protection program with standard operating procedures for respirator selection, maintenance, training, fitting, supervision, cleaning, and use. This program should meet the requirements of the American National Standards Institute (ANSI) Z88.2-1980, "American National Standard-Practices for Respiratory Protection". A copy of the NIOSH Guide to Industrial Respiratory Protection is included to aid in the development to this program.

6. Cutting fluids containing perchloroethylene, or other potential carcinogens, should be replaced with appropriate noncarcinogenic substitutes when possible.

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1. Dowty Corporation, Inc.
2. United Mine Workers of America
3. NIOSH Regional Office
4. Occupational Safety and Health Administration

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

TABLE 1
WELDING FUME CONCENTRATIONS[1]
DOWTY CORPORATION'S WELDING SHOP
MHETA 89-062

CONCENTRATION (MG/M^3)

JOB/OPERATION[2]	DATE	Aluminum	Arsenic	Calcium	Chromium	Copper	Iron	Magnesium	Manganese	Phosphorus	Sodium	Zinc
Stools Welding:												
Welder	03/27/89	0.03	0.01	0.09	ND	0.007	0.93	0.01	ND	ND	ND	0.002
Saw Operator	03/27/89	0.04	ND	0.06	ND	0.004	0.18	0.01	0.007	ND	ND	0.004
Area-Welding	03/27/89	ND	ND	0.04	ND	0.003	0.16	0.006	0.006	ND	ND	ND
Welder	03/28/89	ND	ND	0.02	ND	0.002	0.44	0.004	0.03	0.01	ND	ND
Area-Welding	03/28/89	0.02	ND	0.02	ND	0.004	0.49	0.005	0.03	ND	ND	0.002
Saw Operator	03/28/89	0.01	ND	0.04	ND	ND	0.11	0.005	0.008	ND	ND	ND
Welder	03/29/89	ND	ND	0.01	ND	0.006	0.64	0.002	0.05	ND	ND	ND
Area-Welding	03/29/89	ND	ND	0.02	ND	0.002	0.4	0.002	0.03	ND	ND	0.002
Rollers Welding:												
Welder	03/27/89	0.017	ND	0.05	ND	0.007	0.31	0.008	0.01	ND	ND	0.008
Area-Welding	03/27/89	0.04	ND	0.07	0.001	0.01	0.30	0.01	0.009	ND	0.03	0.007
Welder	03/28/89	ND	ND	0.01	ND	0.001	0.20	0.002	0.01	ND	ND	ND
Area-Welder	03/28/89	0.01	ND	0.02	ND	0.008	0.17	0.006	0.01	ND	ND	ND
Assembly Worker	03/28/89	0.01	ND	0.04	ND	0.002	0.26	0.005	0.02	ND	ND	ND
Welder	03/29/89	ND	ND	0.02	ND	ND	0.13	0.002	0.009	ND	ND	ND
Welder	03/29/89	ND	ND	0.01	ND	ND	0.10	0.001	0.007	ND	ND	ND
Area-Welding	03/29/89	0.02	ND	0.04	ND	0.004	0.29	0.005	0.02	ND	ND	ND
Line Belt Welding:												
Welder	03/27/89	0.02	ND	0.05	ND	0.005	0.19	0.006	0.003	ND	ND	0.006
Area-Welding	03/27/89	0.05	ND	0.08	0.001	0.008	0.27	0.01	0.006	ND	ND	0.01
Line Worker	03/28/89	ND	ND	0.016	ND	ND	0.09	0.001	0.003	ND	ND	ND
Welder	03/29/89	ND	ND	0.01	ND	0.001	0.11	0.002	0.008	ND	ND	0.006

[1] Time-weighted average concentrations in milligram per cubic meter of air (mg/m^3).
[2] Area - designates area samples.
ND - Below analytical detection limits.
C - Ceiling exposure limit.

