AN ABSTRACT OF THE THESIS OF

Charles Chadim for the degree of Master of Science in Environmental Health Management presented on December 6, 1993.

Title: Health Risks Associated with Exposure to Stainless Steel Arc Welding Fumes and Gases

Redacted for Privacy

Abstract approved: ______________________________
Anna Harding

Electric arc welding is the most prevalent welding type in industry. It creates two main groups of health hazards for workers; fumes and gases, and radiant energy. Shielded Metal Arc (SMA) welding is the most widely used welding method in industrial plant welding shops. The main chemical health hazards associated with this type of welding are fumes. Fumes are particles formed when the electrode and base metal constituents are vaporized and condensed in the welding area.

Potential health problems can be anticipated by measuring the concentration of fumes in the welding space and comparing these data to established exposure standards. If high concentrations of these fumes are present, control measures should be undertaken to reduce the potential toxic effect to workers.

Most of the studies have been done on mild (carbon) steel welding where it is generally necessary to monitor only the total amount of fumes. Stainless steel welding differs from carbon steel welding in that it generates considerable fume concentrations of chromium and nickel, which are suspected human carcinogens.

The first part of this study evaluated the health risks posed to workers exposed to chromium and nickel fumes from routine stainless steel welding procedures. All the welding was performed in an industrial plant welding shop by one experienced welder. The welded piece was a three-part stainless steel cylinder. The whole period of welding lasted almost three weeks, although the actual welding was done in eleven days during that period. All sampling was performed with filter cassettes connected to personal air pumps. Sampling was performed in welder's breathing zone, in the general area (background sample), and at conveniently located points outside the breathing zone for evaluation of ratios of chromium and nickel to total fumes. The results indicated that at this particular industrial plant, exposure levels did not exceed the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs) and the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs). The results also indicated that it was not necessary to monitor the general area because of very low concentrations of chromium and nickel fumes. Rather, it is suggested that the monitoring focuses on the welder's breathing zone where it is important to sample hexavalent chromium (chromates) because of its proven carcinogenic effect and therefore very low TLV. Also, it was found that if TLV for chromates is not exceeded, then levels of total chromium and nickel are also likely to be below limits.

The second part of the study sought to devise a simplified method of monitoring of welding operations. The results suggested that it is not always necessary to sample for all the components (total fumes, total chromium, chromates, and nickel) when estimating worker's exposure. Rather, it is possible to simplify the process by establishing the ratios of fume constituents during a period of heavy welding, thus enabling the industrial hygienist to make a reasonable estimate of exposure that occurs at other times. The estimate can be made by sampling either the main constituent (chromates) or total fumes, and predicting the exposure to remaining constituents of interest from these data.

In addition, and in contrast to previous studies, it has been concluded that when fume concentrations are low, a welder's helmet does not provide any additional protection against fumes. Additional protection can be provided with the use of proper local ventilation, such as with a flexible hose, to reduce exposure well below suggested limits.

Health Risks Associated with Exposure to Stainless Steel Arc Welding Fumes and Gases

by

Charles Chadim

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed December 6, 1993

Commencement June 1994

APPROVED:

Redacted for Privacy

Assistant Professor of Public Health in charge of major

Redacted for Privacy

Chair, Department of Public Health

Redacted for Privacy

Dean of College of Health and Human Performance

Redacted for Privacy

Dean of Graduate School

Date thesis is presented______________December 6, 1993______________________

Typed by researcher for______________Charles Chadim________________________

ACKNOWLEDGEMENTS

I would like to express my gratitude to Anna Harding, major professor, who guided me while I was working on my thesis, always understanding and ready to help. Her help in overcoming obstacles in the process was especially valuable to me; it enabled me to finish the work on schedule.

Jon Owens, an industrial hygienist, was instrumental to the realization of the study. He provided all the instruments, taught me how to use them, introduced me to the welding shop, and arranged for the analysis of the samples. Without him, this study would not have been possible.

Art Jager, the welder who for three weeks was required to carry sampling equipment, deserves a high mark for his personal involvement in the monitoring, bringing additional input invaluable for succesful sampling.

The list would not be complete without mentioning my son who helped me to solve some problems when I was working on the computer.

Finally, I can never thank my wife enough for her moral and material support during my graduate studies. She encouraged me to go for a Masters degree, well aware that it meant living alone far away, which proved to be even more difficult than expected.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF TABLES

HEALTH RISKS ASSOCIATED WITH EXPOSURE TO STAINLESS STEEL ARC WELDING FUMES AND GASES.

CHAPTER 1

INTRODUCTION

Welders constitute about 0.5% to 2.0% of the total work force in most technologically advanced countries. The most prevalent and also the most hazardous welding method, arc welding, creates two main groups of health hazards for workers. These hazards include (Battelle 1979):

A. **Radiant energy**, generated by the electric arc, is a well-researched hazard of UV radiation and is also produced in arc welding. Eye protection is obtained with filter glasses in the welding helmet and skin protection is provided by proper clothing.

B. **Fumes and gases** are chemical hazards. Fumes are particles formed when the electrode, and base metal constituents are vaporized and condensed in the welding area. These particles have mass and size and are affected by air movement, gravity, and other external forces, and tend to agglomerate and settle. Because of their small size, fume particles may remain suspended in the aerosol form for long periods, and are likely to be inhaled by persons in the vicinity.Gases associated with welding follow the laws of diffusion and mix freely with the general atmosphere. Several gases including ozone, oxides of nitrogen, and carbon monoxide are toxic to the respiratory system.

Potential problems to welders can be anticipated by measuring the concentration of fumes and gases in the welding area and comparing these data to established exposure standards. If high concentrations of these fumes and gases are present, control measures can be undertaken to reduce the potential toxic effect to workers.

Although clinical records do not suggest that welders have a higher incidence of occupational illness than other industrial workers, the industry is aware that there are potential health hazards associated with welding fumes and gases (Battelle 1973). Numerous investigations have been conducted to collect and analyze fumes and gases produced during welding operations (Battelle 1979) The following observations have been noted: (1) when ferrous metals are arc welded, iron oxide is produced; (2) all arcs emit ultraviolet radiation that reacts with atmospheric oxygen to produce ozone; and (3) phosgene (a toxic gas) may be formed by photochemical reactions between UV radiation from the arc and vapors of chlorinated hydrocarbons (solvents). However, because there are many variables involved in measuring toxic substances produced by the welding process, results of previous studies cannot be generalized.

Experimental fume-sampling programs have produced highly variable results, even when such studies were conducted under seemingly identical circumstances. Some of the reasons for these differences are (Battelle 1973):

- Sampling and analytical techniques varied greatly.
- The welding process (there are several types of arc welding) and welding variables (electrode composition, arc voltage, current , current density, welding speed, shielding-gas flow rate, etc.) have a major effect on the results of fume generation studies.
- Placement of the sampling device has a great effect on the results produced by fume studies. Factors such as distance from the arc, direction and speed of air flow (ventilation), and location of the sampling device in the breathing zone, have a much more profound effect on measured exposure to fumes than their generation itself.

A large number of studies have been done on mild (carbon) steel welding (Battelle, 1979). Most of the studies concentrated on generation of total fumes and some constituents of fumes, mainly iron oxide which in mild steel welding constitutes up to half of the total fumes. Stainless steel welding poses similar health hazards to welders, and also generates considerable fume concentrations of chromium and nickel, which are suspected human carcinogens. Concentrations of nickel and chromium compounds may exceed allowable limits even when fume generation is low. Few studies focusing on the health risks of exposure to chromium and nickel welding fumes have been published. Therefore, the purpose of this study was twofold: (1) to monitor the stainless steel welding operation at an industrial plant welding shop and evaluate health risks to workers from chromium and nickel fumes; and, (2) to devise a simplified method of monitoring of welding operations. The following research questions were posed:

1. What is the exposure of workers at an industrial plant welding shop to chromium and nickel fumes and what control measures can be implemented to reduce that exposure?

2. Is it possible to establish a ratio of specific welding fume constituents to total fumes for a particular welding shop?

Definitions

Alveoli - small sacks in lungs where gas exchange (oxygen and carbon dioxide) takes place between alveolar air and pulmonary capillary blood. It is the end point of the respiratory path.

Asbestosis - a chronic lung disease caused by the inhalation of asbestos fibers that results in the development of fibrosis. There is no treatment.

Asthma - a respiratory disorder characterized by recurring episodes of wheezing on expiration due to constriction of the bronchi. Repeated attacks often result in permanent obstructive lung disease. Often called **bronchial asthma.**

Bronchitis - an acute or chronic inflammation of the mucus membranes of the tracheobronchial tree. The main predisposing factors are cigarette smoking and air pollution.

Emphysema - an abnormal condition of the pulmonary system, characterized by overinflation and destructive changes of alveolar walls, resulting in a loss of lung elasticity and decreased gases. Chronic emphysema usually accompanies chronic bronchitis, a major cause of which is cigarette smoking.

Etiology - the cause of a disease.

Fibrosis - an abnormal condition in which fibrous connective tissue spreads over or replaces normal smooth muscle or other normal organ tissue. Lungs are the organs most often affected.

Flux - covering of an electrode, having multiple purpose (protecting the weld from oxidation, refining the grain structure of the weld, and stabilizing the arc). It consists of up to thirty different elements and compounds.

Gas metal arc (GMA) welding - welding torch has a center consumable wire that maintains the arc as it melts into the weld puddle. The inert environment is secured by flow of helium, argon, carbon dioxide, nitrogen or a blend of these gases.

Gas tungsten arc (GTA) welding - the arc is established between a non consumable tungsten electrode and the workpiece. Argon or helium is fed to the annular space around the electrode to maintain the inert environment. A manually fed filler rod is commonly used.

In vitro - occurring in a laboratory apparatus.

In vivo - occurring in a living organism.

Manual inert gas (MIG) welding is another term for GMA welding.

Manual metal arc (MMA) welding is another term for SMA welding.

Matched-weight filter - consists of two identical filters that have been preweighed and matched within 0.1 mg of each other. The weight of the test contaminant is determined by individually weighing the two filters on an analytical balance after sampling and subtracting the weight of the downstream (non contaminated) filter from the upstream (contaminated) filter.

Mesothelioma - a rare malignant tumor of mesothelium (layer of cells lining the pleura - membrane enclosing the lung) associated with earlier exposure to asbestos.

Morphology - the study of the physical shape and size of a specimen.

Mucous membranes - line cavities or canals of the body that open to the outside such as the linings of the mouth and respiratory passages. It protects the underlying structure and secretes mucus, the purpose of which is to help trap and remove foreign substances from the body.

Oncogene - a potential cancer-inducing gene. Under normal conditions, such genes play a role in the growth and proliferation of cells, but when altered in some way by a cancer-causing agent they may cause the cell to be transformed to a malignant state.

Phagocytosis - a process by which certain white blood cells engulf and dispose of microorganisms and cell debris.

Plume - a visible cloud of fumes and gases originating in the welding arc and rising and gradually mixing with air.

Pneumoconiosis - any disease of the lungs caused by chronic inhalation of dust, usually mineral dusts of occupational or environmental origin. Examples are asbestosis and silicosis.

Pulmonary edema - the accumulation of fluid (extravascular) in lung tissues and alveoli.

Shielded metal arc (SMA) welding is commonly called stick or electrode welding. An electric arc is drawn between a welding rod and the workpiece, melting the metal along a surface. The molten metal from the workpiece and the electrode forms a common puddle and cool to form the bead and its slag cover.

Siderosis - a kind of pneumoconiosis caused by the inhalation of iron dust or fumes.

Slag - solidified flux on the top of the cooled weld.

Tungsten inert gas (TIG) welding is another term for GTA welding.

TWA - time-weighted average, usually over an 8-hour exposure period.

CHAPTER 2

LITERATURE REVIEW

Biological Effects of Exposure to Welding Fumes and Gases

Introduction

Welding involves many processes and produces various emissions. The character and health effects of the effluents emitted are influenced by the type of welding being performed, by the welding electrodes used, by industrial hygiene practices, by the personal habits of the welder, and, possibly, by genetic factors (McMillan, 1983). In most West European and North American countries, welding fumes are monitored and standards are regulated by governmental agencies.

Over the years welding has been evolving from a process that initially was relatively simple into a complex technology in which numerous electrodes are used. Electrodes consist of a central core and outer coats that are formed from metals and other elements and compounds contributing to the weld. A portion of these materials is transformed into fumes and gases in the electric arc, which is a process that produces hazardous emissions. The emission of fumes varies according to the kind of welding taking place, with manual metal arc welding having the highest emissions and tungsten inert gas welding giving off the lowest emissions.

The likelihood that welding fumes reach the lungs depends on the aerodynamic diameter of the fumes. Fumes having a shorter diameter are more likely to penetrate the lungs and lodge in the alveoli. The inhalation of fumes, however, also depends on other factors, including the concentration of fumes in the breathing zone of the welder, the breathing pattern of the welder, and the ventilation present in the workplace.

Humans inhale and deposit many millions of particles in the lungs over the lifetime. For the most part, such particles have no significant effect on lung function (Morgan, 1986). Only when deposition of particles has been excessive and prolonged is there a deleterious effect. In this regard, it is essential to distinguish between a physiological and adaptive response to the inhalation of moderate numbers of such particles and an injury or disease that results from the continued inhalation of many such particles. An adaptive response implies that any particles deposited in the lungs or airways are removed or rendered innocuous by the normal defense mechanisms of the body. In contrast, a disease indicates that the particles have induced a response, or injury, and the tissue has responded in a pathological rather than physiological manner (Morgan 1986).

The following section describes the specific constituents of welding fumes and their health effects on workers. Their presence in the fumes depends on the type of welding, material being welded, and electrodes being used.

Specific Constituents of Welding Fumes

Iron Oxide

Iron oxide constitutes up to 50% of fumes in mild steel welding, and much less in stainless steel welding. It is not generally considered a health hazard because only a very high concentration of fumes could lead to exceeding the TLV for iron oxide (Battelle, 1979). (For more see Siderosis under Respiratory Illnesses Associated with Welding.)

Chromium

Chromium occurs in oxidation states ranging from Cr^{2+} to Cr^{6+}(Casarett, 1986).

Chromium in human tissues is generally in the trivalent form and does not convert to hexavalent forms in the body. Trivalent chromium cannot cross the cell membranes. However, hexavalent chromium, when entering the body, readily crosses cell membranes and is reduced intracellularly to trivalent chromium. Although the harmful effects of chromium to humans have been attributed to the hexavalent form, it has been speculated that the harm from hexavalent chromium was actually caused by the reduction to trivalent chromium and the formation of complexes with intracellular molecules. High concentrations of chromium are normally found in RNA, but its role there is unknown. In contrast, trace quantities of trivalent chromium are essential for carbohydrate metabolism in mammals (Casarett, 1986).

Exposure to chromium, particularly in the chrome production and chrome pigment industries is associated with cancer of the respiratory tract (Norseth, 1981). As early as 1936, German health authorities recognized cancer of the lung among workers exposed to chromium dust. The greatest risk of cancer is attributed to exposure to acid-soluble, water-insoluble hexavalent chromium as occurs in the roasting or refining processes. Other studies have suggested a greater risk of cancer from exposure to slightly soluble hexavalent compounds rather than trivalent chromium compounds. Trivalent chromium compounds are considerably less toxic than the hexavalent compounds.

Whether chromium compounds cause cancer at sites other than the respiratory tract is not clear. A slight increase in cancer of the gastrointestinal tract has been reported in other studies, but each involved only small groups of workers. Animal studies have demonstrated that the most potent carcinogenic chromium compounds are the slightly soluble hexavalent compounds. Studies on *in vitro* bacterial systems, however, show no difference between soluble and slightly soluble compounds. Because there is preferred uptake of the hexavalent form by cells and it is the trivalent form that is metabolically active and binds with nucleic acids within the cell, it has been suggested that the causative agent in chromium mutagenesis is trivalent chromium bound to genetic material after reduction of the hexavalent form (Norseth, 1981).

Significant exposure to chromium may occur during stainless steel welding. In contrast, mild steel welding is not associated with exposure to a higher concentration of chromium. Tandon (1986) reported that trivalent chromium, and both water-insoluble and water-soluble Cr(VI) - hexavalent chromium - in the fume originate from the electrode core and flux.

