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DISSERTATION

EXPOSURE ASSESSMENT AND LONGITUDINAL PULMONARY FUNCTION  
OF ELECTRIC UTILITY POWER PLANT MAINTENANCE WELDERS

Submitted by

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Department of Environmental Health

In partial fulfillment of the requirements

for the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Spring 2001

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Spring 2001

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY ARLEN W. SIERT ENTITLED EXPOSURE ASSESSMENT AND LONGITUDINAL PULMONARY FUNCTION OF ELECTRIC UTILITY POWER PLANT MAINTENANCE WELDERS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION  
EXPOSURE ASSESSMENT AND LONGITUDINAL PULMONARY FUNCTION  
OF ELECTRIC UTILITY POWER PLANT MAINTENANCE WELDERS

An exposure assessment and longitudinal pulmonary function study of electric utility power plant maintenance welders involved industrial hygiene surveys, air monitoring and exposure evaluation in eleven power plants for a six-year period. Eight-hour time-weighted exposures exceeded occupational exposure limits on an intermittent, but not routine basis. Overexposures to fume regularly occurred during all thermal cutting processes. Exposures over the ACGIH TLV for manganese and over both the TLV (soluble form) and OSHA PEL (ceiling) for hexavalent chromium often resulted during flux-cored arc welding on mild steel and shielded metal arc welding on high alloy steel, respectively.

The longitudinal pulmonary function study involved 43 welders in nine power plants, resulting in 195 test results each for FEV<sub>1</sub> and FVC, over periods of time from first to last test ranging from 1.7-19.9 years. Medical surveillance questionnaires, administered at the times of testing, were used to determine potential confounders such as smoking status, smoking consumption in packyears, years in a plant containing asbestos insulation, age at spirometry, change in weight, years of follow-up, and number of tests per subject.

The mean annual decline was 49.4 ml (95% CI 23.3-75.5) for height-adjusted FEV<sub>1</sub>, and 70.8 ml (95% CI 40.4-101.2) for height-adjusted FVC. This rate of decline appears higher than the annual expected age-related decline in a general population that is reported to be 25-30 ml for FEV<sub>1</sub> and FVC. Multiple linear regression was used to evaluate changes in FEV<sub>1</sub> and FVC with the covariates, and the only significant association (95% confidence level) was annual change in body weight for height-adjusted FEV<sub>1</sub> ( $p$ -value = .0148) and height-adjusted FVC ( $p$ -value = .0101).

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## DEDICATION

This dissertation is dedicated foremost to Gordon and Helen Siert, for always being the best guiding example as parents and also helping me believe that I could succeed; and also to my dear grandmother, Ossie Ozbirn, for her continued interest and influence in my life from childhood to present; to my aunt Clara Mae, who was always involved, enthusiastic and supportive; and to my precious wife Diane, who has been encouraging and supportive.

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## **CHAPTER I**

### **INTRODUCTION**

Electric utility power plant welders are exposed to a variety of air contaminants in the form of metal fumes and gases generated by welding and thermal cutting processes. Air contaminants in welding and cutting may include metal oxide fumes such as aluminum, beryllium, cadmium, trivalent and hexavalent chromium, cobalt, copper, iron, lead, manganese, nickel, and zinc; fluorides in particulate and gaseous form; and gases such as ozone and nitrogen dioxide. Some of these air contaminants are known to be potentially harmful to the respiratory system. Chronic exposure to sufficient levels of these air contaminants could cause accelerated decline in pulmonary function.

Electric utility power plant welders' exposures are particularly difficult to characterize due to numerous variables including: the spectrum of fumes and gases generated by a variety of welding and thermal cutting processes conducted on a series of base metals; the numerous and difficult work locations and environmental conditions; and the non-repetitive nature of many job tasks performed. The result is that most welding and cutting in this industry is being conducted in the absence of adequate exposure assessment. The lack of both exposure information and resultant lack of general hazard awareness has resulted, rightly or wrongly, in welding and cutting typically being

conducted without exposure reduction controls, such as local exhaust ventilation and respiratory protection.

Certain air contaminants generated in welding have been shown to be capable of causing harm manifested by respiratory symptoms and decrements in pulmonary function. Some previous studies of welders in shipyards and in other work environments have indicated that welders have greater than expected decrements in pulmonary function. Other studies in industry have indicated no significant changes. Unfortunately, limitations of many of these previous studies have made determinations difficult. These limitations have included inadequate or no exposure information, small sample sizes, respiratory health data that was cross-sectional rather than longitudinal in nature, and lack of information on, or adjustment for confounding variables. To date, even less is known about the respiratory health of welders in the electric utility industry.

For these reasons, an exposure assessment and longitudinal pulmonary function study of electric utility power plant welders is warranted. A thoughtfully structured exposure assessment will provide information on the major variables that influence exposures along with frequency, duration, and magnitude of exposure. A properly designed longitudinal pulmonary function study may yield information important in determining if there is a significant potential for adverse respiratory health effects to occur as a result of work in this type of exposure environment, or if current industry practices and occupational exposure threshold limits are adequately protective.

**CHAPTER II**  
**LITERATURE REVIEW**  
**PART A - EXPOSURE ASSESSMENT STUDY**

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## **CHAPTER II**

### **LITERATURE REVIEW**

#### **A. Exposure Assessment Study**

Chapter II Part A contains the literature review for the welding exposure assessment study.

##### **1. Exposure Assessment Goals**

As referenced in "*A Strategy for Assessing and Managing Occupational Exposures*" (1), exposure assessment has been defined as the process of defining exposure profiles and judging the acceptability of workplace exposures to environmental agents. Exposure assessment goals are explained as follows:

"Before the process 'starts', the exposure assessment goals must be determined. These goals should be clearly articulated and should lead to one of two general exposure assessment strategies: the Comprehensive Strategy or the Compliance Strategy. Organizations are encouraged to adopt the Comprehensive Strategy. This strategy is directed at assessing all exposures for all workers on all days. In addition to ensuring compliance with existing Occupational Exposure Limits (OELs), this strategy provides an understanding of the day-to-day distribution of exposures. Exposure assessment findings

can be used to address present-day health risks and to construct exposure histories. If a historical database is maintained, the exposure assessment data may be used to address future health issues for individual workers or groups of workers. In the latter case, the data may be used to support epidemiological studies (1)."

"The goals of a system for comprehensive exposure assessment include:

1. Characterize exposures to all potentially hazardous chemical, physical, and biological agents, including those without formal OELs.
2. Characterize the exposure intensity and temporal (hour-to-hour/day-to-day) variability faced by all workers.
3. Assess the potential risks (e.g., risk of potential harm to employee health, risk of noncompliance with governmental regulations, etc.).
4. Prioritize and control exposures that present unacceptable risks.
5. Identify exposures that need additional information gathering (e.g., baseline monitoring).
6. Document exposures and control efforts, and communicate exposure assessment findings to all affected workers and those involved in worker health protection (e.g., management, labor representatives, medical staff, engineering staff, etc.).
7. Maintain a historical record of exposures for all workers so that future health issues can be addressed and managed relative to actual exposure information.
8. Accomplish the preceding steps with efficient and effective allocation of time and resources.

The Compliance Strategy is directed at assessing compliance with OELs and usually uses worst-case monitoring with a focus on exposures during the time of the survey. This strategy provides little insight into the day-to-day variation in exposure levels and is not amenable to development of exposure histories that accurately reflect exposures and health risk. In many organizations with more limited funding, however, the Compliance Strategy is an appropriate first step (1)."

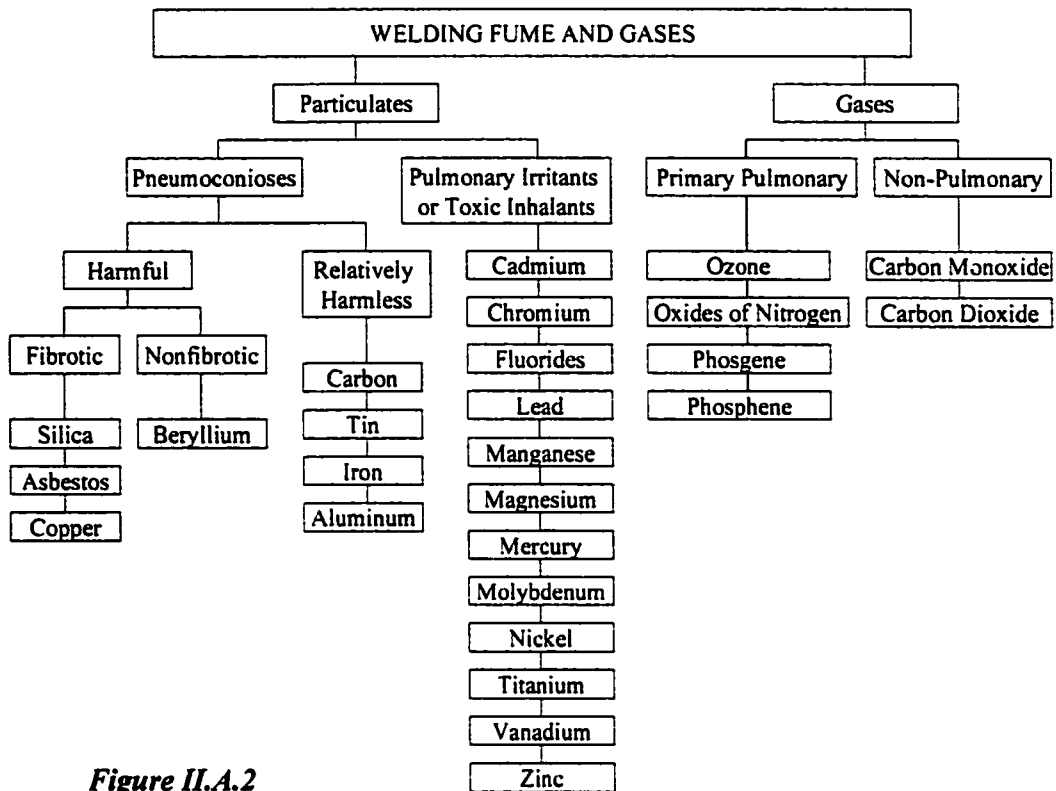
"Because a comprehensive approach to exposure assessment provides a more complete understanding of exposures than the compliance approach, it enables better management of industrial hygiene-related risks. Those risks include not only potential noncompliance with regulations or exposure limits but also potential short-term or long-term damage to employee health; legal liability; and societal and community concerns. It helps provide assurance to an organization's management, customers, and employees (and the communities in which the organization operates) that occupational health risks are understood and that the proper steps are in place to manage the risks (1)."

"Exposure assessment information is important to epidemiological data generation. Epidemiology programs are useful for identifying relationships between exposures and illness. They can determine whether illness outbreaks are related to work exposure. They help assure management and workers that if illnesses or diseases are work-related they will be identified and dealt with appropriately. The results of epidemiological studies add to the available toxicological data for an environmental agent and enable

better judgements on the exposure's acceptability or unacceptability. One of the biggest weaknesses in current epidemiology practice is the lack of useful exposure data (1)."

## **2. Air Contaminants Generated During Welding and Thermal Cutting**

There are numerous air contaminants known to be generated in welding and thermal cutting. The American Conference of Governmental Industrial Hygienists (ACGIH) Documentation of the Threshold Limit Values (TLVs) (2) provides the following statements regarding this subject. "In electric arc or oxygas welding of iron sheet, galvanized iron, or aluminum, the chief components of the fume are ordinarily oxides of iron, zinc, or aluminum. Other fumes (3), as well as toxic gases (4-7) may be present in significant amounts, however. Manganese, silicate, and organic binders are commonly present in the coatings of welding rods for ferrous metals; fluoride in those for aluminum. Elements such as arsenic and copper are sometimes found. Many aluminum rods contain appreciable quantities of silicon and some have traces of beryllium. In shielded arc welding, ozone is often formed, and carbon monoxide has been reported when carbon dioxide was utilized as a shield gas (8,9). In welding mild steel, the fume may consist of metallic oxides from the metal being welded, and from the rod itself and its coating. Numerous other substances are frequently present. These may include as many as 18 different substances contributed by the fluxes including manganese, silica titanium, fluoride, and silicates of sodium and potassium."



**Figure II.A.2**

As referenced in the 1973 American Welding Society (AWS) publication "The Welding Environment" (9), some of the numerous air contaminants known to be generated during welding and thermal cutting and their effect or site of action on the respiratory system are displayed in the flow diagram in *Figure II.A.2*.

**2.1 Origin of Fumes**

Fume generation processes involved during welding are complex and not completely understood. It is generally agreed that the principal mechanism is elemental and oxide vaporization, followed by extremely rapid condensation to form particles. Regardless of the precise mechanism, vaporization occurs mainly at or very near the tip of the electrode where the temperature is highest. The major source of the fumes is the metallic part of

the electrode and the electrode covering or flux. Only a small fraction of the total quantity of fumes is contributed by the molten weld metal pool, because the temperature of the pool is much lower than the temperature at the tip of the electrode. Significant contributions from the base plate can occur, especially if the plate is protected against rusting or corrosion with a metal that has a high vapor pressure: for example, zinc or cadmium (10).

## **2.2 Origin of Gases**

In common with other gases, the gases associated with welding follow the normal laws of diffusion and mix freely with the general atmosphere. They are affected by air movements and by gravity. They pass through the respiratory system along with the other gaseous constituents of the atmosphere (10).

## **2.3 Welding Fumes and Gases Physical Nature**

Welding fume particles are exceedingly small. Virtually all such particles are smaller than 1 micron. In previous studies conducted for the American Welding Society, the observers found that a significant fraction of the fumes produced by covered, solid, and tubular or flux-cored electrodes contained particles that were smaller than 0.25 microns in diameter. Such particle size ranges are in substantial agreement with the observations of other investigators. Particle size is important since it is an indication of (a) the depth to which particles will penetrate into the respiratory system and (b) the number of particles that will be retained therein. Welding fume particles are in the size range of particles that

penetrate deeply into the respiratory system, but they are smaller than particles that are retained with maximum efficiency assuming agglomeration does not occur (10).

#### **2.4 Air Contaminants from Work on Coated Metals**

Fumes produced during the welding process originate mainly from the electrodes, base metals, and the coatings or flux composition of the electrodes. In special cases some other materials may constitute a considerable fraction of the welding fumes. For example, the welding materials whose surfaces have been protected by galvanizing, plating, and painting can alter the fume generation characteristics of the base metals considerably. The air contaminants generated by these coatings may constitute as great or greater exposure potential than those generated by the welding process itself (10).

#### **2.5 Air Contaminants from Interactions with Chlorinated Hydrocarbons**

Chlorinated hydrocarbons are often used to degrease metal parts. When those metals contain residual degreaser and are welded, or the solvent is present in the atmosphere, the chlorinated hydrocarbons are decomposed by the ultra violet light of the arc, or in some cases by heat, to produce phosgene, hydrogen chloride, and chlorine, depending upon the chemical nature of the hydrocarbon (11).

### **3. Other Air Contaminants Associated with Welding Work in Power Plants**

Other air contaminants known to be present in power plants that welders could potentially be exposed to include asbestos and fly ash.

### **3.1 Asbestos**

Prior to welding it is sometimes necessary to protect nearby valves, controls, or sensitive equipment against excessive heat (from welding) by packing or covering with insulation. Before its carcinogenic properties were known, asbestos was widely used for this purpose. A more frequent and serious exposure to asbestos occurs when removing asbestos insulation from pipes, ovens, boilers, structural steel, or other insulated surface prior to welding or cutting (12).

### **3.2 Fly Ash**

Fly ash is a fine-particulate residue produced from coal following combustion. In coal-fueled power plants, combustion gases carry fly ash as they pass through the coal-fired boilers. The interior of the boiler, including boiler tubes and tube shields, may be coated with fly ash. Boiler tube and tube shield repair and removal are tasks sometimes performed by welders. Fly ash accumulations are normally removed by abrasive blasters during power plants planned maintenance outages, prior to welding and cutting. However, during emergency tube repairs, these coatings may be disturbed, resulting in a potential source of exposure. Fly ash constituents constituting potential health hazards include total and respirable dust components, respirable crystalline silica, and various heavy metals (13).

### **4.0 Variables Affecting Welding Fumes and Gases**

Ulfvarson (14) made the following statement, "A list of factors influencing the exposure to air contaminants in arc welding must of course include the parent material (base metal)

and the welding method with details about the electrode used and the current. A number of other factors must also be considered. In principle, local exhaust ventilation may decrease the exposure of most air contaminants substantially; but in practical work, local exhaust ventilation will be perhaps the most unpredictable source of variation in the exposure. The arc-time factor comes next, the exposure being practically proportional to the arc-time factor. The time of the year has a surprisingly big effect on the exposure; the exposure in the cold months being 2-3 times as high as in the rest of the year. It is easily seen that in the case these factors act concurrently, the bias in the judgement of the exposure average over a long time will be considerable. The only way to avoid this is to plan the measurements carefully and specify the work conditions in the observed work places with enough details."

Many factors affect the amount and nature of welding fume constituents including the composition of the base and filler metals, coatings and fluxes, current, voltage, shielding gas, electrode feed rate, arc length, and polarity. The variation of fume content under different operating conditions of the same arc welding process on the same material can be as great as between totally different processes or materials (12).

The quantity and composition of welding fumes and gases are influenced by the following characteristics of the welding process:

- type of process
- welding consumable

- presence of any material coatings
- nature of rod flux coating, or core of flux-cored consumable
- welding parameters
- shielding gas composition

The two most important characteristics are the welding process and the choice of consumable (15).

#### **4.1 Variables Affecting Composition of Welding Fumes and Gases**

The major variables that are known to affect the composition of welding fumes and gases are covered in the information below.

##### **4.1.1 Welding Processes Used**

It has been established that the welding (or thermal cutting) process is an important variable in the composition of fumes and gases generated. *Table II.A.4.1.1a* was published in the NIOSH Welding Criteria Document (16).

**Welding Processes Associated with Specific Inhalation Exposures**

Table II.A.4.1.1a

<b>Process</b>	<b>Hazardous Agent</b>
Shielded metal arc welding (SMAW) low hydrogen electrodes iron or steel stainless steel	Fluorides Iron oxide Hexavalent chromium, nickel
Gas metal arc welding (GMAW) aluminum stainless steel	Ozone Hexavalent chromium, nickel, ozone
Flame cutting, welding	Carbon monoxide Nitrogen oxide Nitrogen dioxide
Plasma cutting/aluminum	Ozone

Gaseous contaminants in the welding environment are largely governed by the welding process. *Table II.A.4.1.1b* lists the gaseous contaminants of concern with various welding processes which are appropriate to sample (17). Of the processes and gases listed in the table, ozone concentrations with high-current gas-shielded welding processes are most likely to exceed OSHA or ACGIH limits.

**Gases Associated with Specific Processes**

Table II.A.4.1.1b

Welding Process	Common Gases			
	CO	F	NO <sub>x</sub>	O <sub>3</sub>
Shielded Metal Arc Welding (SMAW)		X	X	
Flux-Cored Arc Welding (FCAW)	X	X	X	
Gas Metal Arc Welding (GMAW) Shielding Gases: Helium/Argon Carbon Dioxide	X		X X	X
Gas Tungsten Arc Welding (GTAW)			X	X
Submerged Arc Welding (SAW)	X			

CO = carbon monoxide; F = fluorides; NO<sub>x</sub> = nitrogen oxides; O<sub>3</sub> = ozone

Stern (18) reported exposures from some welding processes on various metals that have been presented on *Table II.A.4.1.1c*.

**Exposures by Welding Processes and Metals**

Table II.A.4.1.1c

Process	Consumable/Base Metal	Exposure
MIG metal inert gas	Aluminum	Aluminum oxide, ozone
MIG	Mild Steel (MS)	Ferric oxide, manganese, silicon, copper, nitrogen dioxide
MIG	Stainless Steel (SS)	Same as MIG/SS plus nickel, chromium, ozone
MMA (SMAW) shielded metal arc welding	Mild Steel	Same as MIG/MS plus sodium, potassium, molybdenum, fluorine, titanium, calcium, aluminum, etc.
MMA (SMAW)	Stainless Steel	Same as MMA/MS plus chromium, nickel vanadium

Each welding technique and application produces a characteristic range of particulate composition and morphology. MMA (SMAW) fumes consist of particulates which are either condensed metal vapor or a mixture of metal and slag condensed from the slag-

forming coating, which decomposes, melts and vaporizes during welding. For MMA/MS (SMAW/mild steel) the primary constituents are iron (Fe), manganese (Mn), silicon (Si), sodium (Na), calcium (Ca), and especially fluorides (F). The use of stainless steels introduces chromium (Cr) and Nickel (Ni) into the fume. MIG (gas metal arc welding - GMAW) fumes are less complex because of the absence of flux coating. MIG/MS (GMAW/mild steel) fume consists primarily of Fe, Mn, Si, and their oxides. The fumes from MMA/SS (SMAW/stainless steel) and MIG/SS welding contain Cr and Ni in a wide range of oxidation states and solubilities. MMA/SS fume contains approximately 3-4% Cr, almost all of which is in the hexavalent state (Cr(VI)). Cr(VI) is highly reactive and is often rapidly reduced to Cr(III). Welding produces a number of gaseous pollutants, either through the thermal decomposition of the electrode coating (CO, carbon dioxide (CO<sub>2</sub>), F, hydrogen Fluoride (HF), etc.) or the pyrolytic decomposition of organic substances such as paint or anti-rust coating present on the workpiece. Nitrogen oxide (NO) and nitrogen dioxide (NO<sub>2</sub>) are also produced from the surrounding air. The inert gas welding of aluminum and stainless steel is accompanied by the production of significant concentrations of ozone due to the interaction of ultra-violet radiation and oxygen. Production rates and breathing zone concentrations of gaseous pollutants are process and process parameter dependent (current, voltage, shielding gas, consumables, etc.) (19).

The welding processes used in the power plants of the present study were shielded metal arc welding (SMAW), gas tungsten arc welding (GTAW), flux-cored arc welding (FCAW), and gas metal arc welding (GMAW). A brief definition of each process, along with additional applicable information from the literature, follows.

#### **4.1.1a Shielded Metal Arc Welding (SMAW)**

Shielded metal arc welding is a process by which coalescence (fusion) of metals is produced by heating with an electric arc between a covered (or coated) metal electrode and the work surface. Shielding is provided by decomposition of the electrode covering, known as the flux, while filler metal is obtained from the electrode's metal core and/or metallic particles in the covering (flux). Shielding of the arc serves to:

1. Prevent the atmospheric contamination of the molten metal in the arc and the weld puddle.
2. Provide scavengers and deoxidizers to refine the grain structure of the weld metal.
3. Produce a slag blanket over the molten puddle and the solidified weld.

The extent to which these functions is accomplished depends upon the type of electrode being used. Functions 1 and 3 prevent oxygen and nitrogen pickup from the air by the molten metal in the arc stream, weld puddle and the red-hot solidified weld metal. This, in turn, prevents the formation of oxides and nitrides, which can cause embrittlement of the weld. SMAW may also be referred to as stick, stick rod, coated electrode, or manual metal arc (MMA) welding (20).

Compared to other processes, the shielded metal arc welding (SMAW) process produces more fume per amount of metal deposited, usually in the range of 1-2% by weight. When welding on carbon and low-alloy steel, iron oxide (present as both  $\text{Fe}_2\text{O}_3$  and  $\text{Fe}_3\text{O}_4$ ) may represent as little as 35% of the fume. Welding on stainless and chromium steels and nickel alloys produces significant levels of hexavalent chromium, nickel, and copper. In

addition to oxides from the base metal, fumes from the covered electrodes used in SMAW processes contain iron, manganese, fluoride, nickel, molybdenum, chromium, and copper. Fluoride may be the most important of these because of its toxicity and content (10-20%) in the welding fume, particularly with basic low-hydrogen coverings. Ozone, nitrogen oxides, and carbon monoxide are not usually formed in significant quantities (12).

#### **4.1.1b Gas Tungsten Arc Welding (GTAW)**

Gas tungsten arc welding is a process by which coalescence is produced by the heat of an electric arc maintained between the end of an electrode and the work surface, except that the tungsten electrode is not consumed. Shielding is provided by an inert gas or gas mixture. In this process, filler metal is fed manually to the weld puddle in the form of a welding rod. The rod must be kept in the protection of the inert gas shield. The term "electrode" refers to the component through which current flows to the arc area. The term "welding rod" refers to the component used only as filler metal, with no current being carried. This process may also be referred to as tungsten inert gas (TIG) or heli-arc welding (20).

Because the gas tungsten arc welding (GTAW) process is usually used on stainless and high alloy steels, the fumes are likely to contain chromium and nickel. The GTAW process is also used on aluminum, which produces significant ozone and nitrogen dioxide levels. The tungsten electrode is not consumed, but filler metals are added to the process

and contribute to the fume content. The total fume level is lower than for the other processes discussed (12).

Van der Wal (21) analyzed welder breathing zone samples from 18 different plants and locations in Holland. Numerous processes were conducted on various metals. GTAW was the only welding process for which there were no measurements of breathing zone fume measurements exceeding the Dutch occupational health standard (TLV) of 5 mg/m<sup>3</sup>.

#### **4.1.1c Flux-Cored Arc Welding (FCAW)**

Flux-cored arc welding is a process that produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the work. Shielding is provided by a flux contained within the tubular electrode. Additional shielding may or may not be obtained from an externally supplied gas or gas mixture (20).

The flux-cored arc welding (FCAW) process produces more fume than other welding processes because of the high currents used. Because of the high metal deposition rates (more than double the rate of the SMAW process) the amount of fume per weight of metal deposited is no greater than that for the SMAW process. However, welder exposure to fumes and gases may be much higher. Shielding gas is sometimes used with FCAW electrodes and tends to reduce fume generation. The core of flux material in the electrode contains several compounds, most notably fluorides, which together with oxides from the base metal, contribute to the welding fume. Significant concentrations of

gases, particularly carbon monoxide and nitrogen oxides may often be found. Carbon monoxide comes from decomposition of organic matter in the flux and from CO<sub>2</sub> used as a shielding gas (12).

#### **4.1.1d Gas Metal Arc Welding (GMAW)**

Gas metal arc welding is a process by which coalescence is produced by the heat of an electric arc maintained between the end of an electrode and the work surface. Shielding of the arc is provided by an externally supplied gas or gas mixture which may or may not be inert. The electrode is fed continuously to the weld where it is melted in the intense heat of the arc and deposited as weld metal. This process may also be referred to as metal inert gas (MIG), short arc, CO<sub>2</sub>, or wire feed welding (20).

#### **4.1.2 Thermal Cutting Processes Used**

In contrast to welding operations that add metal to a joint, cutting processes are designed to remove metal, much of it to the air in the form of fumes. Operations that are automatic do not require any workers in the immediate area of fume generation; however, manual processes place the cutter close to a significant fume producing source. Cutting fumes contain many of the same constituents as welding fumes, but the mixtures are generally less complex because there are fewer fluxes, electrode coatings, shielding gases, and their associated by-products. Iron oxide is usually the predominant contaminant when cutting ferrous metals. For high-alloy, nonferrous, painted, and coated metals the fumes reflect the materials being cut (12).

The information presented on *Table II.A.4.1.2* was published in the NIOSH Welding Criteria Document (16).

**Thermal Cutting Processes Associated with Specific Inhalation Exposures**  
**Table II.A.4.1.2**

<b>Process</b>	<b>Hazardous Agent</b>
Flame cutting, welding	Carbon monoxide Nitrogen oxide Nitrogen dioxide
Plasma cutting/aluminum	Ozone

Cutting processes used in power plants of the present study were air carbon arc cutting (ACAC), oxyacetylene cutting (OAC), and plasma arc cutting (PAC). A brief description of each process, along with additional applicable information from the literature, follows.

#### **4.1.2a Air Carbon Arc Cutting (ACAC)**

Arc cutting is the general process in which the cutting or removal of metals is done by melting with the heat of an arc between an electrode and the base metal. Air carbon arc cutting is a process that severs metals by melting them with the heat of an arc between a carbon electrode and the base metal, with use of an air stream to facilitate the process. Air carbon arc cutting is also known as air arcing or carbon arc cutting (20).

#### **4.1.2b Oxyacetylene Cutting (OAC)**

Oxyacetylene cutting is a process in which the metal is cut by means of a chemical reaction of oxygen with the base metal at elevated temperatures. The required temperature is maintained by combustion of acetylene and oxygen. OAC is also referred to as torch or flame cutting (20).

An oxyacetylene flame burning in air produces nitrogen dioxide from nitrogen and oxygen in the atmosphere. The concentrations of nitrogen dioxide can reach high levels (200-400 ppm) when the flame is used in confined spaces (22,23).

#### **4.1.2c Plasma Arc Cutting (PAC)**

Plasma arc cutting severs metals by melting a localized area with a constricted arc and removing the molten material with a high-velocity jet of hot ionized gas issuing from the orifice. PAC is also referred to as plasma cutting (20).