TABLE 1 (continued)
WELDING FUME CONCENTRATIONS[1]
DOWTY CORPORATION'S WELDING SHOP
MHETA 89-062

CONCENTRATION (MG/M^3)

Occupational Exposure Standards [3]:	Aluminum	Arsenic	Calcium	Chromium	Copper	Iron	Magnesium	Manganese	Phosphorus	Sodium	Zinc
NIOSH-REL	NO REL	0.002 - C	NO REL	Varies with Oxidation	NO REL	NO REL	NO REL	NO REL	NO REL	NO REL	5
ACGIH-TLV	5	0.2	2	State-See	0.2	5	10	1	0.1	NO TLV	5
OSHA-PEL	5	0.01	5	Section V	0.1	10	10	1	0.1	NO PEL	10
Analytical Detection Limits:											
Mg/Filter	0.01	0.005	0.01	0.001	0.001	0.001	0.002	0.001	0.01	0.02	0.002
Mg/m^3 in Air	0.01	0.006	0.01	0.001	0.001	0.001	0.002	0.001	0.01	0.02	0.002

1 Time-weighted average concentrations in milligram per cubic meter of air (mg/m^3).
2 Area - designates area samples.
ND - Below analytical detection limits.
C - Ceiling exposure limit.
3 Reported as time-weighted averages unless otherwise listed as short-term exposure limits (STEL) or ceiling limits (C).

TABLE 2
PERSONAL EXPOSURES[1] TO NITROGEN DIOXIDE AND OXIDES OF NITROGEN
DOWTY CORPORATION'S WELDING SHOP
MHETA 89-062

Job/Operation	Date	Concentration (PPM) Nitrogen Dioxide	Nitric Oxide	Oxides of Nitrogen
Stools Area:				
Welder	03/27/89	0.13	0.75	1.1
Welder	03/28/89	0.09	0.49	0.73
Welder	03/28/89	0.10	0.51	0.77
Welder	03/28/89	0.11	0.40	0.63
Welder	03/29/89	0.10	0.27	0.45
Rollers Area:				
Welder	03/27/89	0.10	0.69	1.0
Assembly Worker	03/27/89	0.39	0.31	0.79
Welder	03/28/89	0.09	0.51	0.76
Welder	03/28/89	0.09	0.46	0.69
Assembly/Worker	03/28/89	0.08	0.51	0.74
Welder	03/29/89	0.10	0.40	0.62
Line Belt Area:				
Welder	03/28/89	0.09	0.62	0.90
Welder	03/29/89	0.08	0.23	0.38
Fork Lift Operator	03/29/89	0.10	0.37	0.58
Occupational Exposure Standards:				
NIOSH-REL		1 ppm - 15 min C	25 ppm	NO REL
ACGIH-TLV		3 ppm 5 ppm - STEL	25 ppm	NO TLV
OSHA-PEL		1 ppm - STEL	25 ppm	NO PEL

[1] Time-weighted average personal exposures.
PPM - Parts per million parts air by volume.
C - Ceiling exposure limit; STEL - Short-term exposure limit.

TABLE 3
SHORT-TERM NITROGEN DIOXIDE CONCENTRATIONS[1]
DOWTY CORPORATION'S WELDING SHOP
MHETA 89-062

Operation	Date	Concentration (PPM)
Stools Area:		
Welding	03/27/89	0.3
Welding	03/28/89	0.2
Welding	03/28/89	0.3
Welding	03/28/89	0.2
Welding	03/28/89	0.2
Welding	03/29/89	0.3
Welding	03/29/89	0.2
Rollers Area:		
Welding	03/27/89	0.3
Welding	03/28/89	0.2
Welding	03/28/89	0.2
Welding	03/28/89	0.2
Welding	03/28/89	0.2
Line Belt Area:		
Arc Gouging	03/27/89	0.3

[1] Short-term, area indicator tube samples.
PPM - Parts per million parts air by volume.