Nickel

Nickel has been found to be a respiratory tract carcinogen in workers of the nickel-refining industry. Also severe acute and sometimes fatal toxicity may follow nickel carbonyl exposure. On the other hand, there is evidence that nickel is also an essential trace metal (Casarett, 1986).

It has been known for forty years that occupational exposure to nickel predisposes a person to lung and nasal cancer. Epidemiological studies in 1958 showed that nickel refinery workers in Britain had a fivefold increase in risk of lung cancer and 150-times increase in risk of nasal cancers compared to people in the general population. More recently, an increase in lung cancer in nickel workers has been reported from several different countries (Casarett, 1986).

Metallic nickel combines with carbon monoxide to form nickel carbonyl which is extremely toxic. Many cases of acute toxicity have been reported (Wiseman, 1989). The suspected or alleged formation of nickel carbonyl during the welding of steel and alloys containing nickel has been reported in the literature in the past. However, measurements to confirm the published reports have seldom been attempted, largely because of the scarcity of analytical techniques that are sufficiently sensitive and readily available. In a comprehensive study conducted by Wiseman (1989), thirty-six combinations of welding and cutting processes, base metals, and electrodes were tested under typical industrial conditions, emphasizing those combinations with the best chance of producing nickel carbonyl. No significant concentrations of nickel carbonyl were found despite the confirmed presence of carbon monoxide in the gas and nickel in the fume. Adsorption and possible decomposition prior to the gas analysis were investigated, but the results supported the conclusion that carbonyl was not formed.

Nickel is a recognized cause of asthma and perhaps may play a role in the development of occupational asthma that has been uncommonly reported in stainless steel welders (Seaton, 1984).

Cadmium

Acute exposure to cadmium fumes may occur as a result of various welding and cutting operations (Beton, 1966). Such incidents are rare, and most have occurred in confined, poorly ventilated spaces where dismantling operations have been taking place. It has been subsequently found that the bolts, nuts or various other parts used in the metal frame of the structure had been cadmium plated. The hazards arise when cutting or welding involves metal containing a high percentage of cadmium (5% to 15%), usually as an alloy. Acute cadmium exposure and poisoning have been reported from California and Canada (Blejer, 1966; Anthony, 1978). (Additional explanations are found in the section designated Respiratory Illnesses Associated with Welding under Emphysema).

Lead

Lead is an occasional constituent of the electrode and has not been reported in concentrations above the TLV in the welding environment for many years. Occasional outbreaks of lead poisoning occurred in welders in the past during shipbuilding and scrapping (Rieke, 1969).

Lead-based paints have been commonly used on marine structures and welding on these surfaces may generate high concentration of lead fumes unless the paint is removed before welding (Patty, 1991).

Beryllium

Beryllium is probably the most toxic alloying metal (Battelle, 1979). Inhalation of beryllium dust or fume may result in an acute or chronic disease, depending on the extent of exposure and the nature of the beryllium compound involved. Extreme precautions are observed when these metals are welded (Battelle, 1979).

Copper

Copper in the state of finely divided aerosol may produce metal fume fever (see later in this chapter). In most cases these fumes are produced by welding copper or zinc materials; however, appreciable quantities of copper fume may originate from copper-coated electrodes and filler wires. It is unlikely that hazardous concentrations of copper fumes will be produced during welding with copper-coated filler wires. Only in arc gouging (cutting by melting the metal)with copper-covered electrodes the concentration of copper fumes is high, and adequate ventilation is essential to protect the cutter (Battelle, 1979).

Zinc

Zinc-oxide fumes are formed during the welding of galvanized metals. Inhalation of the fumes may produce a brief, self-limiting illness known variously as metal fume fever (see later in this chapter), zinc chills, brass chills or brass founder's fever. When good ventilation is established, the TLV for zinc is seldom exceeded (Battelle, 1979).

Magnesium

The oxide fumes from magnesium can produce metal fume fever (see later in this chapter). However, experimental work with animals has failed to show any detrimental response in the lungs (Battelle, 1979).

Manganese

Prolonged exposure to manganese may lead to manganese poisoning. Affected workers may develop Parkinson's disease (Newhouse, 1981). However, no workers from either North America or Western Europe have been reported with manganese poisoning, although there have been sporadic reports from Eastern Europe (Newhouse, 1981).

Molybdenum

Little information is known concerning the human exposure to molybdenum or its compounds. Animal studies indicate that molybdenum is only slightly toxic even in larger doses (Battelle, 1973).

Titanium

Slight fibrosis has been observed in human lungs from industrial exposure to high concentration of titanium dioxide dust, although there was no disabling injury (Battelle, 1973).

Vanadium

Vanadium is present in some filler wires. Vanadium pentoxide is moderately hazardous in both acute and chronic exposures (Battelle, 1973).

Fluorides

The use of electrodes whose coating contains fluorides presents a health hazard (Burgess, 1981). The inhalation of fluoride fumes may produce respiratory tract irritation manifested by chills, fever and cough. The fluoride particles are readily absorbed, and promptly produce an increase in urinary fluoride excretion. When excessive amounts are inhaled, this excretion is not sufficient to eliminate all the absorbed fluoride, resulting in a buildup of fluoride in the bones. If storage of fluoride continues over a sufficiently long period, the bones may show an increased radiographic density and structural abnormalities may eventually develop (Battelle, 1973). Fluorides are used in electrode coatings to maintain a hydrogen-free arc environment for critical welding tasks on certain steels. However, exposure to these fumes seems to be a concern only under conditions of poor ventilation. There has been no evidence of systemic fluorosis from exposure during welding (Burgess, 1981).

Gases Generated in Welding

Carbon Monoxide

In some welding processes, carbon dioxide is reduced to carbon monoxide. In the case of carbon dioxide-shielded gas metal arc (GMA) welding, carbon monoxide concentrations exceeding recommended levels have been detected in the fumes near the arc; however, the concentration decreased rapidly with distance from the arc. With adequate ventilation, the carbon monoxide concentration in the welder's breathing zone can be maintained at a harmless level. The carbon monoxide concentration is negligible when using SMA welding (Battelle, 1979).

The toxic effects of carbon monoxide are largely due to the decreased oxygen content of the blood; carbon monoxide combines with hemoglobin to form very stable carboxyhemoglobin which decreases the oxygen-carrying capacity. The hypoxia (oxygen deficiency) resulting from the formation of carboxyhemoglobin does not cease as soon as fresh air is inhaled as with simple asphyxiants, such as carbon dioxide, but it slowly diminishes as carbon monoxide is eliminated from the lungs as fresh air is inhaled (Casarett, 1986).

Oxides of Nitrogen

The oxides of nitrogen encountered in welding include nitric oxide (NO) which is rapidly oxidized to nitrogen dioxide, and exists in two forms, NO_2 and N_2O_4. Both forms of nitrogen dioxide are relatively insoluble red-brown gas which has a pungent odor at high concentrations (Battelle, 1979).

Exposure to moderate concentrations of nitrogen dioxide above the TLV, but of insufficient intensity to affect the lower respiratory tract, causes cough and irritation of the eyes and nose. In contrast, high concentrations are more likely to reach the small airways and alveoli and lead to the development of pulmonary edema and, on rare occasion, death (Morgan, 1984).

Both arc welding and flame cutting lead to the generation of nitrogen oxides . The more serious life-threatening episodes occur when the welder is working in a confined space with poor ventilation (Jones, 1973). Most fatal exposures have occurred in ship's hulls, tanks, or boxcars. Since the oxides of nitrogen are relatively insoluble, exposure to low concentrations can be tolerated with few, if any, effects other than mild irritation. Of the various kinds of arc welding, the highest concentration may be expected in GTA welding. The concentrations in SMA welding are very low.

Ozone

Ozone is produced by the action of ultraviolet light on molecular oxygen. Increased concentrations of ozone may be present around the welding arc. Gas metal arc welding and gas tungsten arc welding are particularly prone to produce ozone (Challen, 1958; Lunau, 1967). Both of these types of welding are frequently used to weld aluminum. The concentrations of ozone in SMA welding are negligible. Concentrations at and somewhat above the TLV lead to irritation of the nose and eyes and are said to cause headache and general irritability. As the concentration increases, tightness of the chest develops and headache becomes worse. Visual disturbances are also reported (Newhouse, 1981). With proper ventilation, exposure to ozone can be minimized so that no symptoms develop.

Phosgene

The decomposition of chlorinated hydrocarbons such as trichloroethylene and perchlorethylene may lead to the formation of phosgene (Dahlberg, 1971). Both of these compounds are contained in degreasants which were often used in the past in the same part of the shop where welding was taking place. Of the various welding methods, metal inert gas (MIG) welding is particularly prone to lead to the formation of high concentrations of phosgene (Battelle, 1979).

Phosgene is an almost odorless and colorless gas which liquefies at $8^{\circ}C$. Its inhalation causes pulmonary constriction. The initial symptoms are those of cough and, after 2 to 8 hours, pulmonary edema may develop (Everett, 1968).

Exposure during welding is exceedingly uncommon, but it is recommended nevertheless, that degreasing solutions should be kept well away from all welding processes (Patty, 1991).

Phosphine

Phosphine or hydrogen phosphide is generated when steel which has been coated with a phosphate rustproofing is welded. High concentrations of the gas are irritating to the eyes, nose, and skin. Effects of chronic exposure are much more serious; however, long term exposure can hardly be expected in welding shops (Battelle, 1973).

Respiratory Illnesses Associated with Welding

Metal Fume Fever

This condition was formerly known as brass founder's fever or Monday morning fever (Morgan, 1984). It usually develops in welders and oxyacetylene cutters several hours after the worker has left his workplace. The symptoms are those of a flu-like illness with fever, chills, and cough. Usually within 12 to 18 hours the person starts to feel better, and the symptoms have cleared up completely within 48 to 72 hours. In general, the disease is self-limiting and pulmonary complications are rare. Many workers recognize the symptoms and tend to ignore them. Moreover, with repeated exposures, attenuation of the symptoms takes place (Doig, 1964).

Metal fume fever is often attributed to an allergic response (Morgan, 1984). The condition often occurs on the evening of the first working day. It may occur on each Monday for several weeks but, as time goes by, becomes less severe. It is suggested that the disease is induced by the inhalation of superheated, ultramicroscopic particles of various metals, but in particular, zinc, copper, and magnesium are the most common causes (Morgan, 1984). Nickel, cobalt, and selenium may also be responsible. No specific treatment is known, although many welders believe that drinking large quantities of milk helps (Battelle, 1979).

Siderosis

Siderosis is a kind of pneumoconiosis caused by the inhalation of iron dust or fumes. It was observed that some welders and oxyacetylene cutters developed a condition that radiographically resembled silicosis. However, over a period of several years, some subjects showed radiographic clearing with regression of both the number and size of the opacities (Doig, 1948). Complicated siderosis as characterized by the presence of one or more large shadows has been reported, but in these workers there always has been concomitant exposure to an additional fibrogenic agent other than iron oxide. In two of the reports, a mass was resected, and it was only afterwards that it became apparent that both workers had a history of sand-blasting (Meyer, 1967).

Studies of lung function in welders with siderosis have shown little, if any, respiratory impairment (Hunnicatt, 1964). Several investigations of the pathological changes that occur in welders' siderosis have been published, and there is general agreement that the inhalation of ferric oxide, the main constituent of welding fumes, does not lead to fibrosis (Hunnicatt, 1964). Although a number of case reports have described workers with lung fibrosis and attributed the lung fibrosis to the welding fumes, most are unconvincing. Other and far more likely explanations for fibrosis, including exposure to other fibrogenic agents, were available (McMillan, 1983.

Bronchitis

A number of well controlled epidemiological studies in welders have been carried out in which the prevalence of respiratory symptoms and pulmonary impairment has been quantified (Sjogren, 1985). Some have demonstrated an increased prevalence of bronchitis. Pulmonary impairment, however, has not been associated with disabling airway obstruction, and indeed, in most studies it has not been possible to show an increased prevalence of chronic airflow limitation except in smokers (McMillan, 1984).

A number of confounding factors exist that contribute to the increased prevalence of respiratory symptoms in those exposed to welding fumes. These include the fact that welders tend to smoke more than the general population (McMillan, 1983), and that welding is often associated with exposure to other significant hazards, such as asbestos and silica, being particularly prevalent in those employed in shipyards (Steel, 1968).

The bronchitis that develops in welders is a nonspecific response to irritant fumes originating in the welding process (Morgan, 1978). The irritants may be gaseous or particulate. The bronchitis that affects welders may be regarded as a form of industrial bronchitis and has the same effects on lung function and the same pathological features that are found in other workers who develop bronchitis from other industrial exposure (cement workers, gold and coal miners, and foundry workers) (Morgan, 1978). While the bronchitis that appears in welders sometimes may be associated with a minimal reduction of ventilatory capacity and minor obstruction of air flow located mainly in the large airways, it is never disabling nor it is associated with the development of emphysema. Moreover, cessation of exposure to irritants usually leads to a decrease or, indeed, complete resolution of, the symptoms of bronchitis (Oxhoj, 1979).

Emphysema

Cadmium is the only known occupational cause of emphysema in welders (Morgan, 1984). Much doubt exists as to whether low exposures to cadmium fumes lead to the development of emphysema, but there is some recent evidence to that effect (Morgan, 1984). However, exposures to cadmium fumes in welding are below the TLV, and it is only when the process involves welding or cutting alloys with a significant percentage of cadmium that a hazard exists (Battelle, 1979).

Asbestosis and Other Asbestos-Induced Pulmonary Conditions

Although it was not until the 1960s that it was realized that welders were exposed to hazardous concentrations of asbestos (Harries, 1976), it is now clear that those who were employed in shipyards (and occasionally elsewhere) in the 50s and 60s may have had sufficient exposure to asbestos to cause asbestosis, mesothelioma, and lung cancer (Sheers, 1980). It was frequently the custom for welding, pipefitting, and lagging to be carried out at the same time in a confined, poorly ventilated area of the ship. While pipefitters wore respiratory protection, welders seldom did because it was believed that intermittent exposures were not harmful. Such coincident exposures have a bearing on many of the so-called "symptomatic cases of welders' siderosis".

Silicosis

Welders are often coincidentally exposed to silica. In the past, work practices involved exposure to silica and the hazard associated with such exposures was seldom recognized. Should a worker be exposed to both free silica and ferric oxide, a condition known as silicosiderosis develops (Levy, 1974). Conglomeration in this condition is not uncommon, and the impairment and disability similar to that observed in classical silicosis occurs. Amorphous silica is the usual form of silica found in welding fumes; however, this is not fibrogenic (only free silica is fibrogenic) (Battelle, 1979).

Carcinogenesis

Welders may be exposed to a number of carcinogenic materials while at work. Of particular concern in the past has been asbestos, and the increased incidence of lung cancer observed in welders, for the most part, can be attributed to coincident asbestos exposure (Newhouse, 1985). Although it has been suggested that chromium and nickel, both of which are found in the fumes generated during stainless steel welding, are a cause of lung cancer, no increased evidence of lung cancer in welders over that of other shipyard workers has been demonstrated which cannot be explained by exposure to asbestos or by the increased smoking habits of welders (Newhouse, 1985). While a number of chromosome studies in welders have been carried out showing that numerous aberrations occur, their significance is dubious because it is difficult to demonstrate an increased incidence of cancer in humans (Hedenstedt, 1978). Since the mutagenicity of hexavalent chromium has been proven beyond any doubt and recognized in a number of countries (NIOSH, 1993), it is only prudent to reduce that exposure as much as reasonably achievable. For more information see Chromium and Nickel under Specific Constituents of Welding Fumes.