In an industrial hygiene exposure assessment of plasma welding and cutting of stainless steel in six Dutch factories, Van der Wal (24) indicated that the Dutch occupational health standard for welding fumes ( $5 \text{ mg/m}^3$ ) was exceeded when plasma cutting was conducted without local exhaust ventilation, but were not exceeded when local exhaust ventilation was used. Total hexavalent chromium was only found in two plants, and its concentration never exceeded  $40 \text{ ug/m}^3$ . Total chromium concentrations did not exceed  $400 \text{ ug/m}^3$ . In no instances were the Dutch standards for nitrogen dioxide (5 ppm) or nickel ( $1 \text{ mg/m}^3$ ) exceeded, even during the process of cutting alloys containing 30-35% nickel. None of the samples contained water-soluble nickel. Breathing zone levels of ozone were excessive because of the proximity of the welders face to the torch.

#### **4.1.3 Consumables and Base Metals Used**

The base metals worked on in the power plants to any significant degree (greater than one percent of the work) may be categorized as follows (20):

Carbon (Mild) Steels	Alloys of iron containing carbon, manganese, and silicon to a total of 1-2%.
Low-Alloy Steels	Carbon steels containing elements such as chromium, nickel, molybdenum (Mo), vanadium, columbium, etc., to a total of approximately 3%.
Chromium-Molybdenum Steels	Carbon steels containing varying combinations of chromium and molybdenum from 1% Cr - 0.5% Mo to 9% Cr - 1% Mo.
Stainless Steels	Carbon steels with either chromium and/or nickel as the primary alloying agent. Ferritic/martensitic: 12-27% Cr. Austenitic: 18% Cr - 8% Ni; to 25% Cr - 20% Ni.

Fumes and gases are produced during all arc welding operations. Their potential effect on the well-being of welding personnel is highly dependent upon their amount and composition. More fumes, for example, are produced when carbon steels are welded with the shielded metal arc process than when austenitic stainless steels are welded in the same manner. On the basis of fume generation rate alone, the carbon steel welding operation appears to be potentially most harmful. Such may not be the case, however, because the fumes associated with the welding of 300-series stainless steels contain nickel and chromium compounds with TLVs much lower than that of iron oxide, the principal constituent in the fumes produced in the welding of carbon steels. In other words, the concentrations of the nickel and chromium compounds associated with the welding of stainless steel may exceed allowable limits even though the fume generation rate is low (10).

As reported in a large Navy welding study (25), "The primary components in mild steel welding fume are oxides of iron, manganese, and silicon. Some low-alloy steel electrodes contain nickel and chromium so Ni, Cr and Cr(VI) can be expected in the welding fume. The primary concerns for Cr(VI) fumes are from welding stainless steels, high-chromium nickel alloys, and hard surfacing electrodes. SMAW and FCAW using electrodes of stainless steel or high-chromium nickel alloys have been shown to produce fumes with significant percentages of Cr(VI). Concern is greatest with these processes compared to GMAW and GTAW fumes from these alloys which contain very little Cr(VI). The production of Cr(VI) during SMAW or FCAW increases when sodium and potassium are present in the electrode coatings or fluxes. Reducing the amount of sodium and potassium in electrodes and fluxes will reduce the production of Cr(VI) in the fume."

Moreton et al. (26), reported that the Cr(VI) in stainless steel SMAW welding fume is at least 90% water soluble (soluble in water or in weak caustic solutions). Kimura et al. (27), reported stainless steel GMAW fume contains very little Cr(VI) which may include both soluble and insoluble portions. Nickel alloys and stainless steels also produce Ni and Mn fumes. Manganese also is a constituent of welding fume from carbon steels and low-alloy steels.

Each (welding) technology produces a unique type of aerosol, 80-90% of which the chemistry is determined by the composition of the consumable material, which is chosen to be metallurgically compatible with the work piece (18).

## **5. Individual Air Contaminants Generated During Welding and Thermal Cutting**

Due to the extensive amount of information on the subject, an attempt was made to primarily restrict the following information to air contaminants of concern that potentially could be experienced with the processes and materials used during welding in the electric power generation facility environment to any significant degree (greater than one percent of the work).

### **5.1 Fumes**

The following section contains information pertaining to the various metal fumes produced in welding.

#### **5.1.1 Manganese**

Manganese is present in small quantities in most carbon/stainless steel alloys and welding electrodes (20).

#### **5.1.2 Chromium**

Chromium is present in stainless steels and chromium-molybdenum alloys (20). Possibly two-thirds of the total Cr in welding fumes may be hexavalent, of which 95% may be water-soluble, and therefore non-carcinogenic; the remaining 5% of that two-thirds would be presumed to be insoluble and carcinogenic (10). The ratio of hexavalent to total chromium is much higher in fumes generated by SMAW and FCAW than in those generated by GMAW and GTAW (28). The large amount of Cr(VI) present in most

fumes from MMA (SMAW) welding has been shown to be associated with sodium and potassium compounds in MMA welding fluxes, and it is almost certain that the Cr(VI) is present in such fumes as chromates of these metals (29).

Van der Wal (21) analyzed welder breathing zone samples from 18 different plants and locations in Holland. All the work was performed in large rooms without local exhaust ventilation. SMAW and GMAW of stainless steel produced Cr(VI) levels above the Dutch TLV (0.05 mg/m<sup>3</sup>), but plasma welding or cutting of stainless steel did not produce excessive levels of total chromium or chromium (VI).

### **5.1.3 Nickel**

Nickel is present in stainless steels and alloys such as monel, inconel, and incoloy (20).

### **5.1.4 Cadmium**

Cadmium can be present as a pigment in painted surfaces, as a plating on metal, and as an ingredient in silver brazing solder (20).

### **5.1.5 Copper**

Copper may be found in alloys (monel, brass, bronze), metal overlays and in copper coated welding electrodes (20).

### **5.1.6 Iron Oxide**

The most common welding fume constituent and main component is iron oxide (20). Iron oxide, is present in the form of both  $\text{Fe}_3\text{O}_4$  (magnetite) and  $\text{Fe}_2\text{O}_3$ , the major portion being  $\text{Fe}_3\text{O}_4$  (30). Iron oxide has a TLV of  $5 \text{ mg/m}^3$ , the same as for total welding fume. It is not likely, therefore, that the iron oxide TLV will be exceeded unless the total welding fume TLV is also exceeded (12).

### **5.1.7 Zinc**

Zinc is a major component in galvanized coatings and in some primers/coatings (20).

### **5.1.8 Lead**

The welding and cutting of lead-bearing alloys or metals whose surfaces have been painted with lead-based paint generates lead oxide fumes (31).

### **5.1.9 Fluorides**

Fluoride and its compounds are found when using electrodes with basic low-hydrogen coverings or fluoride fluxes. Low-hydrogen electrodes contain calcium fluoride in their covering and are used for high-strength welds on difficult-to-weld materials such as heavy armor plate. Fluoride fumes may produce respiratory tract irritation with chills, fever, shortness of breath, and cough. Excretion is slower than absorption and repeated exposure causes a buildup that can eventually lead to bone changes (12).

### **5.1.10 Welding Fumes**

The term "welding fumes" refers to the aggregation of total particulate material generated during welding or thermal cutting. Conclusions based on total concentration of (welding fume) are generally adequate if no toxic elements are present in welding rod, metal, or metal coating, and conditions are not conducive to the formations of toxic gases (32).

## **5.2 Gases**

Ozone, carbon dioxide, carbon monoxide, carbon dioxide, and nitrogen oxides are the principal gases generated by welding (28).

### **5.2.1 Ozone**

Ozone, a respiratory irritant, is generated by reaction of ultraviolet light (UV) with atmospheric oxygen (33). Ozone is formed by electric arcs and by ultraviolet photochemical reactions that take place mostly within a few inches of the arc where the UV radiation is the most intense. Ozone is a highly reactive irritating gas that readily breaks down or combines harmlessly with other fume constituents as it moves away from the arc. All of the arc welding processes can produce some ozone, but the highest relative concentrations are produced during welding on aluminum or stainless steel (due to surface reflectance) or when using argon as a shielding gas (due to its particular spectral emission properties) (12).

With regard to the welding processes, ozone is produced in greater quantities by GMAW, GTAW, and PAC (31). GMAW and GTAW of aluminum generate the highest ozone

levels, but GTAW and GMAW of stainless steel can also generate substantial amounts of ozone, particularly with argon shielding. Ozone is unstable in air due to its high reactivity and its decomposition is accelerated by metal oxide fumes. Because of this, welding processes such as SMAW and FCAW which generate large quantities of fumes, are not usually associated with significant quantities of ozone. Conversely, a reduction in the fume generation rate may result in increased UV radiation and, consequently, increased ozone formation (33).

Regarding the effect of shielding gas on ozone formation, the NIOSH Criteria Document (16) made the following statement. "Ferry and Ginther [1953] (34) found that the shielding gas had a decided effect on ozone formation. Changing from argon to helium in gas tungsten arc welding caused ozone concentrations in the breathing zone to decrease from 0.5-0.6 ppm to 0.1 ppm regardless of the current level. Frant [1963] (35) observed a similar reduction when using a CO<sub>2</sub> shield."

Van der Wal (21) measured ozone levels in welder breathing zone samples from 18 different plants and locations in Holland. All the work was performed in large rooms without local exhaust ventilation. Ozone concentrations did exceed the Dutch TLV of 0.1 ppm for GMAW of stainless steel and aluminum, FCAW of mild steel, and plasma cutting of inconel alloy.

### **5.2.2 Nitrogen Dioxide**

Nitrogen oxides (NO<sub>x</sub>) arise from thermal oxidation of molecular nitrogen in air that may result from an arc or a very high temperature flame. NO<sub>x</sub> may be generated during most welding process, but the concentrations of NO<sub>x</sub> are greatest during oxyfuel gas welding and plasma arc cutting. Chronic exposure to NO<sub>x</sub> may cause reduced pulmonary function (36).

OSHA, in the *Construction Safety and Health Outreach Program* (31), states that "Nitrogen oxides are produced by GMAW, GTAW, and PAC. Even greater quantities are formed if the shielding gas contains nitrogen." One combustion product, nitrogen dioxide (NO<sub>2</sub>), has been detected in shielded arc welding, oxyacetylene welding, arc gouging, gas metal arc welding, submerged arc welding, and oxyacetylene and oxypropane cutting (16). According to AWS (10), "Nitrogen dioxide presents a potential problem based on published ACGIH Threshold Limit Values when welding is done with processes in which the arc is shielded by argon or gas mixtures containing large amounts of argon." Nitrogen dioxide has been associated especially with argon shielded welding on aluminum or stainless steel, and confined spaces (12).

Van der Wal (24) measured NO<sub>2</sub> levels in welder breathing zone samples from 18 different plants and locations in Holland. All the work was performed in large rooms without local exhaust ventilation. Numerous processes were conducted on various metals. No measurements for NO<sub>2</sub> exceeded the Dutch TLV of 5 ppm.

### **5.2.3 Carbon Monoxide**

Carbon monoxide and carbon dioxide are formed by the decomposition of organic compounds in electrode coatings and cores, and from inorganic carbonates in coatings. They are formed in the oxyacetylene flame, and carbon monoxide is formed by the decomposition of carbon dioxide used in the gas shielded metal arc process (11).

## **6. Variables Influencing Air Contaminant Concentrations**

The quantity of fume generated during welding depends on the welding process, welding parameters, and consumables (10). Gas shielded processes (GTAW, PAW, GMAW) produce less fume than open-arc processes, such as SMAW and self-shielded FCAW. Shielding gases with high oxygen potentials, such as CO<sub>2</sub>, produce more fume than argon-based shielding gases. The rate of fumes generated by GTAW and PAW are very low. Their fumes primarily come from vaporization of the molten weld pool, which is relatively small. Fume generation rates for GMAW are higher than GTAW but lower than SMAW or FCAW. The primary source of GMAW fume is vaporization and oxidation of filler metal as molten droplets are transferred through the arc. Short circuiting transfer and droplet spray transfer generate low fume levels while globular transfer and spray transfer at high welding currents and high arc voltages generate the highest fume levels. SMAW and FCAW processes generate more fumes than other processes because of the highly volatile ingredients in electrode coatings and fluxes (10). Increasing welding current and voltage will increase fume due to increased arc temperature. Elements with low vapor pressures will vaporize more rapidly than those

with high vapor pressures. Arc stability also influences fume generation as unstable arcs tend to entrain more air into the arc atmosphere, and therefore generate more fumes (10).

### **6.1 Ventilation and Air Movement**

In addition to the other variables that influence welding air contaminant concentrations, the concentration is also a function of the volume of the space in which the welding is being done, the number of air changes of that space per hour, and/or the rate of direct removal from the welder's breathing zone by the presence of ventilation (37). General room ventilation can effectively control contamination levels within a general area, but, in many cases, does not provide the local control needed to protect the welding operator. Local ventilation is an effective way of providing this protection (10).

A U.S. Navy study (25) conducted controlled laboratory tests of worker exposure to metal fumes during SMAW and GMAW. Results indicated that local exhaust ventilation reduced worker exposure by more than 50% compared to natural ventilation. A study by Gray and Gerin (38) gathered exposure data to total fume, chromium, Cr(VI), and nickel fumes from stainless steel welding and cutting in industrial companies. They estimated that the use of properly positioned local exhaust ventilation would reduce exposure by a factor of two.

### **6.2 Confined and Enclosed Spaces**

In general, welding fume concentrations are higher when welding is performed in confined spaces rather than open air (37). The bulk of the fumes generated during

welding consists of small particles that remain suspended in the air for a considerable period of time. As a result, their concentration in a closed work area builds up over a period of time, as does the concentration of any gases evolved or used in the welding process (10). Without attention to local ventilation or the provision of a respiratory protective device, some welding processes in enclosed spaces can lead to the rapid buildup of irritant gases, metal fume and particles (37). A Gray and Gerin study (38) that gathered exposure data to total fume, chromium, Cr(VI), and nickel fumes from stainless steel welding and cutting in industrial companies, estimated that welding in confined spaces would increase exposure by a factor of two.

### **6.3 Welding and Thermal Cutting Processes Used**

Various studies have indicated significant differences in the air concentration levels of contaminants according to the process conducted. Lyon et al. (39) reported approximate fume generation rates for some arc welding processes on mild steel. The fume generation rate was highest to lowest, respectively, for flux-cored arc welding, shielded metal arc welding, gas metal arc welding, and gas tungsten arc welding. According to the American Welding Society (11), SMAW and FCAW produce more fumes, while GTAW produces less fume than other welding processes. The fume emission of the SMAW process is at least 100 times higher than GTAW. Van der Wal (24) conducted an industrial hygiene survey in six Dutch factories, and showed that the fume and gas exposures from plasma arc cutting of stainless steel were comparable to those produced by SMAW. Maxild et al. (40) reported that SMAW of stainless steel produced 3 to 6 times more fumes (per mass of weld metal) than GMAW.

#### **6.4 Consumables and Base Metals**

Fumes and gases are produced during all arc welding operations. Their potential effect on the well-being of welding personnel is highly dependent upon their amount and composition. More fumes, for example, are produced when carbon steels are welded with the shielded metal arc process than when austenitic stainless steels are welded in the same manner. On the basis of fume generation rate alone, the carbon steel welding operation appears to be the most harmful. Such may not be the case, however, because the fumes associated with the welding of 300-series stainless steels contain nickel and chromium compounds with TLVs much lower than that of iron oxide, the principal constituent in the fumes produced in the welding of carbon steels. In other words, the concentrations of the nickel and chromium compounds associated with the welding of stainless steel may exceed allowable limits even though the fume generation rate is low (10). SMAW and FCAW processes generate more fumes than other arc welding processes because of the highly volatile ingredients in electrode coatings and fluxes (25). Volatile coatings, such as paint, plastic, primer, rust, oil, or zinc on the surface of the base metal can cause significant increases in the amount of fume generated (25).

#### **6.5 Operational Parameters**

Besides the type of process used, some general comments apply to other factors affecting arc welding fume generation (12):

- Current - higher currents produce more fume

- Voltage/arc length- longer arcs and corresponding higher voltages produce more fume.
- Electrode feed rate - faster feed rates increase fume generation rates as well as metal deposition rates.
- Polarity - when dc power is used, electrons flow in one direction only, from negative to positive poles. When the electrode is used as the positive pole (straight polarity), the electrode burns faster, the base metal is not penetrated as deeply and the fume generation rate is higher than when the base metal is used as the positive pole (reverse polarity).

## **6.6 The Welding Helmet**

The natural tendency of welding fumes is to rise vertically, due to the heating of the air and gases in the immediate vicinity of the electric arc. The welder's head is usually close to or in the plume above the arc; therefore, the welding fumes will flow around the helmet as they move vertically upward, and a portion will also penetrate behind the helmet. The amount or concentration of fumes behind the helmet will be a function of the welder's position, the fume generation rate, and the local ventilation rate and direction (10).

It is generally accepted that some attenuation of fume exposure occurs with welding helmet use (41). Because of the assumed reduction of fumes behind the helmet, the ACGIH TLV has been established on the basis of fume levels inside the hood (2), and the

American Welding Society's standard method for sampling welding fumes specifies this method (42).

Slavin stated that "Comparisons of fume concentration outside with those inside the welding helmet do not show much agreement. Outside levels may be 5-15 times higher than inside levels. Even samples taken from the welder's collar slightly behind the helmet during welding show considerably higher levels than inside the helmet (12)."

This has called into question the adequacy of industrial hygiene monitoring outside the helmet. Nonetheless, data are limited on which this assumption of helmet attributable exposure attenuation is based. Liu et al (43), stated "The welding helmet would offer some degree of respiratory protection were the level of metal fumes (and gases) inside meaningfully lower than that in the breathing zone outside the helmet." However, a most recent investigation conducted by Liu et al (43), studied metal fume exposures inside the welding helmet versus in the breathing zone for 23 experimental welding exposures. Observations produced a mean ratio of inside to outside metal fume concentrations of  $0.9 \pm$  S.D. 0.2, with a highly variable effect. They found that in acute heavy exposure situations, welding helmet attenuation of metal fume exposures is highly variable and frequently negligible. They stated that the welding helmet may provide some exposure reduction in situations of very concentrated metal fume exposure. However, the data from their study indicated that in situations of low to moderate exposure, environmental sampling based on outside-the helmet, personal breathing zone monitoring may in fact be fairly representative of the actual dose to the worker.

On the other hand, as referenced in the ACGIH Documentation of the TLV's (2), the following older studies had different findings. Goller and Paik (44) reported that concentrations of metal fumes in a platform gas-shielded welding operation demonstrated a mean value 1.4 times higher when measured at the shoulder than in the welding helmet, or the equivalent to an inside:outside ratio of 0.7 (ratio range 0.4 to 1.4). In that study, iron oxide fume concentrations at the breathing zone inside the helmets of welders were reduced to 36-71% of concentrations outside the helmets, depending upon the type of welding and postures of the welders. Several other studies also observed varying degrees of welding helmet exposure attenuation. One of these studies also found an inside:outside helmet ratio of approximately 0.7; two other studies had somewhat higher and lower ratios (45-47). Also referred to, was the Alpaugh et al. study (48), an experimental exposure model, employing a welding dummy, where fume concentrations were higher. This study found levels outside the welding helmet more than 20 times the concentration inside, yielding an inside:outside ratio of less than 0.05. However, in that study the dummy was designed to inhale ambient air and exhale clean (nonexposed) air, the helmet had a cup-type chin, and sampling took place during arc time only; important differences as compared to other studies. Johnson, in the 1959 study (47), concluded that samples taken outside the helmet were considerably higher than those within. In view of the studies which demonstrated that the concentration of contaminants was lower inside the welding helmet (the 1995 Liu study 15 was not available for review at this time), in 1992, the ACGIH TLV Committee stated that it was their intent that the TLV be applied to samples obtained inside the welding helmet (2).

**7. Air Sampling for Specific Welding/Cutting Processes, Materials, or Conditions**

In evaluating problems associated with the welding environment, the following must be taken into account (10):

- 1) Welding process
- 2) Welding consumables
- 3) Welding conditions
- 4) Base metal
- 5) Characteristics of the welding area (size, height, air movement, etc.).

In addition, some knowledge concerning the relative hazards of the fume and gas constituents is needed.

The following was stated in the American Conference of Governmental Industrial Hygienists (ACGIH) *2000 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices* (32): "Welding fumes cannot be classified simply. The composition and quantity of both are dependent on the alloy being welded and the process and electrodes used. Reliable analysis of fumes cannot be made without considering the nature of the welding process and system being examined; reactive metals and alloys such as aluminum and titanium are arc-welded in a protective, inert atmosphere such as argon. These arcs create relatively little fume, but they do create an intense radiation that can produce ozone. Similar processes are used to arc-weld steels, also creating a relatively low level of fumes. Ferrous alloys are also arc-welded in oxidizing environments that generate considerable fume and can produce carbon

monoxide instead of ozone. Such fumes are generally composed of discrete particles of amorphous slags containing iron, manganese, silicon, and other metallic constituents depending on the alloy system involved. Chromium and nickel compounds are found in fumes when stainless steels are arc-welded. Some coated and flux-cored electrodes are formulated with fluorides and the fumes associated with them can contain significantly more fluorides than oxides. Because of the above factors, arc-welding fumes frequently must be tested for individual constituents that are likely to be present to determine whether specific TLVs are exceeded. Conclusions based on total concentration are generally adequate if no toxic elements are present in the welding rod, metal, or metal coating and conditions are not conducive to the formation of toxic gases."

Much of the information reviewed earlier may be used to infer what air contaminants may be present in specific welding/cutting processes on various materials, and thus what constituents should be sampled/analyzed. In addition, Slavin (12) provided the following guidance with regard to sampling welding air contaminants. "There are many conditions under which a welding gas or a particular component of the welding fume may exceed its TLV even though the total welding fume level is below the TLV. In these cases, the total fume level is not the best indicator of the hazard. Properly evaluating an arc welding process and preparing for sampling requires a review of material safety data sheets and other available information to find out which base metals, coverings, electrodes, filler metals, shielding gases, and other contaminants may be present. However, some generalizations can be made about evaluations that should be made for specific arc

welding processes, materials, and conditions." *Table II.A.7a* specifies the air sampling that should be done for several common welding operations according to Slavin (12).

**Air Sampling for Specific Arc Welding Processes or Conditions**

**Table II.A.7a**

<b>Process or Condition</b>	<b>Evaluation</b>
SMAW, GMAW, and FCAW on ferrous alloys	total fume
Arc welding on stainless or high-alloy steel	hexavalent chromium, nickel
Arc welding on aluminum or titanium	ozone, nitrogen oxides
GMAW with copper-covered electrodes	total fume, copper
Carbon dioxide shielding gas	carbon monoxide
Argon shielding gas	ozone
SMAW or FCAW with basic flux	fluoride

AIHA states in its *Welding Health and Safety Resource Manual* (20), "Some general statements can be made concerning the welding processes and conditions most likely to produce potential exposures near or above the permissible exposure limits". These processes and conditions are specified on *Table II.A.7b*.

**Processes and Conditions Most Likely to Produce Potential Overexposures**

**Table II.A.7b**

<b>Process</b>	<b>Base Metal/Consumable</b>	<b>Potential Overexposure</b>
Air carbon arc cutting (ACAC)	stainless steels	total chromium, hexavalent chromium, nickel, copper
Plasma arc cutting (PAC)	stainless steels	iron oxide, total chromium, nickel, copper, nitrogen oxide, ozone
Shielded metal arc welding (SMAW)	stainless steels, nickel alloys, high chromium steel alloys	total fume, hexavalent chromium, nickel, copper
SMAW	carbon and low alloy steels	total fume
Gas metal arc welding (GMAW)	aluminum	total fume, ozone
GMAW	stainless steels	total chromium, ozone, total fume (in confined spaces)
Gas tungsten arc welding (GTAW)	aluminum	nitrogen oxides, aluminum

## **8. Welding Air Contaminant Occupational Exposure Limits (OELs)**

Potential health problems can be anticipated by measuring the concentrations of fume and gas constituents in the welding area and comparing these data to established exposure standards. The occupational exposure limit (OEL) is a generic term used to represent a pair of numbers: 1) the agent concentration or intensity that is allowable (based on health effects data); and 2) the period over which one averages workplace concentrations to evaluate whether the measured concentrations are less than the allowable limit. Some substances may have several occupational exposure limits (e.g., an 8-hour time-weighted average [TWA], a short-term exposure limit [STEL] of 15 minutes, or a ceiling limit [C] never to be exceeded). OELs applicable to welding air contaminants may be: authoritative - recommended by a nonregulatory credible organization such as the American Conference of Governmental Industrial Hygienists (ACGIH) or the National Institute for Occupational Safety and Health (NIOSH); or regulatory - established by law or regulation, such as those promulgated by the Occupational Safety and Health Administration (OSHA) (1). In the United States, the OEL is usually either a Threshold Limit Value (TLV), developed by the ACGIH, or a Permissible Exposure Limit (PEL), promulgated by OSHA (49).

### **8.1 American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs)**

ACGIH (2) recommended a TLV 8-hour time weighted average (TWA) of 5 mg/m<sup>3</sup> total fume concentration in the breathing zone of the welder or others in the area when welding iron, mild steel, or aluminum (Welding Fumes, Not Otherwise Classified). For fumes

from stainless steel, cadmium, or lead-coated steel, which are considerably more toxic, ACGIH states that the worker's exposure concentration should generally be kept at a lower level, depending on the TLVs of the specific metal or other constituent involved. Current (as of the year 2000) TLVs (32) for specific air contaminants potentially generated during welding and thermal cutting along with the basis for each TLV, with regard to adverse health effects, are provided in *Table II.A.8* as follows.

**Individual Air Contaminant Occupational Exposure Limits**

Table II.A.8

Air Contaminant	ACGIH TLV TWA mg/m <sup>3</sup>	OSHA PEL TWA mg/m <sup>3</sup>	ACGIH TLV Basis
Welding fume	5	15 (PNOR)	Metal fume fever; irritation
Aluminum (Al)	5 (fume)	5 (respirable)	Irritation
Beryllium (Be)	0.002	0.002	Cancer (lung); berylliosis
Cadmium (Cd)	0.01	0.005	Cancer; kidney; metal fume fever
Cobalt (Co)	0.02	0.1	Asthma; lung; CVS
Chromium (Cr) elemental	0.5 (metal)	1 (metal)	Irritation; dermatitis
Hexavalent Cr (Cr <sup>VI</sup> )		0.1 mg/m <sup>3</sup> (chromates)* ceiling	
-Cr <sup>VI</sup> water-soluble	0.05	---	Cancer; liver; kidney
-Cr <sup>VI</sup> insoluble	0.01	---	Cancer; irritation
Copper (Cu)	0.2 (oxide fume)	0.1	Irritation; GI; metal fume fever
Iron oxide (Fe <sub>2</sub> O <sub>3</sub> )	5 (oxide fume)	10 (total particulate)	Pneumoconiosis
Lead (Pb)	0.05	0.05	CNS; GI; blood; kidney; reproductive
Magnesium oxide (MgO)	10	15 (fume)	Irritation; metal fume fever
Manganese (Mn)	0.2	5 ceiling (fume)	CNS (manganism); lung; reproductive
Nickel (Ni) elemental	1.5	1	Dermatitis; pneumoconiosis; ; kidney
-Ni soluble compounds	0.1	1	CNS; irritation; dermatitis
-Ni insoluble compounds	0.2	0.2	Cancer (lung); irritation; dermatitis
Zinc oxide (ZnO) fume	5	5 (fume)	Lung; metal fume fever
Fluorides (F)	2.5	2.5	Irritation; bone; fluorosis
Nitrogen dioxide (NO <sub>2</sub> )	3 ppm	9 (5 ppm) ceiling	Irritation; pulmonary edema
Ozone (O <sub>3</sub> )		0.2	Pulmonary function; irritation; headache
-O <sub>3</sub> heavy work	0.1	---	
-O <sub>3</sub> moderate work	0.16	---	
-O <sub>3</sub> light work	0.2	---	
-O <sub>3</sub> any work ≤ 2 hours	0.4	---	

PNOR-particulates not otherwise regulated; CNS-central nervous system; CVS-cardiovascular system; GI-gastrointestinal

\* The current OSHA PEL for hexavalent chromium is a ceiling value of 0.1 mg/m<sup>3</sup>, measured as chromium (VI) and reported as chromic anhydride (CrO<sub>3</sub>). The amount of chromium (VI) in the compound equates to a PEL of 0.052 mg/m<sup>3</sup>. This ceiling limit applies to all forms of hexavalent chromium (50).

## **8.2 Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs)**

In the 1989 Final Rule (51), OSHA established a PEL 8-hour TWA of 5 mg/m<sup>3</sup> for particulates generated during welding of aluminum, iron, or mild steel, measured as total particulate inside the welder's breathing zone. In the Final Rule, OSHA concluded that a PEL was necessary to protect workers involved in the welding of aluminum, iron, or mild steel from the significant risk of metal fume fever and respiratory irritation associated with the generation of welding fumes. However, this limit was vacated by a Federal Court ruling and currently is not enforceable. Since 1989, OSHA has not reestablished a PEL for total welding fume; thus, there is no specific welding fume OSHA PEL in the current Air Contaminant Standard. There is, however, a PEL for total particulate not otherwise regulated (PNOR) at 15 mg/m<sup>3</sup> as an 8-hour TWA (52). Individual PELs have been set for various constituents found in welding fume. Current (as of 2000) PELs for specific air contaminants (52) are provided in *Table II.A.8* in the preceding section.