TABLE 4
CARBON MONOXIDE SAMPLING RESULTS[1]
DOWTY CORPORATION'S WELDING SHOP
MHETA 89-062

Job/Operation[2]	Date	Type[3]	Concentration (PPM)
Stools Welding:			
Welder	03/27/89	D	9.4
Area-Welding	03/27/89	D	8.3
Area-Welding	03/27/89	D	7.9
Area-Welding	03/27/89	LT	10.0
Welder	03/28/89	D	6.4
Welder	03/28/89	D	7.7
Welder	03/28/89	D	6.4
Area-Welding	03/28/89	D	6.4
Area-Welding	03/28/89	LT	6.0
Welder	03/29/89	D	2.7
Area-Saw	03/29/89	LT	5.3
Rollers Welding:			
Welder	03/27/89	D	9.2
Assembly Worker	03/27/89	D	3.6
Area-Welding	03/27/89	D	8.7
Area-Welding	03/27/89	LT	9.3
Welder	03/28/89	D	7.2
Welder	03/28/89	D	4.1
Assembly Worker	03/28/89	D	6.7
Area-Welding	03/29/89	LT	14.0
Line Belt Welding:			
Area-Welding	03/27/89	D	4.7
Area-Welding	03/27/89	LT	6.3
Line Worker	03/28/89	D	5.1
Welder	03/29/89	D	1.4
Fork Lift Operator	03/28/89	D	5.1
Occupational Exposure Standards:			
NIOSH-REL			35 ppm 200 ppm - C
ACGIH-TLV			50 ppm 400 ppm - STEL
OSHA-PEL			35 ppm 200 ppm - C

[1] Time-weighted average concentrations from detector tubes samples.
[2] Area designates area samples.
[3] D - Diffusion indicator tubes, LT - Long-term indicator tubes.
PPM - Parts per million parts air by volume.

TABLE 5
SHORT-TERM CARBON MONOXIDE CONCENTRATIONS[1]
DOWTY CORPORATION'S WELDING SHOP
MHETA 89-062

Area/Operation	Date	Concentration (PPM)
Stools Area:		
Welding	03/27/89	6
Welding	03/28/89	10
Welding	03/28/89	10
Welding	03/29/89	5
Welding	03/29/89	4
Rollers Area:		
Welding	03/27/89	7
Welding	03/28/89	5
Assembly	03/28/89	5
Welding	03/28/89	10
Assembly	03/28/89	8
Welding	03/29/89	8
Assembly	03/29/89	9
Welding	03/29/89	5
Assembly	03/29/89	5
Line Belt Area:		
Cutting	03/27/89	6
Arc Gouging	03/27/89	10
Cutting	03/28/89	7
Fork Lift Operator (Paint Spray Booth Area)	03/28/89	28

[1] Short-term, area indicator tube samples.
ppm - Parts per million parts air by volume.

TABLE 6
ORGANIC VAPOR CONCENTRATIONS[1]
DOWTY CORPORATION'S WELDING SHOP
MHETA 89-062

Job/Operation[2]	Date	Concentration (PPM)				
Stools Welding:						
Area - Welding	03/27/89	ND	LOQ	4.1	ND	4.2
Area - Saw Line	03/27/89	ND	0.06	4.8	ND	5.4
Welder	03/28/89	ND	ND	2.5	ND	2.2
Area - Welding	03/28/89	ND	0.48	3.7	ND	3.1
Welder	03/29/89	ND	0.07	0.14	LOQ	0.32
Saw Operator	03/29/89	ND	LOQ	0.58	0.04	0.69
Area - Welding	03/29/89	ND	0.18	0.30	0.08	0.34
Rollers Welding:						
Assembly Worker	03/27/89	ND	LOQ	3.6	ND	4.8
Machinist	03/28/89	ND	LOQ	1.8	ND	1.8
Area - Welding	03/28/89	ND	ND	0.18	ND	1.2
Assembly Worker	03/29/89	ND	LOQ	1.1	ND	1.1
Area - Welding	03/29/89	ND	ND	1.5	ND	1.6
Line Belt Welding:						
Line Worker	03/27/89	ND	ND	0.8	ND	0.7
Paint Spray Booth:						
Painter	03/27/89	LOQ	LOQ	13	ND	20
Painter	03/28/89	ND	ND	5.4	ND	6.5
Painter	03/28/89	0.82	ND	66	ND	47
Painter	03/29/89	LOQ	LOQ	16	LOQ	12
Area - Parts Drying	03/29/89	ND	LOQ	4.8	LOQ	5.4
Degreasing Tank:						
Area - Degreasing	03/27/89	ND	ND	4.2	ND	3.8
Area - Degreasing	03/28/89	ND	ND	2.6	ND	2
Occupational Exposure Standards:						
NIOSH - REL		NO REL	200 350 - C	100 200 - C	LFL	100 200 - C
ACGIH - TLV		50	350 450-STEL	100 150-STEL	50 200-STEL	100 150-STEL
OSHA - PEL		50	350 450-STEL	100 150-STEL	25	100 150-STEL