Epidemiological Studies

A number of studies have evaluated chronic effects of welding, especially in regard to the prevalence and effects of bronchitis (Morgan, 1989). Hunnicutt and colleagues (Hunnicutt, 1964), in a group of welders from the Newport News shipyard, found that the prevalence of symptoms such as cough and sputum were significantly higher in welders than in nonwelders. There also was an increased prevalence of airway obstruction, but only smoking welders were affected. Similar findings resulted from a study of Boston shipyard welders (Peters, 1973). In this study it was recognized that many welders had significant exposure to asbestos. Peters and his colleagues concluded that no detectable ventilatory defect was present in welders who did not smoke. Anne Fogh and her colleagues (Fogh, 1969) observed similar findings in 156 Danish welders. They concluded that there was no significant difference between welders and controls in the occurrence of chronic bronchitis and ventilatory function after controlling for smoking.

In a series of well carried out and detailed studies, McMillan investigated the health of welders employed in the Royal Navy dockyards in Britain. In a well controlled retrospective study, McMillan analyzed the morbidity and incidence of respiratory disease over a five-year period (McMillan, 1979). Five relatively comparable groups who also worked in the shipyard were included as a reference population. These included boiler makers, shipwrights, electrical fitters, painters, and joiners. He concluded that there was no evidence of a significant excess of chronic respiratory disease in the welders.

In another study, McMillan and Heath measured lung function in 25 welders (with a reference population of 25 electrical fitters) at the beginning and end of a shift. No significant differences were found in lung function changes over the day (McMillan, Heath, 1979).

McMillan has also published a general review of the health of welders in naval dockyards and has concluded that there was no evidence of a causal relationship between welding and respiratory diseases or other ill health, with the exception of injuries. He indicated that the welders who appear to be susceptible to the effects of fumes and gases are usually the workers who also have obstructive airway diseases such as asthma or emphysema. Neither the asthma nor the emphysema, however, were related to welding exposure (McMillan, 1979).

Because it has been suggested that most studies of welders have been carried out on welders with relatively short exposure to welding fumes (less than 15 years), McMillan and Pethybridge decided to examine 135 welders age 45 and over who also have prolonged exposures (McMillan, 1984). The average duration of welding was 33.1 years. Those exposed had detailed clinical, radiological, and pulmonary function examinations and were compared with a comparable control group age 45 and over. McMillan concluded that prolonged exposure to welding fumes did not cause significant clinical abnormality nor any serious impairment of lung function. They expressed the opinion that minimal airway obstruction may result from exposure to welding fumes. Rather similar findings have been reported by Hayden and colleagues for welders employed in three engineering factories in the British Midlands (Hayden, 1984).

Symptomatic Lung Disease in Welders

Over the last three or four decades, there has been a tendency to associate the symptoms and the disease present in the welders with their occupation, despite the fact that the nature of the disease, whether restrictive or obstructive, have differed. In addition, the absence of consistent pathophysiological effects and of supportive epidemiological evidence to confirm the association casts doubt in the validity of the association of welding to the disease described (Morgan, 1989).

For example, McMillan in a carefully controlled case control study has found that neither the diffusing capacity nor the total lung capacity were significantly different in welders as compared to control subjects (McMillan, 1984). Thus the evidence to suggest that welding fumes induce pulmonary fibrosis is tenuous in the absence of a clear-cut history of exposure to recognized fibrogenic substances, such as asbestos and silica. There is little or no evidence that nitrogen dioxide, chromium or any other metal emitted in welding fumes will induce pulmonary fibrosis, although the introduction of new technology may lead to new and unrecognized hazards.

The evidence suggests that welding is not a particularly hazardous occupation provided care is taken to limit exposure to the toxic effects of any fumes that are generated (Morgan, 1989).

Difficulty in the Assessment of True Exposure

Since the health effects of fume or its constituents are the result of the initial deposition in the respiratory system and subsequent mobility, more attention should be given to fume morphology and the solubility of its constituents, and not only the toxicity of the compound.

Morphological Properties and Fractional Deposition of Welding Fumes

Determination of the morphology of welding fume particles is useful in estimating how far from the point of generation they can reach before being deposited. Further, morphological properties are of great importance in determining the fate of particles in the air passages. Large particles (with aerodynamic diameter over 5 microns) will be deposited in the nose, pharynx, and larynx. Small particles (with aerodynamic diameter below 5 microns) deposit in the trachea and bronchial passages, while only particles with aerodynamic diameter below about 2 microns deposit in the bronchioli and alveoli (Farrants, 1989).

Studies by Hewitt and Hicks (1983) showed that approximately 20% of SMA welding fume was initially deposited in the lungs of laboratory animals, with the balance being exhaled or excluded from intake dependent on particle size (Hewitt, 1983). This is comparable with the predicted deposition in human lungs for workers of moderate activity based on published data from the International Commission on Radiological Protection (ICRP, 1966).

Particles generated by different welding techniques and electrode compositions are expected to possess different morphological characteristics, which may be related to differing biological effects (Farrants, 1989). Most of the particles collected on a stationary (background) sample are small compared to fumes collected from the breathing zone, sample of which contains mostly large particles. This can be caused by the more rapid deposition of the large particles after generation, resulting in a lower amount reaching the sampling point some distance away. Thus, monitoring of welding exposure should be performed as close to the breathing zone as possible, because samples collected some distance away may possess different properties than those fumes to which a worker is exposed. Filters used for background monitoring collect particles which may be generated by other processes in the vicinity to a greater extent than the filters used for personal monitoring. Personal samples may also contain a significant proportion from other processes, but since sampling is performed in the breathing zone, this reflects accurately the concentration to which that particular worker is exposed.

Only few quantitative discussions of fume morphology have been presented. The reason for this scarcity of quantitative fume analysis may be the considerable work load involved in manual quantitative procedures. The reduction of the price of computing power in recent years, however, has made available a large range of automatic image analysis systems at reasonable cost. These systems are excellently suited to the geometric measurement of large numbers of particles and to the statistical analysis of the results obtained. In the future, thorough assessments of fume particle morphology will provide considerable additional information to chemical determinations (Farrants, 1989).

Solubility of Welding Fume Constituents

Considerable confusion is caused by an inadequate definition of the words "soluble" and "solubility". Solubility means the maximum amount of substance which is capable of being dissolved in a given volume of a specified solvent at a given temperature. It is a thermodynamic (equilibrium) value. For chemical analysis, it is necessary to ensure that equilibrium (maximum solubility) is reached and that for practical reasons, this occurs reasonably quickly. In terms of biological effects, the rate of dissolution can be important, as well as the solubility. "Soluble" means capable of being dissolved and could be misleading if the rate, concentration, temperature and solvent are not defined. In particular, *in vivo* solubility can be very different from water or dilute acid solubility determined in the laboratory (*in vitro*) (Hewitt, 1983).

Toxic properties of the fume particles are related not only to their chemical composition, but also to their solubility, which depends, among other factors, on their surface area (Hewitt, 1983). In general, particles or agglomerates with a larger surface will be more reactive than particles or agglomerates of the same mass with smaller surface area since a greater surface is available for the reaction to take place. In this case the substructure of agglomerates must be considered. An agglomerate composed of many small primary particles will have a larger available surface area than one of similar mass composed of few large primary particles (Farrants, 1989).

Effects of Grinding on Monitoring Results

Grinding is generally integrated in welding operations, and collected fumes will contain a mixture of welding fumes and grinding dust. The grinding time depends on the welding method; shielded metal arc (SMA) welding results in more extensive grinding than does tungsten inert gas (TIG) welding. Workpieces with many corners also result in more grinding (Patty,1991).

In a joint German-Norwegian project, chemical analysis showed that the contents of iron and nickel were slightly lower, and contents of manganese and total chromium considerably lower in grinding dust than in welding fumes (Karlsen, 1992). The contents of hexavalent chromium in grinding dust were undetectable. Samples collected in welding shops where intermittent grinding was performed contained about 30% less of hexavalent chromium than those collected under laboratory conditions during continuous welding (Karlsen, 1992).

Quite often, solutions for environmental problems in welding shops have been tried using laboratory experiments instead of field studies. On the other hand, field studies are difficult to control and are not uniform. Under controlled conditions it is possible to identify the type of pollutant to which the welder is exposed and obtain separate results for welding and for grinding. During regular welding, welders are often exposed to background aerosols (broader term - includes dust and fumes) from a variety of processes. Grinding is mostly an integrated part of the welding process. A welder might have tasks other than welding that generate aerosols and still other tasks that do not generate aerosols. Each welder is not only exposed to his own welding fumes but sometimes to considerable amounts of other's welding fumes also. During indoor welding in workshops, it is impossible to study one isolated welding process as is done in the laboratory because of the surroundings (Karlsen, 1992).

Threshold Limit Values (TLVs)

The published threshold limit values provide a means to estimate the hazards that may be presented by welding fumes and gases. TLVs as time-weighted average (TWA) represent airborne contaminant levels to which it is believed a worker can be subjected to in an 8 hour day, without adverse effects on his or her health (Battelle, 1973). These limits are based on the best available information from industrial experience and from experimental human and animal studies. The basis on which the limit values are established varies from substance to substance; protection against the impairment of health may be the guiding factor for some substances while freedom from irritation, nuisance, and other forms of stress or discomfort may form the basis for others. Since these values are subject to revision , the latest values should be used. The threshold limit values should be used as a guide in controlling health hazards, but with few exceptions they should not be regarded as a fine line between safe and hazardous conditions. For example, few slight overexposures among many well below the TLV do not necessarily mean that worker's health is in danger. On the other hand, consistent exposure to concentrations just below the TLV would suggest some control measures. These procedures may be revised as experience in their use is acquired and as improved methods to collect and analyze welding fumes and gases are developed (Battelle, 1973).

There are some problems with application of TLVs:

TLVs for many elements and compounds are derived from industrial processes other than welding. Their application for welding may be questioned, since in the fume, the constituent elements are in different physical and chemical forms that in the studies from which the TLVs were determined.

The complex mechanism involved in fume formation gives rise to a wide range of airborne particles, from fine chains to spherical particles. For an accurate evaluation, only the respirable fraction should be collected for industrial hygiene assessment. Typically, less than a quarter of the fume is initially deposited in the respiratory system and it is then subject to clearance mechanisms. TLVs for welding fumes and its constituents largely ignore both fractional deposition and *in vivo* solubilities (Hewitt, 1983).

Synergistic Effect

When two or more hazardous substances are present in the atmosphere (welding fumes), their combined or synergistic effect, rather than the effect of each individually, should be given primary consideration. In the absence of information to the contrary, the effects of the hazardous substances should be considered as additive (Battelle, 1973). If the sum of the following fractions exceeds unity, the threshold limit value of the mixture should be considered as being exceeded (Battelle, 1973):

$C_1 / T_1 + C_2 / T_2 + \ldots\ldots C_n / T_n$ where

$C_1, C_2 \ldots\ldots C_n$ indicates the observed concentrations

$T_1, T_2 \ldots\ldots T_n$ indicates the corresponding TLVs

The term "synergistic" is improperly used as a general term which includes additive; in fact, these two are mutually exclusive terms. A synergistic effect is a situation in which the combined effect of two or more chemicals is much greater than the sum of individual effects (Casarett, 1986).

Control of Exposure

OSHA Interpretation

OSHA regulations on welding fumes and their various components were established in 1989, together with the methods to use in order to comply with the regulations:

- **Administrative controls**. This means limiting the amount of time a worker is exposed to fumes, so that the overall 8-hour exposure is below the established PEL. It is not a preferred method by OSHA and is not generally applied to welding operations.

- **Engineering controls** means reducing the concentration of fumes in the air in general and in the breathing zone of welders in particular. Ventilation is an effective way of reducing fumes generated by the welding process.

- **Personal protective equipment (PPE)** includes the use of fume respirators and, in extreme cases, clean air welding helmets. The use of PPE as a primary method of control is permitted by OSHA only when engineering controls are proven not feasible for technical or economical reasons. OSHA allows the use of PPE as the main protection method during implementation of engineering controls or a period of maintenance (CFR, 1992).

Engineering Controls

There are two basic ways to achieve compliance through engineering controls: local ventilation (source capture), and general (dilution) ventilation.

Conventional arc welding (SMA) on ferrous metals in open areas can usually be performed safely with dilution ventilation; however, welding in enclosed spaces will always require local exhaust. Local exhaust ventilation is also needed when using GTA or GMA techniques on stainless steel, high alloy steels, nickel or copper alloys, or when the base metal is coated with a toxic metal (Patty, 1991).

General Ventilation (Dilution)

General ventilation may include using fans to keep fumes out of the worker's breathing zone, exhausting shop air outdoors and bringing in adequate make-up air. Usually the ventilation is more complex, depending on the nature of the shop and the time when it was built. There is a serious drawback to the dilution ventilation approach; because it requires an enormous amount of fresh air to reduce the concentration of fumes, the operative cost is usually quite high, especially in winter when not only air exchange but also heating of the incoming air is required (Reding, 1992).

Local Ventilation (Source Capture)

Collecting welding fumes near their source is generally preferable because: (1) It offers the welder the best protection from fumes. (2) It minimizes the fume exposure of other employees in the area. (3) It reduces the volume of air used to control fumes by up to 90% when compared to general ventilation (Cheney, 1985).

It can be accomplished in three basic ways:

1. Suction devices attached to the welder's gun. The capture opening travels with the arc and low volumes of air can capture the fume. The welder's acceptance of the added weight and size of the gun seems to be the chief obstacle to use of this device

(Cheney, 1985). In addition, it cannot be used with SMA welding, (though it may be effective on wire feed applications - GMA welding).

2. A fixed local hood is a fabricated hood which is mounted in a fixed position and hard ducted to an exhaust or a filtration system. A flanged opening hood is a common design. It is important to keep the weld as close as possible to the hood, which is difficult to do when welding large pieces. Canopy hood is a common type of fixed overhead hood, that takes advantage of the natural thermal rise of the welding plume and requires high air volume. It offers little protection to the welder's breathing zone and may even be counterproductive because it pulls the air through the welder's breathing zone. At present it is seldom used (Reding, 1992).

3. Flexible hose (a term used by the author throughout the study) has a number of different terms used in the literature; however, the purpose is identical and the basic description is similar. The main advantage is that it offers the worker the flexibility to move the hose (hood) where is needed. It can be placed within just few inches from the arc and is extremely efficient compared to any other type of ventilation device. It can be used to exhaust the fumes outdoors or it can be connected to a filtration system. The filtration system may be a portable unit or a collector to handle multiple work stations (Reding, 1992).

CHAPTER 3

METHODS

This chapter describes the welding process being monitored, sampling methods and analysis of samples. All the welding was performed in an industrial plant welding shop by one welder, thirty seven years old, with fifteen years of welding experience. He was selected for this welding by the supervisor of the welding shop. The period of welding lasted almost three weeks, although the actual welding was done in eleven days during that period. For particular dates see Appendices B and C.

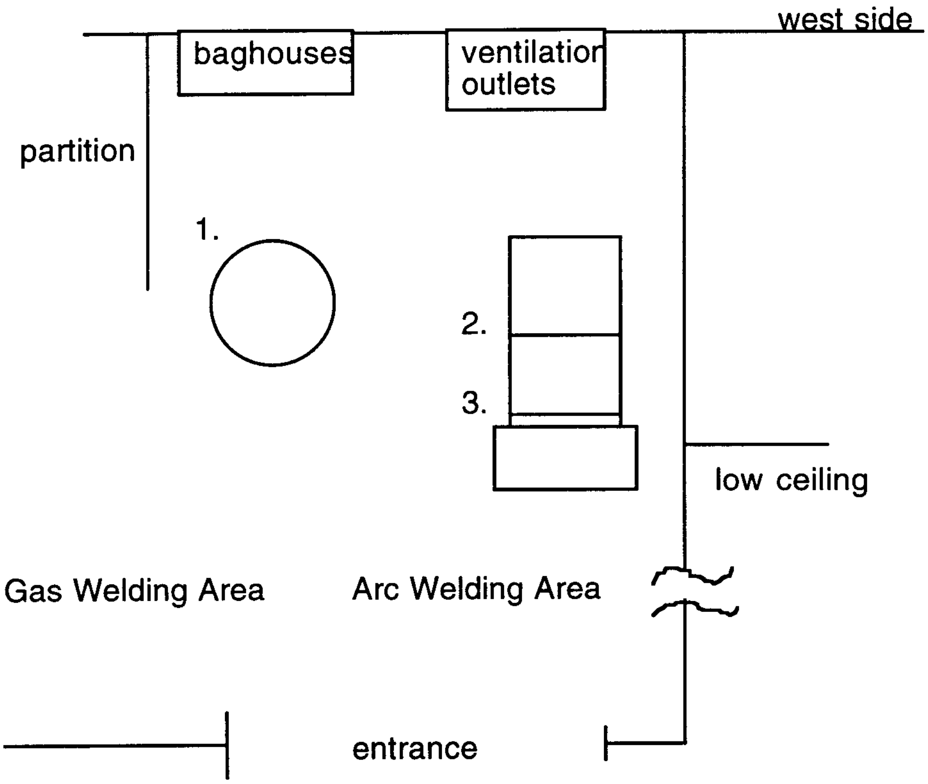


Figure 1. Position and sequence of welds

Sampling

Description of Welding Site and Process

The welded piece was a three-part stainless steel cylinder approximately 5' in diameter with 1.5" thick walls. The cylinder was made of stainless steel 316 (contains 18.5% chromium and 12.5% nickel).