## **8.3 National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limits (RELs)**

NIOSH established a REL of a reduction of worker exposure to all chemical and physical agents associated with welding to the lowest concentrations technically feasible (16). NIOSH did not concur with the OSHA PEL for welding fumes. NIOSH recommended that exposures to all welding emissions be reduced to the lowest feasible concentration using state-of-the-art engineering controls and work practices and that OSHA label welding fumes as a potential occupational carcinogen (51).

## 9. Air Sampling and Analytical Methods for Monitoring Welding

Recommended NIOSH and OSHA sampling and analytical methods for metals and gases generated during welding and thermal cutting are provided in *Table II.A.9*. References for each method are cited in the table.

**Sampling and Analytical Methods for Welding Fumes and Gases**

Table II.A.9

Air Contaminant	Sampling Media	Flow Rate	Analysis	Analytical Method	Reference Number	
Welding fumes	0.8 u MCEF MW or 0.8 u PVC	2 LPM	gravimetric	NIOSH 0500	(53)	
Aluminum (Al)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300	(54)	
Beryllium (Be)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300		
Cadmium (Cd)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300		
Cobalt (Co)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300		
Chromium (Cr) elemental	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300		
Hexavalent Cr (Cr <sup>VI</sup> )	0.8 u PVC	2 LPM	IC	OSHA ID-215		(55)
Copper (Cu)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300	(54)	
Iron oxide (Fe <sub>2</sub> O <sub>3</sub> )	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300		
Lead (Pb)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300		
Magnesium oxide (MgO)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300		
Manganese (Mn)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300		
Nickel (Ni) elemental	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300		
Zinc oxide (ZnO) fume	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300		
Fluorides (F) aerosol & vapor	MCEF, Na <sub>2</sub> CO <sub>3</sub> treated back-up pad	1.5 LPM	ISE	NIOSH 7906		(56)
Nitrogen dioxide (NO <sub>2</sub> )	TEA-treated molecular sieve tube	0.2 LPM	UV-VIS	NIOSH 6014 OSHA ID-182		(57) (58)
Ozone (O <sub>3</sub> )	two nitrite-impregnated Gff	0.25 LPM	IC	OSHA ID-214		(59)

Sampling media: MCEF MW-mixed cellulose ester filter match-weigh; PVC-polyvinyl chloride; TEA-triethanolamine; Gff-glass fiber filter; u-micron

Analysis: ICP-inductively coupled plasma atomic emission spectroscopy; IC-ion chromatography; ISE-ion selective electrode; UV-VIS-ultra violet visible spectroscopy

Pedersen, Thomsen, and Stern (60) examined the effects of sample collection method, storage time, and analytical procedure on the concentration of hexavalent chromium on welding fumes. Hexavalent chromium was reduced to the trivalent state when SMAW fume samples were stored for up to 15 days on cellulose acetate, but not on polyvinyl chloride (PVC) membrane filters.

## **10. Exposure-Related Information to be Recorded in a Database**

If the appropriate information has been recorded, occupational exposure databases may be valuable for epidemiological studies. An exhaustive reference for determining appropriate information to be recorded and for designing a database was published in 1996 in *Applied Occupational and Environmental Hygiene* titled "Data Elements for Occupational Exposure Databases: Guidelines and Recommendations for Airborne Hazards and Noise (61)."

## **11. Statistical Measures for Occupational Exposure Evaluation**

Descriptive statistics are used to summarize data - typically their central tendency (mean, median, and geometric mean) and spread (range, minimum, maximum, standard deviation, and geometric standard deviation). The following descriptive statistics should be calculated routinely for all industrial hygiene monitoring data (1).

- number of samples
- maximum
- minimum
- range
- percent above OEL
- mean
- median
- standard deviation
- mean of the logtransformed data

- standard deviation of the logtransformed data
- geometric mean
- geometric standard deviation

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**CHAPTER II  
LITERATURE REVIEW  
PART B - PULMONARY FUNCTION STUDY**

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## CHAPTER II

### LITERATURE REVIEW

#### **B. Pulmonary Function Study**

Chapter II Part B contains the literature review for the welder pulmonary function study.

##### **1. Pulmonary Function Testing and Spirometry**

Pulmonary function tests aid in understanding the individual effectiveness of ventilation and respiration. Spirometry, lung volumes, diffusing capacity, airway mechanics, and airway reactivity are the most common pulmonary function tests (1). Pulmonary function tests are of vital importance in diagnosing occupational respiratory disease and in objectively assessing the degree of impairment resulting from it. They are most useful in assessing chronic, irreversible conditions (2). Pulmonary function tests also assume a key role in epidemiologic studies investigating the incidence, natural history, and causality of environmental lung disease (3). *Table II.B.1* contains common measurements of pulmonary function (4).

**Common Measurements of Pulmonary Function**

**Table II.B.1**

<b>Test</b>	<b>Abbreviation</b>	<b>Notes</b>
Forced Vital Capacity	FVC	Maximum volume of air that can be exhaled after a maximum inhalation. FVC is reduced in restrictive lung disease* and to a lesser extent in obstructive lung disease*.
Residual Volume	RV	Air remaining in lung after maximum exhalation.
Total Lung Capacity	TLC	Sum of FVC and RV.
Forced Expiratory Volume in 1 second	FEV <sub>1</sub>	Volume that can be exhaled in one second with maximum exertion. FEV <sub>1</sub> % is reduced in restrictive lung disease and in obstructive lung disease.

### Common Measurements of Pulmonary Function (continued)

**Table II.B.1**

Test	Abbreviation	Notes
FEV <sub>1</sub> as Percent of FVC	FEV <sub>1</sub> /FVC	Reduced in obstructive lung disease, normal or slightly increased in restrictive lung disease.
Volume of Trapped Gas	VTG	Increase in VTG is a sensitive indicator of asthma.
Lung Diffusing Capacity for Carbon Monoxide	DLCO	A decrease in the pulmonary diffusing capacity, as measured by DLCO, may be seen in patients with diffuse interstitial disease who have normal spirometric tests.
Airway Responsiveness to Methacholine	PD <sub>20</sub>	The provocative cumulative dose of methacholine causing a 20% decrease in FEV <sub>1</sub> .
Forced Expiratory Flow	FEF	Flow rate measured during forced exhalation.
Mid range (25-75%)	FEF <sub>25-75</sub>	
Terminal flow (75-85%)	FEF <sub>75-85</sub>	Reductions in FEF75-85 indicate impairment in small airways (alveolar region of the lung).
Maximum Expiratory Flow	MEF <sub>25</sub>	Measured at 25% of FVC.
	MEF <sub>50</sub>	Measured at 50% of FVC, also known as maximum mid expiratory flow (MMEF).
	MEF <sub>75</sub>	Measured at 75% of FVC.
Peak Expiratory Flow Rate	PEFR	Peak momentary expiratory flow rate during maximum exhalation. Subnormal or declining values in PEFR are indicative of asthma.
Mean Transit Time	MTT	Derived from mathematical analysis of flow-volume curves.

\* Obstructive lung disease affects airflow through the airways and includes pathological conditions such as bronchial asthma, chronic bronchitis and emphysema. Restrictive lung disease affects diffusion of gases through the lung parenchymal tissue and includes conditions such as interstitial lung disease and diffuse pulmonary fibrosis.

Spirometry is the most commonly used test of pulmonary function. It is the cornerstone of respiratory evaluation, and is the most basic and most valuable test for clinical assessment of workers at risk for respiratory disorders (5). Thus, spirometry is often used in industry, and is considered essential as part of a respiratory surveillance program for workers with potential exposure to airborne pulmonary hazards (3). Virtually all of the

guidelines for evaluating respiratory impairment begin with measurements of spirometry and pulmonary diffusing capacity (DLCO) (2).

Spirometry involves a series of tests that measure the volume of air an individual inhales or exhales, as a function of time, during several respiratory maneuvers. The subject is coached to expire maximally, to make a good seal on the mouthpiece, and then to attempt maximal inspiration, followed by maximal expiration. At least three measurements are made, and the best effort is recorded. Measurements can be displayed as either volume versus time or flow rate versus time (1).

To perform spirometry, the device used must be able to measure either volume of expired air or expiratory airflow as a function of time. These two basic types of spirometers may be referred to as volume spirometers and flow spirometers (5).

## **2. Quality Control of Spirometry**

A spirometry quality control program is necessary to ensure that accurate and consistent results are obtained. Lack of coaching, poor patient (subject) effort, incorrect technique, and equipment malfunction contribute to unreliable measurements (1).

Spirometric measurements are most reliable when performed by a trained technician in a pulmonary function laboratory (1). In order to obtain valid results, the laboratory obtaining the tests should use equipment meeting the specifications and techniques conforming to the guidelines set forth by the American Thoracic Society (ATS) (2). The

initial ATS statement, *Standardization of Spirometry*, was published in 1979 (6). Updates followed in 1987 (7) and 1995 (8). The 1987 ATS Update includes a statement with reference to the importance of routine equipment preventive maintenance, cleaning, calibration checks, verification, and quality control as important steps to assure accurate spirometry results.

Spirometers, like other monitoring and diagnostic instruments, can generate erroneous information. However, if they are calibrated and leak tested (volume-displacing spirometers) every day of use, the likelihood of error is greatly reduced (9).

Equipment calibration and verification are two distinctly different procedures. All spirometry equipment should be calibrated using procedures recommended by the manufacturer. After calibration is complete, the following verification procedures are recommended to ensure and document the accuracy of the spirometry systems. Verification procedures should generally be performed using the following recommended frequency, although certain studies may require changes to meet specific needs (10).

*Daily:*

- A. Spirometer leak test.
- B. 0 to 3 liter volume verification.
- C. Time verification of chart drive.

*Monthly:*

- A. Pressure test spirometer hoses
- B. Manual measurement of FEV1 and FEF25-75%.

*Quarterly:*

- A. Entire volume range linearity test.

In addition to verifying the accuracy of equipment, a quality assurance program should include measures to verify the accuracy of testing technique (10). Spirometric technique is very important in obtaining quality results. Successful spirometry depends on numerous factors, including: a) proper patient preparation, b) explaining and demonstrating the maneuver, and c) proper performance and careful inspection of each maneuver (9).

Since spirometry requires a certain amount of subject cooperation, it is essential that the test results meet the quality control criteria for reproducible, maximal efforts. The results should be reported as absolute values and expressed as percentages of predicted values appropriately corrected for age, height, gender, and in certain instances, race or ethnic origin (2).

With regard to quality control of testing, McKay made the following statement in a 1994 publication (3). "With improvements made in spirometry equipment, a major source of variability in testing is now caused by procedural issues, such as failure to obtain maximal effort, not recognizing improperly performed trials, not obtaining an adequate number of valid trials, and having tests performed by technicians with less-than-optimal skill and/or training. A written spirometry procedures manual should be available and should be updated at least annually. The manual should include a quality control plan, procedures for calibration, step-by-step directions regarding spirometry procedures, and values that may trigger physician notification. To ensure that high-quality data are obtained, a quality control monitoring program is needed to provide feedback to all

technicians regarding their performance. Quality control programs identify technicians who may need additional training; furthermore the very fact that tests undergo critical review may provide enough incentive to improve or at least maintain a certain level of performance."

### **3. Most Utilized Spirometric Indices - FVC, FEV<sub>1</sub>, FEV<sub>1</sub>/FVC**

Spirometry test results are derived from the forced expiratory curve. Although there are many spirometry measures, the simplest and generally the most useful ones for evaluating work-related respiratory disease are forced vital capacity (FVC), forced expired volume in the first second (FEV<sub>1</sub>) of a forced vital capacity maneuver, and the ratio of these two measurements (FEV<sub>1</sub>/FVC) (1,11).

FVC and FEV<sub>1</sub> are the most widely used of all lung function tests. FVC is the volume expired when the forced expiration is continued until no more air can be expelled from the lungs. FEV<sub>1</sub> is the maximal volume of air that the subject can exhale in the first second of a forced expiration following a full inspiration (12). The ratio of FEV<sub>1</sub>/FVC is used as an indicator of the presence of airflow obstruction. The FEV<sub>1</sub>% is used to quantify the degree or severity of obstruction. The FVC is used to quantify the degree of impairment in restrictive disorders (5,13). Spirometry may be diagnostic of abnormal airway resistance (obstructive lung disease). Although it may suggest restrictive lung disease, it is insufficient to make the diagnosis. Lung volume measurements are necessary to diagnose restrictive lung disease (1).

The simplicity, standardization, and reproducibility of the maximal expiratory maneuvers (particularly FEV<sub>1</sub> and FVC) make them the measurement of choice in epidemiologic studies (14). The FEV<sub>1</sub> is the most reproducible measurement used in pulmonary function testing (5).

#### **4. Spirometry in Respiratory Medical Surveillance Programs**

Medical surveillance programs for respiratory evaluation in industry utilize spirometry. One of the benefits of spirometry in medical surveillance is early detection of respiratory health problems. Because the lung capacity of healthy individuals greatly exceeds the demands of ordinary occupations, a significant loss of function can occur, and may be detected in lung function tests, before respiratory symptoms develop (15).

In a spirometry surveillance program, tests may be performed annually, but each is interpreted individually (at one point in time) to determine whether that particular test is "within normal limits" (16). There is a wide range of normal values for spirometry that depends on the subject's demographic group. Age, height, ethnicity, and sex are all-important predictors of spirometry (1). Large groups of healthy subjects have been examined in order to establish the normal range of lung function and to develop adjustments for age, height, sex, and ethnicity (15). It is a common practice to compare each measured or calculated variable in an individual's spirometry test with a reference or predicted value. Predicted values have been derived from studies of large groups of healthy individuals. This comparison provides the basis for interpretation (9). In 1991, the American Thoracic Society (17) proposed a useful strategy for interpreting the results

of spirometry. The results are compared to predicted values in order to determine how much capacity was lost (impairment), or conversely, how much capacity remains. This remaining capacity may be compared with the respiratory demands of specific jobs or activities to document disabling impairment (2).

## **5. Spirometry in Epidemiology Studies**

Epidemiologic investigations of chronic occupational lung diseases pose a range of challenges: exposures are often mixed; disease outcomes may be uniquely occupational (e.g., pneumoconioses) or quite nonspecific (e.g., chronic airway dysfunction); and subjects available for study move in and out of the workforce, in part depending on health status. The basic tools used have included employment histories, air contaminant measurement to estimate exposure, questionnaires, chest radiographs, and spirometry to assess health response (18).

In order to compare spirometry results from different facilities, it is essential that the technique of spirometry performance be quite consistent. This is particularly true when data from groups rather than individuals are compared, since relatively small differences in average spirometry results may be statistically significant if based on a large enough number of subjects. Only rigid adherence to a common set of procedures, such as those provided by the American Thoracic Society, can facilitate comparability. Many experts believe that a spirometry testing program should be overseen by a supervising physician (or other highly qualified individual) who can monitor the test performances at the sites

in order to assure comparability. This is particularly important if analysis of group data is anticipated (10,16).

## **6. Cross-Sectional Spirometry Studies and Limitations**

Spirometry results have often been utilized in studies of occupationally-exposed groups. The vast majority of these studies have been cross-sectional in design, comparing mean spirometric values of the study group, collected at one point in time, with an unexposed matched control group or predicted values derived from a reference population. Although cross-sectional studies are of shorter duration, less difficult and expensive than longitudinal studies, they have significant limitations. Attfield and Wagner (18) stated that "Cross-sectional studies consist of snapshots of the workforce employed at the facilities visited during the short period of the medical surveys. They often do not reflect accurately features of workers ever exposed to the contaminant of concern. Affected workers may have died, left the industry, or sought work in areas of the industry with low exposure, leaving the unusually hardy or healthy to remain at the highest risk. Furthermore, they may have been healthier than the average population initially in order to seek or be selected for work in dusty or unpleasant conditions. Smokers may have given up smoking in response to the effects of both dust and tobacco smoke. Exposure estimation for cross-sectional studies is often difficult because of the frequent paucity of prior industrial hygiene data; in addition, work histories have to be drawn from worker interviews. The medical status of a study participant is known at only one point in time, and it is often difficult or impossible to determine how he or she developed that condition. For instance, a person with lower than expected lung function may have

started work that way or suffered abnormal declines due to toxic exposures at work or elsewhere. They may have changed jobs or stopped smoking because of perceived changes in health, but none of this information is available to the investigator."

#### **7. Case-Control Spirometry Studies and Limitations**

A case control study is a study in which cases of disease are compared with a sample of nondiseased persons with respect to various exposures (19). The case-control approach attempts to determine whether the proportion of people with the risk factor is higher among those with, than among those without, the disease (20). Attfield and Wagner (18) stated that "Case-control methods are typically applied in situations in which the outcome is rare. They provide a powerful and efficient approach and have been use extensively in studies of cancer outcomes. They have been used infrequently in studies of chronic respiratory disease, generally because most of the outcome variables studied are common. Another reason for their disfavor is the difficulty in identifying appropriate comparison groups."

#### **8. Benefits and Difficulties of Longitudinal Spirometry Studies**

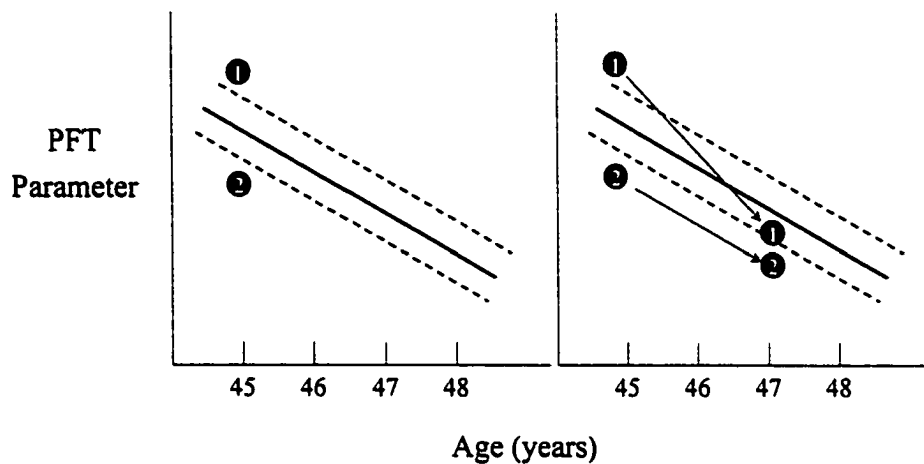
In addition to comparing subjects' values at a point in time to their predicted values, it may also be important to observe and compare changes over time (a longitudinal study). Sequential tests done yearly, for example, can determine whether the subjects' pulmonary functions are worsening, improving, or not changing - except for aging (9). Harber and Lockey (16) state that "A common error is not considering data longitudinally as well as cross-sectionally, thereby decreasing the utilization of the available information.

Longitudinal analysis of lung function data is a potentially very powerful technique when properly utilized. Many lung disorders, such as chronic obstructive pulmonary disease, can be best defined by the rate of decline of lung function over time rather than the absolute value at any particular time. For example, increasing the rate of decline with aging by only 30 to 60 ml a year (well within the 'noise' of routine spirometry testing) will over a period of years produce very significant disability. The cumulative effects of exposure at the worksite may eventually lead to severe respiratory impairment."

Most lung disease yields results or accelerated declines within the "normal" ranges before the onset of clinical symptoms, especially if patients are followed at regular 1-3 year intervals (11). From a medical surveillance perspective, this window provides an opportunity for early detection and response. Hankinson and Wagner (21) stated that "The real benefit of longitudinal surveillance appears to be for those whose FEV<sub>1</sub> (or FVC) is well above the lower limit of normal (LLN) cross-sectional cutoff but dropping at a precipitous rate. Screening using longitudinal data will generally identify these people earlier than a cross-sectional approach."

Wanger (9), in *Figures II.B.8a-b*, demonstrates why observing and comparing changes in a subject over time can be more valuable than simply comparing results with a reference value. Wanger explains the illustration by stating the following. "*Figure II.B.8a* shows two subjects on a graph of a spirometry value reference equation. The solid regression line of the equation slopes downward (declines) with age, and the area between the dashed lines represents the 95% confidence interval. *Subject #1* is above the regression

line, in fact above the 95% confidence interval, and might be called supranormal. *Subject #2*, however, is below the 95% level and would be called abnormal. *Figure II.B.8b* shows the same two patients measured again two years later. *Subject #2* is still below the 95% level and would still be called abnormal but is declining at the expected normal rate. However, although *subject #1* is still normal, he or she is declining at a rate much faster than expected."



**Figure II.B.8a**

**Figure II.B.8b**

Harber and Lockey (16) stated that "Examination of sources of variance in lung function results among individuals demonstrates the second reason for using longitudinal analysis whenever possible. The variability within an individual over time is much less than the variability among similar distinct individuals. For example, the long-term (week-to-week) coefficient of variation for  $FEV_1$  in an individual is approximately 6%, whereas the comparable measure of variability for a population is more than double that. Hence, the

best reference value is that of the individual rather than that of a reference population (even if optimally comparable to the characteristics of the individual)."

Similarly, McKay and Horvath (3) stated, with regard to follow-up testing and longitudinal studies, "Although comparison of an individual's test result to a set of reference standards may be useful, an even more desirable approach is comparing a subject's observed value with his or her own previous studies. Because the coefficient of variation of a given test within a single subject is smaller than the population coefficient of variation, this approach should be used. Using the subject as his or her control is the basis of longitudinal testing."

Another benefit of the longitudinal approach was stated by Attfield and Wagner (18). "In contrast to cross-sectional studies, the longitudinal study permits examination of temporal factors related to both exposure and outcome, because the same individuals are observed over time. Moreover, prospective longitudinal studies have the potential for exposure assessment during the study interval and thus provide exposure data of much better quality than is typically available for cross-sectional studies."

Longitudinal studies have limitations, however. Attfield and Wagner (18) stated "If they are based solely on employed workers, they suffer from the potential for bias due to healthy worker selection, because workers who are affected by exposure and leave the industry are not in the group studied. This bias may be greater than that intrinsic to cross-sectional studies, especially with lengthy follow-up periods. In addition, longitudinal

studies can be complicated and difficult to analyze compared with cross-sectional studies. Whereas the cross-sectional study provides single variables (e.g., one statement concerning cough, one measurement of FEV<sub>1</sub>), the longitudinal study has repeated measures of each variable. Deciding on the appropriate way to summarize and model these variables can be perplexing. The method of longitudinal analysis seems attractive, because each worker acts as his own control, thereby removing inter-person variation from the analysis and apparently eliminating the need for adjustment. In reality, the perceived potential advantages are not always realized, and adjustment may still be required. In addition, because the outcome variable in longitudinal analysis often involves some measure of change and thus depends on multiple measurements, it may be less reliable than single point outcome variables, involving more random error. For example, change in ventilatory function derived from two endpoints suffers from twice the degree of measurement variation (equipment plus day-to-day) compared with cross-sectional analyses. Finally, a disturbing factor in longitudinal analysis may be the presence of survey effects. Apparently random factors may cause data points to be shifted from one survey to another. Potential causes include differences among technicians, interviewers, equipment, and season, although it is often difficult or impossible to determine the cause. These effects can severely affect the analysis of longitudinal change in health status."

Harber and Lockey (16) stated that "The use of longitudinal analysis is technically difficult and should be considered a surveillance tool rather than a method for individual diagnosis, except when there are very prominent differences over time in the individual.

A problem with longitudinal analysis is 'regression to the mean.' Because there is natural variability of results (both due to technical inaccuracies of measurement and due to actual variability in individuals), by chance, some persons will have higher than typical at an early stage in the sequential testing. If the subsequent results are 'typical', there would appear to be an accelerated rate of decline. The major problem, however, with longitudinal analysis is its great sensitivity to technical factors. Because the typical rate of decline of 30 ml a year is extremely small in comparison to the FEV<sub>1</sub> and FVC and 'noise of measurement,' small technical errors can be interpreted as being significant. Absolutely scrupulous attention to detail in testing procedures is mandatory."

#### **9. Defining a Meaningful Change Over Time in Longitudinal Spirometry**

When examining longitudinal spirometric results, it is important to define what is a meaningful change. In order to determine if a meaningful change over time has occurred, the expected decline with aging must be accounted for. Harber and Lockey (16) state that "First, the natural history of lung function change over time needs to be understood. In the past, it was thought that there was a two-phase pattern-linear growth in a child and teenager followed by onset of linear decline. More recent data (22), however, suggests that there is actually a three-phase pattern: growth as a child, a plateau phase through much of the twenties (in which lung function remains stable), and linear decline thereafter." Hence, initiation into a study at too early an age may be potentially misleading. Declines in lung capacity and airflow normally occur in males after age 25 (15). The FVC and FEV<sub>1</sub> are the two variables to use in this type of evaluation. The

expected decrease in these parameters from aging is approximately 25 to 30 ml/year (3,5,9,16,17).

Additionally, there is the factor of test variability. On repeated testing, FEV<sub>1</sub> and FVC may vary up to 5% per day, 12% per week, and 15% per year in normal people. In patients with obstructive lung disease, the variation may be twice as high (1). Therefore, for FVC and FEV<sub>1</sub>, yearly changes that exceed 15% should be considered meaningful (3,5,17).

McKay and Horvath (3) made the following statement with regard to detection of meaningful changes in spirometric values. "Longitudinal studies done over longer intervals (e.g., annually) are designed to detect more insidious or chronic changes at the earliest possible state; however, the magnitude of decline needed to represent a meaningful change is not as well understood. The proper interpretation of longitudinal or follow-up studies requires the ability to distinguish lung function changes due to disease from other sources of variability. Adherence to recommended spirometry standards should minimize the variability due to inconsistent technique, fluctuating patient effort, or instrument inaccuracy. In longitudinal studies over a period of many years, the decline in pulmonary function due to aging must also be considered. It has been commonplace in longitudinal monitoring to compare the annual change in lung function in a group of workers with that obtained from cross-sectional studies of normal populations. Annual declines from such cross-sectional reference groups average approximately 25 to 30 ml for FEV<sub>1</sub> and FVC. Given this rather small yearly decrement and the relatively large

variability in the test itself, the decline in pulmonary function in a given individual must be either very large, or the subject must be observed over a long period of time in order to distinguish if this change is due to disease. Further, the use of predicted annual declines derived from cross-sectional studies in the longitudinal monitoring of workers has been questioned. In one study, (Glindmeyer et al. (23)), the investigators found that the age regression coefficient for FEV<sub>1</sub> and FVC determined cross-sectionally was more than twice the longitudinal annual change computed from the same data." McKay and Horvath (3) cautioned that "This could lead to an underestimate of adverse effects from inhaled airborne substances and advised that in interpretation of annual changes in lung function, longitudinal observation should be compared only with longitudinal data derived from reference groups. However, until adequate longitudinal studies are available, the current practice of considering age regression coefficients as estimates of annual decline will necessarily continue."

## **10. Longitudinal Study Design Issues for Chronic Occupational Respiratory Disease**

The following information pertaining to epidemiological study design issues, with an emphasis on longitudinal spirometry studies, has been excerpted from appropriate references.

### **10.1 Longitudinal Versus Other Study Designs**

The longitudinal study design has been compared more favorably with other study designs in the previous discussion. Because the limitations of cross-sectional studies and

other designs have been recognized, some of the more recent spirometry studies of occupationally exposed groups have utilized a longitudinal approach to the evaluation of spirometry (24-26).

## **10.2 Study Agent Exposure Estimation**

Exposures are assessed in reference to the intensity (concentration) of the substance in the workplace environment and the duration of time during which the substance is encountered. Cumulative exposure is probably the most appropriate exposure metric for use in connection with chronic occupational respiratory disease (18).

When broader exposure categories are studied (e.g., welders or foundry workers), a more-detailed characterization of exposure is necessary. For example, there are many different welding methods, and these methods produce fumes with different chemical compositions, particle sizes, and other characteristics. In such situations, a proper characterization of the exposure composition is necessary for identifying the specific conditions causative of the respiratory condition under study. Failure to define the exposure probably accounts for at least part of the confusion now occurring in the literature on respiratory symptoms among welders. Exposure intensities should also be measured, especially when the study aims at establishing exposure-response relationships and the determination of a no effect level (27).

### **10.3 Selection of Subjects**

Selection of the entire base is optimal. The enrollment of the entire study base into to a study should reduce the potential for selection bias to occur (27).

### **10.4 Selection of Controls**

Subjects serving as their own controls is the preferred approach, as previously covered in Section 8. *Benefits and Difficulties of Longitudinal Spirometry Studies* (3,16).

### **10.5 Sample Sizes for Subjects and Health Outcome Measurements**

Studying the same subjects repeatedly may be advantageous in terms of statistical efficiency because there is usually less variability in measurements within individuals than between groups (28). Interpersonal variability for spirometry is much greater than intrapersonal variability, which may also be considerable. Repeated measures on the same subjects, serving as their own controls, allows for increased statistical power per number of subjects enrolled in the study (29).

### **10.6 Precision**

Sources of error in a study include random error and systematic error. Random error results from imprecision that occurs whenever the method of measurement is insensitive or its specificity is poor (27). Reducing random error increases precision. Random error arises from sources of variation due to chance, for example sampling error. Random error may be reduced by 1) increasing the sample size, or, 2) modifying the study design to increase efficiency (20).