TABLE 6 (continued)
ORGANIC VAPOR CONCENTRATIONS[1]
DOWTY CORPORATION'S WELDING SHOP
MHETA 89-062

Job/Operation[2]	Date	Concentration (PPM)				
Analytical Detection Limits:						
ND		0.05	0.01	0.01	0.008	0.01
LOQ		0.16	0.03	0.04	0.02	0.04

1 Time-weighted Average Concentrations in Parts Per Million Parts Air (PPM).
2 Area - Designates Area Samples.
ND - Below the Analytical Detection Limit; LOQ - Below the Analytical Quantification Limit.
STEL - Short-term Exposure Limit; C - Ceiling Exposure Limit.

TABLE 7
VOLUMETRIC AIR FLOW MEASUREMENTS
STOOLS LOCAL EXHAUST VENTILATION SYSTEM
DOWTY CORPORATION'S WELDING SHOP
MHETA 89-062

Exhaust Hood		Volumetric[1] Flow (CFM)	Average Capture Velocity(FPM)[2] Hood Opening (FPM)	Weld Point (FPM)	Average[1] Duct Velocity (FPM)
Station 1.	Facing Shop Center	1710	285	90	1920
Station 2.	Closest to Wall	1340	95	58	1510
Station 3.	Canopy	4800	2400	Near 0	2440

1 Measurements made with a pitot tube and inclined manometer.
2 Measurements taken with a rotating vane anemometer.
CFM - Cubic feet per minute.
FPM - Feet per minute.

APPENDIX A
POTENTIAL TOXIC EFFECTS FROM OVEREXPOSURE TO THE METAL FUMES DETECTED IN AIRBORNE SAMPLES
DOWTY CORPORATION'S WELDING SHOP
MHETA 89-062

Toxic Effects[a]

Metal/Fume	Short-term	Long-term
Aluminum	Irritation of mucous membranes of upper respiratory system at higher concentrations.	None known
Arsenic	Dermatitis, gastrointestinal symptoms (nausea, vomiting, diarrhea)	Cancer (lung, lymphatic, skin), skin hyperpigmentation, palmar/plantar warts, hyperkeratosis), anemia, leukopenia, cardiomyopathy, hepatic cirrhosis, peripheral neuritis (numbness, weakness, ataxia).
Calcium	Irritation of mucous membranes of upper respiratory tract at higher concentrations.	None known
Chromium	Skin irritation (dermatitis, ulcer), respiratory tract irritation, and effects on nose (epistaxis, septal perforation), eyes (conjunctivitis), and ears (tympanic membrane perforation)	Cancer (lung - chromium VI), kidney and liver damage (suspected).
Copper	Metal fume fever[b], nasal mucosa irritation.	None known

APPENDIX A (continued)
POTENTIAL TOXIC EFFECTS FROM OVEREXPOSURE TO THE METAL FUMES DETECTED IN AIRBORNE SAMPLES
DOWTY CORPORATION'S WELDING SHOP
MHETA 89-062

Toxic Effects[a]

Metal/Fume	Short-term	Long-term
Iron	Irritation of mucous membranes of upper respiratory system at higher concentrations.	Siderosis (pulmonary deposition of iron dust)
Magnesium	Irritation of nasal mucosa and conjunctiva, metal fume fever[b]	None known
Manganese	Chemical pneumonitis	Nervous system (irritability, drowsiness, impotence, muscular rigidity, spasmodic laughing/weeping, speech and gait disturbances).
Phosphorus	Irritant of skin, eyes throat and respiratory tract. Chemical burns.	Cough, bronchitis, pneumonia, periostitis, ulceration, necrosis, deformity of the mandible and maxilla, bone sequestration, and polymorphic leukopenia.
Zinc	Metal fume fever[b], skin eruption (oxide pox).	None known

[a] Distinction between short-term and long-term effects is not clear-cut and is somewhat arbitrary. Short-term effects are usually the result of acute exposure(s) and may appear immediately to several days or weeks after the exposure. Long-term effects are usually the result of chronic, repeated low-dose exposures extending from several months to many years. However, long-term effects may also include the aftereffects of single or repeated acute exposures. The toxic effects information in this appendix is from references 9, 13, and 14.

[b] Metal fume fever is manifested by fever, chills, cough, joint and muscle pains, and general malaise.