The position and sequence of welds are shown in Fig. 1. Numbered lines represent the three welds completed in sequence as numbered. During the first two days the top enclosure was welded to the first part while the cylinder was in the upright position (see number 1 in Figure 1). The welder moved around the perimeter of the cylinder while welding. The weld was at the height of his shoulders and the sampling cassette was attached to the lapel very close to the plume. The actual sampling started on the second day of this period. The first day was devoted to trial sampling for total fume concentration only - results of which were immediately available and provided guidance about what to expect during the actual sampling. During the remaining days the parts of the welded cylinder were in a horizontal position (see numbers 2 and 3 in Figure 1), turned as needed by welder with the remote control. This enabled the welder to perform welding at the bottom of the cylinder when inside and at the top when outside (welding in horizontal position prevents the flow of molten metal out of the weld). There were two periods of two days each of welding inside the cylinder, each followed by period of welding outside, on the top of the cylinder.

Sampling Method

All sampling was performed with filter cassettes connected to personal air pumps - there were four pumps available. These pumps were calibrated daily just before the sampling and flow rate checked before, during and at the end of each sampling period.

Two different filters were used; cellulose 0.8 micron filters for analysis of chromium and nickel, and matched-weight filters for total fumes analysis. Three points of sampling were established:

1. Welder's breathing zone. The sample was taken just outside the helmet on the lapel during actual welding operation. On three occasions (see Appendix C), the sample was taken concurrently inside the helmet to evaluate the ratio between the fume concentration outside and inside the helmet. The welder worked under various conditions as dictated by the welding process or as asked by the author of this study.

2. A point outside the breathing zone, usually close to the welder but not obstructive to work performed, for evaluation of ratio of metals (chromium and nickel) to total fumes. Two pumps with the same air flow were used; one was attached to the cassette with the filter for analysis of metals, and the other was attached to cassette with matched-weight filter for gravimetric analysis of total fumes.

3. A point in the general area where it was expected that other workers may be exposed to higher concentrations of fumes. These data were collected to establish the level of fumes at the shop under different ventilation conditions. Natural ventilation always existed during this period of sampling.

Daily Data Sheet for Welding Fumes (see Appendix A) was used to record important variables of welding such as ventilation, distance of sampler from the weld, use of the respirator, electrode being used, and other conditions considered pertinent for evaluation of the results.

Analysis

Gravimetric Analysis for Total Fumes

Matched-weight filters were used for sampling total fumes because they are readily available and suggested for collection of fumes. The traditional use of a preweighed filter (PVC, not cellulose) was intentionally avoided. This type of filter may provide more accurate results for scientific study but it is relatively cumbersome to use in sampling; it has to be sent to a laboratory for preweighing, then sent back to the workplace.

The method enabled the author to perform the gravimetric analysis personally at the plant analytical laboratory . Each sample was weighed three times with the mean value used in calculations. The analytical scale is periodically calibrated and accuracy of the measurements is within ±0.1 mg of measured value. The matched-weight filters are also matched within ±0.1 mg, guaranteed by the manufacturer.

Analysis for Chromium and Nickel

Cassettes with samples on 0.8 cellulose filters were sent in two batches for analysis to CNA Environmental Health Laboratory in Chicago that routinely perform analysis of environmental samples for this industrial plant. Each sample was analyzed for total chromium and nickel using OSHA method ID121 - Flame Atomic Absorption.

Methodological Limitations

The researcher could not repeat the study applying the experience gained in this study. He did not have much experience in sampling because it was his first independent project in the industrial hygiene. However, the researcher is confident that the study does not have a fundamental flaw because the monitoring was discussed in detail with an experienced industrial hygienist.

Inability to sample for chromates represented a drawback that should be avoided. The author used the most conservative estimate based on previous studies. However, only the samples can provide reliable results.

Welder's posture and working habits represent one of many variables influencing welder's exposure to fumes. The welding was performed by one welder. However, if more welders participate in the process, the results would differ.

The number of samples was higher than in a routine industrial hygiene monitoring. However, in order to obtain more reliable results from statistical evaluation, more samples, under various conditions of welding, should be taken.

CHAPTER 4
RESULTS AND DISCUSSION

Compliance with Exposure Limits

The first of the two main goals of this study was to evaluate the exposure of workers to chromium and nickel in this particular welding shop. It is expected that the welder would be exposed to the highest concentrations of fumes, but little is known about the concentration levels to which other workers are exposed. The exposure evaluation was conducted in two groups: for the welder and for the general area, and within each group for chromium, chromates - also known as hexavalent chromium or Cr (VI), and nickel. In this study chromium (or total chromium) includes elemental chromium as well as chromium compounds.

Analytical results of sampling, together with other pertinent information such as location of sample, date taken, ventilation, respirator use, electrode used, and appearance of sample, are displayed in the appendices. Appendix B contains the results of gravimetric analysis. The samples are marked with capital letters. Three pages of Appendix C display the results of analysis for chromium and nickel. The samples were numbered in sequence as taken and this numbering was used consistently throughout the study. Sample numbers used in Figures represent those samples that were pertinent for particular evaluation.

Analytical results were compared with Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PEL), American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV), and National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limits (REL). These exposure limits can be found in many publications; the author used the *NIOSH Pocket Guide to Chemical Hazards, 1990* (the most recent edition). The exposure limits were arranged in a table (Appendix E). All exposures were evaluated as Time-Weighted Average (TWA) for 8-hour exposure.

Welder's Exposure

Exposure to Chromium

TLV was used as a standard because TLVs are considered by professionals to be the most accurate with respect to the current workplaces. OSHA PELs represent the legal limits but are not updated fast enough to follow current knowledge. NIOSH standards, on the other hand, represent the scientists' effort to lower the standards to levels excluding almost any risk, such as in case of the limit that exists for chromates (Plog, 1988).

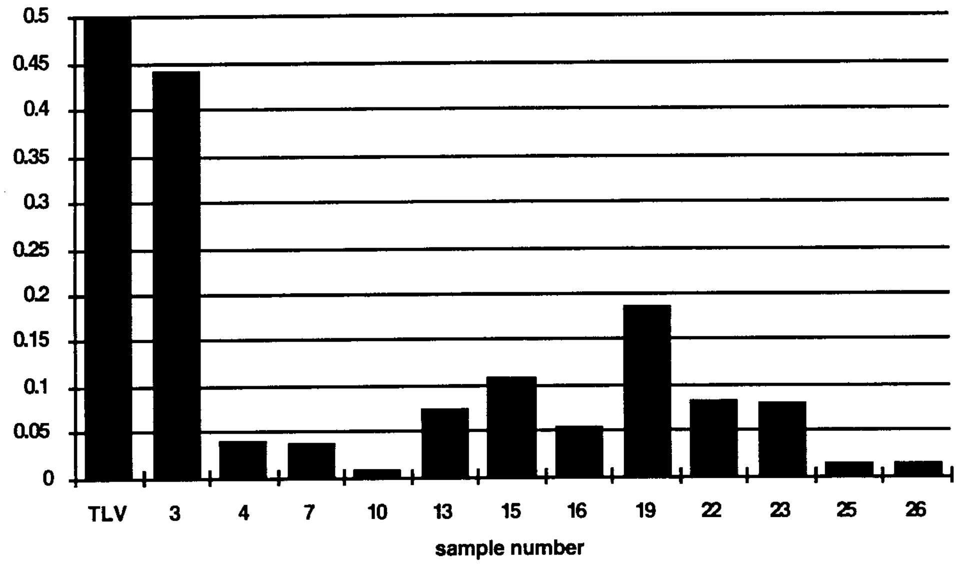


Figure 2. Chromium concentration in welder's breathing zone

Figure 2 displays the concentration of Cr in the breathing zone, not actual exposure (which would be 10x lower for samples 3, 7, 16, and 19 when the welder wore a fume respirator). As seen from the graph, even without the protection of the respirator the welder was never exposed to a chromium concentration higher than TLV (0.5 mg/m^3). This compares with the OSHA PEL of 1.0 mg/m^3.

Exposure to Chromates

Again, TLV was used as a standard; the limit is 10x lower than that for total chromium - 0.05 mg/m^3. Since chromates as proven carcinogens (NIOSH 1993) appear to be the main health hazard in stainless steel welding, it was necessary to estimate their content as a percentage of total chromium because the author only had the opportunity to monitor for total chromium and nickel.

Few studies focusing on chromates (hexavalent chromium or Cr VI) were available. In the Canadian study (Hewitt, 1983), the total fumes in Shielded Metal Arc welding (SMA) contained 5.86% Cr and 2.40% Cr(VI), which means that about 40% of chromium would be in the hexavalent state. The joint German-Norwegian project (Karlsen, 1992), performed in a shipyard, found the amount of Cr(VI) to total Cr (all numbers in mg/m^3) was 0.014 to 0.062 for welder's exposure and 0.014 to 0.047 for general area, (23% and 30% respectively). 22% of Cr(VI) in total Cr was found by the Australian study (Tandon, 1986). The Texas A&M University study (Lautner, 1978) used two different methods for analysis of Cr(VI) with excellent correlation and was the only one found to provide statistical evaluation.

According to the Texas A&M University study (Lautner, 1978), the mean of Cr(VI) to total Cr is 73% with standard deviation 1.23%. This is the oldest study of those mentioned above; its results differ from the later studies which correlate quite well with respect to percentage of Cr(VI). However, there was no statistical evaluation provided and it is possible that the results were based on very few samples. After the discovery of carcinogenicity of chromates, it was suggested that electrodes of the future should generate less Cr(VI). That would be one plausible explanation of the difference; another reason could be that newer analytical methods are more accurate. The author decided to use the most conservative estimate and opted for 75% of Cr(VI) in total Cr. That should represent the worst case scenario.

Fig. 3 displays the welder's exposure to chromates (expressed as 75% of total Cr), considering the protection provided by the fume respirator. That is the reason that this graph differs from Fig. 2. Four samples (representing two exposures since #13 and #15 were taken concurrently and so were #22 and #23) exceeded the TLV.

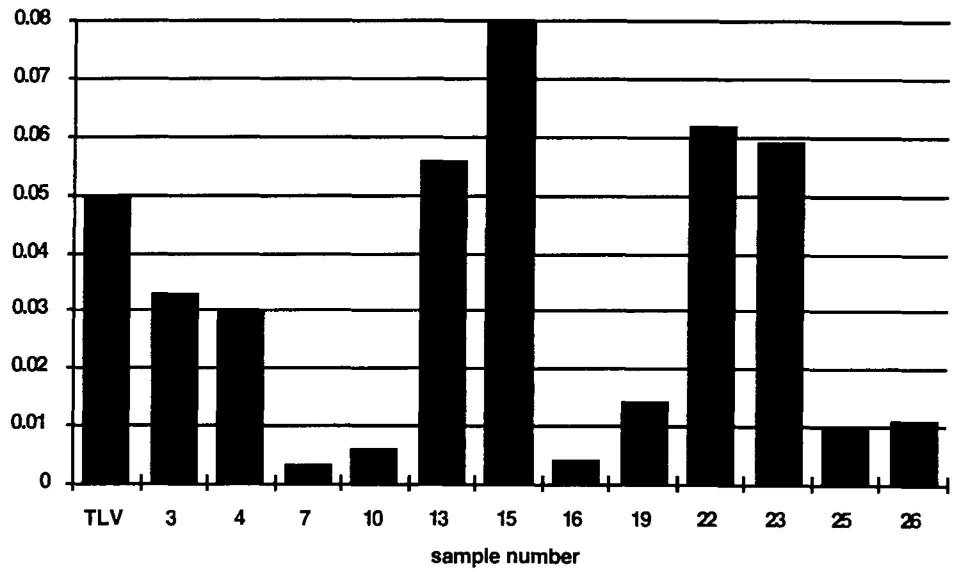


Figure 3. Welder's exposure to chromates

According to the OSHA interpretation, if sample result is below the required limit, no statistical evaluation is necessary and exposure is in compliance. Even in case when result is slightly over the limit, it could be considered by OSHA only as a possible overexposure, depending on the relation of Lower Confidence Limit (LCL) to the exposure limit. Since the statistical mean (sample result) and standard deviation (here called relative standard deviation - S_r) are known, the computation of LCL follows:

LCL = sample result -1.645 × S_r

S_r is inherent to a particular method and may be expressed as % of sample result; in this case it is 7%.

1.645 is a number of S_r considered for the degree of certainty of the result. In this case it means 95% confidence that result will be higher than LCL (one-sided confidence interval). The results of the statistical evaluation are expressed in the following Table 1.

SAMPLE NUMBER	13	15	22	23
CHROMIUM (VI) MG/M^3	0.056	0.080	0.062	0.059
LCL MG/M^3	0.049	0.070	0.055	0.052

Table 1. LCLs of exposure to chromates for selected samples

Even if the results appear as an overexposure, one should be aware that the result is based on a very conservative ratio estimate. There would be only two slight overexposures in the series of nine measurements. Considering the definition of TLV (see p. 27) and low frequency of stainless steel monitoring, it is the researchers opinion that this exposure does not represent a health risk. However, in the future stainless steel welding operations, control measures should be taken to avoid this overexposure.

Exposure to Nickel

As seen in Fig. 4, the exposure to nickel was very low when compared to the PEL and TLV of 1.0 mg/m^3. Since the highest exposure is more than ten times lower than the exposure limit, the NIOSH REL was marked on the graph. Of the nine exposures, only three exceeded that ideal limit. Of those, only sample #4 was taken while local ventilation was used, which means that compliance with even the very low NIOSH limit is achievable.

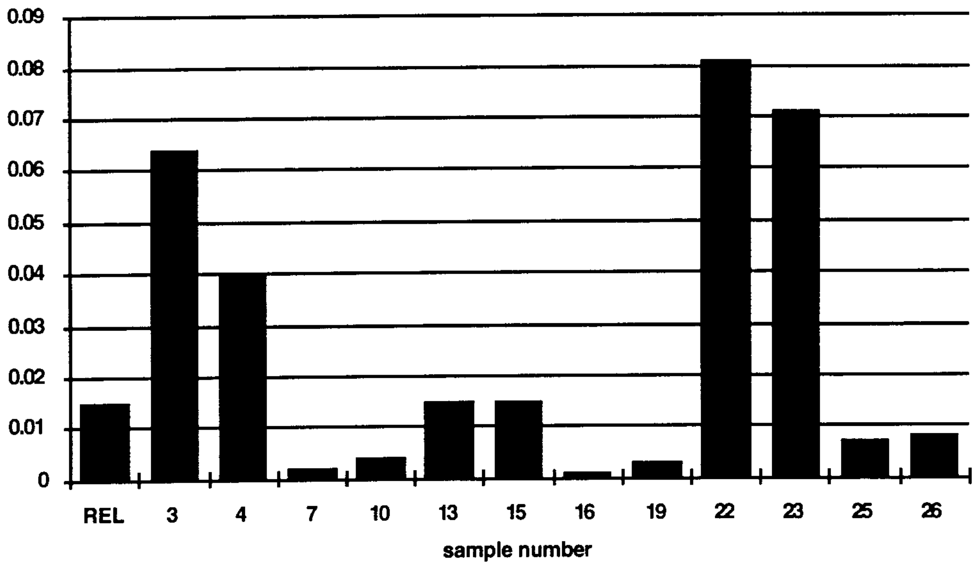


Figure 4. Welder's exposure to nickel

General Area Concentration Levels

The data plotted in Fig. 5 - 7 do not take into account values that would have been obtained if the worker had been equipped with a respirator.