With regard to the longitudinal spirometry study, the "Laird Ware" mixed model is able to handle data consisting of unequal sample sizes and intervals, missing or otherwise unbalanced data. Use of the model in a longitudinal study of repeated measures on the same subjects (versus the more traditional approach of comparing spirometry to predicted values derived from a reference population or to a control group) increases the power of the study, enhancing the detection of smaller differences in distinguishing true change from random variability (29).

## **10.7 Validity**

Reducing systematic error increases validity. External validity pertains to the target population, and internal validity pertains to within the study group. Internal validity is a prerequisite for external validity. External validity must be concerned with whether the study results are abstractable to the target population, and whether the target population is chosen wisely. Threats to abstractability include representativeness of the sample and nonparticipation. Internal validity must be concerned with whether the effect found in the study group accurately reflects the *true* effect in the study group. A threat to internal validity is bias (20). Bias is systematic error, which results in an incorrect estimate of the association between cause and effect (30). Bias may be considered to be present in three forms: 1) selection bias, 2) information bias, and 3) confounding (20).

### **10.7.1 Selection Bias**

A selection bias is a distortion of the effect measured; it results from procedures used to select subjects that lead to an effect estimate among subjects included in the study

different from the estimate obtainable from the entire population theoretically targeted for study (30). Selection bias involves biases arising from the procedures by which the study subjects are chosen from the study base. Thus, selection bias is generally not a problem in cohort studies, since these use all the information from the study base (19).

#### **10.7.1.1 Healthy Worker Effect**

The healthy worker effect is one form of selection bias, and is a negative bias with a complex nature. Health-based selection into a certain employment, or into the entire workforce for that sake, is the most important cause of the healthy worker effect (27). This healthy worker effect, presumably derives from a screening process, perhaps largely self-selection, that allows relatively healthy people to become or remain workers, whereas those who remain unemployed, retired, disabled, or otherwise out of the active worker population are as a group less healthy (30).

Harber and Lockey (16) stated that "Absence of a deviation from a mean spirometry value of 100% of predicted should not necessarily imply absence of an adverse effect in a worker population. Healthy worker effects would tend to make a group of workers selected for arduous tasks (which are often associated with adverse exposure) 'more healthy' than average, so that a finding of average results in the worker population might represent a decline from initial 'supernormal' values. In addition, self-selection occurs, so individuals with subtle abnormalities may leave particularly adverse jobs." In accord with the previous statement, a large cross-sectional spirometry study (31) of young

shipyard welders yielded mean baseline FEV<sub>1</sub> values at 109% of predicted. The authors attributed this to "healthy worker" selection bias.

The above-mentioned example demonstrates one of the many limitations of a cross-sectional study design. However, a longitudinal study of repeated measures using subjects as their own controls can detect an accelerated rate of decline over that expected for aging alone. It is not comparing spirometric results to predicted values derived from a reference population. The expected rate of decline due to aging is known and approximately linear for the age group to be studied. Therefore, welders with initial spirometric values significantly above those expected are not of consequence for this study design, which should substantially reduce the healthy worker effect versus other study designs (29).

### **10.7.2 Information Bias**

Information bias involves misclassification of the study subjects with respect to disease or exposure status. It is customary to consider two types of misclassification: nondifferential and differential misclassification. Nondifferential information bias occurs when the likelihood of misclassification is the same for both groups compared. This can occur if exposed and nonexposed persons are equally likely to be misclassified according to exposure. Nondifferential misclassification will bias the effect estimate toward the null value. Hence, it is of particular concern in studies that show no association between exposure and disease. Differential information bias occurs when the likelihood of misclassification of exposure is different in diseased and nondiseased persons or the

likelihood of misclassification of disease in different in exposed and nonexposed persons. This can bias the observed effect estimate either toward or away from the null value (32).

#### **10.7.2.1 Instrumentation/Recorder Bias**

Instrumentation/recorder bias would be considered a form of information bias. In measuring and recording spirometry tests, instrument or recorder bias could occur. The proper interpretation of longitudinal or follow-up studies requires the ability to distinguish lung function changes due to disease from other sources of variability. Adherence to recommended spirometry standards should minimize the variability due to inconsistent technique, fluctuating patient effort, or instrument inaccuracy (3).

#### **10.7.2.2 Subject/Respondent Bias**

Subject/respondent bias would be considered a form of information bias. Two types of subject/respondent bias would include recall bias and reporting bias (20). Work history and smoking are examples of exposures that could be affected by this bias.

#### **10.7.3 Confounding**

Confounding is a distortion in an effect measure that results from the effect of another variable that is associated with the exposure under study. A confounding factor must:

1) be a risk factor for the disease among the nonexposed; 2) be associated with the exposure variable in the population from which the cases derive; and 3) not be an intermediate step in the causal path between the exposure and the disease (30). Thus, other concomitant exposures (in addition to the agent under study) should also be

identified and, if possible, quantified because they can be confounders if they are asymmetrically distributed across study groups. It is, therefore, important to define exactly who is or has been exposed to what, and how much, when adverse effects to the respiratory system of the agent under study are being assessed (27). Confounding can be controlled in the study design, in the analysis, or both. Control at the design phase in epidemiology studies may involve restriction or matching. Adjustment for confounding may be conducted in the statistical analysis through stratification or by multivariate statistical modeling (30). The use of subjects as their own controls in a repeated measure structure for longitudinal data reduces the effect of confounding. In addition, potential known confounders may be measured and adjusted for in the mixed model (29).

### **10.8 Effect Modification**

Effect modification refers to a change in the magnitude of an effect measure according to the value of some third variable (after exposure and disease), that is called an effect modifier. Effect modification differs from confounding in several ways. The most central difference is that, whereas confounding is a bias that the investigator hopes to prevent or, if necessary, to remove from the data, effect modification is a finding to be reported rather than a bias to be avoided. Epidemiologic analysis is generally aimed at eliminating confounding and discovering and describing effect modification (30). Thus, other concomitant exposures should also be identified and, if possible, quantified because they can modify the effects of the agent under study (27). Multivariate analysis permits evaluation of interactions (effect modifiers) for a host of variables (30).

## **10.9 Smoking**

Smoking can have a strong adverse effect on pulmonary function. Conversely, smoking cessation can result in lung function improvement, or a decrease in the rate of loss. Thus smoking status and changes in smoking should be accounted for in occupational studies of pulmonary function.

As with other studies of occupation and lung function, epidemiologic studies of welding are complicated by smoking, which in the past was more common among welders than in the general U.S. population (33). Studies on work-related respiratory disorders can rarely be valid if one does not account for smoking. Usually the smoking habits are not known prior to the study, or existing data are crude or unreliable. Detailed data on past and current smoking activity must therefore be collected by interview or questionnaire as a part of the study protocol. When the study is being designed, the contrasts between subcategories of smoking should be made great enough. Often the most pertinent information comes from comparisons between exposed and unexposed heavy smokers because the agent/material in question and smoking may act synergistically (27).

Numerous cross-sectional and longitudinal studies have shown that current smokers do not perform as well on pulmonary function tests as former or never smokers. In a 10-year longitudinal study of smoking (268 adult male cigarette smokers, 181 quitters, and 254 who had never smoked) aging, and pulmonary function, Bosse et al. (34) determined that FEV<sub>1</sub> and FVC were related to smoking status. For all age groups, nonsmokers performed the best on spirometry, while current smokers performed the worst. The

decline in FEV<sub>1</sub> in milliliters over time was greatest in current smokers. Loss of FVC over time was not influenced by smoking status.

In a more recent study (35), the effects of cigarette smoking and smoking cessation on the rate of FEV<sub>1</sub> decline over six years were examined in 4,451 Japanese-American men from the Honolulu Heart Program who were 45 to 68 years of age at baseline (1965-1968). Within-person regression was used to calculate annual change in FEV<sub>1</sub>. Rates of FEV<sub>1</sub> decline varied strongly with smoking status and increased significantly with age. Overall, men who continued to smoke experienced steeper rates of decline compared to men who never smoked. Rates of decline in milliliters for those who quit smoking during the first two years were nearly the same as for those who continued smoking. After quitting, their rates of decline diminished to a level similar to that of the men who had never smoked. FEV<sub>1</sub> decline in continuing smokers was significantly associated with duration of smoking, whereas associations with intensity and pack-years were of borderline significance. Among 216 men with impaired pulmonary function, those who quit smoking had significantly slower rates of FEV<sub>1</sub> decline than in those who continued smoking. The authors concluded that these results extend previous reports of accelerated rates of FEV<sub>1</sub> decline in persons who continue to smoke, and they indicate that smoking cessation leads to less steep rates of decline in pulmonary function over a short time in middle-aged men, as well as in men with established pulmonary impairment.

### **10.10 Asbestos**

Chronic high asbestos exposure can cause decrements in spirometric results. Chronic asbestos inhalation exposure is capable of causing asbestosis, a lung-scarring disease, resulting from an inflammatory reaction that evolves in a fibrosing repair process. The diagnosis of asbestosis is a judgement based in part on a restrictive pattern of lung function that progresses as the disease worsens. Abnormalities in the traditional lung function tests, such as determination of lung volumes and diffusing capacity, will appear at about the same time as the change in the chest radiograph. Lung function tests usually reveal a restrictive change associated with mild end-expiratory airflow limitation (36).

### **10.11 Changes in Body Weight**

Some studies have reported that changes in body weight may effect ventilatory performance. Chinn et al. (37), studied the relationship between lung function and body mass in shipyard welders. Spirometry ( $FEV_1$  and FVC), physical examinations including measurement of body mass and body fat, and questionnaires concerning exposures and respiratory symptoms were administered at the beginning and end of the study, approximately seven years later. During the seven years, body mass increased for the youngest subjects and decreased for the oldest. Increases in body mass index (weight divided by height squared) were significantly correlated with decrements in FVC and  $FEV_1$ . The authors concluded that neglecting the effects of body mass changes may lead to erroneous conclusions in studies of changes in lung function over time.

McKay et al. (24), evaluated the relationship between body weight gain and longitudinal changes in lung function in 361 men exposed to refractory ceramic fibers. The subjects each provided at least five pulmonary function tests. The spirometry tests were conducted approximately annually from 1987 to 1994. The authors reported a relationship between weight gain and longitudinal loss in FEV<sub>1</sub> and FVC that was comparable to that of aging. The authors concluded that change in weight becomes a very important variable that requires consideration whenever longitudinal studies of pulmonary function are conducted, else other factors may be falsely identified as contributing to changes in lung function or weight change may mask factors that do change lung function.

#### **10.12 Statistical Methods for Group Longitudinal Spirometric Evaluation**

Some statements regarding more recent statistical methods used in longitudinal spirometric studies and related issues are provided as follows.

Harber and Lockey (16) stated that “Determining the rate of change over time is generally performed by fitting a linear regression to the data from each individual subject, the estimated regression data with appropriate weights for the subjects, depending upon the number of points and their temporal distribution. Simply performing testing many times does not significantly improve the precision of the slope estimate. Rather, it is more important that the points be dispersed in time to estimate the slope of the individual's rate of decline. Theoretical analysis suggests that an initial spirogram be performed and the repeat spirometry be done relatively early because initial data have great influence on the

estimated slope. The first spirometry session may give slightly inaccurate data, with an increase to the second due to a training effect."

McKay and Horvath (3) stated that "The proper interpretation of longitudinal or follow-up studies requires the ability to distinguish lung function changes due to disease from other sources of variability. Adherence to recommended spirometry standards should minimize the variability due to inconsistent technique, fluctuating patient effort, or instrument inaccuracy. In longitudinal studies over a period of many years, the decline in pulmonary function due to aging must also be considered. It has been commonplace in longitudinal monitoring to compare the annual change in lung function in a group of workers with that obtained from cross-sectional studies of normal populations. Annual declines from such cross-sectional reference groups average approximately 25 to 30 ml for FEV<sub>1</sub> and FVC. In assessing longitudinal changes, a decline in FEV<sub>1</sub> or FVC greater than 10% over the course of 1 to 2 years has often been regarded as potentially abnormal, although the 1991 ATS statement (17) suggests the yearly change of 15% to more clinically important."

With regard to statistical analysis of longitudinal data, Laird and Ware (38) developed and utilized a two-stage random effects analysis. A mixed model for random and fixed effects may be used to analyze longitudinal pulmonary function data (29). A statistical software program and function that may be utilized for this type of analysis is the SAS procedure PROC MIXED (39).

In two recent studies, McKay et al. (24) and Lockey et al. (25) utilized a two stage random effects model. The units of pulmonary function outcomes for FVC and FEV<sub>1</sub> were ml/year. First, individual slopes of height-adjusted FVC and FEV<sub>1</sub> measurements on age were calculated by simple linear regression of FVC and FEV<sub>1</sub> on age, recorded to the nearest tenth of a year. This yielded a linear age regression (slope) for each worker. Second, each individual's slope was regressed on covariates. Results were obtained using the SAS procedure PROC MIXED assuming a random effects model, in which maximum likelihood estimates of slope parameters were obtained allowing slope variances to differ as a result of differences in number and timing of test sessions among individuals. The two-stage random effects model fits a line to all the data regressed on age, and simultaneously fits a line to each individual's deviation from the population line. In the latter study, variables included in the analysis were mean age from first to last test, initial duration of exposure (refractory ceramic fiber), accumulated exposure from first to last test, continuous smoking over study period compared with never smoking, previous smoking, smoking before initial test compared with never smoking, starter or quitter during study period compared with never smoking, pack-years during study period, weight at initial test, and slope of weight change during study period obtained by a least squares regression of weight on time. All were multiplied by the difference of age at each test minus age at first test to obtain slope estimates.

## **11. Previous Welder Spirometry Study Findings**

The respiratory health of welders has been studied extensively. The results have been conflicting, probably due to the variety of welding techniques, exposure intensities, and smoking habits in the different studies (27).

The most frequently studied outcome of occupational welding fume exposure has been an effect on lung mechanics and gas exchange. The purpose of these studies has been to detect early or subclinical effects at an asymptomatic stage. At more advanced stages, more severe changes can be correlated with symptoms, exercise tolerance, and pulmonary disease morbidity and mortality risk (40).

The contribution of welding to the development of pulmonary function deficits and respiratory disorders such as bronchitis and asthma remains uncertain, and conflicting results have been reported by different investigators. In studies that have identified a positive relationship between welding and respiratory disorders, it has not been possible to identify specific components of the exposure responsible for these conditions (41).

Because of the complexity of welding exposure, the marked variation in level of exposure between welders, and the lack of individual exposure measurements in these studies, it is difficult to assume that the findings of one study are applicable to another exposed group. Most studies have been cross-sectional in design, using workplace, nonwelder controls for comparison. Most have examined only actively working welders, who may represent a “survivor” population. Within these constraints, many studies have found no

differences between groups, whereas others have found small differences only between welding and nonwelding cigarette smokers or effects on mid-flows or closing volume without effects on FEV<sub>1</sub> (42).

### **11.1 Reviews of Welder Spirometry Studies**

The following studies of welder pulmonary function (spirometry) have been published. They have been divided into those that reported deficits or accelerated declines in FEV<sub>1</sub> or FVC, and those that did not find an adverse effect on these indices.

### **11.2 Studies Indicating Reduced FEV<sub>1</sub> and/or FVC**

1) Hunnicutt et al. (43) studied 100 shipyard welders and 100 controls and reported reduced FEV<sub>1</sub> in shipyard welders exposed for > 10 years and smoking ≥ 20 cigarettes/day. No differences were found in subjects smoking less. Seventy-one of the 100 welders and 59 of the 100 controls in the study smoked ≥ 20 cigarettes/day.

2) Peters et al. (44), who studied 61 welders at a shipyard, reported lower spirometric values in smoking and formerly smoking shipyard welders; however, the welders were also exposed to asbestos while they were engaged in ship repair work. Welders who had never smoked had values of FVC and FEV<sub>1</sub> almost exactly what was predicted (98% and 101%), while ex-smokers were considerably lower (83% and 84%). For current smokers, the values were 82% of predicted for FVC and 92% for FEV<sub>1</sub>.

3) Akbarkhanzadeh (45) compared 209 welders and 109 non-welder controls in a shipyard, matching for age, height, smoking habits, residence, and social class. Of the

welders, 51% had one or more respiratory symptoms, while only 26% of the controls had any symptoms. Chronic bronchitis was found to be confined to welders who smoked or had smoked. The welders experienced increased impairment of lung function, and with advancing years, a deterioration in lung function greater than the controls, but in general, they did not show serious pulmonary insufficiency. The mean values of FEV<sub>1</sub> in both the smoking and the nonsmoking groups of welders were less ( $p < 0.025$ ) than those of the corresponding groups of controls. The difference in FVC between the two groups of smokers, though lower for welders (4.91 vs. 5.07), was not statistically significant; between the two groups of nonsmokers the difference was more marked (5.10 vs. 5.40) and of borderline significance ( $0.05 < p < 0.1$ ).

4) Lygenbo et al. (46) studied 74 high-exposed welders and 31 age-matched electricians in 1982. The welders conducted manual metal arc welding of mild steel, never smoked, and had no known history of chemical exposure that can cause lung damage, such as asbestos. The controls were never exposed to welding fumes, never smoked, and were not exposed to chemicals which can cause lung damage. The welders were significantly ( $p < 0.05$ ) lower than the controls on several spirometric measures of lung function, including FVC, FEV<sub>1</sub>, total lung capacity, peak expiratory flow rate, maximal expiratory flow rate at 75% of vital capacity, diffusing capacity, and slope of the alveolar plateau. Based on the regression equation for vital capacity versus age for the welders and controls, Lygenbo et al. (46) estimated that the lungs of the welders were physiologically 10-15 years older than those of the age-matched controls. Thirty percent of the welders had a well-defined respiratory disease. Their lung function impairment was

predominantly obstructive (16 persons), but restrictive patterns were also seen (6 persons).

5) Cotes et al. (47) studied shipyard welders and caulker/burners. 607 men, aged 17 to 69, comprised a stratified sample of workers from one shipyard who completed a respiratory questionnaire, clinical examination, and detailed spirometry. Chest radiographs were available on 332 men. Among the men aged 50-69, the 'prevalence of persistent cough and phlegm' (chronic bronchitis) was 40%, of 'wheeze on most days' was 25%, and of undue breathlessness on exertion was 25%. After allowing for age, the relative risk of welders and caulker/burners having these symptoms were respectively 2.8, 2.2, and 3.1 compared with other shipyard tradesmen. The effects were of comparable magnitude to, and interacted with, those of current smoking. Among the welders and caulker/burners who smoked, the relative risk of developing chronic bronchitis or undue breathlessness was related to the average fume exposure in all smoking categories, with the strongest association in the ex-smokers. The occurrence of wheeze was also associated with a history of previous metal fume fever. A history of pleurisy, but not pneumonia, was related to the fume exposure in the welders. After allowing for age and stature,  $FEV_1$  was on average higher in young welders (age less than 30) than other tradesmen. In welders and caulker/burners who were current or ex-smokers,  $FEV_1$  and peak expiratory flow (PEF) were reduced in relation to the average fume exposure (mean reductions, respectively, 0.25 L and 0.99 L/sec). The  $FEV_1\%$  (of forced vital capacity), the flow rates at small lung volumes (MEF50%FVC and MEF25%FVC), the mean transit time, and its standard deviation were also reduced by fume exposure or the declines with

age were increased, or both. No impairment was demonstrable in the nonsmokers and many men had given up smoking with apparent beneficial results. The authors (47) further stated that the occupational component of the respiratory impairment related mainly to exposures in the past, and information was lacking on the effects of present conditions in the industry.

6) Marquart et al. (48) conducted spirometry five days before and after the work shift of 11 welders of zinc-coated steel, 10 nonwelders who were indirectly exposed to welding fumes, and 17 controls. The exposure to dust and zinc of all participants was monitored personally using PAS-6 samplers. Geometric mean concentrations for welders were 0.91 mg/m<sup>3</sup> (dust) and 34.0 µg/m<sup>3</sup> (zinc). Cross-sectional analysis of Monday morning values showed no differences in lung function parameters between groups. However, the number of years the participants were engaged in welding was of borderline statistical significance and correlated negatively with values of FEV<sub>1</sub> and FEV<sub>1</sub>/FVC. Changes in lung function over a work shift, or a working week, were not related to the exposure level.

7) Kilburn et al. (49) conducted a cross-sectional spirometry study of 90 welders from a stainless steel fabricating plant, who had minimal asbestos exposure. They had welded for a mean of 11 years, mean age was 44 years, and mean smoking duration was 20 years in 62 current smokers. Baseline spirometric tests were significantly reduced for FEV<sub>1</sub> to 94.5 % of predicted (pop), FVC to 95.4% pop, FEF<sub>25-75</sub> to 85.9 pop, and FEFR<sub>75-85</sub> to 74.8 pop. Current smokers had greater reductions in flow rates and FVC than nonsmokers

even after adjustment of their predicted values for the effects of duration of smoking. The authors suggested this might be due to a synergistic effect on airways of smoking with welding fumes and gases. The authors further stated that 11 years of welding had reduced vital capacities and expiratory flows.

8) Chinn et al. (50) conducted a respiratory sample survey of 609 male shipyard workers in 1979. They were reassessed an average of 7.2 years later. The 53 deaths between the surveys were related to age, level of lung function, and smoking but not to trade as a welder or caulker/burner. Of the survivors, 488 (88%) were re-evaluated, including 425 men who had retired or been dismissed. Redundancy was related to age, smoking, and respiratory symptoms; the average reduction in duration of employment per symptom was 0.44 years. Changes in respiratory symptoms included onset of chronic bronchitis, and wheeze on most days (numbers respectively 77 and 109) and increased breathlessness on exertion (n = 89); significant related factors included smoking, previous metal fume fever or pneumonia, and, for breathlessness, trade as a welder or caulker/burner. Electrocardiographic evidence for myocardial ischemia was also associated with increased breathlessness. The annual declines in FEV<sub>1</sub> and other spirometric indices were related to age, to being a smoker at the time of the initial survey, and to trade as a welder or caulker/burner compared with trades that did not involve welding or burning. There were significant interactions among these effects. In a subsample of 124 redundant workers, there was also significant interaction between the effects of fumes and atopy (skin test positive to common antigens) or a raised serum IgE concentration. The authors concluded that welding fumes interacted with smoking and an atopic constitution to cause

respiratory impairment. They further stated that the results related mainly to exposures in the past and were not necessarily relevant for present day conditions in the industry.

10) Chinn et. al. (51) conducted a study to assess the effectiveness of the current measures for protecting shipyard welders and caulker/burners (WCBs) from the respiratory effects of fumes. Shipyard tradesmen, born after 1953 (cohort 1), and 181 older men, subjects of a previous study (cohort 2), were assessed, then followed up after an average interval of 6.7 years. The respiratory associations with shipyard trades were assessed cross-sectionally and longitudinally, and an estimate was made of the likely effects of selection bias. Cohort 1 comprised 90% of the 462 eligible WCBs and 239 other tradesmen; there were 31 exclusions. At follow up, 139 of the 146 men still in the shipyard, and 43% of those who had left, were reassessed. The lapses were mainly due to migration. All members of cohort 2 were followed up for respiratory symptoms (from Medical Research Council (MRC) questionnaire) which were recorded, and indices reflecting all aspects of lung function were measured. Results indicated at the initial assessment, and independent of smoking, that trade as a WCB was associated with increased prevalence of chronic cough, phlegm, wheeze, a reduced transfer factor (diffusing capacity), and an enhanced age-related deterioration in peak expiratory flow (measured cross-sectionally). Continued work as a WCB was associated with enhanced deterioration in lung function despite some amelioration of respiratory symptoms; the deterioration was influenced by whether or not exhaust ventilation had been used for every weld. Effects of fume on FEV were independent of, and at least as large as, those due to smoking. Enhanced deterioration in peak expiratory flow was confined to WCBs

who smoked. These effects of trade, but not those of smoking, were nearly independent of atopy. In conclusion, the authors stated that in WCBs, working practices over the period of the study did not prevent the development of mild respiratory impairment. In WCBs who used local exhaust ventilation at all times, impairment seemed to reverse by discontinuation of exposure. Thus, existing hygiene measures should be applied rigorously. The biological effectiveness of these and other necessary measures should be assessed by long term monitoring of FEV and peak expiratory flow.

11) Ozdemir et al. (52) compared 110 manual arc welders exposed primarily to mild steel to 55 clerks (controls) with a similar distribution of age, height, and smoking habits, from two companies in Ankara, Turkey. Arc welding and occasional oxyacetylene welding were performed for about 25 hours/week in confined spaces with poor ventilation, and without the use of respirators. Respiratory symptoms and chronic bronchitis were more prevalent in welders ( $p < 0.05$ ). Welders who smoked showed a higher frequency of chronic bronchitis than controls who smoked ( $p < 0.05$ ). No significant difference in the occurrence of chronic bronchitis was found between welders who smoked and welders who were nonsmokers or ex-smokers. Compared with controls, FVC, FEV<sub>1</sub>, peak expiratory flow (PEF), and maximum mid-expiratory flow (MMEF) were significantly lower in welders ( $p < 0.01$  for FVC, FEV<sub>1</sub>). There was no significant difference in pulmonary function tests between welders who were nonsmokers and controls who were nonsmokers; whereas FVC, FEV<sub>1</sub>, PEF, and MMEF were significantly lower in welders who smoked than controls who smoked ( $p < 0.01$ ). However, there were no significant differences between welders who had never smoked and controls who had never smoked.

The authors concluded that welders working in conditions of inadequate ventilation have an increased risk of chronic bronchitis and impaired pulmonary function.

12) Bradshaw et al. (53) conducted a cross-sectional study of respiratory symptoms and lung function in welders at eight New Zealand welding sites, with 62 current welders and 75 nonwelders as a comparison group participating. A questionnaire was administered to record demographic data, smoking habits, and current respiratory symptoms. Current and previous welding exposures were recorded to calculate a total lifetime welding fume exposure index. FEV<sub>1</sub>, FVC, and peak expiratory flow (PEF) were measured before the start of the shift. There were no significant differences in ethnicity, smoking habits, or years of work experience between welders and nonwelders. Symptoms of chronic bronchitis were more common in current welders (11.3%) than in nonwelders (5.0%). Of those workers with a cumulative exposure index to welding fume  $\geq 10$  years, 16.7% reported symptoms of chronic bronchitis compared with 4.7% of those with a cumulative exposure index  $< 4$  years (odds ratio (OR) 4.1, 95% confidence interval (CI) 0.90 to 17.6). Workers with chronic bronchitis had significantly lower measures of baseline PEF ( $p = 0.008$ ) and FEV<sub>1</sub>/FVC ratio ( $p = 0.001$ ) than workers without chronic bronchitis. Multivariate analysis showed that current smoking (OR 9.3, 1.0 to 86.9) and total exposure index to welding fumes  $> 10$  years (OR 9.5, 1.3 to 71.9) were independent risk factors for chronic bronchitis. The report of any work-related respiratory symptom was more prevalent in welders (30.7%) than nonwelders (15.0%), and workers with these symptoms had significantly lower FEV<sub>1</sub>, ( $p = 0.004$ ) and FVC ( $p = 0.04$ ) values. Multivariate analysis identified a high proportion of time spent welding in confined

spaces as the main risk factor for reporting these symptoms (OR 2.8, 1.0 to 8.3). In conclusion, the authors (53) stated that the study had documented a high prevalence of symptoms of chronic bronchitis and other work-related respiratory symptoms in current welders. Also, workers with chronic bronchitis had reduced PEF and FEV<sub>1</sub>/FVC compared with those without chronic bronchitis. These symptoms related both to cigarette smoking and a measure of lifetime exposure to welding fume.

### **11.3 Studies Indicating No Reduction in FEV<sub>1</sub> and/or FVC**

1) Oxhoj et al. (54) conducted an investigation that included spirometry on 119 shipyard welders and 90 controls matched with respect to age, height, and smoking habits. The study comprised 92% of the welders with at least five years of exposure employed at the shipyard at the time of the investigation. Mean total dust levels were reported to be 10 mg/m<sup>3</sup>. Respiratory symptoms, according to a questionnaire, were more prevalent in the welders. Compared to the controls, closing volume and closing capacity (i.e., closing volume + residual volume) were significantly higher, and total lung capacity was significantly lower in the welders who were nonsmokers or ex-smokers, whereas there were no differences among smokers. The authors stated that these findings may be attributable to deposition of welding fume particles in peripheral small airways or alveoli. No spirometric differences were observed.