Concentration of Chromium

As is shown in Fig. 5, the highest chromium concentration in the sample is ten times lower than the TLV.

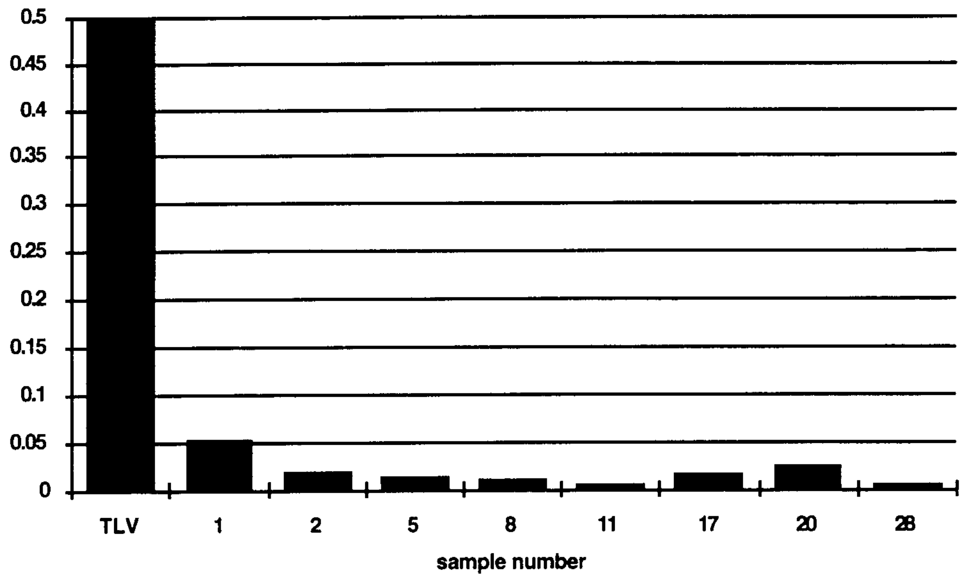


Figure 5. Chromium concentration in the general area

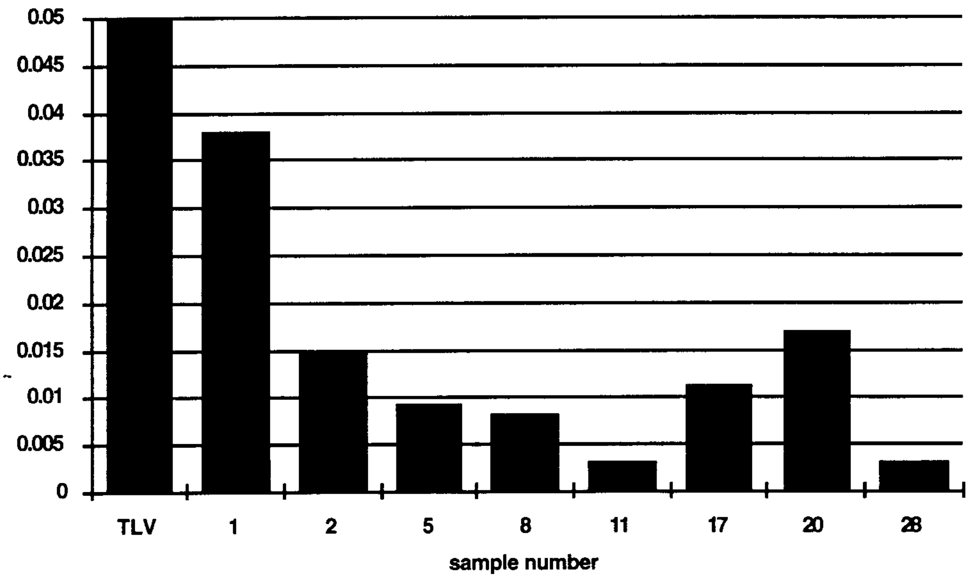


Figure 6. Chromates concentration in the general area

Concentration of Chromates

All the concentrations are well below the exposure limit as shown in Fig.6. Even sample #1 which was taken on the first day without the use of local ventilation, and with large generated volume of fumes, did not exceed the TLV. It was found that the NIOSH REL of 0.001 mg/m^3 is difficult to measure because it is very close to the detection limit. The detection limit for Visible Absorption Spectrophotometry, which is the analytical method for chromates, is 0.0002 mg/m^3. Another method, Flame Atomic Absorption, used for analysis of chromium, and in this case for subsequent estimate of chromates, has a variable detection limit. The variability is based on the size of the sample. It is estimated from practical experience, working with the CNA Environmental Health Laboratory, that the lowest detection limit would be 0.001 mg/m^3.

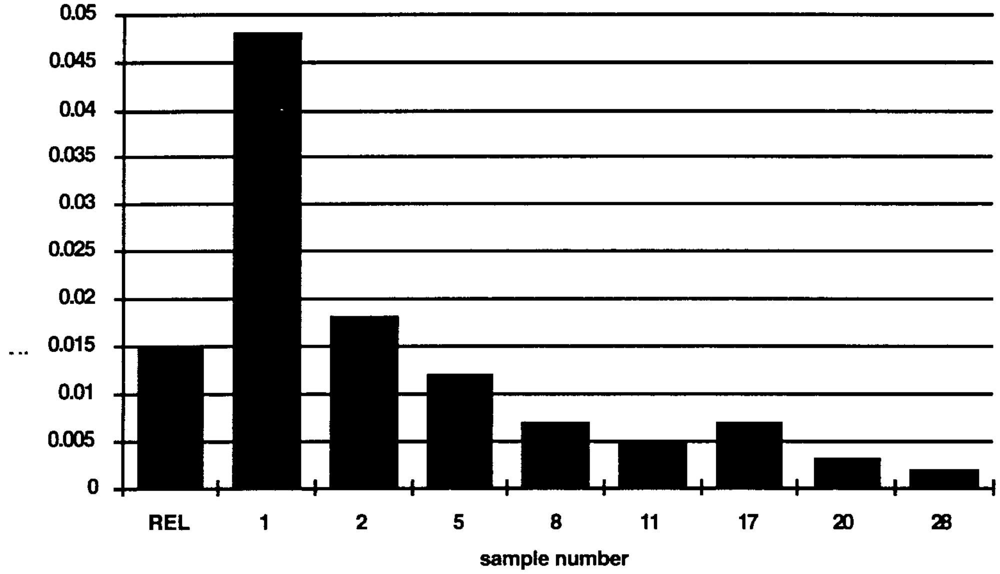


Figure 7. Nickel concentration in the general area

Concentration of Nickel

As shown in Fig. 7, the highest concentration of nickel in the samples was more than twenty times lower than TLV (or PEL) of 1.0 mg/m^3. The concentrations would even comply with extremely low REL (used as a standard in Fig. 7), except samples #1 and #2, both taken on the first day in heavy welding and without the use of local ventilation.

Ventilation

It was not originally a goal to evaluate the ventilation of welding shop. However, during the monitoring it became clear that the local ventilation was by far the most important factor in controlling exposure. Therefore assessment of health hazards associated with welding must take ventilation into consideration.

Code of Federal Regulations, Title 29, Labor, §1910.252 *Regulations for Welding, Cutting and Brazing* states that general ventilation has to be provided: (1) In a space of less than 10,000 cubic feet per welder, (2) in a room having a ceiling height of less than 16 feet, (3) in confined spaces or where the welding space contains structural barriers to the extent that they significantly obstruct cross ventilation, (4) when toxic substances as product of welding exceed allowable limits.

These general ventilation regulations require that a minimum rate of 2,000 cubic feet per minute per welder should be provided, except where local ventilation is used (CFR, 1992).

Description of Ventilation

The completely unobstructed section of the shop where arc welding was performed has 23,000 cubic feet with an additional space of about 7,000 cubic feet divided into two levels at a height of 9 feet. All this space is fully open to an adjacent area even larger than the arc welding section. The height of the whole space was variable between 16 and 20 feet high. Because three workers or fewer were observed welding at any particular time, and the periods of welding were quite short, the space requirements per welder were met and natural ventilation was considered sufficient.

Compliance with the space requirements does not guarantee compliance with allowable limits for certain elements and compounds, such as chromium and nickel. In this particular arrangement the ventilation system in the shop allowed for additional control through the combination of general and local ventilation. A number of flexible hoses ending at various points in the welding shop were connected to a baghouse and air in the shop was pulled through the hoses, filtered through bags and returned back through two rectangular openings. The positions of the baghouse and ventilation outlets were marked on Daily Data Sheet (see Appendix A).

After measuring the ventilation outlets, it was determined that the air was filtered at the rate of 8,000 to 10,000 cubic feet per minute. This level of exchange meets the minimum required rate for four welders, at 2,000 cubic feet per welder.

Efficiency of Local Ventilation

It has been found that natural or general (dilution) ventilation can greatly reduce the concentration of contaminants in the general area (background) (Plog, 1988). In this particular situation, natural ventilation provided sufficient control in general area. On the other hand, the importance of local ventilation cannot be overstated when controlling the exposure of the welder. Of the several different systems, the most appropriate and efficient for SMA welding is "source reduction" (Cheney, 1985) with the flexible hose, a variation of which is installed in this welding shop.

The efficiency of fume control depends on the distance of the mouth of the hose from the weld. It was observed that with the hose 6" to 8" from the weld most of the plume is pulled to the hose, and does not enter the welder's breathing zone. With the hose as close as 1" to the weld, all the fumes disappear into the hose and level of contaminants in the breathing zone is hardly measurable. This type of control has a great positive effect on the concentrations in the general area; contaminants are trapped in the baghouse before having a chance to disburse in the air. Notice in Appendix C that concentrations of samples #11 and #12 taken concurrently with #10 were below the detection limit.

Efficiency of Filtration

In order to evaluate the amount of contaminants in filtered, returned air, two dual samples were taken, each 3 feet from the front of ventilation outlets. Results are expressed in Table 2.

DATE	8-SEPT.	9-SEPT.
TOTAL FUMES MG/M^3	0.59	0.70
CHROMIUM MG/M^3	0.009	<0.003
NICKEL MG/M^3	0.004	<0.003

Table 2. Total fumes, Cr and Ni in filtered air

The concentrations of total fumes appear to be similar to the concentrations in the general area close to the welder (Appendix B). One explanation may be that filtration bags are clogged and do not filter properly. The baghouse should be checked, since clogged filters not only decrease the quality of air but also waste energy. A second explanation is that the concentrations of these samples may have been caused partly by air in the room; the result of turbulence, mixing air in the room with air coming from the outlets. Or it could be the combination of both which seems to be the most likely explanation.

Simplification of Monitoring Process

Finding a method to simplify the monitoring was the second goal of this study. The main research question was "can a ratio of chromium and nickel to total fumes be established for particular welding shop".

Ratios of Chromium and Nickel to Total Fumes

The concentration of total fumes should not exceed 5 mg/m^3 in any kind of arc welding. In stainless steel welding, exposures of workers to chromium, chromates and nickel should not exceed the levels expressed in Appendix E, as discussed in the previous section. That would mean using three different sampling methods which can be time consuming and costly. Since most of the plants' welding shops do a certain type of work year after year, with certain types of materials and electrodes, unique to the particular shop, it is desirable to have a method to reduce the amount of monitoring and still guarantee compliance with the exposure limits.

The amount of fumes depends on a number of variables, but it is assumed that their ratio would stay within certain range. For example, heavier welding would generate more total fumes but also more Cr and Ni in fumes. Knowing the ratio, subsequent sampling only for total fumes would enable industrial hygienist to estimate Cr and Ni content in sample.

In the course of monitoring, ten double samples, each consisting of sample for total fumes and sample for metals (Cr, Ni), were taken; for more see Chapter 3, Methods.

Evaluation of Dual Samples

Sampling results are displayed in Appendix B and C, computed ratios in Appendix D. Only three samples were used for further statistical evaluation. All other samples, while providing useful information, were excluded for the following reasons:

A - 1: Substantially different electrode (E 330) with three times higher content of nickel and a little less chromium was used only the first day.

B - 6: Due to very efficient local ventilation and short sampling time the amount of total fumes was zero (not measurable); it was not possible to express the ratio in real terms.

C - 9: Because of heavy grinding on this particular day, there were distinct black spots in the centers of the filters, formed by particulates from grinding that do not represent fumes.

D - 12: Concentration of Cr and Ni was below the detection limits because of extremely efficient local ventilation.

E - 14: There was not enough of a sample to compute total fumes (explanation follows).

F - 18 and G - 21: Those were not representative samples, they were taken at the ventilation outlets.

Results and evaluation of samples 24, 27, and 29 are displayed in Table 3. Samples J, K, and L were entered under the matched respective numbers.

- Computing the range of results for metals was done by determining the confidence limit (CL) for each individual sample; 95% 2-sided confidence interval was chosen. Relative standard deviation for chromium analysis was 7%; for nickel analysis 4.8% (CNA Laboratory).

$$CL_{Ni} = Ni_{conc.} \pm 1.96 \times 4.8\% Ni_{conc.}$$

$$CL_{Cr} = Cr_{conc.} \pm 1.96 \times 7.0\% Cr_{conc.}$$

- The range for gravimetric analysis was based on known factors: the accuracy of the analytical scale and the precision of matching the filter (Chapter 3, Methods, Gravimetric Analysis). Because absolute, not relative, numbers were used, the low and high confidence limits for total fumes were computed by adjusting the reading on analytical scale by the amount of possible error (±0.2 mg/m^3) first and then extrapolating to high and low results as concentrations per cubic meter. That was the reason for sample E to be too low to use (see Appendix B).

- Computed ratio was determined simply by entering the analytical results.

- high ratio Cr / total = Cr_{high} / $total_{low}$

- low ratio Cr / total = Cr_{low} / $total_{high}$.

SAMPLE NUMBER	24	27	29	AVERAGE
TOTAL FUMES MG/M^3	2.27	1.02	1.64	1.64
TOTAL FUME LOW MG/M^3	1.82	0.77	1.34	1.31
TOTAL FUME HIGH MG/M^3	2.73	1.28	1.94	1.98
CHROMIUM LOW MG/M^3	0.078	0.012	0.053	0.048
CHROMIUM HIGH MG/M^3	0.104	0.016	0.071	0.064
RATIO LOW	0.029	0.009	0.027	0.022
RATIO HIGH	0.057	0.021	0.053	0.044
COMPUTED RATIO CR /TOTAL FUMES	0.040	0.014	0.038	0.031
NICKEL LOW MG/M^3	0.063	0.004	0.009	0.025
NICKEL HIGH MG/M^3	0.075	0.004	0.011	0.030
RATIO LOW	0.023	0.003	0.005	0.010
RATIO HIGH	0.041	0.005	0.008	0.018
COMPUTED RATIO NI/TOTAL FUMES	0.030	0.004	0.006	0.013

Table 3. Ranges of concentrations and ratios for Cr, Ni and total fumes

The same formula is applicable to nickel by substituting nickel for chromium. Ratio range contains the numbers between the high and low ratios. Results are expressed in Figures 8. and 9.

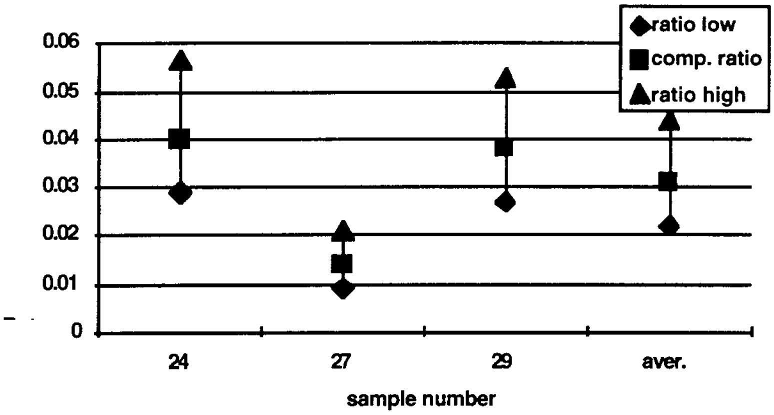


Figure 8. Ratio of chromium to total fumes

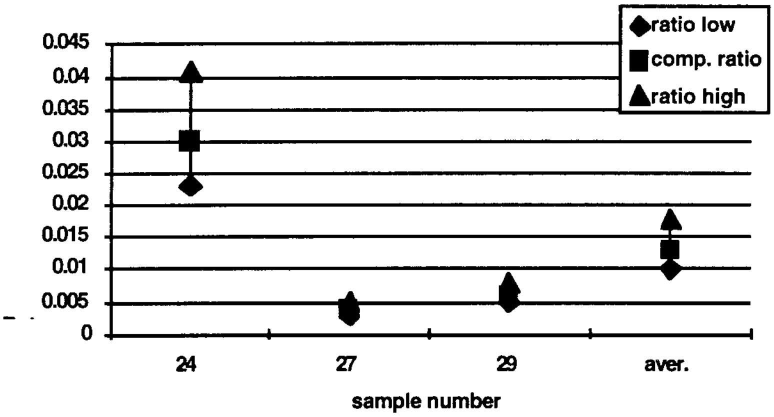


Figure 9. Ratio of nickel to total fumes

Discussion

All 3 samples were taken under nearly identical conditions:

- within the same distance and position with respect to the weld; 2 feet above and 3 feet away, just at the edge of the plume
- only natural ventilation existed and air movement was minimal
- no other welding was performed
- welder's position with respect to the weld was identical.

Certain differences in the rate of welding and slight change of air movement would be reflected in total fumes and also in metals concentrations. The differences expected between individual ratios would be slight, such as in the correlation of the ratios of chromium to total fumes between samples #24 and #29; yet, the ratio for sample #27 was much lower (Fig. 8). When comparing the ratios of nickel to total fumes, again, two samples correlated well, but this time they were samples #27 and #29, while sample # 24 was quite different (Fig. 9).

There was no plausible explanation of the seemingly erratic changes in the concentration of individual compounds of the fumes. However, this study managed to determine the range of ratios which may be used for purpose stated earlier.The results were arranged in Table 4., expressed as percentage of total fumes.

RATIO	HIGH	LOW	AVERAGE
CR / TOTAL FUMES	5.7%	0.9%	3.1%
NI / TOTAL FUMES	4.1%	0.3%	1.3%

Table 4. Range of ratios of metals to total fumes

A comparison with other studies was quite useful. In the Texas A&M University study (Lautner 1978), the electrode used was E-308 with slightly higher content of Cr (19.5%); the experiment was done under laboratory conditions and statistically evaluated; the mean for Cr was 5.8% with standard deviation of 3.2%. In the American Welding Society study (Battelle 1979), two E-316 electrodes, same as in this study, were used with Cr of 5.8% and 6.5% and Ni of 1.1% and 1.5%. The results were based on one sample for each electrode. Sampling was done in the laboratory. The Canadian study (Hewitt 1983) found 5.86% of Cr and 0.66% of Ni , again under laboratory conditions. The electrode specification was incomplete. The result for comparable electrode in the Australian study (Tandon 1986) was 5.5% for Cr and 0.03 for Ni. The experiment was performed in the laboratory with an automatic welding machine. The most recent results came from the joint German - Norwegian project (Karlsen 1992), where the experiment was done under semilaboratory conditions and results reflected the averages of using a variety of different electrodes. For the breathing zone sample the total fumes concentration was 6.4 mg/m^3, chromium concentration 0.480 mg/m^3, and nickel concentration 0.052 mg/m^3. That corresponded to 7.5% of Cr and 0.8% of Ni.

The results of these studies, mostly averages, are comparable to the upper confidence limit of this study for chromium and to the lower range for nickel. Most of the studies were done under laboratory conditions, which differ from the welding shop. The likely explanation seems to be that fumes dissipate at a slower rate in the laboratory. Using laboratory results for welding shop estimate would thus represent a more conservative method of evaluation (ratios are generally higher).

Ratio of Nickel to Chromium

Introduction

The ratio of nickel to chromium can be derived from the ratios of those two metals to total fumes. The following represents a possible alternative: chromium would be determined from the ratio of Cr to total fumes, nickel from the ratio of Ni to Cr for a particular shop.

It became apparent during the results evaluation of this study that for a majority of shops the most important point of monitoring is the welder's breathing zone. The evaluation of Cr and Ni ratios to total fumes in the previous section was based on a monitoring point very close to welder's breathing zone but still not a part of it. The distance of the sampling point from the weld seems to be a factor influencing the ratio. Since the author did not have a chance to repeat the monitoring for ratio in the welder's breathing zone, further evaluation of results from breathing zone concentrations provided some insight about the ratios there.

The results of Cr and Ni concentrations were sorted into 3 groups:

1. Just outside the breathing zone (samples 24, 27, and 29 again)
2. inside the cylinder
3. outside the cylinder.

From personal samples only lapel samples were used. The purpose of this categorization was to eliminate as many variables as possible and try to find out what particular factors had an impact on the result. Each of the following sections provides a graph of metals concentrations, a table of results and another graph displaying the range of ratios. The confidence limits for metals were determined as in the previous section - Evaluation of Dual Samples.

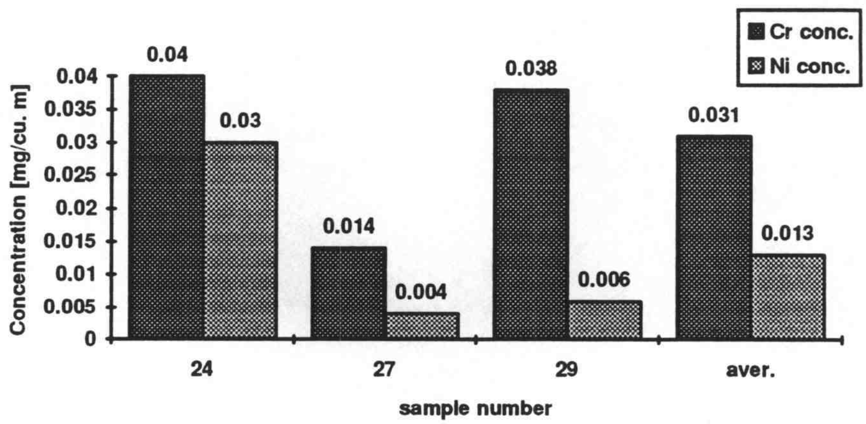


Figure 10. Concentration of Cr and Ni out of breathing zone

$RATIO_{high} = Ni_{high} / Cr_{low}$ $\qquad$ $RATIO_{low} = Ni_{low} / Cr_{high}$

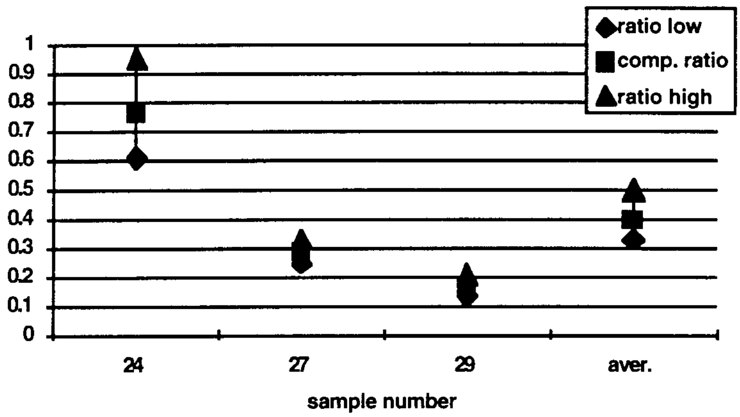


Figure 11. Ratio of Ni to Cr out of breathing zone

SAMPLE #	24	27	29	AVERAGE
NICKEL CONC. MG/M^3	0.069	0.004	0.010	0.028
NICKEL HIGH MG/M^3	0.075	0.004	0.011	0.030
NICKEL LOW MG/M^3	0.063	0.004	0.009	0.025
CHROMIUM CONC. MG/M^3	0.091	0.014	0.062	0.056
CHROMIUM HIGH MG/M^3	0.104	0.016	0.071	0.064
CHROMIUM LOW MG/M^3	0.078	0.012	0.053	0.048
NI / CR	0.76	0.29	0.16	0.40
NI / CR HIGH	0.96	0.33	0.21	0.50
NI / CR LOW	0.61	0.25	0.13	0.33

Table 5. Ratio of Ni to Cr out of breathing zone

Ratio of Nickel to Chromium Out of Breathing Zone

As seen in Table 5, the ratios for samples #27 and #29 are similar. The ratio for sample #24 is much higher because of a disproportionately higher concentration of nickel in that sample as seen in Fig. 10.

Ratio of Nickel to Chromium Inside the Cylinder

Local ventilation was always applied when welding inside the cylinder which was a partially closed space where the accumulation of fumes could reach high levels. When taking samples #4 and #7, the hose was 6" away from the weld, while with samples #16 and #19, the hose was about 10" away. A possible explanation for outlier in Fig. 12 is that more efficient local ventilation pulled away a larger portion of chromium, possibly chromates, than nickel. The large increase in the chromium concentration of sample #19 was probably caused by the use of larger diameter electrode, thus creating more fumes of chromium, possibly chromates.

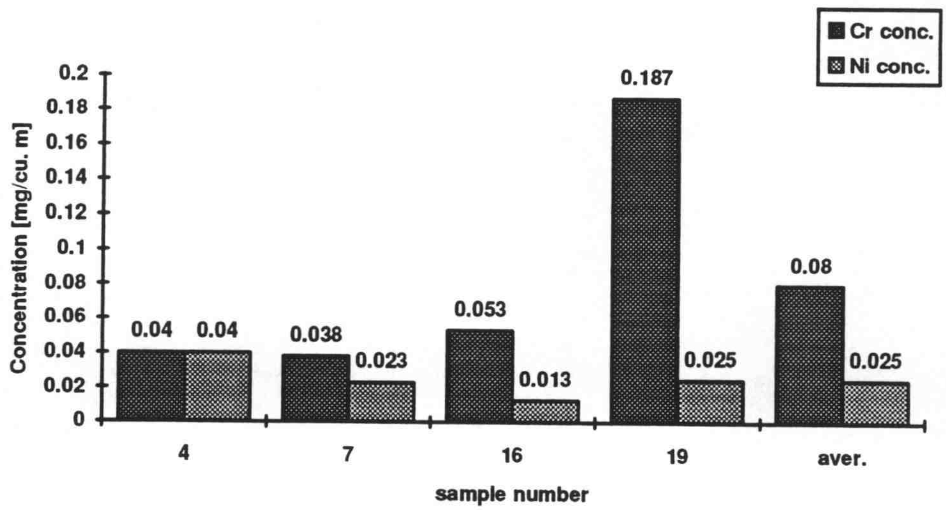


Figure 12. Concentrations of Cr and Ni inside the cylinder

SAMPLE #	4	7	16	19	AVERAGE
NICKEL CONC. MG/M^3	0.040	0.023	0.013	0.025	0.025
NICKEL HIGH MG/M^3	0.044	0.025	0.014	0.027	0.027
NICKEL LOW MG/M^3	0.036	0.021	0.012	0.023	0.023
CHROMIUM CONC. MG/M^3	0.040	0.038	0.053	0.187	0.080
CHROMIUM HIGH MG/M^3	0.046	0.043	0.060	0.213	0.091
CHROMIUM LOW MG/M^3	0.034	0.033	0.046	0.161	0.069
NI / CR	1.00	0.61	0.25	0.13	0.50
NI / CR HIGH	1.29	0.76	0.30	0.17	0.63
NI / CR LOW	0.78	0.49	0.20	0.11	0.40

Table 6. Ratios of Ni to Cr inside the cylinder

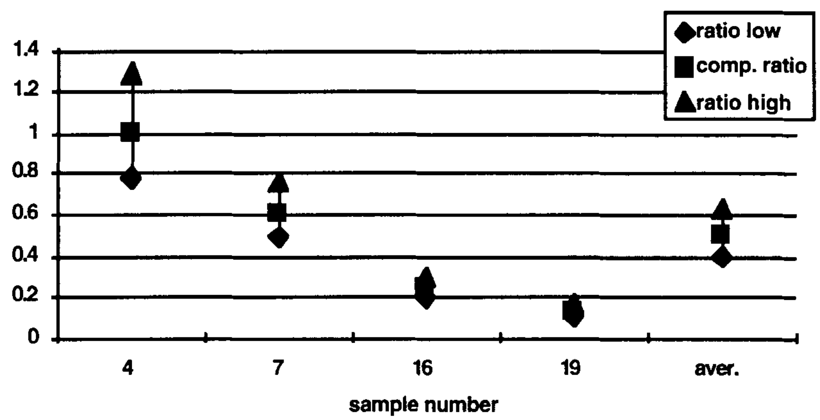


Figure 13. Ratios of Ni to Cr inside the cylinder

Ratio of Ni to Cr Outside the Cylinder

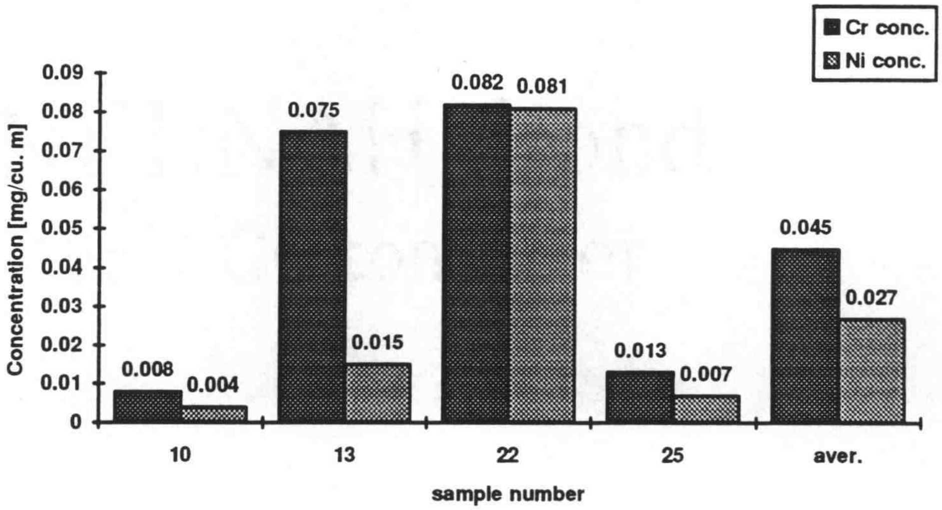


Figure 14. Concentrations of Cr and Ni outside the cylinder

SAMPLE #	10	13	22	25	AVERAGE
NICKEL CONC. MG/M^3	0.004	0.015	0.081	0.007	0.027
NICKEL HIGH MG/M^3	0.004	0.016	0.089	0.008	0.030
NICKEL LOW MG/M^3	0.004	0.014	0.073	0.006	0.024
CHROMIUM CONC. MG/M^3	0.008	0.075	0.082	0.013	0.045
CHROMIUM HIGH MG/M^3	0.009	0.086	0.093	0.015	0.051
CHROMIUM LOW MG/M^3	0.007	0.064	0.071	0.011	0.039
NI / CR	0.50	0.20	0.99	0.54	0.56
NI / CR HIGH	0.57	0.25	1.25	0.73	0.70
NI / CR LOW	0.44	0.16	0.78	0.40	0.45

Table 7. Ratios of Ni to Cr outside the cylinder

With sample #10 the hose was extremely close to the weld; the amount of Cr and Ni in the sample was too small to comment on the ratio. Local ventilation was not used with sample #13. That may correspond with the idea of higher efficiency of local ventilation for chromium than nickel. Samples #22 and #25 were taken under only natural ventilation. Sample #22 had an unusually high concentration of both metals, virtually identical. It also had an unusually high concentration of total fumes. This may be explained by the fact that this period of monitored welding followed the period of heavy

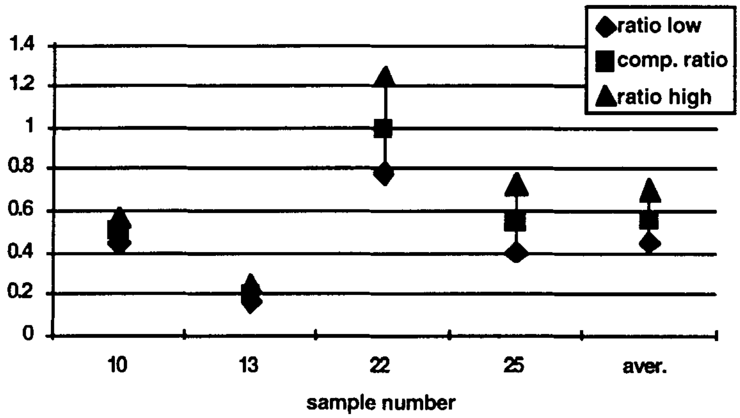


Figure 15. Ratios of Ni to Cr outside the cylinder

grinding which was not monitored, but those fumes were still in the air during the welding and picked up by samplers.