2) Keimig et al. (55) studied 91 male welders of mild steel (46 nonsmokers, 45 smokers) with a mean exposure of 108 months, and 80 male factory controls (35 nonsmokers, 45 smokers). Pulmonary function measurements, respiratory symptoms, smoking history,

and occupational history were obtained. Welding processes conducted were gas metal arc welding and flux-cored arc welding. Breathing zone air samples indicated iron oxide concentrations of 1.3-8.5 mg/m<sup>3</sup>, with an average of 3.9 mg/m<sup>3</sup>. No detectable amounts of chromium, copper, fluoride or lead were found in any samples. Welders and controls that smoked had a higher frequency of respiratory symptoms than nonsmokers. Nonsmoking welders and smoking welders, compared with respective controls did not have significantly decreased mean values of FEV<sub>1</sub> or FVC. Welders who did not smoke had a reported increase (p<0.05) in phlegm and episodes of cough and phlegm when compared to nonsmoking controls. Mean mid-expiratory flow rates and forced expiratory flow rates at 75% of FVC were lower, but not significantly different for welders, compared to controls. The authors stated that these decrements in peripheral flow rates could be trivial, or they could represent the initial stages of chronic obstructive pulmonary disease, and that long-term follow-up, provided by a large prospective study, is needed to make this distinction.

3) Hayden et al. (56) studied respiratory symptoms, smoking habits, chest radiographs, sickness absence, and pulmonary function among 258 welders and an equal number of matched control subjects in three engineering factories. Welders who smoked had a higher frequency of chronic phlegm production than control subjects but there was no difference in cough or dyspnea. The frequency of abnormality on chest radiographs was low and similar in welders and controls. Upper respiratory infections were a more frequent cause of sickness absence in welders than in controls but no difference was found in other respiratory diseases. FEV<sub>1</sub> and peak expiratory flow rate were similar in

welders and controls. In a subset of 186 subjects the maximum expiratory flow rate at low lung volumes was significantly less in welders who smoked than in control subjects who smoked, but there was no difference in nonsmokers. The authors stated that welders working under these conditions in the engineering industry appear to have no increased risk of chronic obstructive lung disease.

4) Mur et al. (57) conducted a cross-sectional study 346 arc welders and 214 control workers from a factory producing industrial vehicles. Neither group had been exposed to asbestos. Respiratory impairments were evaluated by using a standardized questionnaire, a clinical examination, chest radiography, and several lung function tests (spirometry, bronchial challenge test to acetylcholine, DLCO using both the breath-holding and steady-state methods, and nitrogen wash-out test). The only significant differences between the welders and the controls were a slightly higher bronchial hyper-reactivity to acetylcholine and a lower DLCO in the welders. Although there were no significant spirometric differences between welders and controls, signs of obstruction were more frequent in the most exposed welders (welding inside tanks) than in welders working in well ventilated workplaces. The nature of the metal welded did not seem to have an influence on the respiratory impairments. In the mild steel welders, respiratory symptoms (dyspnea, recurrent bronchitis) and obstructive signs were more frequent in the welders using a manual process than in the welders involved with the semi-automatic process (MIG). For all the workers (welders and controls), smoking had a markedly adverse effect on respiratory symptoms and lung function. Moreover, smoking seemed to

interact with welding since DLCO was more impaired in smoking welders than in smoking controls.

5) Sjogren and Ulfvarson (58) studied 64 aluminum welders, 46 stainless steel welders, and 149 railroad track welders regarding respiratory symptoms and pulmonary function ( $FEV_1$  and FVC). Referents consisted of nonwelding industrial workers and railroad workers. All groups of welders showed a higher frequency of chronic bronchitis symptoms than their respective referents. Respiratory symptoms were related to ozone concentrations in welders working with aluminum. In stainless steel and railroad track welders, respiratory symptoms were related to chromium exposure rather than total particle exposure. Pulmonary function was not affected in any of the welding groups studied.

6) Kilburn and Warshaw (59) used a multiple regression model to study the effects of welding and smoking on pulmonary function, and adjusted each individual value for height, age, and years of cigarette smoking. The 226 welders included 151 current cigarette smokers, 43 nonsmokers and 32 ex-smokers with a mean duration of welding of 21.3 years. Welders were excluded if they had welded for less than five years, had worked in shipyards, or had asbestosis signs on chest radiographs. Results were compared with those of historical controls from the same geographic area (percent of predicted). In 151 current cigarette smokers, mean midflows and terminal flows were decreased ( $FEF_{25-75}$  to 93.2 % of predicted (pop) and  $FEF_{75-85}$  to 91.2 pop. However, FVC,  $FEV_1$ , and thoracic gas volume (TGV) were normal. The 43 nonsmokers also had

reductions in flows but normal FVC and TGV. Flows in both groups were significantly ( $p < 0.05$ ) below those of the referent group. The regression coefficient was -0.0031 for years of welding and FVC pop, -0.0035 for FEV<sub>1</sub> pop, and -0.0080 for midflow pop (FEF<sub>25-75</sub>) (all significant at  $p < 0.05$ ), but the coefficient for FEF<sub>75-85</sub> pop was not significant. As calculated from regression equations, 40 years of welding would reduce FVC to 95.2 pop, FEV<sub>1</sub> to 92.2 pop, midflow to 79.2 pop, and FEF<sub>75-85</sub> to 81.7 pop. In conclusion, the authors (59) stated that the cigarette smoking welders' reductions were more than additive, that is more than the addition of the effects of welding in nonsmokers and the effects of smoking in nonwelders. They further stated that long-term exposure to welding gases and fumes reduced air flow in small airways of welders without asbestosis.

7) Kilburn et al. (60) studied 145 male welders from a West Coast shipyard cross-sectionally and across a Monday work shift by pulmonary function tests and a questionnaire. Ten years of welding was associated with chronic bronchitis in 23.3% of nonsmokers compared to 3.3% of male controls, shortness of breath in 31.5% of nonsmokers compared to 1.5% of controls, and chest pain or heaviness in 38.4% compared to 4.4% of controls. Men who welded aluminum but had never smoked had more frequent wheezing, chest tightness, phlegm, fever and fatigue than those welding mild (black) or stainless steel. There were no significant cross-shift effects from welding exposure on measurements of pulmonary function. Although baseline expiratory flows were reduced slightly when compared to Caucasian-predicted values, ethnic specific comparisons for the largest subgroup showed only that FEF<sub>25-75</sub> was reduced to 92.9 percent of predicted values. DLCO was significantly reduced as compared to referents.

The pulmonary function values of 25 current smokers were indistinguishable from the 41 who had never smoked, which the authors stated probably reflected their low consumption of cigarettes.

8) Mur et al. (61) reexamined the same population five-years later that had been studied previously (Mur et al. (57), 1985). Subjects completed respiratory symptom questionnaires and were subjected to physical examinations, chest X-rays, and lung function tests. Subjects who had begun or stopped welding or had changed their smoking habits after the initial study was completed were excluded from the follow-up study. The population remaining in the study and tested five-years later consisted of 138 active GMAW welders (82 welded on mild steel exclusively) and 106 nonwelding controls. In the follow-up study, once again, a lower DLCO in the welders was detected versus controls. There was a significant decrease in the maximum expiratory flow ( $MEF_{25}$ ) in the nonsmoking welders compared with nonsmoking controls, that was not found in the initial study. The rate of decline in lung function over the five-year period did not differ significantly between the nonsmoking welders and nonsmoking controls.

9) Hjortsberg et al. (62) studied 14 never smoking nonatopic Swedish shipyard welders who had worked for 10-31 (mean 22) years in their occupation. Spirometry and nitrogen washout data were compared with a reference group of 14 white-collar, never smoking nonatopic men. Both groups were free of all pulmonary diseases and had normal chest X-rays. A methacholine provocation test was conducted. The effect was measured by change in  $FEV_1$  and increased volume of trapped gas (VTG). The maximum decrease in

FEV<sub>1</sub> after inhalation of methacholine was 6% in welders and 2% among referents. Before provocation, VTG and VTG total lung capacity (TLC) was higher among welders (127 ml vs. 98 ml and 1.76% vs. 1.38%). The increase in VTG and VTG/TLC was higher in welders after inhalation of methacholine at concentrations of 0.001% to 2% and remained increased after inhalation of salbutamol. The authors stated that FEV<sub>1</sub> in the welder group was not different from that in the reference group, indicating normal large airways. The authors further stated that these other differences indicated small airways disease among shipyard welders, even in the absence of atopy and smoking.

10) Nielsen et al. (63) studied the effect of welding fumes on small airways in 25 male subjects who performed GMAW and GTAW on aluminum, and to some extent also, SMAW on stainless steel. Exposures to total dust, aluminum, hexavalent chromium, ozone, and oxides of nitrogen were measured in the breathing zone of 19 of the welders and were all below the Swedish permissible exposure limits. Despite a low exposure to welding fumes as compared to these thresholds, excretion of aluminum in urine was found to be increased in all subjects (median value: 0.29 mmol/mol creatinine on Friday afternoon, as compared to an upper reference level of 0.10 mmol/mol creatinine). In addition, the welders displayed increased prevalences of work-related eye and airways (pharyngitis and non-specific bronchial hyperreactivity) symptoms, as compared to 25 controls from a wine warehouse, matched for age and smoking history. Less experienced welders (< or = 2.5 years) had more symptoms related to the upper airways than did long-term welders, which may indicate a selection. Spirometry, closing volume and volume of trapped gas (VTG) did not deviate. However, after methacholine inhalation, the long-

term welders had a significantly steeper slope of the alveolar plateau on the single-breath nitrogen wash-out test, and a slight increase in VTG, as compared to the short-term welders and the controls. The authors concluded that these findings may indicate a welding fume-induced increase in the reactivity of the small airways. Because aluminum welding was far more frequent than stainless steel welding, an association with the former seems likely.

11) Wang et al. (64) studied lung function in 23 active stainless steel and 23 mild steel welders, together with a reference group of 26 vehicle assemblers in four factories in Sweden. The stainless steel welders conducted the shielded metal arc welding process (SMAW) and the mild steel welders conducted the gas metal arc welding process (GMAW). Age, smoking habits, and welding history were accounted for. There was no difference in the incidence of welding-associated asthma (5% for stainless steel, 7% for mild steel welders per 1,000 welding-years). Bronchial responsiveness and lung function in the welders was normal and did not differ between stainless and mild steel welders or the reference group of vehicle assemblers. However, the welders had a significantly higher prevalence of airway symptoms as compared to vehicle assemblers.

12) Rossignol et al. (65), contrary to the findings of most other studies, in a longitudinal study of pulmonary function in 229 male welders in Montreal, Canada, found a significant increase in  $FEV_1/FVC$  with length of employment as a welder or burner. The welders had typically worked in open spaces without exhaust ventilation. Lifetime exposure was calculated from the job history of each welder and an industrial hygienist's

estimation of the fume concentrations encountered in each type of job. Spirometric tests had been administered twice at five-year intervals to 229 welders/cutters from 31 metal manufacturing plants. The data were analyzed by multivariate linear regression, accounting for age, height, and smoking. A high lifetime exposure to welding fumes was associated with better lung functions in a cross-sectional approach (healthy worker effect) but not in a longitudinal approach, where no association was found. The unexpected findings of an improvement with increased exposure duration were potentially attributed to the learning effect as it relates to increased subject spirometric performance, misclassification of exposure due to recall bias on a questionnaire, a borderline duration of follow-up, and loss of subjects to follow-up.

13) Beckett et al. (66) compared changes in lung function, airways responsiveness and respiratory symptoms in 51 shipyard welders and 54 controls welders in a British shipyard, observed in four annual examinations. They also examined changes in lung function that occurred across a work shift and compared them with changes that occurred during a non-working day in a group of 49 welders, 32 of whom also participated in the 3-year study. The subjects had welded stainless steel for an average of nine years at the start of the three-year study. Controls were draftsmen and technicians employed in the same shipyard, living in the same community, and without any current or previous welding exposure. Negative pressure respirators were provided to all of the welders in the shipyard, but their use was at the discretion of the welder. Local exhaust ventilation was routinely used during welding in enclosed spaces. In the work shift study, spirometric lung function tests ( $FEV_1$ ,  $MEF_{50}$ , and FVC) were administered at both the

beginning and end of a day off from work. The average duration of active welding was 4 hours during the 8-hour work shift, and only 33 percent of the welders reported having used a respirator during that time. Each of the welders and controls was subjected to spirometric tests and to high-dose methacholine challenge (measured by the PD<sub>20</sub>) at yearly intervals. These tests were usually done at the end of a work shift. Each worker provided annual work histories that were used to calculate an index of annual exposure (the percentage of a full-time working year spent in active welding during the year prior to each respiratory evaluation). This factor declined after the first year due to work stoppage, reduction in demand for welding, and migration out of welding by some of the subjects. None of the welders who left the trade reported doing so because of a respiratory condition (although three left because of work-related back injuries). In the cross-workshift study, maximal midexpiratory flow rate declined reversibly during a welding day, whereas FEV<sub>1</sub> and FVC were unchanged. In the longitudinal study, The mean annual decline in FEV<sub>1</sub> among welders older than 25 was 4 ml per year, there was no excess decline in lung function in welders compared with controls, nor was there a significant effect of welding on airways reactivity to methacholine in welders compared with controls. The authors concluded that welding is associated with a transient, across work shift decrement in maximal mid-expiratory flow (MEF<sub>50</sub>) and also with reversible, work-related respiratory symptoms. However, no decline in lung function, in terms of FEV<sub>1</sub>, FVC or increased airways reactivity was seen among the welders over the 3-year observation period, which, as stated by the authors, was not optimal for detecting a chronic effect on lung function.

14) Wolf et al. (67), in an Austrian study, analyzed respiratory symptoms and pulmonary function in welders and controls, with particular emphasis on small airways dysfunction. Cross-sectional analysis, using spirometry and a standardized questionnaire, was used to evaluate 521 participants, 166 of whom (64 welders and 102 controls) were evaluated for pulmonary symptoms, occupational inhalative exposures, leisure time activities, and medical history. The welders reported more pulmonary symptoms than the controls. They exhibited a decreased mean expiratory flow (MEF) at 25% and 50% of vital capacity ( $MEF_{25}$ ,  $MEF_{50}$ ) while the other parameters tested (FVC,  $FEV_1$ ) were unchanged compared with the controls. Multivariate regression analysis revealed that smoking explained the observed variance; only in  $MEF_{25}$  did the duration of welding exposure have a significant effect. The authors concluded that the significantly reduced flow values among welders compared with the controls indicated the presence of small airways disease. Differences in smoking habits accounted for more than double the differences in  $MEF_{25}$  than did chronic welding fume exposure, confirming the role of the former as the main risk factor leading to the decline in lung function. The authors further stated that longitudinal studies are needed to evaluate the long-term effects of chronic welding fume exposure, in particular with a view to identifying especially susceptible workers.

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## **CHAPTER III**

### **PURPOSE AND SCOPE**

#### **Purpose**

The purpose of this research was to conduct an exposure assessment and longitudinal pulmonary function study of electric utility power plant welders. The exposure assessment was comprised of industrial hygiene surveys and exposure monitoring and evaluation. Industrial hygiene surveys were conducted to identify and estimate variables known to influence welding/thermal cutting exposures including: task/time allocation, exposure frequencies and durations, power plant systems worked on, welding environmental conditions, materials worked on and utilized, and exposure controls employed. The process/material-based exposure evaluation was to measure and characterize exposures of welders by partitioning exposure data into strata, based on the welding or thermal cutting process employed on the specific metal categories. Results in the form of both 8-hour time weighted average (TWA) exposures and air contaminant concentrations were used to identify processes, materials, and circumstances where exposures may exceed occupational exposure thresholds, based upon individual air contaminants of concern. The frequency and magnitude of overexposures was indicated. Summary statistical measures calculated for 8-hour TWA air contaminant exposures included: arithmetic and geometric means and standard deviations, maximum exposure

levels, and fraction of samples that exceeds the applicable occupational exposure limit for each air contaminant.

The purpose of the longitudinal pulmonary function study was to evaluate electric utility power plant welder pulmonary function (spirometry) as an indicator of respiratory health status. It is known that spirometric performance in terms of forced expiratory volume in one second (FEV<sub>1</sub>) and forced vital capacity (FVC) declines at a more or less fixed rate with aging. A study population of welders, used as their own controls, and followed over time could determine if pulmonary function, as a group, declined at an accelerated rate versus the rate normally expected from aging alone. This involved tabulation and statistical analysis of historical pulmonary function test results and respiratory protection program medical surveillance questionnaire information that pertained to welding and other relevant exposure history, plus smoking. Smoking history and other potential confounders or effect modifiers were obtained and adjusted for in the statistical model, in an attempt to determine if an accelerated decline was present, that it was due to welding exposures, smoking, other exposures, or multiple factors.

This study was expected to yield information potentially generalizable to power plant welder exposures and respiratory health status across the electric utility power generation industry.

## Scope

The welding industrial hygiene surveys were conducted from 1994 to 2000. In most cases, welding shops were resurveyed on an annual basis, with visits made several times per year to conduct exposure monitoring. There were a total of 11 welding shops surveyed at the same number of power plants, located in two states. Approximately 70 in-house welders were represented by these surveys. Those interviewed during the surveys included numerous welders, supervisors, planner schedulers, metallurgists, quality assurance inspectors, and project managers. In addition, numerous contract welders performing the same tasks as in-house welders were interviewed. The welding industrial hygiene exposure monitoring was conducted from June 1994 through May 2000. Welding was sampled periodically throughout the year during the course of the study with visits made to each plant several times per year. There were a total of 11 power plants included in the exposure monitoring. In addition, numerous contract welders performing the same tasks as in-house welders were monitored as surrogates to increase sample size. The total number of air contaminants sampled, analyzed, and included in statistical calculations during the study was 1,853.

The scope of the pulmonary function study consisted of tabulation and statistical analysis of spirometric data adjusted for by years of welding, smoking history, and age, obtained from 43 welders in nine electric utility power plants over a 19-year period. There was a total of 195 spirometric tests (each test consisting of FEV<sub>1</sub> and FVC) conducted on the 43 welders, with an average of 4.54 observations per subject.

**CHAPTER IV  
METHODS AND MATERIALS**

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## **CHAPTER IV**

### **METHODS AND MATERIALS**

#### **A. Exposure Assessment Study**

The exposure assessment study was comprised of two components, an industrial hygiene survey of power plant welding, and welder monitoring and exposure evaluation.

##### **1.0 Welding Industrial Hygiene Surveys**

Welding industrial hygiene surveys and process/task analyses were conducted in all power plant welding shops, mostly on an annual basis. In addition to welding shop inspections and job observations, the surveys gathered the following information by verbal interviews:

- Welder task/time allocation, and frequency and duration of exposure
- Power plant systems worked on, environmental conditions and ventilation use
- Welding/thermal cutting processes, base metals worked on/consumables/gases used
- Types and prevalence of surface coatings and associated work practices
- Welder hazard awareness and respiratory protection practices

From these interviews, answers and estimates were obtained to a series of standardized questions pertaining to exposure-related issues. From these data, consensus answers were derived in order to present a description of the "typical power plant welder". Those

interviewed during the surveys included numerous welders, supervisors, planner schedulers, metallurgists, quality assurance inspectors, and project managers for welding. In addition, numerous contract welders performing the same tasks as in-house welders were interviewed. Consensus answers were determined by the most frequent response, along with a range, where applicable. Other relevant information was found in applicable welding references such as compositions of various base metal and consumable grades.

### **1.1 Welding Industrial Hygiene Survey Duration and Scope**

The welding industrial hygiene surveys were conducted from 1994 to 2000. In most cases, welding shops were resurveyed on an annual basis, with visits made several times per year to conduct exposure monitoring. There were a total of 11 welding shops surveyed at the same number of power plants. Approximately 70 in-house welders were represented by these surveys.

### **2.0 Exposure Monitoring and Evaluation**

Welder industrial hygiene exposure monitoring was conducted in all power plants, on a random basis, within strata consisting of welding or thermal cutting process, and base metal/consumable, which are major variables in air contaminant generation.

### **2.1 Exposure Monitoring Duration and Scope**

The welding industrial hygiene exposure monitoring was conducted from June 1994 through May 2000. Welding was sampled periodically throughout the year during the course of the study, with visits made to each plant several times per year. There were a

total of 11 power plants included in the exposure monitoring. The monitoring represented the exposures of approximately 70 in-house welders. In addition, numerous contract welders performing the same tasks as in-house welders were monitored as surrogates to increase sample size. In the latter case, where contractors on occasion worked longer shifts, e.g., 9-10 hours, either the cassette was changed or the sample was discontinued within eight hours for comparability with in-house welder exposures. The total number of air contaminants sampled and analyzed for during the study was 1,853.

## **2.2 Air Contaminants Sampled and Analyzed**

Air contaminants sampled and analyzed in the study are listed in *Table IV.A.2.4*.

## **2.3 Sampling Media Placement Inside Versus Outside the Welding Hood**

Wherever possible, sampling media were positioned inside the welding hood. Exceptions occurred in instances where the welder was required to wear respiratory protection by corporate industrial hygiene policy. In these cases, there was not sufficient space inside the hood for the respirator filters plus the sampling media, which necessitated sampling outside the hood in the breathing zone. These exceptions occurred on work with high alloy steel where concerns regarding carcinogenic hexavalent chromium exposure triggered the requirement for respiratory protection. The other example would be thermal cutting. Once some overexposures had occurred, the need for respiratory protection during thermal cutting became apparent. In situations where lead or otherwise toxic painted steel was welded/thermal cut, the use of full face powered air-purifying or pressure demand airline respirators dictated sampling in the breathing zone. This was due

to a shaded lens installed in the respirator facepiece used in lieu of a welding hood. In almost all cases, the placement of the sampling device was consistent along these lines. Placement was documented in the exposure monitoring records. Sampling device placement is discussed as it pertains to each air contaminant in *Chapter V Results and Discussion*.

#### **2.4 Exposure Monitoring and Laboratory Analytical Methods**

NIOSH Analytical Methods and OSHA Reference Methods for sampling and laboratory analysis utilized in the study are provided in *Table IV.A.2.4*. There was strict adherence to sampling device calibration to a primary standard prior to and after each sample was collected, to ensure accuracy of flow rates. A standardized industrial hygiene air sampling form was used to record calibration, sampling, and work-related information.

## Sampling and Analytical Methods for Welding Fumes and Gases

*Table IV.A.2.4*

Air Contaminant	Sampling Media	Flow Rate	Analysis	Analytical Method
Welding fumes	0.8 u MCEF MW or 0.8 u PVC	2 LPM	gravimetric	NIOSH 0500
Aluminum (Al)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300
Beryllium (Be)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300
Cadmium (Cd)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300
Cobalt (Co)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300
Chromium (Cr)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300
Hexavalent Cr <sup>VI</sup>	0.8 u PVC	2 LPM	IC	OSHA ID-215
Copper (Cu)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300
Iron oxide (Fe <sub>2</sub> O <sub>3</sub> )	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300
Lead (Pb)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300
Magnesium oxide (MgO)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300
Manganese (Mn)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300
Nickel (Ni)	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300
Zinc oxide (ZnO) fume	0.8 u MCEF MW	2 LPM	ICP	NIOSH 7300
Fluorides (F) aerosol & vapor	MCEF, Na <sub>2</sub> CO <sub>3</sub> treated back-up pad	1.5 LPM	ISE	NIOSH 7906
Nitrogen dioxide (NO <sub>2</sub> )	TEA-treated molecular sieve tube	0.2 LPM	UV-VIS	NIOSH 6014 OSHA ID-182
Ozone (O <sub>3</sub> )	two nitrite-impregnated Gff	0.25 LPM	IC	OSHA ID-214

Sampling media: MCEF MW-mixed cellulose ester filter match-weigh; PVC-polyvinyl chloride; TEA-triethanolamine; Gff-glass fiber filter; u-micron

Analysis: ICP-inductively coupled plasma atomic emission spectroscopy; IC-ion chromatography; ISE-ion selective electrode; UV-VIS-ultra violet visible spectroscopy

### 2.5 Air Sample Analytical Laboratories

Three industrial hygiene analytical laboratories were utilized for air sample analysis. The laboratories were accredited by the American Industrial Hygiene Association (AIHA) for the analyses conducted.

### 2.6 Paint Bulk Sample Analytical Method

Paint bulk samples were acid digested and analyzed by inductively coupled plasma atomic emission spectrometry (ICPAES) for lead, chromium, zinc, and cadmium content. The analytical method utilized was EPA 200.7. Zinc chromate was stoichiometrically

estimated as a maximum percent potentially present by calculation using the amounts of zinc and chromium present in the sample.

### **2.7 Paint Bulk Sample Analytical Laboratory**

The in-house analytical laboratory was utilized for paint chip metals analysis. The laboratory was accredited by the American Association for Laboratory Accreditation (A2LA), and successfully participated in the AIHA Environmental Lead Proficiency Analytical Testing Program (ELPAT).

### **2.8 Air Contaminant 8-Hour TWA Exposure Calculations**

The standard formula was to calculate 8-hour time weighted average (TWA) exposures from the air contaminant concentrations provided by laboratory analysis.

### **2.9 Selection of Occupational Exposure Limits as Thresholds**

Occupational exposure limits (OELs) used as thresholds for comparison were ACGIH TLVs and/or OSHA PELs, whichever was more stringent. “Action Levels” (ALs) were also used as comparison thresholds for the purposes of this study, and were defined as one half of the particular OEL. OELs for air contaminants generated during welding and thermal cutting are provided on *Table IV.A.2.9*. The most stringent OELs (as of the year 2000), which were those applied, are marked in bold.

## Occupational Exposure Limits for Welding/Thermal Cutting

*Table IV.A.2.9*

Air Contaminant	ACGIH TLV TWA mg/m <sup>3</sup>	OSHA PEL TWA mg/m <sup>3</sup>
Welding fume	5	15 (PNOR)
Aluminum (Al)	5 (fume)	5 (respirable)
Beryllium (Be)	0.002	0.002
Cadmium (Cd)	0.01	0.005
Cobalt (Co)	0.02	0.1
Chromium (Cr) elemental	0.5 (metal)	1 (metal)
Hexavalent Cr (Cr <sup>VI</sup> )		1mg/10m <sup>3</sup> (chromates)
-Cr <sup>VI</sup> water-soluble	0.05	---
-Cr <sup>VI</sup> insoluble	0.01	---
Copper (Cu)	0.2 (oxide fume)	0.1
Iron oxide (Fe <sub>2</sub> O <sub>3</sub> )	5 (oxide fume)	10 (total particulate)
Lead (Pb)	0.05	0.05
Magnesium oxide (MgO)	10	15 (fume)
Manganese (Mn)	0.2	5 ceiling (fume)
Nickel (Ni) elemental	1.5	1
-Ni soluble compounds	0.1	1
-Ni insoluble compounds	0.2	0.2
Zinc oxide (ZnO) fume	5	5 (fume)
Fluorides (F)	2.5	2.5
Nitrogen dioxide (NO <sub>2</sub> )	3 ppm (5.6 mg/m <sup>3</sup> )	9 ppm (5 ppm) ceiling
Ozone (O <sub>3</sub> )		0.2 ppm (0.1 ppm)
-O <sub>3</sub> heavy work	0.05 ppm (0.1 mg/m <sup>3</sup> )	---
-O <sub>3</sub> moderate work	0.08 ppm (0.16 mg/m <sup>3</sup> )	---
-O <sub>3</sub> light work	0.1 ppm (0.2mg/m <sup>3</sup> )	---
-O <sub>3</sub> any work ≤ 2 hours	0.2 ppm (0.4mg/m <sup>3</sup> )	---

*PNOR = particulates not otherwise regulated*

### 2.10 Air Contaminant Exposure Recordkeeping

Air contaminant exposure records were maintained in several well-organized systems that served various purposes and ensured retention of sufficient information as described in subsequent sections.

#### 2.10.1 Employee Exposure Notification Reports

These reports, sent to employees and their supervisors contained:

- air contaminant 8-hour TWA exposures and concentration levels as compared to the most stringent occupational exposure limits (OELs)

- welding or thermal cutting process conducted by the welder
- base metal worked on and consumable used, or toxic coating worked on
- power plant system worked on, and environmental location and conditions
- estimated welding or thermal cutting arc-on (or in the case of OAC flame-on) time expressed as a percent
- estimated actual exposure time and the welder's perception as whether exposure duration was longer, shorter, or typical for that type of job
- use of local exhaust ventilation, general ventilation, or influence by air movement from wind or other sources
- respiratory protection worn
- health hazards of occupational exposure to the air contaminants present
- exposure reduction controls required (by corporate Industrial Hygiene) for future work involving that process on the particular base metal/consumable, and the circumstances applicable.

Reports were archived in chronological order in binders for each year. Within each year, reports were subdivided by power plant and placed in chronological order. Attached to each report was the field form used to record sampling device calibration and placement, and sampling and job-related information. Also attached was the laboratory analysis report.

### **2.10.2 Exposure Database**

The exposure database (Microsoft Access 97) was a streamlined record of the exposures and related variables contained in the Employee Exposure Notification Reports. Data could be readily retrieved and sorted chronologically, or by welding or thermal cutting process, then by base metal/consumable category or toxic coatings.

### **2.10.3 Statistical Calculation Spreadsheets**

The Statistical Calculation Spreadsheets (Microsoft Excel 97) contained the 8-hour TWA for every exposure sampled, sample number, date, power plant, and plant system worked on, and were used to perform statistical analysis. The data were stratified for statistical analysis hierarchically, first by welding or thermal cutting process, then by base metal/consumable category. Within each stratum, sampled exposures were also grouped by power plant system worked, but not statistically calculated due to sample size constraints.