	OUT OF BREATHING ZONE	INSIDE CYLINDER	OUTSIDE CYLINDER	AVERAGE
NI / CR	0.40	0.50	0.56	0.49
NI / CR HIGH	0.96	1.29	1.25	1.17
NI / CR LOW	0.13	0.11	0.16	0.13

Table 8. Comparison of Ni to Cr ratio ranges

Summary of Ni to Cr Ratio Evaluation

Table 8 shows that the monitoring outside the breathing zone was the best controlled sampling of those three groups with respect to variables; it has the narrowest range of results. Ratio ranges for welding inside and outside were very similar and quite broad. The review of concentrations of metals and total fumes indicated that concentrations of metals fluctuated considerably more than concentration of total fumes (see Table 4 and Fig. 10). It was thus concluded that the ratio of Cr or Ni to total fumes is more influenced by fluctuation of concentrations of Cr and Ni than by fluctuation of concentration of total fumes. It means that the additional dual sampling in welder's breathing zone, for Cr, Ni and total fumes, would probably provide results similar to the ones in this study.

Helmet Protection with Respect to Fumes

It was the overwhelming opinion in the welding community that the welder's helmet reduces the exposure to fumes. To answer the question of "how much", a number of studies were performed with various results. A comprehensive welding study "The Welding Environment" (Battelle 1973) evaluated the protection provided by the helmet with samples taken concurrently inside and outside the helmet and for three different electrodes. The conclusion stated that a helmet provided a high degree of protection against the fumes produced during welding. The ratio was between low 3.3 and high 15. The conditions under which the experiment was performed were fundamentally different from real welding. In the part showing the highest protection, the concentration of total fumes was 713 mg/m^3, which is unimaginable in today's workplace. The filter was clogged in less than 1.5 minutes of sampling time. For comparison, collecting an amount corresponding to the exposure limit of 5 mg/m^3 cannot clog the filter over the entire shift of sampling. Another fundamental flaw was using the sampling time of 1.5 to 2 minutes for uninterrupted welding with helmet covering the face over that period. In real welding the total time the helmet is up is greater than the time it is down during the shift.

A thorough, well done study (Goller 1985), performed with mild steel, using real conditions of welding, with forty samples statistically evaluated, provided very different results. While monitoring for iron oxide which constitutes up to 50% of total fumes, it concluded that concentrations inside the helmet were between 36% and 71% of those outside the helmet; protection factor thus would be between 1.4 and 2.8.

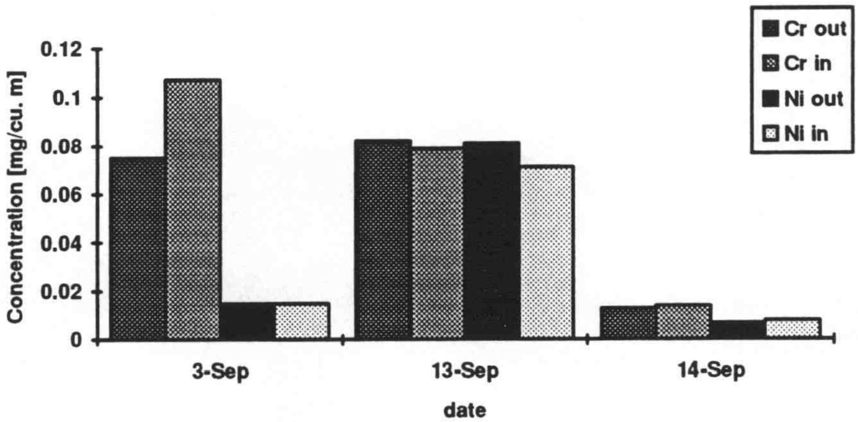


Figure 16. Impact of helmet on concentrations of Cr and Ni

Study Results and Comparison

On three occasions, the samples for metals were taken concurrently inside and outside the helmet. The results are shown in Figure 16.

The samples taken on Sept.3 indicated an identical amount of nickel and an even higher amount of chromium inside than outside. It was probably caused by the adjustment of lapel sample further away from breathing zone and thus from the arc. An open type helmet with the low edge straight down was used. The remaining two dual samples, taken with a closed type helmet - low edge bent under the chin, indicated an excellent correlation, meaning that helmet did not have any impact at all.

The difference between this and the previously mentioned study (Goller 1985) may be explained by the fact that concentrations of total fumes in the previous study were still up to ten times higher than in this one.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Compliance with Exposure Limits

The results of comprehensive monitoring over the whole period of stainless steel welding show that this welding shop was in compliance with both OSHA PELs and ACGIH TLVs. With this rate of welding and ventilation provided, there is hardly any reason to monitor the general area. The important point for monitoring is welder's breathing zone. If concentrations there are below the limits, then monitoring of other points is unnecessary.

The most serious health effects may be caused by chromates emitted during stainless steel welding. If compliance with limits for chromates is achieved, then compliance with limits for chromium and nickel is guaranteed. Samples for chromates are collected with PVC filters and CNA Environmental Health Laboratory routinely performs the analysis for chromates.

Even without any additional monitoring, a high assurance of low concentration levels can be achieved by proper use of existing local ventilation. At present, the flexible hoses are rarely being used as means of local ventilation because it is cumbersome and time consuming to move and position the hose. An improvement is possible without any significant additional cost. All that is needed is a type of movable stand with adjustable arm holding the hose in proper position with respect to the weld. This stand can be manufactured in a plant maintenance shop.

Welding samples were taken at the end of summer, in a well ventilated area. The doors were open all day. The situation in winter may be quite different, because natural ventilation is minimal (all doors are kept closed). Because general ventilation creates an unpleasant draft, it is not frequently used. Actually, because air is recirculated with general ventilation , accumulation of fumes during winter months would be higher than in summer months. Proper application of local ventilation might improve that situation. The problem is that local ventilation is an inseparable part of general ventilation. It is suggested that most of the welding be grouped timely together and ventilation used only during that period of time. The supervisors and workers there would know best how to accomplish that.

The situation is somewhat different when welding only mild steel. In that situation, it is important to monitor total fumes, which can be done easily with matched-weight filters. If the concentration of total fumes is below the limit, then there is no reason to monitor for iron oxide, the limit of which is twice as high (10 mg/m^3) , but constitutes at most 50% of total fumes.

Simplification of Monitoring Process

Results of this study, together with some conclusions from other studies, may enable an industrial hygienist to focus on important points in monitoring stainless steel welding in shops and avoid wasting time and funds on sampling that is not necessary. The following is not meant as a set of instructions; it is an observation that should be applied properly, taking into consideration the type of welding shop, means of monitoring available to an industrial hygienist, and personal experience with respect to welding.

The following suggestions may simplify the monitoring process:

Samples for evaluation of the welding process should be taken during one of the periods of heavy welding, since compliance with regulations at that time assures compliance when the rate of welding is lower, provided that other variables, such as ventilation, are at comparable levels.

Most of the welding shops are reasonably well ventilated and rate of welding compared to production welding, such as in shipyards, is low. If that is the case and sampling in the welder's breathing zone shows results considerably lower than exposure limits, then sampling of the general area is generally unnecessary.

Establishing the ratios of contaminants and subsequent monitoring for only one or two instead of all four may be helpful in cutting monitoring costs.

In the first thorough sampling of welder's breathing zone, a series of dual samples should be taken. One of the samples should be taken for gravimetric analysis (matched-weight filter) and subsequent analysis for Cr and Ni. The other sample should be collected on PVC filter for analysis of chromates.

The number of samples taken during the initial evaluation depends on particular circumstances; however, a larger number of samples will increase the precision of the results. It is recommended that at least 3 dual samples be taken while using natural ventilation, possibly together with general ventilation. Another set of 3 dual samples may be taken using the best local ventilation readily available; if using flexible hose, it may be positioned at the distance about 6" from the weld. If any particular set of welding conditions is predominantly used, it should be included in sampling.

Analytical results should be then used to establish the ratios in a way similar to this study.

Compliance with limits for chromates virtually guarantees compliance with limits for chromium and nickel. This means that any subsequent monitoring for chromates, together with sampling for total fumes, provides complete evaluation. Levels of Cr and Ni may be estimated by using the ratios.

If the initial evaluation was properly performed, any subsequent monitoring for total fumes should be reasonably sufficient to estimate the concentrations of Cr, Ni and chromates.

When using the ratios, it is recommended that the conservative estimate be used.

If the estimate is close to the exposure limit, it is suggested that a sample be taken for evaluation. That would validate the original results.

The most effective means of reducing the concentrations for both the welder's breathing zone and the general area is source reduction, in most cases using a flexible hose. When in doubt about the exposure, it is recommended that ventilation be increased if at all possible.

The lower the concentration of fumes, the less protection a helmet provides, even in relative terms; at certain level it provides none. Under welding conditions of plant shops the protection against fumes provided by a helmet is negligible.

There are two important points to be made based on experience from this study:

A. It is necessary to collect enough sample , especially for total fumes. For example, collected sample of 0.4 mg and possible error of ±0.2 mg relates to ±50% error; a sample of 2.0 mg with the same absolute error of ±0.2 mg reduces the error to ±10%. Since increasing the concentration of fumes is not desirable, increasing the sampling time should be the solution. That may be the situation in welding shops with a low rate of welding and good ventilation. In this study, while about half day samples were representative for 8-hour shift, for several reasons it was not possible to monitor over the whole shift.

B. Heavy grinding should not be included in sampling. It is only a physical process, producing particles of the metals involved. But chromates are evolved only in arc welding, to a large degree a chemical process. Researchers separated the processes of welding and grinding (Karlsen 1992) and found that Cr(VI) in grinding was always below the detection limit. Since Cr(VI) is the most serious contaminant in stainless steel welding, inclusion of significant portion of grinding in sampling may distort the true ratio . Another reason is the fact that particles of grinding are larger than the respirable fraction and would be trapped in the upper respiratory tract. Size of particles with respect to physiological effect is discussed in detail in Review of Literature.

The author, when discussing exposure control, focused on engineering controls, especially ventilation. Engineering controls should be the priority. Administrative controls, such as organization of work in winter may have some positive impact. The use of a fume respirator is highly recommended in closed spaces, during grinding and, in some circumstances, as additional protection. Awareness of the problems and solutions is the important first step in keeping a healthy work environment.

BIBLIOGRAPHY

Abell, M. T., Carlberg, J. R. (1974). A simple reliable method for the determination of airborne hexavalent chromium. *American Industrial Hygiene Association Journal, 85,* 229-233.

American National Standards Institute: ANSI / ASC Z49.1 (1988). *Safety in Welding and Cutting.* Miami, FL: American Welding Society.

Anthony, J. S., Zamel, N., Aberman, A. (1978). Abnormalities in pulmonary function after brief exposure to toxic metal fumes. *Canadian Medical Association Journal, 119,* 586-588.

Battelle-Columbus Laboratories (1973). *The Welding Environment.* Miami, FL: American Welding Society.

Battelle-Columbus Laboratories (1979). *Fumes and Gases in the Welding Environment.* Miami, FL: American Welding Society.

Bauer, L. (1990). Welding fumes spark controversy. *Welding Design & Fabrication, 63,* 24-26.

Beton, D. C., Andrews, J. S., Davies, H. J., Howells, L., Smith, G. F. (1966). Acute cadmium fume poisoning. Five cases with one death from renal necrosis. *British Journal of Industrial Medicine, 23,* 292-301.

Blejer, H. P., Caplan, P. E., Alcocer, A. E. (1966). Acute cadmium fume poisoning in welders: A fatal and non-fatal case in California. *California Medicine, 105,* 209-296.

Browning, E. (1961). *Toxicity of Industrial Metals,* 296. London, England: Butterworths.

Burgess, W. A. (1981). *Recognition of Health Hazards in Industry,* 117-132. New York, NY: John Wiley & Sons.

Casarett and Doull's *Toxicology: The Basic Science of Poisons,* chapter 19 (1986). Edited by C. D. Klaassen, M. O. Amdur, J. Doull. New York, NY: Macmillan Publishing Company.

Challen, P. J. R., Hickish, D. R., Bedford, J. (1958). An investigation of some health hazards in welding. *British Journal of Industrial Medicine, 15,* 276-281.

Cheney, W. A. (1985). Hoods for capture of welding fumes. *Welding Journal, 64,* 90.

Code of Federal Regulations, Title 29, Labor, § 1910.252 (1992). *Regulations for Welding, Cutting and Brazing.* Washington, D. C.: U. S. Government Printing Office.

Dahlberg, J. A., Myrin, L. H. (1971). The formation of dichloracetylchloride and phosgene from thichlorethylene in the atmosphere of a welding shop. *Annals of Occupational Hygiene, 14,* 269-274.

Data sheet, (1985). How the human body eliminates welding fume dust. *Welding Journal, 64,* 62.

Doig, A. T., Challen, P. J. R. (1964). Respiratory hazards in welding. *Annals of Occupational Hygiene, 7,* 223-231.

Doig, A. T., McLaughlin, A. I. G. (1948). Clearing of X-ray shadows in arc welders. *Lancet, 1,* 789-791.

Everett, E. D., Overholt, E. L. (1968). Phosgene poisoning. *Journal of American Medical Association, 205,* 103-105.

Farrants, G., Schuler, B., Karlsen, J. (1989). Characterization of the morphological properties of welding fume particles by transmission electron microscopy and digital image analysis. *American Industrial Hygiene Association Journal, 50,* 473-479.

Fogh, A., Frost, J., George, J. (1969). Respiratory symptoms and pulmonary function in welders. *Annals of Occupational Hygiene, 12,* 213-218.

Goller, J. W., Paik, N. W. (1985). A comparison of irone oxide fume inside and outside of welding helmets. *American Industrial Hygiene Association Journal, 46,* 89-93.

Harries, P. G. (1976). Experience with asbestos disease and its control in Great Britain's naval dockyards. *Environmental Resources, 11,* 261-267.

Hayden, S. P., Pincock, A. C., Hayden, J., Tyler, L. E., Cross, K., Bishop, J. M. (1984). Respiratory symptoms and pulmonary function of welders in the engineering industry. *Thorax, 39,* 442-447.

Hedenstedt, A. D., Jensen, D., Lidesten, B. M. (1978). Mutagenicity of fume particles from stainless steel welding. *Scandinavian Journal of Work, Environmental Health, 3,* 203-211.

Hewitt, P. J., Gray, C. N. (1983). Some difficulties in the assessment of electric arc welding fume. *American Industrial Hygiene Association Journal, 44,* 727-732.

Hunnicutt, T. N., Cracovaner, D. J., Myles, J. T. (1964). Spirometric measurements in welders. *Archives of Environmental Health, 8,* 66-69.

Husgafvel-Pursiainen, K., Kalliomaki, P. L., Sorsa, M. (1982). A chromosome study among stainless steel welders. *Journal of Occupational Medicine, 24,* 762-766.

Jones, G. R., Proudfoot, A. I., Hall, J. I. (1973). Pulmonary effects of acute exposure to nitrous fumes. *Thorax, 28,* 61-65.

Kalliomaki, P. L., Junttila, M. L., Kalliomaki, K. (1983). Comparison of the retention and clearance of different welding fumes in rat lungs. *American Industrial Hygiene Association Journal, 44,* 733-738.

Karlsen, J. T., Farrants, G., Torgrimsen, T. (1992). Chemical composition and morphology of welding fume particles and grinding dusts. *American Industrial Hygiene Association Journal, 53,* 290-297.

Keskinen, H., Kalliomaki, P. L., Alanko, K. (1980). Occupational asthma due to stainless steel welding fumes. *Clinical Allergy, 10,* 151-159.

Kobayashi, M., Maki, S., Hashimoto, Y. (1983). Investigations on chemical composition of welding fumes. *Welding Journal, 62,* 190-196.

Lautner, G. M., Carver, J. C., Konzen, R. B. (1978). Measurement of chromium VI and chromium III in stainless steel welding fumes with electron spectroscopy for chemical analysis and neutron activation analysis. *American Industrial Hygiene Association Journal, 39,* 651-659.

Levy, S. A., Margolis, I. (1974). Sidero-silicosis and atypical hyperplasia. *Journal of Occupational Medicine, 16,* 796-799.

Lunau, F. W. (1967). Ozone in arc welding. *Annals of Occupational Hygiene, 10,* 175-188.

Manning, D. (1992). Will welding stand the test of time? *Welding Design & Fabrication, 65,* 20-22.

McGraw-Hill Encyclopedia of Science & Technology (1992). *Welding and Cutting of Metals,* volume 19, 429-438. New York, NY: McGraw-Hill, Inc.

McMillan, G. H. G. (1983). The health of welders in naval dockyards. Final summary report. *Journal of Royal Navy Medical Service, 69,* 125-131.

McMillan, G. H. G., Pethybridge, R. J. (1984). A clinical, radiological and pulmonary function case-control study of 135 dockyard welders aged 45 years and over. *Journal of Society of Occupational Medicine, 34,* 3-23.

McMillan, G. H. G. (1979). Studies of the health of welders in naval dockyards. *Annals of Occupational Hygiene, 21,* 377-392.

McMillan, G. H. G., Heath, J. (1979). The health of welders in naval dockyards: Acute changes in respiratory function during standardized welding. *Annals of Occupational Hygiene, 22,* 19-32.

Meyer, E. C., Kratzinger, S. F., Miller, W. H. (1967). Pulmonary fibrosis in arc welder. *Archives of Environmental Health, 15,* 464-469.

Moreton, J. (1980). *Analysis of Airborne Pollutants in Working Atmospheres: The Welding and Surface Coating Industries.* London, England: The Chemical Society, Burlington House.

Morgan, W. K. C. (1989). On welding, wheezing, and whimsy. *American Industrial Hygiene Association Journal, 50,* 59-69.

Morgan, W. K. C. (1986). The respiratory effects of particles, vapors and fumes. *American Industrial Hygiene Association Journal, 47,* 670-673.

Morgan, W. K. C., Seaton, A. (1984). *Occupational Lung Diseases*, chapter 20. Philadelphia, PA: W. B. Saunders Co.

Morgan, W. K. C. (1978). Industrial bronchitis. *British Journal of Industrial Medicine, 35,* 285-291.

National Institute of Occupational Safety and Health (NIOSH), (1993). Chromium VI. *RTECS (Registry of Toxic Effects of Chemical Substances).*

National Institute of Occupational Safety and Health (NIOSH) (1990). *Pocket Guide to Chemical Hazards.* DHHS (NIOSH) Publication No. 90-117. Washington, D.C.: U. S. Government Printing Office.

Newhouse, M. L., Murray, R. (1981). *The present position concerning the biological effects of exposure to fumes in welders.* Abington Hall, Cambridge, England: The Welding Institute.

Newhouse, M. L., Oakes, D., Wooley, A. J. (1985). Mortality of welders and other craftsmen at a shipyard in N. E. England. *British Journal of Industrial Medicine, 42,* 406-410.

Norseth, T. (1981). The carcinogenicity of chromium. *Environmental Health Perspectives, 40,* 121-130.

Oxhoj, H., Bake, B., Wedel, H., Wilhemsen, L. (1979). Effects of electric arc welding on ventilatory lung function. *Archives of Environmental Health, 34,* 211-217.

Patty, F. A. (1991). *Industrial Hygiene and Toxicology, General Principles.* New York, NY: John Wiley & Sons.

Peters, J. M., Murphy, R. L. H., Ferris, B. G. Jr. (1973). Pulmonary function in shipyard welders. *Archives of Environmental Health, 26,* 24-31.

Plog, B. A. (1988). *Fundamentals of Industrial Hygiene,* chapters 7, 18, 20-22. National Safety Council.

Reding, L. (1992). Controlling welding fume: A design approach. *Welding Journal, 71,* 61-64.

Rieke, F. F. (1969). Lead intoxication in shipbuilding and ship scrapping (1941-1968). *Archives of Environmental Health, 19,* 521-539.

Seaton, A. (1984). *Occupational Lung Diseases,* chapter 22. Edited by W. K. C. Morgan and A. Seaton. Philadelphia, PA: W. B. Saunders Co.

Sheers, G., Coles, R. M. (1980). Mesothelioma risks in a naval dockyard. *Archives of Environmental Health, 35,* 276-280.

Sjogren, B., Ulfvarson, U. (1985). Respiratory symptoms and pulmonary function among welders working with aluminum, stainless steel, and railroad tracks. *Scandinavian Journal of Work, Environmental Health, 11,* 27-32.

Steel, J. (1968). Respiratory hazards in shipbuilding and ship repairing. *Annals of Occupational Hygiene, 11,* 115-121.

Tandon, R. K., Ellis, J., Crisp, P. T. (1986). Chemical investigation of welding fumes from hardfacing and HSLA-steel electrodes. *Welding Journal, 65,* 231-236.

Tandon, R. K., Ellis, J., Crisp, P. T. (1984). Fume generation and melting rates of shielded metal arc welding electrodes. *Welding Journal, 63,* 263-266.

Therrien, J. (1992). A ten-point program for fume, smoke and particle collection. *Welding Journal, 71,* 71-72.

Welding Handbook (1968). *Fundamentals of Welding,* volume 1. Miami, FL: American Welding Society.

Wiseman, L. G. (1989). No nickel carbonyl detected when welding stainless steel or nickel alloys. *Welding Research, May 1989 supplement,* 192-197.

APPENDICES

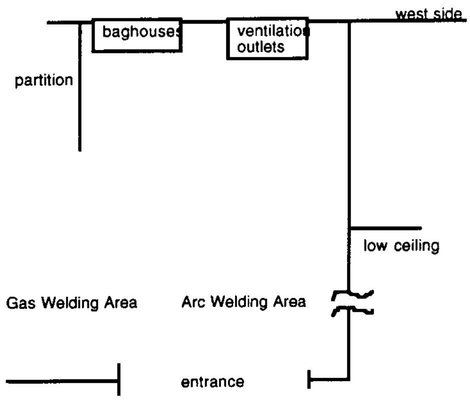
Appendix A

Daily Data Sheet for Welding Fumes

Daily Data Sheet for Welding Fumes

Date:____________________

Location of stainless steel weld, samples, other welding performed.



LEGEND:

È air flow direction

\# position and number of sample

fl#‡ average distance of sample from weld

VENTILATION:

Natural____

General____

Local____

DUST/FUME RESPIRATOR:____

ADDITIONAL INFORMATION:____

sample #	pump #	liters per minute	start time	stop time	sample volume m^3	note	result mg/m^3

APPENDIX B - GRAVIMETRIC ANALYSIS

SAMPLE NUMBER	DATE TAKEN	WEIGHT 1 [MG]	WEIGHT 2 [MG]	WEIGHT 3 [MG]	AVERAGE WEIGHT [MG]	SAMPLE VOLUME [M^3]	**TOTAL FUME CONCENTRATION [MG/M^3]**	MATCHED SAMPLE NUMBER	APPEARANCE OF THE SAMPLE (OBSERVATION)
A	8/27	0.3	0.4	0.3	0.3	0.510	**0.59**	1	medium load, evenly spread
B	8/30	0.0	0.0	0.0	0.0	0.176	**0.00**	6	hardly distinguishable from the blank - extrem. light load
C	8/31	0.3	0.4	0.3	0.3	0.495	**0.61**	9	medium load, evenly spread
D	9/2	0.2	0.2	0.2	0.2	0.319	**0.63**	12	medium load, evenly spread
E	9/3	0.1	0.2	0.2	0.2	0.473	**0.42**	14	lighter load overall with a black spot in the middle
F	9/8	0.3	0.3	0.3	0.3	0.506	**0.59**	18	medium load, evenly spread
G	9/9	0.4	0.4	0.3	0.4	0.572	**0.70**	21	medium load overall, light irreg. black spot in the middle
J	9/13	1.0	1.0	0.9	1.0	0.440	**2.27**	24	heavy load, distinct black spot in the middle
K	9/14	0.7	0.8	0.8	0.8	0.781	**1.02**	27	medium load, medium black spot in the middle
L	9/15	1.1	1.0	1.1	1.1	0.671	**1.64**	29	medium-high load; small, distinct black spot in the middle

APPENDIX C - ANALYSIS FOR CHROMIUM AND NICKEL

DATE	SAMPLE NUMBER	Cr [MG/M^3]	Ni [MG/M^3]	MATCHED WITH	LOCATION OF SAMPLE	VENTILATION	FUME RESP	NOTE
8/27	1	0.051	0.048	A	general area 5-10 ft away in wind direction	general	N/A	electrode E 330: 15.5% Cr, 35% Ni welded piece upright large amount of fumes
	2	0.020	0.018	–	general area 5-10 ft away opposite wind dir.	general	N/A	see note for sample #1
	3	0.442	0.643	–	welder - lapel	general	YES	see note for sample #1
8/30	4	0.040	0.040	–	welder - lapel **inside** cylinder	general local - 6" away from the weld	NO	electrode E 316: 18.5% Cr, 12.5% Ni welded cylinder in horizontal position;
	5	0.012	0.012	–	general area 5 ft away	see sample #4	N/A	see note for sample #4
	6	0.009	0.009	B	general area 6 ft away	see sample #4	N/A	see note for sample #4
8/30	7	0.038	0.023	–	welder - lapel **inside** cylinder	see sample #4	YES	see note for sample #4 larger electrode = more fumes dark spots on filters - grinding
	8	0.010	0.007	–	general area 12 ft away	see sample #4	N/A	see note for sample #7
	9	0.010	0.008	C	general area 6 ft away	see sample #4	N/A	see note for sample #7

APPENDIX C (continued)

DATE	SAMPLE NUMBER	Cr [MG/M^3]	Ni [MG/M^3]	MATCHED WITH	LOCATION OF SAMPLE	VENTILATION	FUME RESP	NOTE
9/2	10	0.008	0.004	–	welder - lapel top of cylinder	general local - hose extr. close to the arc - getting all fumes	NO	see note for sample #4 smaller electrode = less fumes
	11	<0.004	<0.005	–	general area 12 ft away	see sample #10	N/A	see note for sample #10
	12	<0.004	<0.004	D	general area 5 ft away	see sample #10	N/A	see note for sample #10
9/3	13	0.075	0.015	15	welder - lapel top of cylinder	general only to be able to collest fumes	NO	see note for sample #4 larger electrode
	14	0.016	0.003	E	general area 6 ft away	see sample #13	N/A	see note for sample #13
	15	0.107	0.015	13	welder - inside helmet (left cheek)	see sample #13	NO	see note for sample #13 open type helmet
9/8	16	0.053	0.013	–	welder - lapel **inside** cylinder	general local - 10" away	YES	see note for sample #4 another piece attached
	17	0.015	0.007	–	general area 5 ft away	see sample #16	N/A	see note for sample #16
	18	0.009	0.004	F	3 ft in front of vent. outlet	see sample #16	N/A	see note for sample #16 heavy grinding

APPENDIX C (continued)

DATE	SAMPLE NUMBER	Cr [MG/M^3]	Ni [MG/M^3]	MATCHED WITH	LOCATION OF SAMPLE	VENTILATION	FUME RESP	NOTE
9/9	19	0.187	0.025	–	welder - lapel **inside** cylinder	general local - 10" away	YES	see note for sample #16 larger electrode = more fumes
	20	0.023	0.003	–	general area 5 ft away	see sample #19	N/A	see note for sample #19
	21	<0.003	<0.003	G	3 ft in front of vent. outlet	see sample #19	N/A	see note for sample #19
9/13	22	0.082	0.081	23	welder - lapel top of cylinder	natural only !	NO	see note for sample #16 close type helmet
	23	0.079	0.071	22	welder - inside helmet (left cheek)	natural only !	NO	see note for sample #16 close type helmet
	24	0.091	0.069	J	3 ft above weld, away from plume	natural only !	N/A	see note for sample #16 sampling for ratios
9/14	25	0.013	0.007	26	welder - lapel top of cylinder	natural only !	NO	see note for sample #22, plume away from breathing zone
	26	0.014	0.008	25	welder - inside helmet (left cheek)	natural only !	NO	see note for sample #22, plume away from breathing zone
	27	0.014	0.004	K	3 ft above weld, away from plume	natural only !	N/A	see note for sample #16 sampling for ratios
9/15	28	0.004	0.002	–	general area 15 ft away	natural only !	N/A	see note for sample #16
	29	0.062	0.010	L	3 ft above weld, away from plume	natural only !	N/A	see note for sample #16 sampling for ratios

APPENDIX D - RATIOS OF Cr AND Ni TO TOTAL FUMES

DATE	TOTAL FUME CONCENTRATION [MG/M^3]	Cr CONCENTRATION [MG/M^3]	RATIO OF Cr TO TOTAL FUMES	Ni CONCENTRATION [MG/M^3]	RATIO OF Ni TO TOTAL FUMES	NOTE
8/27	0.59	0.051	0.086	0.048	0.081	using E-330: 15.5% Cr, 35% Ni (only day) weld (cylinder) in upright position large amount of fumes in breathing zone
8/30	0.0	0.009	NA	0.009	NA	very efficient local ventilation sampling time too short for total fumes
8/31	0.61	0.010	0.016	0.008	0.013	larger electrode - more fumes heavy grinding - dark center spots (filters)
9/2	0.63	<0.004	<0.006	<0.004	<0.006	extremely efficient local ventilation
9/3	0.42	0.016	0.038	0.003	0.007	local ventilation not used
9/8	0.59	0.009	0.015	0.004	0.007	at the ventilation outlet (incoming air)
9/9	0.70	0.003	0.004	<0.003	<0.004	at the ventilation outlet (incoming air)
9/13	2.27	0.091	0.040	0.069	0.030	3 ft above weld, edge of the steady plume only a natural ventilation
9/14	1.02	0.014	0.014	0.004	0.004	3 ft above weld, edge of the steady plume only a natural ventilation
9/15	1.64	0.062	0.038	0.010	0.006	3 ft above weld, edge of the steady plume only a natural ventilation

APPENDIX E - EXPOSURE LIMITS

CHEMICAL HAZARD	OSHA		ACGIH	NIOSH	NOTE
	PEL[1] -TWA[2] [MG/M^3]	PEL - C[3] [MG/M^3]	TLV[4] - TWA [MG/M^3]	REL[5] - TWA [MG/M^3]	
CHROMIUM METAL	1.0		0.5	0.5	
CHROMIUM (II) AND (III) COMPOUNDS	0.5		0.5	0.5	
CHROMATES = CHROMIUM (VI) COMPOUNDS = HEXAVALENT CHROMIUM		0.1*	0.05	0.001	* Ceiling limit is not applicable to welding process; it is impossible to measure grab (instant) sample for fumes. The goal is to comply with TLV which is lower.
NICKEL METAL AND OTHER COMPOUNDS	1.0 0.1**		1.0	0.015	** For soluble compounds; it is not applicable to welding process.

[1]Permissible Exposure Limit
[2]Time-Weighted Average limit over an eight-hour period
[3]Ceiling limit which cannot be exceeded at any time
[4]Threshold Limit Value
[5]Recommended Exposure Limit