### **2.10.4 Profiles for Welding, Thermal Cutting, and Welding/Thermal Cutting on Toxic Coatings - Air Contaminant 8-Hour TWA Exposures Over the OELs**

These profiles (on MS Word Tables) recorded information pertaining to rank ordered 8-hour TWA overexposures, including: process, base metal/consumable type, analyte, applicable OEL, rank order, fraction of exposures (numerator) over the OEL versus the sample size (denominator), 8-hour TWA (TWA), ratio of the 8-hour TWA divided by the OEL (TWA/OEL), plant system worked on, environmental location, use of local exhaust ventilation, exposure time, estimated arc-on time as a percent, and sampling media

placement with regard to inside the welding hood or outside but in the breathing zone (in/out hood).

#### **2.10.5 Profiles for Welding, Thermal Cutting, and Welding/Thermal Cutting on Toxic Coatings - Air Contaminant Concentration Exposures Over the OELs**

These profiles recorded information (MS Word tables) pertaining to rank-ordered air concentration (TWA) overexposures, including: process, base metal/consumable type, analyte, applicable OEL, rank order, air concentration (AC), 8-hour TWA (TWA), ratio of the air concentration divided by the OEL (AC/OEL), plant system worked on, environmental location, use of local exhaust ventilation, exposure time, estimated arc-on time as a percent, and sampling media placement with regard to inside the welding hood or outside but in the breathing zone (in/out hood).

#### **2.10.6 Eight-Hour TWA Exposure Summary Statistical Measures**

These statistics were recorded in a fashion suitable for presentation on a series of tables (MS Word) containing data stratified by welding or thermal cutting process, and within each process category by base metal/consumable category. The statistical measures are described in *Section 2.11* below.

#### **2.11 Air Contaminant Exposure Statistical Analysis**

The software program Excel was used to perform statistical calculations on air contaminant 8-hour TWA exposure data. Exposure data were stratified within categories first, by welding or thermal cutting process, and, within each process category, by base

metal/consumable category. Additional information recorded included sample number, date, and power plant system worked on. Statistical summary measures obtained for each air contaminant, within the above-mentioned strata, were:

- sample size (n)
- highest exposure (High)
- arithmetic mean (AM)
- geometric mean (GM)
- fraction of sampled exposures less than or equal to one half of the applicable occupational exposure limit (OEL), defined as the "action level" (AL) ( $\%n \leq AL$ )
- fraction of sampled exposures greater than one half of the OEL, but less than or equal to the OEL ( $AL < \%n \leq OEL$ )
- fraction of sampled exposures greater than the OEL ( $\%n > OEL$ )

## **B. Pulmonary Function Study**

A study was conducted of pulmonary function (spirometry) in power plant welders employed by a utility company. The study was longitudinal in design, rather than cross-sectional. On an individual basis, longitudinal studies are capable of detecting changes that are considered significant from a trend analysis perspective, predicting future abnormality in time for intervention. Longitudinal studies are more sensitive for detecting subtle changes, due to the inherent homogeneous structure of the data.

### **1.0 Longitudinal Spirometry Evaluation**

Spirometric indices forced expiratory volume in one second (FEV<sub>1</sub>) and forced vital capacity (FVC) were evaluated longitudinally for the group of welders as a whole, to determine if declines were accelerated over those expected for aging alone. Previous studies have reported that the average rate of aging-related decline expected for both indices is 25-30 milliliters per year. All of the independent variables were examined for their effect on change in FEV<sub>1</sub> and FVC over time.

### **1.1 Longitudinal Spirometry Study Scope and Duration**

The scope of the pulmonary function study consisted of collection, tabulation, and statistical analysis of spirometric test data, interpreting and adjusted for by years of welding, smoking history, other relevant exposures, age, height, and body weight. The spirometric testing and other medical surveillance information were obtained on a periodic basis, from 43 welders working in nine electric utility power plants over a 19-year period. There were 195 total observations, resulting in an average of 4.54

observations per welder. The distribution of the number of observations by number of subjects is presented on *Table IV.B.1.1*.

**Number of Observations by Number of Welders**  
*Table IV.B.1.1*

<b># Observations</b>	2	3	4	5	6	7	8	9
<b># Welders</b>	6	7	7	11	8	2	1	1

## **1.2 Selection of Welder Study Population**

The population of power plant welders employed at the utility company had been identified and tracked through industrial hygiene surveys since 1994. Those workers classified as welders in 1994 were potentially available for the study. Most welders were long-term employees. Employment time as a welder prior to 1994 was identified through initial employment records and previous periodic medical surveillance examination records. The study population was selected to potentially contain the entire group of power plant welders employed by the electric utility at any of nine electric power generation plants located in a single state. Only those welders with sufficient spirometric data points over time, e.g., two, to enable longitudinal analysis were included in the data analysis (the vast majority). The power plant welders were almost exclusively white males with a considerable number of years of service in this trade within the company. The welding workforce was a very stable population with little change during the time span of the study.

### **1.3 Selection of Study Design**

The study design was a semi-historical cohort type. The study group was followed forward in time to evaluate an outcome. However, the longitudinal spirometric test data was largely retrospective. The spirometry testing program was designed, conducted, and recorded under the direction of the utility company Medical Director, an occupational medicine physician Board Certified in Internal Medicine. The air contaminant exposure data was prospective, in that the exposure assessment effort was designed, conducted, and recorded by the study principal investigators.

### **1.4 Selection of Controls**

The exposed study group served as their own controls. This approach is preferred for longitudinal studies of pulmonary function, because of the benefit of eliminating interpersonal variability, which may be considerable for pulmonary function. This type of study tends to require fewer subjects for detection of statistically significant changes. Spirometric performance for the group was evaluated over time to determine if an accelerated decline was present versus the rate of decline expected for aging.

### **1.5 Historical Spirometric Testing of Welders**

Welders were administered respiratory health questionnaires and spirometric tests on a periodic basis. Testing was conducted prior to 1994 on a Spirometrics Flowmate spirometer. Testing from 1994 was with a Schiller SP-10 spirometer. Both were volume-sensing devices. Testing from fall of 1999 through 2000 was with a Renaissance Spirometry System Model 5707219, a flow-sensing digital readout spirometer. Tests

were administered with the subject in a standing position. Subjects were asked their current height (without shoes) and body weight, which were recorded. Testing was conducted by occupational health nurses or medical technicians trained and certified in spirometry testing. Maximal subject effort was obtained through coaching during the tests.

#### **1.6 Historical Spirometric Data Quality Control**

Calibration, on each day of use, and maintenance of spirometers were performed per the manufacturer's specifications. This was verifiable for portions of the data archived. Quality statements were obtained by the spirometry technicians and incorporated into testing, such as the need to continue testing until three quality tests were obtained with regard to maximal effort, and measures within 5% of each other, separately, for FEV<sub>1</sub> and for FVC.

#### **1.7 Spirometric Data Quality Assurance**

Spirometric test data were screened prior to tabulation. Data associated with incomplete or questionable information was not included.

#### **1.8 Spirometric Data Collection and Tabulation**

Data were collected from medical surveillance examination records and questionnaires that had been administered periodically during welders' employment and archived in a secured filing system. Information obtained from these records included: birthdate, date of employment with the utility, years of employment with the utility, years as a welder

total, years as a power plant welder for the utility, other relevant exposures; and corresponding to each pulmonary function test date: the spirometric measures FEV<sub>1</sub> and FVC, age, height, weight, and current smoking practices and history. This information was extracted and recorded on tables by hand. The data were then entered on an Excel spreadsheet in a format suitable for insertion into the statistical program SAS for analysis.

### **1.9 Selection of Statistical Methods**

Simple linear regression was used to determine annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC, and annual change in weight for individual subjects. Multiple linear regression was used to analyze the effects of the independent variables (age, years of welding, other exposures (asbestos), smoking status and consumption, height, weight change, follow-up years, and number of tests per subject) on changes in pulmonary function.

Smoking history and other potential confounders or effect modifiers were adjusted for in the model, or identified and described, in an attempt to determine if in fact accelerated decline was present, whether it was related to welding exposures, other exposures (asbestos), smoking, or multiple factors. The SAS system was used for all statistical analyses.

### **1.10 Selection of Variables Included in the Statistical Model**

Variables identified and included in the statistical model were: height, age, years of welding; other relevant occupational exposures that could affect pulmonary function

(e.g., asbestos); and smoking history, categorized as nonsmoker (never smoked), former smoker, and smoker. Smoking history was also quantified in terms of pack-years. Cigarette consumption level and changes in smoking habits over time were included. Pulmonary function tests (spirometry) included in the model were FEV<sub>1</sub> and FVC. Spirometric performance was evaluated over time to determine if an accelerated decline had occurred versus that expected for aging.

### **1.11 Assumptions, Limitations, and Potential for Bias**

A brief discussion of study assumptions, limitations, and potential for bias is presented below.

#### **1.11.1 Study Design**

A purely prospective study is ideal for a study such as this because prospective studies present the opportunity for total design and control of the measurement and evaluation of exposure and the health outcome. In this case, the exposure assessment, while conducted over a limited portion of the span of the study, was designed and controlled by the study investigators. The health outcome measurement protocol and documentation was not, and was largely retrospective. It is more difficult to verify the accuracy of information under the latter circumstance, but the considerable time span and resources were not available in this case to conduct a pure prospective study.

### **1.11.2 Sample Size for Subjects Versus Health Outcome Measurements**

Compared with previous welder respiratory health studies, we did not have a particularly large sample size in terms of number of subjects; however, it was a very large sample size in terms of number of observations (spirometric tests) on the subjects over time. This is why the general linear mixed model is useful. The large number of observations per subject allows for small changes in pulmonary function to be detected.

### **1.11.3 Selection of Controls**

The exposed study group served as their own controls. This approach is preferred for longitudinal studies of pulmonary function, because of the benefit of eliminating interpersonal variability, which may be considerable for pulmonary function. In addition, this eliminated other problems pertaining to the comparability of subjects and controls that could introduce bias, such as smoking history, other exposures, age, height, weight, etc.

### **1.11.4 Welding Air Contaminant Exposures**

The exposure evaluation was based on information collected during the period 1994-2000. The spirometry data were collected during the time span of 1981-2000. It was assumed, based on numerous industrial hygiene survey worker interviews conducted from 1994 to 2000, that the exposures were likely very similar for the time period prior to 1994. The interviews that provided information on the types and relative proportions of work, materials used, and conditions could have been subject to inaccurate recall and responses; however, the large numbers of interviews over time with various experts

produced consistent responses. It was recognized that welders' exposures may vary among individuals during the same time period; however, the fact that work was largely randomly assigned, and the uniformity of responses obtained during interviews, rationalized the decision to assume a large degree of comparability. However, variability does exist in terms of exposure duration, and was addressed by including "years of welding" in the model. It is possible that years of welding could have been subject to recall bias. However, the potential for recall bias should have been somewhat controlled, as once again, subjects were asked to fill out questionnaires on a regular basis (usually at least every two years) during the period of spirometric testing. The comprehensive exposure information obtained by observations, interviews, sample size and exposure evaluation was unprecedented compared with previous welder respiratory health studies.

#### **1.11.5 Health Outcome Measurement and Recording**

Observer/recorder bias is sometimes a potential form of bias, but in this case, spirometric results were recorded by the instrument. Coaching (or lack thereof) of subjects could introduce bias if inconsistent, but in numerous observations made, coaching was consistently and assertively applied to ensure maximal effort. Testing was administered by health professionals trained and certified in spirometry. Instrumentation bias is also a possibility. Because spirometers were calibrated before each use per the manufacturer's specifications, the potential for instrumental/measurement bias was minimal. In order to reduce the possibility of errors in tabulation, when spirometry test data were obtained from medical surveillance records and transferred to Excel spreadsheets for later SAS

statistical analysis, the process was conducted twice. Any discrepancies were checked again and resolved.

#### **1.11.6 Subject Self-Selection Regarding Health Outcome Data**

The utility company had a policy of administering respiratory health questionnaires and requiring spirometric testing for welders every two years during most of the time span of the study. At times, this schedule was not enforced for various reasons. For example, at times, some welders missed scheduled spirometry testing and were either never rescheduled or failed to attend follow-up testing. Tests may have been missed for reasons due to illness, vacation, work emergency maintenance projects, or intentional absence. Therefore, over the span of the study some welders accumulated more spirometry test data than others. This could potentially have some effect on results in the form of self-selection bias, if welders who were more health conscious and more responsive to testing, accumulated more test data points. It would be expected that more data (greater sample size) would lead to less error due to random variability for those welders. If these welders, through self-selection, had more spirometric testing and better spirometric performance, which is effort dependent, this could bias results toward the null hypothesis. In addition, if welders with more data points were more health conscious and used ventilation or respiratory protection more than others, the potential exists for this reduced exposure to result in a reduced decline (after accounting for aging) in spirometric values; which could bias results toward the null hypothesis. In response to these issues, a covariate was introduced in the model to determine if the number of observations on a subject is a significant independent variable.

### **1.11.7 Healthy Worker Effect**

It was possible that there was a higher proportion of individuals healthier than the average among the subjects, reflected as higher than average spirometric values. However, a cross-sectional study would be more subject to selection bias, in the form of the healthy worker effect than a longitudinal study such as this. Even if workers started out initially with higher than average spirometric values, a longitudinal study such as this detects more subtle change over time. Thus, a longitudinal study may determine that even while workers may not be "abnormal" due previous exposures by the endpoint of a study, they may be trending towards dysfunction at a rate accelerated over that expected for aging alone.

### **1.11.8 Confounding**

Variables that may have been potential confounding factors were included and adjusted for in the model. Potential confounders were years of welding, smoking history, other relevant exposures (asbestos), age, height, weight change, follow-up years, and number of tests per subject.

### **1.11.9 Effect Modification**

Interactions of independent variables were included in the model in order to determine if effect modification was present. If an effect modification was found to be present, its effect was described.

#### **1.11.10 Smoking History**

Smoking history was obtained from respiratory health medical surveillance questionnaires. This could have been subject to recall bias or inaccurate responses, leading to misclassification. However, the potential for recall bias should have been somewhat controlled, as once again, subjects were asked to fill out questionnaires on a regular basis (usually at least every two years) during the period of spirometric testing. It was commonly understood that medical surveillance information was kept confidential. This may have somewhat alleviated the potential for individuals' concerns pertaining to revealing smoking status.

#### **1.11.11 Asbestos Exposure**

Power plants constructed prior to the 1980's often contain asbestos thermal system insulation. Asbestos thermal system insulation is a more friable form of asbestos, more subject to damage or deterioration and resultant exposure. The much-publicized asbestos hazard generated significant concern in the company during the 1980's and many power plant workers, including most welders, were enrolled in the asbestos medical surveillance program during this time. This was more often done at employee request in response to their concerns, rather than for documented exposure reasons, although some welders did perform limited asbestos work. Since this time, most welders have voluntarily discontinued participation in asbestos medical surveillance. In general, it is believed, based on interviews, that welders were perceived and treated as more skilled craftsmen than others assigned to maintenance such as insulators, laborers, or mechanics. As such, welders, would normally have been preferentially reserved for, and assigned to, welding

work rather than asbestos removal. However, it is possible that some welders may have had exposure to asbestos, some more so than others. If significant asbestos exposure did occur, it is probably more likely that it occurred in older plants containing thermal system insulation. In addition, asbestos hazard awareness and training have increased over the years and asbestos regulations have become more stringent. Therefore it is more probable that older welders have had more asbestos exposure. Significant asbestos exposure could have an effect on pulmonary function manifested as decrements in FVC. Significant exposure from smoking and/or welding fumes would be expected, more likely, to be manifested as decrements in FEV<sub>1</sub>. Historical asbestos exposure information on individual welders was not available for the study. In lieu of this, potential surrogates for exposure could be the status of a welder's assigned power plant(s) regarding thermal system insulation, and the number of years served in those plants, in conjunction with that welder's age. Therefore, these variables were included as covariates to see if they were significant independent variables, and adjusted for, or the effect was described in the model.

#### **1.11.12 Changes in Body Height or Weight**

Significant changes in body height or weight, often also associated with aging - or in the case of weight - sometimes also associated with a lack of physical fitness, may be related to spirometric performance. Height and weight (provided by the subject) were recorded on questionnaires and during testing. It is recognized that actual measurement would have been more accurate. As height and weight change could potentially account for some variability, these values (and their changes) were included in the model.

### **1.12 Confidentiality of Medical Information and Human Subjects Review**

Study information was obtained from the utility company respiratory protection program medical surveillance and asbestos program medical surveillance records. Access to this information had been authorized by the company medical director. In order to ensure confidentiality, the relevant information was provided to the study investigators without subject identifiers. This prevented the study investigators from having knowledge of the identities of the particular individuals from whose medical files the data were obtained.

This study was reviewed and given exempt status by the Colorado State University Human Research Committee based on the above-mentioned conditions.

**CHAPTER V**  
**RESULTS AND DISCUSSION**  
**PART A - EXPOSURE ASSESSMENT STUDY**

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## **CHAPTER V**

### **RESULTS AND DISCUSSION**

#### **A. Exposure Assessment Study**

The exposure assessment study was comprised of two components, an industrial hygiene survey of power plant welding, and welder monitoring and exposure evaluation.

#### **1.0 Welding Industrial Hygiene Surveys**

Welding industrial hygiene surveys were conducted in all power plant welding shops, mostly on an annual basis. The surveys gathered the following information:

- Welder task/time allocation, and frequency and duration of exposure
- Power plant systems worked on, environmental conditions and ventilation use
- Welding/thermal cutting processes, base metals worked on/consumables/gases used
- Types and prevalence of surface coatings and associated work practices
- Welder hazard awareness and respiratory protection practices

#### **1.1 Study Duration and Scope**

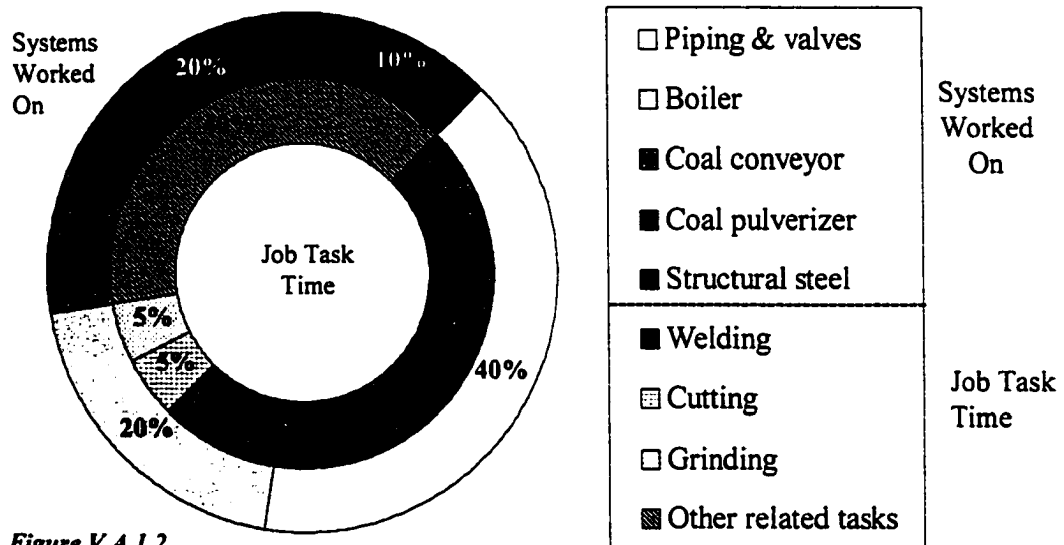
The welding industrial hygiene surveys were conducted from 1994 to 2000. In most cases, welding shops were resurveyed on an annual basis, with visits made several times

per year to conduct exposure monitoring. There were a total of 11 welding shops surveyed at the same number of power plants. Approximately 70 in-house welders were represented by these surveys. Those interviewed during the surveys included numerous welders, supervisors, planner schedulers, metallurgists, quality assurance inspectors, and project managers. In addition, numerous contract welders performing the same tasks as in-house welders were interviewed. From these interviews, answers and estimates were obtained to a series of standardized questions pertaining to exposure-related issues. From these data, consensus answers were derived in order to present a description of the "typical power plant welder". These consensus answers were determined as the most frequent response, along with a range where applicable.

## **1.2 Welder Average Task/Time Allocation**

To better estimate the long-term exposure of welders, their average daily exposure time was estimated by interviews. In-house welders may work more than 8-hour shifts and 40-hour weeks. Interviews indicated that although variable during the year, the average may be closer to 45 hour work weeks, factoring in two days of overtime per month of unplanned emergency maintenance. A typical power plant welder may perform welding work an average of 47 weeks per year. This was estimated based on subtracting (from 52 weeks/year) 3 weeks for vacation, one week for holidays, and one week for sick leave, training, etc. Potential exposure work time within a normal 8-hour shift would be close to 6 hours and 45 minutes. This was estimated based on subtracting one hour for a 30-minute lunch and two 15-minute breaks, and 15 minutes to get to the work location. However, actual long-term average exposure time is probably significantly less. Daily

tasks, and thus exposure time, may vary significantly due to the non-repetitive nature of maintenance work. Welders interviewed were asked to estimate the long-term average time spent on typical work tasks. The welder average work task/time breakdown was estimated as relative proportions in *Figure V.A.1.2*.



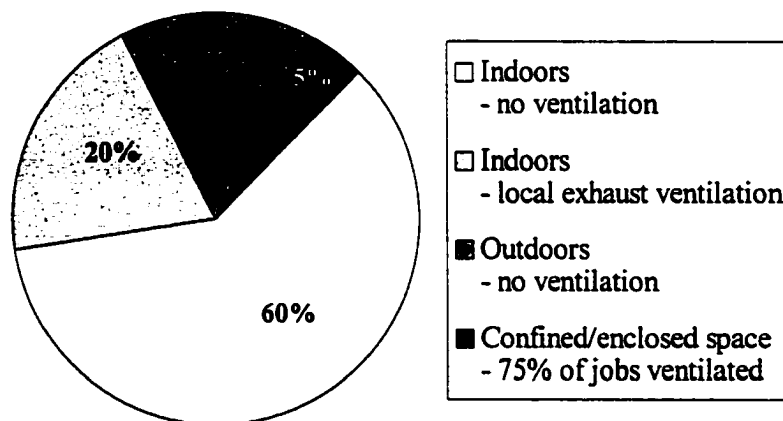
**Figure V.A.1.2**  
**Power Plant Systems Worked On &**  
**Welder Average Task/Time Allocation**

### 1.3 Power Plant Systems Worked On

To understand the welding work environment and nature of the tasks, a scheme was employed to categorize the proportionate amount of work by power plant system. The systems worked on, from greatest to least amount of work, included piping and valves, boiler and boiler tubes, coal conveyors, coal pulverizers, and structural steel. Work allocation by power plant system was estimated as relative proportions in *Figure V.A.1.2*.

#### 1.4 Welding Environmental Locations/Ventilation Use

Air movement may disperse welding air contaminants, as confined or enclosed areas may allow contaminants to accumulate, thus potentially influencing exposures. To better understand where the welding environmental locations and air movement may influence exposures, the relative proportions of work by location, and by use of local exhaust ventilation was estimated by interviews. The greatest to least amount of welding work was conducted: inside the plant (without mechanical ventilation); inside the welding shop (with local exhaust ventilation); outdoors (no mechanical ventilation, but subject to air movement from wind); and in enclosed or confined spaces, with and without local exhaust ventilation. The welding environmental locations and ventilation use were estimated as relative proportions in *Figure V.A.1.4*.

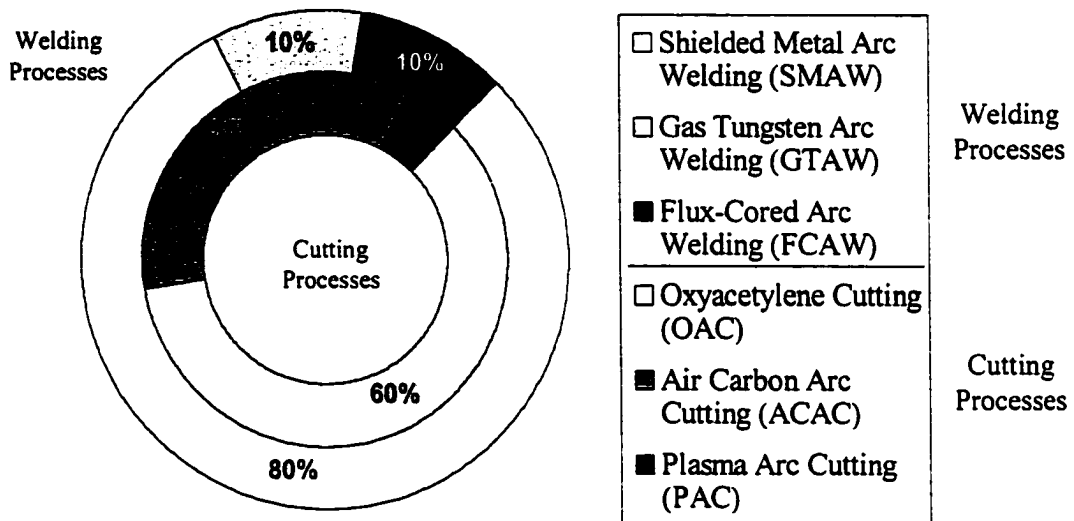


**Figure V.A.1.4**  
**Welding Environmental Locations/Ventilation Use**

#### 1.5 Welding and Thermal Cutting Processes

The welding processes used in order of greatest to least proportion of work were: shielded metal arc welding (SMAW), gas tungsten arc welding (GTAW), flux-cored arc welding

(FCAW), and rarely, gas metal arc welding (GMAW). The cutting processes used in order of greatest to least proportion of work were oxyacetylene cutting (OAC), air carbon arc cutting (ACAC), and plasma arc cutting (PAC). These processes were estimated and ranked as relative proportions in *Figure V.A.1.5*.



**Figure V.A.1.5**  
Welding and Thermal Cutting Processes

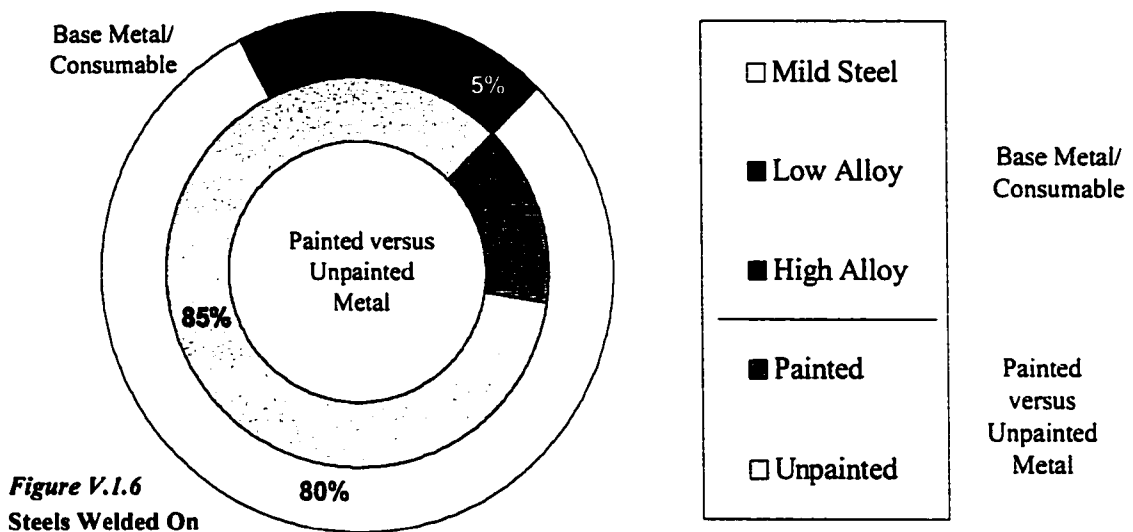
### 1.6 Base Metals/Consumables by Estimated Fraction of Welding Work

The main base metals worked on were categorized as follows:

- "mild steel", also referred to as carbon steel;
- "low alloy" containing either 1.25% chromium (Cr) / 0.5% Molybdenum (Mo), or 2.25% Cr / 1% Mo;
- "medium alloy", containing 9% Cr / 1% Mo;
- "high alloy", comprised of either stainless steel, containing 18-25% Cr / 8-14% nickel (Ni); or hardsurfacing, containing 27% Cr.

- or "other", consisting of other metals (aluminum), alloys (inconel, monel), or cladding (galvanized, cadmium).

The above categorization scheme allows for differentiating percent of work and exposures for various metals by chromium content, one of the more toxic constituents. The consumables are normally very similar in metal composition to the base metals, except where differential metals are welded, e.g., in a stainless to carbon steel weld, the higher alloy will dictate the similar consumable grade chosen. The vast majority of the work was on mild steel, followed by low alloy, and then high alloy. Medium alloy was a term selected to designate nine-percent chromium, which was starting to be used in place of low alloy for some types of boiler tubes in some plant units at the latter part of the study. It was not a factor as far as retrospective exposure of the in-house welders studied, but its use may increase in the future, and thus was included in the survey. The "other" category of work on miscellaneous alloys and cladding comprised less than one percent of plant welding work. The main base metals worked on and corresponding consumables used were estimated as proportions of work by category of mild steel, low alloy, or high alloy steel, in *Figure V.A.1.6*. More detail is provided in *Table V.A.1.6*, including estimates within categories for low alloy "one and one quarter chromium" versus "two and one quarter chromium", and high alloy grades of stainless steel and hardsurfacing.



**Base Metals / Consumables by Estimated Fraction of Welding Work**  
*Table V.A.1.6.*

Base Metal	Alloy Type	Base Metal Grade	Consumable Grade
Mild Steel (85%)	NA	Mild Steel	Mild Steel
Low Alloy Steel (10%)	Chromium-molybdenum	1.25% Cr (25%)	1.25% Cr (25%)
		2.25% Cr (75%)	2.25% Cr (75%)
Medium Alloy Steel (<1%)	Chromium-molybdenum	9% Cr (<1%)	9% Cr (<1%)
High Alloy Steel (5%)	Stainless	304 (94%)	308 (90%), 309 (4%)
		316 (3%)	316 (3%)
		347 (3%)	347 (3%)
high alloy work is 85% stainless versus 15% hardsurfacing	Hardsurfacing	usually applied over mild steel	unclassified

## 1.7 Base Metals/Consumables by AWS Classification

*Table V.A.1.7* lists the main base metals welded/cut on and identifies the corresponding consumables used by American Welding Society (AWS) Classification.

## Base and Filler Metals by AWS Classification

Table V.A.1.7

Main Base Metal Classifications			AWS Consumable Classifications by Process			
Base Metal	Alloy Type	Grade	SMAW	GTAW	FCAW	GMAW
Mild Steel	NA	NA	E7018 E6010	ER70S	E71T-1	ER70S
Low Alloy Steel	Chromium-molybdenum	1.25% Cr	E8018	ER80S-B2	not used	not used
		2.25% Cr	E9018	ER90S-B3	not used	not used
Medium Alloy Steel	Chromium-molybdenum	9% Cr	E9015-B9	ER90S-B9	not used	not used
High Alloy Steel	Stainless	304	E308 E309	ER308 ER309	E309LT E309LT	not used
		316	E316	ER316	not used	not used
		347	E347	ER347	not used	not used
	Hardsurfacing	----	not classified	not used	not used	not used

## 1.8 Consumable Toxic Metal Compositions

Chromium, nickel, and manganese content of consumables are provided in Table V.A.1.8.

### Consumable Toxic Metal Compositions

Table V.A.1.8

Base Metal	Alloy Type	Grade	Welding Process	Consumable AWS Class.	%Cr	%Ni	%Mn	
Mild	NA	NA	SMAW	E7018	0.2	0.3	1.6	
				E6010	---	---	0.5	
			GTAW	ER70S	---	---	0.9-1.4	
			GMAW	ER70S	---	---	0.9-1.4	
Low Alloy Steel	Chromium-molybdenum	1.25% Cr	SMAW	E8018-B2	1-1.5	---	0.9	
			GTAW	ER80S-B2	1-1.5	0.2	0.4-0.7	
		2.25% Cr	SMAW	E9018-B3	2-2.5	---	0.9	
			GTAW	ER90S-B3	2-2.5	0.2	0.4-0.7	
Medium Alloy Steel	Chromium-molybdenum	9% Cr	SMAW	E9015-B9	8-10	<2	<3	
			GTAW	ER90S-B9	8-10	<1	<1	
High Alloy Steel	Stainless	304	SMAW	E308	19.5-22	9-11	1-2.5	
			GTAW	ER308	19.5-22	9-11	1-2.5	
			FCAW	E308LT	19-21	8-10	1-3	
			309	SMAW	E309	22-25	12-14	0.5-2.5
				GTAW	ER309	23-25	12-14	1-2.5
				FCAW	E309LT	23-25	11-13	1-3
		316	SMAW	E316	18-20	11-14	1-2.5	
			GTAW	ER316	18-20	11-14	1-2.5	
		347	SMAW	E347	18-21	9-11	0.5-2.5	
			GTAW	ER347	19-21.5	9-11	1-2.5	
		Hardsurfacing	Mild Steel	SMAW	unclassified	27	---	0.5

## 1.9 Shielding Gases Used for Metals and Welding Processes

The methods used to provide shielding gas, and the types of gases may influence air contaminant types and levels generated during welding. Therefore, the types of shielding gases used in the various processes on different metals were recorded in *Table V.A.1.9*. SMAW and FCAW produce shielding gases via flux coatings or cores respectively, on versus in the electrode. Other processes such as GTAW and GMAW utilize externally supplied shielding gas. FCAW is sometimes also used with additional externally supplied shielding gas.

**Shielding Gas Used for Metals and Welding Processes**

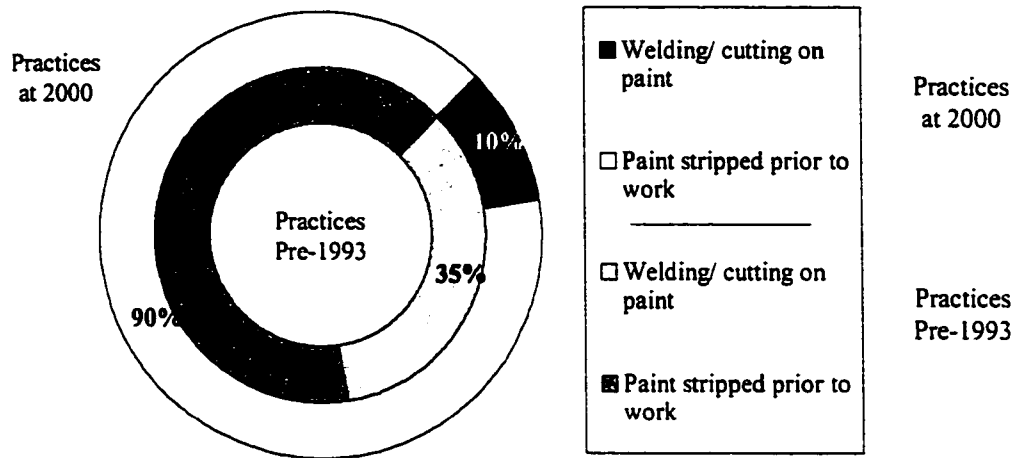
*Table V.A.1.9*

Base Metal	Alloy Type	Base Metal Grade	Welding Process	Consumable AWS Class.	Shielding Gas Source
Mild Steel	NA	NA	SMAW	E7018	covered rod
				E6010	covered rod
			GTAW	ER70S	Argon (Ar)
			GMAW	ER70S	Ar(75%)/CO <sub>2</sub> (25%)
			FCAW	E71T-1	flux-cored wire, +/- Ar(75%)/CO <sub>2</sub> (25%)
Low Alloy Steel	Chromium-molybdenum	1.25% Cr	SMAW	E8018-B2	covered rod
			GTAW	ER80S-B2	Argon
		2.25% Cr	SMAW	E9018-B3	covered rod
			GTAW	ER90S-B3	Argon
Medium Alloy Steel	Chromium-molybdenum	9% Cr	SMAW	E9015-B9	covered rod
			GTAW	ER90S-B9	Argon
High Alloy Steel	Stainless	304	SMAW	E308	covered rod
			GTAW	ER308	Argon
			FCAW	E308LT	flux-cored wire, +/- Ar(75%)/CO <sub>2</sub> (25%)
		309 used in differential welds	SMAW	E309	covered rod
			GTAW	ER309	Argon
			FCAW	E309LT	flux-cored wire, +/- Ar(75%)/CO <sub>2</sub> (25%)
		316	SMAW	E316	covered rod
			GTAW	ER316	Argon
		347	SMAW	E347	covered rod
			GTAW	ER347	Argon
Hardsurfacing	Mild Steel	SMAW	unclassified	covered rod	

### **1.10 Welding/Cutting on Painted Steel**

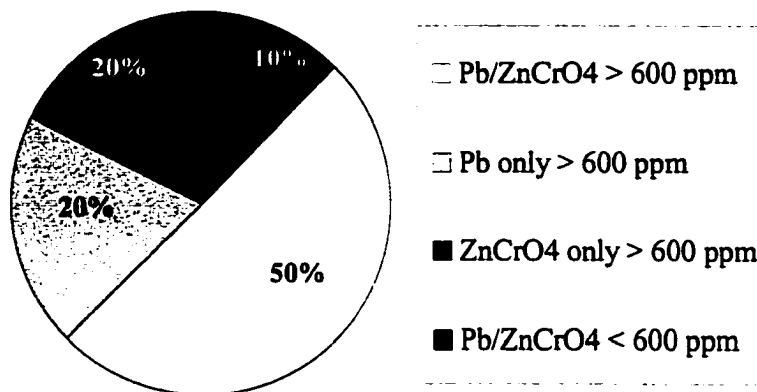
Steel is often painted for corrosion resistance or cosmetic reasons. Welding or thermal cutting on paint may release toxic decomposition products as air contaminants. Industrial hygiene survey interviews indicated that 10-20% of steel to be welded or cut is painted, the vast majority of which is mild steel. Of the painted steel, it was estimated in the year 2000 that 90% of the time, it is stripped back first, mostly by using abrasive methods such as grinders or needle scalers with attached HEPA vacuums, and occasionally by vacuum blasting. Smaller surface areas may be stripped by caustic paste. The remaining 10% of the time, it is burned off during welding or cutting. Historically (pre-1993, previous to the influence of the OSHA Lead in Construction Standard), the paint was described as being burned off a higher proportion of the time. It was estimated that during this time period, 60-70% of paint was stripped back prior to welding or cutting by using grinders without attached HEPA vacuums. For some smaller jobs, methylene chloride strippers, since substituted by caustic paste, would have been used. Respiratory protection probably was worn on a discretionary basis. The proportions for current versus historical practices of stripping back paint are presented in *Figure V.A.1.10.a*. In 1993, in response to new OSHA requirements, the company had implemented a "lead and toxic surface coating program" to identify, and prevent or control exposures to lead, zinc chromate, and cadmium in paints. Thus, numerous paint bulk samples were collected from steel surfaces prior to hot work. Lead and zinc chromate were frequently found, either in combination or alone. Occasionally lead chromate was detected. On two

occasions cadmium was identified, once on coal chutes, and once on handrails.



**Figure V.A.1.10.a**  
**Welding/Cutting on Painted Steel at Year 2000 versus Pre 1993**

A random sample survey of 300 of the paint bulk sample records for some of the larger power plants indicated that a very high proportion of painted surfaces contained lead and/or zinc chromate. *Figure V.A.1.10.b* displays the relative proportions of samples containing these metals at levels designated "toxic" by internal company-established threshold (paint containing higher than 0.06% lead, zinc chromate, or cadmium).



**Figure V.A.1.10.b**  
**Proportions of Toxic Paint Types**  
 (lead and zinc chromate, lead only, zinc chromate only, neither present at greater than 0.06% (600 ppm) )

### 1.1.11 Welder Hazard Perception and Respiratory Protection/Ventilation Practices

Welders were frequently unaware of the types and hazards of the air contaminants to which they may be exposed. Especially in the case of contract welders, had the company not intervened and stripped paint or required appropriate respiratory protection, lead and zinc chromate-painted surfaces would likely been frequently subjected to hotwork by unprotected personnel. With regard to welding/cutting on unpainted steel, respiratory protection was worn rarely by in-house welders, except at times in confined spaces, and more rarely by contractor welders. Respiratory protection was often perceived by welders as a hindrance to conducting their work. Ventilation was often perceived as unwieldy and impractical for most plant work locations, except for inside the welding shops, where fixed local exhaust ventilation with hanging flexible ducts was installed.

## **2.0 Exposure Evaluation**

Welder industrial hygiene exposure monitoring was conducted in all power plants, on a random basis, within strata consisting of welding or thermal cutting process, and base metal/consumable.

### **2.1 Study Duration and Scope**

The welding industrial hygiene exposure monitoring was conducted from June 1994 through May 2000. Welding was sampled periodically throughout the year during the course of the study, with visits made to each plant several times per year. There were a total of 11 power plants included in the exposure monitoring. The monitoring represented the exposures of approximately 70 in-house welders. In addition, numerous contract welders performing the same tasks as in-house welders were monitored as surrogates to increase sample size. In the latter case, where contractors on occasion worked longer shifts, e.g., 9-10 hours, either the cassette was changed or the sample was discontinued within eight hours for comparability with in-house welder exposures. The total number of air contaminants sampled and analyzed for during the study was 1,853.

### **2.2 Eight-Hour TWA Exposures Exceeding OELs**

Eight-hour time-weighted average (8-hr TWA) welding and thermal cutting exposures that exceeded the "Occupational Exposure Limit" (OEL) -ACGIH TLV or the OSHA PEL, whichever was the most stringent, are presented below. The data are stratified by welding or cutting process with base metal/consumable. Beside the specific air

contaminant is the ratio of the number of overexposures (numerator) to total samples (denominator) for that contaminant within that stratum.

### 2.2.1 Welding 8-Hour TWA Exposures Exceeding OELs

Welding processes with air contaminant 8-hour TWA exposures over the OELs included SMAW and FCAW, but not GTAW. The sample size for GMAW was inadequate, as this was a rarely performed process. SMAW overexposures to hexavalent chromium and welding fume occurred on 29% and roughly 17% of the high alloy samples respectively. For SMAW, there was no reason to believe that the metal type in itself influenced the level of total fume generation, except that the heaviest exposure jobs were probably conducted on high alloy steel. Flux-cored arc welding yielded manganese overexposures in 25% of 16 samples, and welding fume and beryllium overexposures in 13 and 14 samples respectively. This information is presented in detail in *Table V.2.2.1*.

**Welding 8-Hour TWA Exposures Exceeding OELs**

*Table V.A.2.2.1*

Main Base Metal Classifications		Overexposures by Welding Processes Utilized (fraction of 8-hr TWA samples exceeding OEL)			
Base Metal	Alloy Type	SMAW	GTAW	FCAW	GMAW
Mild Steel	NA	no OELs exceeded	no OELs exceeded	Manganese (4/16) Welding fume (1/13) Beryllium (1/14)	no OELs exceeded (n=2)
Low Alloy Steel	Chromium-molybdenum 1.25-2.25% Cr	no OELs exceeded	no OELs exceeded	not used	not used
Medium Alloy Steel	Chromium-molybdenum 9% Cr	no OELs exceeded	not sampled	not used	not used
High Alloy Steel	Stainless 18-24%Cr; 8-12% Ni Hardsurfacing xx%Cr	Chromium <sup>VI</sup> (5/17) Welding fume (4/24)	no OELs exceeded	Welding fume (1/8)	not used

## 2.2.2 Thermal Cutting 8-Hour TWA Exposures Exceeding OELs

All three thermal cutting processes utilized - air carbon arc cutting (ACAC), plasma arc cutting (PAC), and oxyacetylene cutting (OAC) - resulted in 8-hour TWA air contaminant exposures over the OELs. Most samples of cutting yielded overexposures to welding fume. The sample sizes for PAC and OAC were small. The most heavily sampled process, ACAC on mild steel, also produced overexposures to copper twice, and manganese and iron oxide once out of 12 samples. For cutting, there was no reason to believe that the metal type in itself influenced the level of total fume generation, except that the heaviest exposure jobs were probably conducted on mild steel. This information is presented in greater detail in *Table V.A.2.2.2*.

**Thermal Cutting 8-Hour TWA Exposures Exceeding OELs**

*Table V.A.2.2.2*

Main Base Metal Classifications		Overexposures by Thermal Cutting Processes Utilized (fraction of 8-hr TWA samples exceeding OEL)		
Base Metal	Alloy Type	ACAC	PAC	OAC
Mild Steel	NA	Welding fume (9/12) Copper (2/12) Iron oxide (1/12) Manganese (1/12)	Welding fume (1/1)	Welding fume (3/3)
Low Alloy Steel	Chromium-molybdenum 1.25-2.25% Cr	Welding fume (2/3)	Welding fume (1/1)	Welding fume (3/3)
High Alloy Steel	Stainless 18-24%Cr, 8-12%Ni Hardsurfacing 27%Cr	Welding fume (3/4)	Welding fume (2/4)	Welding fume (2/2)

## 2.3 Air Contaminant Concentrations (TWA) Exceeding OELs

Welding and thermal cutting air contaminant concentrations (TWA) may under some circumstances exceed OELs. However, if jobs sampled are of shorter duration, the 8-hour averaging time may lead to indications of no overexposures where acute, high-level

exposures exist. Additionally, the true magnitude of identified overexposures may not be recognized. Therefore, sample air contaminant concentrations were scrutinized to determine if there were other potential - but as of yet unidentified - overexposures. The data were stratified by welding or cutting process with base metal/consumable. Beside the specific air contaminant is the ratio of the maximum air concentration found (numerator) to the OEL (denominator) for that contaminant within that strata.

### 2.3.1 Welding Air Contaminant Concentrations Exceeding OELs

Welding air contaminant concentrations that exceeded the OELs were identified for SMAW on mild steel, which included manganese and welding fume; SMAW on high alloy, consisting of hexavalent chromium and welding fume; FCAW on mild steel, with manganese, welding fume, and beryllium. During one GTAW job on high alloy, an ozone air concentration equal to the TLV occurred. No air concentrations exceeding OELs occurred for GTAW, the welding process with the lowest fume generation rate.

This information is presented in *Table V.A.2.3.1*.

**Welding Air Contaminant Concentrations Exceeding OELs**

*Table V.A.2.3.1*

Main Base Metal Classifications		Exceedence Exposures by Welding Processes Utilized (contaminant air concentrations exceeding OEL (max)/OEL )			
Base Metal	Alloy Type	SMAW	GTAW	FCAW	GMAW
Mild Steel	NA	Manganese Welding fume	no OELs exceeded	Manganese Welding fume Beryllium	none, rarely used
Low Alloy Steel	Chromium- molybdenum 1.25-2.25% Cr	no OELs exceeded	not sampled	not used	not used
Medium Alloy Steel	Chromium- molybdenum 9% Cr	no OELs exceeded	not sampled	not used	not used
High Alloy Steel	Stainless 18-24%Cr, 8-12%Ni Hardsurfacing 27%Cr	Chromium <sup>VI</sup> Welding fume	no OELs exceeded	Welding fume	not used

### 2.3.2 Thermal Cutting Air Contaminant Concentrations Exceeding OELs

ACAC was the cutting process with the most air contaminant concentrations exceeding OELs. Air contaminant concentrations that exceeded the OELs included welding fume, copper, cobalt, iron oxide, and manganese for work on mild steel, and welding fume for low alloy and high alloy steel. PAC generated air contaminant levels over the OELs for welding fume on mild steel; welding fume and iron oxide on low alloy steel; and welding fume, hexavalent chromium, and nitrogen dioxide on high alloy steel. The OAC jobs sampled produced air contaminant concentrations over the OEL only for welding fume on mild, low alloy and high alloy steels. This information is presented in *Table V.A.2.3.2*.

**Thermal Cutting Air Contaminant Concentration Exposures Exceeding OELs**

*Table V.A.2.3.2*

Main Base Metal Classifications		Exceedence Exposures by Thermal Cutting Processes Utilized (contaminant air concentrations exceeding OEL ((max)/OEL) )		
Base Metal	Alloy Type	ACAC	PAC	OAC
Mild Steel	NA	Welding fume Copper Cobalt Iron oxide Manganese	Welding fume	Welding fume
Low Alloy Steel	Chromium-molybdenum 1.25-2.25% Cr	Welding fume	Welding fume Iron oxide	Welding fume
Medium Alloy Steel	Chromium-molybdenum 9% Cr	no OELs exceeded	no OELs exceeded	no OELs exceeded
High Alloy Steel	Stainless 18-24%Cr, 8-12%Ni Hard surfacing xx%Cr	Welding fume	Welding fume Chromium <sup>VI</sup> Nitrogen dioxide	Welding fume -Chromium <sup>VI</sup> only sampled 1x

### 2.4 Discussion of Welding and Cutting Processes as Related to Exposures

A discussion of welding and cutting processes as related to exposures is presented as follows.

#### **2.4.1 Shielded Metal Arc Welding (SMAW)**

The only 8-hour TWA exposures over the OELs in SMAW were found in work on high alloy steel. The fraction of overexposures was 5 of 17 (29%) for hexavalent chromium, and 4 of 24 (16.7%) for welding fume. The thresholds applied were the ACGIH TLVs for hexavalent chromium (soluble) at  $0.05 \text{ mg/m}^3$ , and welding fume at  $5 \text{ mg/m}^3$ .

#### **2.4.2 Flux-Cored Arc Welding (FCAW)**

Of the three major welding processes utilized in the power plants, the only process with mild steel 8-hour TWA exposures in excess of the OELs was FCAW. Overexposures occurred: to manganese in 4 of 16 (25%) samples; to beryllium in 1 of 14 samples (7.1%); and to welding fume in 1 of 13 samples (7.7%). FCAW was the only process sampled with a beryllium air concentration in excess of the OEL. The OELs applied were the ACGIH TLVs, except in the case of beryllium, the OSHA PEL was equivalent. For high alloy (stainless) steel, welding fume was an overexposure in 1 of 8 samples (12.5%)

#### **2.4.3 Gas Tungsten Arc Welding (GTAW)**

There were no 8-hour TWA exposures or air contaminant concentrations in excess of the OELs in GTAW. The exception was for welding on stainless steel, where the highest ozone air concentrations were found for any process. In the highest sample, the 8-hour TWA was equal to the OEL (ACGIH TLV) of  $0.2 \text{ mg/m}^3$ .

#### **2.4.4 Gas Metal Arc Welding (GMAW)**

GMAW was a rarely performed process. As a result, the sample size was inadequate to determine whether this was a potential overexposure process or to characterize exposures.

#### **2.4.5 Air Carbon Arc Cutting (ACAC)**

ACAC was the most frequently conducted and sampled thermal cutting process. ACAC was the process involving the highest exposure levels to the most metal fume air contaminants for both cutting and welding. Of 12 8-hour TWA welding fume samples collected, nine (75%) exceeded the ACGIH TLV of 5 mg/m<sup>3</sup>. The highest 8-hour TWA exposure was 123.4 with an air concentration of 141 mg/m<sup>3</sup> for work on structural mild steel outside a boiler bottom. The highest air concentration, 166, was a similar job for only 96 minutes, with an 8-hour TWA exposure of 33.2 mg/m<sup>3</sup>. Welding fume overexposures occurred across all metal types with eight-hour TWA levels sufficiently high so as to exceed the NIOSH assigned protection factor of 10 for a half face respirator on the four highest welding fume samples on mild steel (33%). Eight-hour TWA overexposures also occurred twice (16.7%) for copper, and once each (8.3%) for manganese and iron oxide, out of 12 samples. In one instance, the air concentration (0.032) exceeded the OEL for cobalt (ACGIH TLV 0.02 mg/m<sup>3</sup>) but the 260-minute exposure time on a boiler bottom job was insufficient to result in an 8-hour TWA overexposure. ACAC was the only process sampled with a cobalt air concentration in excess of the OEL.

#### **2.4.6 Plasma Arc Cutting (PAC)**

PAC was the least conducted, and least sampled thermal cutting process. Of six 8-hour TWA welding fume samples collected, four (66.7%) exceeded the ACGIH TLV of 5 mg/m<sup>3</sup>. The highest 8-hour TWA exposure was 10.5 with an air concentration of 20.1 mg/m<sup>3</sup> for work on structural mild steel. The highest air concentration, 68, was cutting on high alloy (stainless) steel for only 40 minutes, with an 8-hour TWA exposure of 5.67 mg/m<sup>3</sup>. Air contaminant concentrations exceeded the OELs for hexavalent chromium and nitrogen dioxide (high alloy stainless steel), and iron oxide (low alloy steel) once each, but exposure times were insufficient to result in 8-hour TWA overexposures. PAC was the only process sampled with a nitrogen dioxide air concentration over the OEL.

#### **2.4.7 Oxyacetylene Cutting (OAC)**

Welding fume was the only 8-hour TWA air contaminant found in excess of the OEL, which in this case was the ACGIH TLV of 5 mg/m<sup>3</sup>. However, it was an overexposure in all eight samples (100%) collected across all metal types. The highest exposure in recorded in OAC was 26.9 with an air concentration of 43 mg/m<sup>3</sup>, for 300 minutes on mild steel.

### **2.5 Discussion of Air Contaminants Generated in Welding and Cutting Processes**

A discussion of air contaminants generated in welding and cutting processes is presented as follows.

### **2.5.1 Manganese (Mn)**

Eight-hour TWA overexposures (ACGIH TLV 0.2 mg/m<sup>3</sup>) to manganese occurred during flux-cored arc welding (FCAW) and air carbon arc cutting (ACAC) on mild steel. Overexposures resulted during FCAW in 4 of 16 samples (25%). The highest exposure (0.32 mg/m<sup>3</sup>) was 1.6 times the TLV. The four overexposures had estimated arc-on percent times of 50% for the three highest and 60% for the fourth highest, indicating the potential for higher exposures given greater arc-on percent times. The only other 8-hour TWA overexposure (0.424 mg/m<sup>3</sup>), at 2.12 times the TLV, was experienced during ACAC in 1 of 12 samples (8.3%). Interestingly, this ACAC sample was only the ninth highest with regard to total welding fume, with a sampling time of 425 minutes. All manganese samples were collected inside the welding hood.

### **2.5.2 Hexavalent Chromium (Cr<sup>VI</sup>)**

It should be noted that the sample analysis method utilized yielded total hexavalent chromium, as it was not possible to quantify both soluble and insoluble fractions individually on the same sample. The OSHA reference method was chosen to allow comparison with the OSHA PEL for total hexavalent chromium. This was done in case a future proposed OSHA PEL for total hexavalent chromium is adopted, as has been conjectured, that is significantly more stringent than the current ACGIH TLV. In contrast, the ACGIH TLV is listed for both soluble and insoluble fractions of hexavalent chromium. As the ACGIH TLV is much more stringent than the OSHA PEL, the TLV is the OEL that has been applied. Since we are comparing total hexavalent chromium to a threshold for only the soluble fraction, there may be some overestimation of the actual

results; however, this overestimation is believed to be very small, as previous studies have indicated that almost all hexavalent chromium from welding is of the soluble form. Eight-hour TWA exposures over the OEL (ACGIH TLV 0.05 mg/m<sup>3</sup> (soluble)) to hexavalent chromium Cr<sup>VI</sup> occurred only during shielded metal arc welding (SMAW) in 5 of 17 samples (29.4%). The highest exposure (0.22 mg/m<sup>3</sup>) at 4.4 times the OEL, along with the second (0.207 mg/m<sup>3</sup>), third (0.1348 mg/m<sup>3</sup>) and fifth highest (0.0631 mg/m<sup>3</sup>), was a coal mill overlay where hard surfacing electrodes (27% Cr) are applied to increase wear resistance on the insides of a coal mills, which are confined spaces. Local exhaust ventilation was used during the highest exposure, as well as during the third and fifth highest exposures. The fourth highest exposure (0.121 mg/m<sup>3</sup>) involved welding on the boiler wet bottom seal inside the boiler bottom, an enclosed space with limited general ventilation, using stainless steel electrodes. This latter exposure was only sampled for 255 minutes due to logistical problems. In addition, the estimated arc-on percent time on this job was only 50%. For the purposes of comparison with in-house welding, it is estimated that if a hypothetical 8-hour shift involving an actual exposure time of 6 hours and 45 minutes had been sampled at that air concentration (0.227 mg/m<sup>3</sup>), the resultant 8-hr TWA exposure would have been 0.192 mg/m<sup>3</sup>. An air concentration (0.245 mg/m<sup>3</sup>) 4.9 times the TLV was detected in one sample during PAC on high alloy (stainless) steel. The work was inside the plant on a boiler burner, but lasted only 40 minutes, with an arc-on time of 50%, and was sampled outside the hood. The 8-hour TWA was 0.020 mg/m<sup>3</sup>. All hexavalent chromium samples were collected outside the hood, as respiratory protection was a company requirement for high alloy welding due to the reported carcinogenic effects of hexavalent chromium. The tight fit of respirator protection under

the hood did not allow additional space for the sampling cassette. In these cases, the cassette was attached to the collar, in the breathing zone.

### **2.5.3 Welding Fume**

Eight-hour TWA exposures over the ACGIH TLV 5 mg/m<sup>3</sup> to welding fume occurred during shielded metal arc welding (SMAW), flux-cored arc welding (FCAW), and during all thermal cutting processes. Overexposures occurred during SMAW only welding with high alloy metal in 4 of 24 samples (16.7%). These four jobs involved coal mill overlay where hard surfacing electrodes were applied to increase wear resistance on the insides of coal mills (confined spaces). The highest two exposures (15.6 and 12.7 mg/m<sup>3</sup>) occurred on jobs without the use of local exhaust ventilation; the third and fourth highest exposures (8.56 and 8.17 mg/m<sup>3</sup>) occurred with local exhaust ventilation. Other welding overexposures to welding fume occurred during FCAW in 1 (5.67 mg/m<sup>3</sup>) of 13 samples (7.7%) on mild steel, and 1 (7.16 mg/m<sup>3</sup>) of 8 samples (12.5%) on high alloy steel. In contrast, most thermal cutting samples involved overexposure to welding fume across all processes and types of metals. Overexposures occurred in 14 of 19 samples (73.7%) for air carbon arc cutting (ACAC); 4 of 6 samples (66.7%) for plasma arc cutting (PAC); and 8 of 8 samples (100%) for oxyacetylene cutting. The highest exposures occurred during the most heavily sampled process, ACAC. The four highest values for ACAC were 123.4, 96.8, 68.15, and 65.8 mg/m<sup>3</sup>. These values were respectively 24.68, 19.36, 13.63, and 13.16 times the TLV, and were in excess of the NIOSH assigned protection factor of 10 for a half face respirator. The next highest exposure processes were OAC with a high value of 26.9, and PAC at 10.5 mg/m<sup>3</sup>.

#### **2.5.4 Beryllium (Be)**

Beryllium was present, inside the hood, in 1 of 14 samples (7.1%) at a level above the analytical limit of detection (LOD), during FCAW on structural mild steel with an estimated arc-on time of 50%. Perhaps it is a very occasional contaminant in the steel making process, as speculated in the literature. The 8-hour TWA was 0.012 with an air concentration for 200 minutes of 0.029, versus an OSHA PEL/ACGIH TLV of 0.002 mg/m<sup>3</sup>. In the 1999 ACGIH TLVs, beryllium was placed on the List of Intended Changes for the year 2000, with a proposed TLV of 0.0002 mg/m<sup>3</sup>.

#### **2.5.5 Cobalt (Co)**

Cobalt was found in 1 of 8 samples (12.5%), outside the hood, at an air concentration (0.032 mg/m<sup>3</sup>) greater than the ACGIH TLV of 0.02 mg/m<sup>3</sup>. This was during ACAC on mild steel on a boiler bottom for 260 minutes. The exposure time was not sufficient to result in an overexposure as the 8-hour TWA was 0.017 mg/m<sup>3</sup>.

#### **2.5.6 Copper (Cu)**

The only process with significant air concentrations of copper was ACAC. Copper was present, inside the hood, in excess of the OSHA PEL in two 8-hour TWA samples of 12 collected (16.7%). The source was likely the copper arc-gouging rod. The work was on mild steel boiler bottoms. The highest sample had an 8-hour TWA of 0.448 with an air concentration for 130 minutes of 0.659 versus the OSHA PEL of 0.1 mg/m<sup>3</sup>.

### **2.5.7 Iron Oxide (Fe<sub>2</sub>O<sub>3</sub>)**

The highest levels of iron oxide were found in ACAC on mild steel. Iron oxide was an overexposure in 1 of 12 (8.3%) ACAC jobs sampled on mild steel. The 8-hour TWA, inside the hood, was 34.75 with an air concentration of 57.5 for 130 minutes with an arc-on time of 75%. This sample corresponded to the third highest welding fume sample for ACAC (68.15 mg/m<sup>3</sup>). In three additional boiler bottom samples, air concentrations exceeded the ACGIH TLV of 5 mg/m<sup>3</sup>, but lacked sufficient exposure time to exceed the 8-hour TWA TLV. These air concentrations were 18.1, 17.6, and 9.22 mg/m<sup>3</sup>. Sampling was conducted inside the hood for the 8-hour TWA overexposure and the two highest air concentration samples. An air concentration of 5.4 mg/m<sup>3</sup> inside the hood was detected during PAC on low alloy metal in the boiler water wall outdoors for 96 minutes. The 8-hour TWA was 1.08 mg/m<sup>3</sup>.

### **2.5.8 Ozone (O<sub>3</sub>)**

The highest air concentrations to ozone in the processes monitored were in GTAW. Ozone was detected in an air concentration as high as the ACGIH TLV (0.2 mg/m<sup>3</sup> light work) in only 1 of 8 samples (12.5%) collected during gas tungsten arc welding (GTAW) on high alloy (stainless) steel. The 8-hour TWA for this 320-minute exposure was 0.133 mg/m<sup>3</sup>. The next three highest ozone air concentrations and their respective 8-hour TWA exposures (given in parentheses) for GTAW on stainless steel were 0.085 (0.046), 0.061 (0.0352), and 0.059 (0.05). The estimated arc-on time did not exceed 30% in the three highest samples. All were collected outside the hood.

### **2.5.9 Nitrogen Dioxide (NO<sub>2</sub>)**

Of the processes monitored, NO<sub>2</sub> was found in the highest air concentration in PAC on stainless steel. Nitrogen dioxide was detected in an air concentration (6mg/m<sup>3</sup>) higher than the ACGIH TLV (5.6 mg/m<sup>3</sup>) in the only NO<sub>2</sub> sample collected during PAC on high alloy (stainless) steel. The exposure was for 40 minutes, with an arc-on time of 50%, sampled outside the hood. The 8-hour TWA was 0.5 mg/m<sup>3</sup>.

### **2.5.10 Fluorides**

Fluorides were never detected in significant concentrations in the two welding processes that utilized fluoride-containing consumables, SMAW and FCAW.

## **2.6 Profiles for 8-Hour TWA Exposures Exceeding OELs**

The 8-hour TWA welding and thermal cutting exposures that exceeded OELs are rank ordered, categorized by process and base metal/consumable, in the tables below. All exposures greater than the threshold are included. In cases where only one exposure is over the threshold, the next highest has been included for comparison. Additional information includes: the OEL in mg/m<sup>3</sup> for each air contaminant, the fraction of exposures over the OEL versus total sample size (#/n), the ratio of each individual 8-hour TWA exposure versus the OEL (TWA/OEL), the plant system worked on, the environmental location and use of local exhaust ventilation, exposure time, the estimated percent of the exposure time that the welding arc was on, and whether the sample was collected inside or outside of the welding hood. Samples were collected inside the hood whenever possible; however, for jobs where respiratory protection was required by

company policy, sampling normally took place outside the hood by necessity, because of insufficient space in the hood due to the presence of the respirator filters. Thus, any high alloy work was normally sampled outside the hood because of the reported carcinogenicity of hexavalent chromium. Cutting processes were sampled likewise, due to heavy fume levels that triggered respiratory protection, with the exception of some early samples.

### **2.6.1 Profiles for Welding 8-Hour TWA Exposures Exceeding OELs**

For SMAW, there were no manganese exposures above the ACGIH TLV of 0.2 mg/m<sup>3</sup> in power plant welding; however, one overexposure did occur on mild steel in a fabrication welding shop manufacturing natural gas compressors for the utility company. Thus, this sample was not included in the database for power plant welding, but was included on *Table V.A.2.6.1* to demonstrate the potential for high manganese levels in SMAW. The highest hexavalent chromium and welding fume samples were found in coal mill high alloy hardsurfacing applications. The highest hexavalent chromium exposure was 4.4 times the ACGIH TLV of 0.05 mg/m<sup>3</sup>, on a job where local exhaust ventilation was applied in the confined space. The fourth highest non-coal mill exposure occurred during work on the stainless steel seal and castable refractory hangers inside a boiler bottom. Only 255 minutes of a 9-hour exposure was sampled due to a logistical problem, nevertheless, the exposure was 2.4 times the TLV. With regard to FCAW, the highest manganese exposure was during work on structural mild steel at 1.6 times the TLV.

### Profiles for Welding 8-Hour TWA Air Contaminant Exposures

#### V.A.2.6.1

Process	Metal	Analyte	#	TWA	TWA/OEL	Plant System	Location	Time	Arc-on%	In/out Hood
SMAW	Mild Steel	Mn [0.2] (1/38)	1	0.587	2.94	structural steel	indoors	83	70%	in
			2	0.149	0.75	coal mill	outdoors	160	90%	in
	High Alloy	Cr <sup>VI</sup> [0.05] (5/17)	1	0.22	4.4	coal mill	CS/vent	320	80%	out
			2	0.207	4.14	coal mill	CS	243	80%	out
			3	0.1348	2.7	coal mill	CS/vent	280	75%	out
			4	0.121	2.42	boiler bottom	ES	255	50%	out
			5	0.0631	1.26	coal mill	CS/vent	370	60%	out
		Fume [5] (4/24)	1	15.6	3.12	coal mill	CS	320	80%	out
			2	12.7	2.54	coal mill	CS	243	80%	out
			3	8.56	1.71	coal mill	CS/vent	370	60%	out
	4	8.17	1.63	coal mill	CS/vent	280	75%	out		
	FCAW	Mild Steel	Mn [0.2] (4/16)	1	0.32	1.6	structural steel	indoors	187	50%
2				0.288	1.44	structural steel	indoors	247	50%	in
3				0.264	1.32	pipng/valves	indoors	226	50%	in
4				0.22	1.1	pipng/valves	indoors	157	60%	in
Fume [5] (1/13)		1	5.67	1.13	structural steel	indoors	200	50%	in	
		2	3.93	0.79	structural steel	indoors	187	50%	in	
Be [0.002] (1/14)		1	0.012	6	structural steel	indoors	200	50%	in	
		2	<LOQ	NA	pipng/valves	indoors	93	75%	in	
High Alloy		Fume [5] (1/8)	1	7.16	1.43	boiler bottom	ES	405	30%	out
			2	2.64	0.53	boiler tubes	indoors	235	60%	in

**Legend** [ ] = OEL in mg/m<sup>3</sup> (ACGIH TLV or OSHA PEL\* - whichever is more stringent)  
 (/) = fraction of samples that exceeds the OEL; # = rank order of 8-hr TWA exposures from highest  
 TWA = 8-hr TWA; TWA/OEL = ratio of 8-hr TWA divided by OEL  
 System: Piping /valves, Boiler tubes, Boiler skin, Coal mill, Coal conveyor, Structural steel  
 Location: CS = Confined space; vent = local exhaust ventilation; ES = enclosed space  
 Time = exposure time in minutes; In/out Hood = location of sampling device  
 Arc-on% = estimate of percent of sampling time welding/cutting arc (or flame) was on

## 2.6.2 Profiles for Thermal Cutting 8-Hour TWA Exposures Exceeding OELs

### Profiles for Thermal Cutting 8-Hour TWA Air Contaminant Exposures

Table V.A.2.6.2

Process	Metal	Analyte	#	TWA	TWA/OEL	Plant System	Location	Time	Arc-on%	In/out Hood
ACAC	Mild Steel	Fume [5] (9/12)	1	123.4	24.68	boiler bottom	indoors	420	80%	out
			2	96.8	19.36	boiler wall	outdoors	430	20%	in
			3	68.15	13.63	boiler bottom	indoors	425	75%	in
			4	65.8	13.16	boiler bottom	indoors	420	80%	out
			5	33.2	6.64	boiler bottom	indoors	96	80%	in
			6	23.4	4.68	boiler wall	outdoors	335	75%	in
			7	17.11	3.42	boiler bottom	indoors	134	95%	in
			8	13.28	2.66	boiler bottom	indoors	154	55%	in
			9	9.7	1.94	boiler bottom	indoors	260	75%	out
	Cu [0.1] (2/12)	1	0.448	4.48	boiler bottom	indoors	425	75%	in	
		2	0.109	1.09	boiler bottom	indoors	154	55%	in	
	Fe <sub>2</sub> O <sub>3</sub> [5] (1/12)	1	34.75	6.95	boiler bottom	indoors	425	75%	in	
		2	4.99	0.99	boiler bottom	indoors	260	75%	out	
	Mn [0.2] (1/12)	1	0.424	2.12	boiler bottom	indoors	425	75%	in	
		2	0.059	0.30	boiler bottom	indoors	154	55%	in	
	Low Alloy	Fume [5] (2/3)	1	26.2	5.24	boiler tubes	in boiler	480	50%	out
			2	15.2	3.04	boiler tubes	in boiler	425	50%	out
	High Alloy	Fume [5] (3/4)	1	23.6	4.72	boiler bottom	indoors	385	50%	out
			2	19.2	3.84	boiler bottom	indoors	460	60%	out
			3	14.15	2.83	boiler tubes	in boiler	320	65%	out
	PAC	Mild Steel	Fume [5] (1/1)	1	10.5	2.1	hydroveyor tank	indoors	250	75%
Low Alloy		Fume [5] (1/1)	1	6.6	1.32	boiler water wall	outdoors	96	50%	in
High Alloy		Fume [5] (2/4)	1	8.25	1.65	boiler bottom	indoors	410	70%	out
			2	5.666	1.13	boiler burners	indoors	40	50%	out
OAC	Mild Steel	Fume [5] (3/3)	1	26.9	5.38	windboxburner	indoors	300	50%	in
			2	7.75	1.55	windboxburner	indoors	120	50%	in
			3	6.83	1.37	rotary dump	outdoors	420	75%	out
	Low Alloy	Fume [5] (3/3)	1	20.9	4.18	boiler tubes	in boiler	424	75%	in
			2	15.1	3.02	boiler tubes	in boiler	430	75%	in
			3	13.9	2.78	boiler tubes	in boiler	470	75%	in
	High Alloy	Fume [5] (2/2)	1	8.39	1.68	boiler bottom	indoors	395	70%	out
			2	6.14	1.23	boiler bottom	indoors	220	90%	out

**Legend)** [ ] = OEL in mg/m<sup>3</sup> (ACGIH TLV or OSHA PEL\* - whichever is more stringent)

( / ) = fraction of samples that exceeds the OEL

# = rank order of 8-hr TWA exposures from highest

TWA = 8-hr TWA; TWA/OEL = ratio of 8-hr TWA divided by OEL

System: Piping /valves, Boiler tubes, Boiler skin, Coal mill, Coal conveyor, Structural steel

Location: CS = Confined space; vent = local exhaust ventilation; ES = enclosed space

Time = exposure time in minutes

Arc-on% = estimate of percent of sampling time welding/cutting arc (or flame) was on

In/out Hood = location of sampling device

### 2.6.3 Profiles for Welding/Thermal Cutting on Toxic Surface Coatings 8-Hour TWA Exposures Exceeding OELs

The 8-hour TWA welding/thermal cutting exposures that from hot work on lead and zinc chromate-painted steel that exceeded OELs is rank ordered on the *Table V.A.2.6.3*. Additional information for each exposure includes: the process, the toxic metal by weight percent present in the paint, the OEL in mg/m<sup>3</sup> for each air contaminant, the ratio of each individual 8-hour TWA exposure versus the OEL (TWA/OEL), the plant system worked on, the environmental location, and the exposure time. These sample were collected outside of the welding hood, as respiratory protection, ususally in the form of full face powered air-purifying or the pressure demand airline type.

**Thermal Cutting/Welding on Toxic Paint  
Highest 8-Hour TWA Air Contaminant Exposures**

*Table V.A.2.6.3*

Process	Metal %	Analyte	#	TWA	TWA/OEL	Plant System	Location	Time
ACAC	10.1	Pb[0.05*]	1	0.2867	5.73	inside boiler penthouse	indoors	430
OAC	11.3		2	0.146	2.92	structural steel	outdoors	90
ACAC	10.1		3	0.13	2.6	inside boiler penthouse	indoors	210
ACAC	9.027		4	0.1279	2.56	archway inside boiler	indoors	105
ACAC	9.027		5	0.12	2.4	archway inside boiler	indoors	215/ 250
ACAC	9.027		6	0.1107	2.21	archway inside boiler	indoors	435
OAC	17.2		7	0.08864	1.77	pipng/valves cooling tower	outdoors	223
OAC	17.2		8	0.0826	1.65	supply piping to cooling tower	outdoors	133
ACAC	9.027		9	0.0723	1.45	archway inside boiler	indoors	220
OAC	9.027		10	0.0516	1.03	structural steel	outdoors	95
SMAW	2.8		11	0.0449	0.90	structural steel	indoors	189
OAC	9.027		12	0.041	0.82	structural steel	outdoors	135
PAC	5.57		13	0.03656	0.73	coal conveyor	indoors	135

*Note: Table continued on the following page.*

**Thermal Cutting/Welding on Toxic Paint  
Highest 8-Hour TWA Air Contaminant Exposures**

*Table V.A.2.6.3 (Continued)*

Process	Metal %	Analyte	#	TWA	TWA/OEL	Plant System	Location	Time
ACAC	0.08	ZnCrO <sub>4</sub> [0.01]	1	0.04	4	de-watering bin	outdoors	427
ACAC	0.46		2	0.034	3.4	or inside boiler penthouse	indoors	210/ 225
ACAC	0.08		3	0.03322	3.32	de-watering bin	outdoors	200
ACAC	0.08		4	0.0332	3.32	de-watering bin	outdoors	210
ACAC	0.46		5	0.0314	3.14	or inside boiler penthouse	indoors	430
PAC	1.36		6	0.02194	2.19	coal conveyor	indoors	135
ACAC	NA	Fume [5]	1	463.3	92.66	inside boiler penthouse	indoors	210/ 225
ACAC			2	261.5	52.2	inside boiler penthouse	indoors	210/ 225
ACAC			3	233.3	46.67	inside boiler penthouse	indoors	400
ACAC			4	205.15	41.03	inside boiler penthouse	indoors	430
ACAC			5	82.10	16.42	archway inside boiler	indoors	225/ 210
ACAC			6	39.5	7.8	inside boiler penthouse	indoors	180
ACAC			7	37.5	7.4	inside boiler penthouse	indoors	320
ACAC			8	35.5	7.1	inside boiler penthouse	indoors	325
ACAC			9	23.6	4.72	boiler bottom	indoors	165/ 220
ACAC			10	19.2	3.84	boiler bottom	indoors	460
ACAC			11	17.14	3.43	archway inside boiler	indoors	235/ 215
OAC			12	8.39	1.68	boiler bottom	indoors	395
PAC			13	8.25	1.65	boiler bottom	indoors	410
OAC			14	6.14	1.23	boiler bottom	indoors	220
ACAC			15	5.9	1.18	boiler bottom	indoors	135

**Legend** [ ] = OEL in mg/m<sup>3</sup> (ACGIH TLV or OSHA PEL\* - whichever is more stringent)

# = rank order of 8-hr TWA exposures from highest

TWA = 8-hr TWA; TWA/OEL = ratio of 8-hr TWA divided by OEL

System: Piping /valves, Boiler, Coal mill, Coal conveyor, Structural steel

Location: CS = Confined space; vent = local exhaust ventilation; ES = enclosed space

Time = exposure time in minutes

Shaded areas represent samples affected by fly ash, which may influence gravimetric welding fume results

## **2.7 Profiles for Air Contaminant Concentration Exposures Exceeding OELs**

Information on air contaminant concentrations (TWA) may be used in estimating the potential magnitude of exposures and determining whether an exposure is potentially capable of exceeding a threshold. Particular jobs may be identified as potential overexposures even in the absence of 8-hour TWA exposure data indicating this. This situation may arise where the exposure monitoring was conducted by chance on days where the task/exposure duration was shorter, thus 8-hour TWA exposure was underestimated. This problem may be overcome by increasing sample size and strategic sampling in conjunction with determining task/ exposure durations during industrial hygiene surveys. In the interim, the air concentration data is useful for this purpose. It may also be used in evaluation of engineering controls or work practices for exposure reduction, and respirator selection. The air contaminant concentrations in welding and thermal cutting exposures that at times exceeded OELs referencing the actual sampling period are rank ordered, categorized by process and base metal/consumable, on the tables below. The air contaminant concentration exposures greater than the thresholds are included. In cases where only one exposure is over the threshold, the next highest has been included for comparison. Additional information presented includes the OEL in  $\text{mg}/\text{m}^3$  for each air contaminant, the fraction of exposures over the OEL versus total sample size ( $\#/n$ ), the ratio of each individual air contaminant concentration exposure versus the OEL ( $AC/OEL$ ), the plant system worked on, the environmental location and use of local exhaust ventilation, exposure time, the estimated percent of the exposure time that the welding arc was on, and whether the sample was collected inside or outside of the welding hood.

## 2.7.1 Profiles for Welding Air Contaminant Concentration Exposures Exceeding OELs

### Welding Highest Air Contaminant Concentration Exposures

Table V.A.2.7.1

Process	Metal	Analyte	#	AC TWA	AC/ OEL	Plant System	Location	Time	Arc- on%	In/out Hood
SMAW	Mild Steel	Mn [0.2]	1	0.447 0.149	2.235	coal mill trunion overlay	outdoors	160	90%	in
			2	0.29 0.042	1.45	pipng/valves	outdoors in pit	69	70%	in
			3	0.26 0.034	1.3	pipng/valves	indoors	63	80%	out
			4	0.22 0.083	1.1	meter headers	shop/ no vent	182	65%	in
		Fume [5]	1	10.3 3.85	2.06	coal mill trunion overlay	outdoors	135	90%	in
			2	9.95 3.32	1.99	coal mill trunion overlay	outdoors	160	90%	in
			3	8.8 1.01	1.76	coal mill trunion overlay	outdoors	55	95%	in
			4	7.6 3.85	1.52	coal mill trunion overlay	outdoors	60	90%	in
			5	5.35 2.029	1.07	meter headers	shop/no vent	182	65%	in
			6	5.2 4.3	1.04	windboxburner	indoors	398	90%	in
	High Alloy	Cr <sup>VI</sup> [0.05]	1	0.621 0.207	12.42	coal mill hard surfacing	CS	95	80%	out
			2	0.457 0.22	9.14	coal mill hard surfacing	CS	115	80%	out
			3	0.272 0.207	5.44	coal mill hard surfacing	CS	148	80%	out
			4	0.255 0.22	5.1	coal mill hard surfacing	CS	205	80%	out
			5	0.231 0.1348	4.62	coal mill hard surfacing	CS/vent	280	75%	out
			6	0.227 0.121	4.54	boiler bottom seal trough	ES	255	50%	out
			7	0.082 0.063	1.64	coal mill hard surfacing	CS/vent	370	60%	out
			8	0.06 0.023	1.2	boiler tube shields CA	in boiler	185	25%	out
Fume [5]		1	32.5 12.7	6.5	coal mill hard surfacing	CS	95	80%	out	
		2	27.9 15.6	5.58	coal mill hard surfacing	CS	115	80%	out	
		3	20.9 15.6	4.18	coal mill reject cone	CS	205	80%	out	
		4	20.4 12.7	4.08	coal mill hard surfacing	CS	148	80%	out	
5	14.0 8.17	2.8	coal mill hard surfacing	CS/vent	280	75%	out			

Note: Table continued on the following page.

**Welding Highest Air Contaminant Concentration Exposures**

*Table V.A.2.7.1 (Continued)*

Process	Metal	Analyte	#	AC TWA	AC/ OEL	Plant System	Location	Time	Arc- on%	In/out Hood
SMAW	High Alloy	Fume [5]	6	11.1 8.6	2.22	coal mill hard surfacing	CS/vent	370	60%	out
			7	9.05 4.8	1.81	boiler bottom seal trough	ES	255	50%	out
			8	6.6 3.4	1.32	boiler tube shields	in boiler	247	10%	out
			9	5.9 3.04	1.18	boiler tube shields	in boiler	247	10%	out
			10	5.8 2.24	1.16	boiler tube shields	in boiler	185	25%	out
FCAW	Mild Steel	Mn [0.2]	1	1.0 0.32	5	structural steel	indoors	187	50%	in
			2	0.67 0.22	3.35	pipng/valves	indoors	157	60%	in
			3	0.56 0.288	2.8	structural steel	indoors	247	50%	in
			4	0.56 0.264	2.8	pipng/valves	indoors	226	50%	in
			5	0.26 0.034	1.3	pipng/valves	indoors	63	80%	in
			6	0.22 0.1095	1.1	pipng/valves	indoors	239	50%	in
			7	0.22 0.045	1.1	structural steel	shop/ vent	96	85%	in
		Fume [5]	1	13.6 5.67	2.72	structural steel	indoors	200	50%	in
			2	12.4 3.93	2.48	structural steel	indoors	99	50%	in
			3	9.12 3.93	1.824	structural steel	indoors	55	50%	in
			4	8.6 2.4163	1.72	inside coal chute	ES	69	85%	out
			5	7.3 3.43	1.46	pipng/valves	indoors	226	50%	in
			6	7.0 2.4163	1.4	inside coal chute	ES	81	85%	out
			7	6.9 2.257	1.38	pipng/valves	indoors	157	60%	in
	8	6.7 3.45	1.34	structural steel	indoors	247	50%	in		
	Be [0.002]	1	0.029 0.012	14.5	structural steel	indoors	200	50%	in	
		2	<LOD		(all samples)					
	High Alloy	Fume [5]	1	8.49 7.16	1.698	boiler bottom	indoors	405	30%	out
			2	1.44 1.11	0.288	in boiler bottom	indoors	370	30%	out
			3	1.25 0.651	0.25	inside boiler	CS	250	30%	out

*Note: Table continued on the following page.*

**Welding Highest Air Contaminant Concentration Exposures**

**Table V.A.2.7.1 (Continued)**

Process	Metal	Analyte	#	AC TWA	AC/ OEL	Plant System	Location	Time	Arc- on%	In/out Hood
GTAW	High Alloy	O <sub>3</sub> [0.2]  9/22/99 PA	1	0.2 0.133	1	pipng/valves	shop no vent	320	30%	out
			2	0.085 0.046	0.425	pipng		258	30%	in
			3	0.061 0.0352	0.305	turbine wheel	indoors	277	25%	out
			4	0.059 0.05	0.295	turbine	ES/vent	415	50%	out

**Legend)** [ ] = OEL in mg/m<sup>3</sup> (ACGIH TLV or OSHA PEL\* - whichever is more stringent)

# = rank order of air contaminant concentration exposures from highest

AC = air contaminant concentration TWA; TWA = 8-hr TWA; AC/OEL = ratio of AC divided by OEL

System: Piping /valves, Boiler tubes, Boiler skin, Coal mill, Coal conveyor, Structural steel

Location: CS = Confined space; vent = local exhaust ventilation;

ES = enclosed space; Time = exposure time in minutes

Arc-on% = estimate of percent of sampling time welding/cutting arc (or flame) was on

In/out Hood = location of sampling device

**2.7.2 Profiles for Thermal Cutting Air Contaminant Concentration Exposures Exceeding OELs**

**Thermal Cutting Highest Air Contaminant Concentration Exposures**

**Table V.A.2.7.2**

Process	Metal	Analyte	#	AC TWA	AC/ OEL	Plant System	Location	Time	Arc- on%	In/out Hood
ACAC	Mild Steel	Fume [5]	1	166.0 33.2	33.2	boiler bottom	outside indoors	96	80%	in
			2	141.0 123.4	28.2	boiler bottom	indoors	420	80%	out
			3	108 96.8	21.6	boiler water wall tubes	outdoors	430	20%	in
			4	71.4 13.28	14.28	boiler bottom	indoors	70	55%	in
			5	61.3 17.11	12.26	boiler bottom	indoors	134	95%	in
			6	38.5 4.57	7.7	boiler bottom	indoors	57	75%	in
			7	33.4 23.4	6.68	boiler water wall tubes	outdoors	337	75%	in
		Cu [0.1]	1	0.659 0.448	6.59	boiler bottom	indoors	130	75%	in
			2	0.57 0.109	5.7	boiler bottom	indoors	70	80%	in
			3	0.438 0.448	4.38	boiler bottom	indoors	295	75%	in
			4	0.15 0.109	1.5	boiler bottom	indoors	84	80%	in

*Note: Table continued on the following page.*

**Thermal Cutting Highest Air Contaminant Concentration Exposures**

**Table V.A.2.7.2 (Continued)**

Process	Metal	Analyte	#	AC TWA	AC/ OEL	Plant System	Location	Time	Arc- on%	In/out Hood
ACAC	Mild Steel	Co [0.02]	1	0.032 0.017	1.6	boiler bottom	indoors	260	75%	out
			2	0.008 0.005	0.4	boiler bottom	indoors	130	75%	out
		Fe <sub>2</sub> O <sub>3</sub> [5]	1	57.5 34.75	11.5	boiler bottom	indoors	130	75%	in
			2	18.1 3.620	3.62	boiler bottom	indoors	96	80%	in
			3	17.6 3.433	3.52	boiler bottom	indoors	70	55%	in
			4	9.22 4.99	1.844	boiler bottom	indoors	260	75%	out
		Mn [0.2]	1	0.8 0.424	4	boiler bottom	indoors	130	75%	in
			2	0.338 0.424	1.69	boiler bottom	indoors	295	75%	in
	Low Alloy	Fume [5]	1	26.2 26.2	5.24	boiler bottom	indoors	480	50%	out
			2	4.95 2.27	0.99	boiler	indoors	220	30%	out
	High Alloy	Fume [5]	1	41.5 23.6	8.3	boiler bottom	indoors	220	50%	out
			2	24.7 14.5	4.94	boiler bottom	indoors	275	65%	out
			3	17.2 15.2	3.44	in boiler on steam header	indoors	425	50%	out
	PAC	Mild Steel	Fume [5]	1	20.1 10.5	4.02	structural steel	indoors	250	75%
Low Alloy		Fume [5]	1	33 6.6	6.6	boiler water wall tubes	outdoor tent	96	90%	in
		Fe <sub>2</sub> O <sub>3</sub> [5]		5.4 1.08	1.08	boiler water wall tubes	outdoor tent	96	90%	in
High Alloy		Fume [5]	1	68 5.67	13.6	boiler burner	indoors	40	50%	out
			2	9.66 8.25	1.932	boiler bottom	indoors	410	70%	out
			3	3.18 1.39	0.636	boiler tube shields	indoors	210	30%	out
		Cr <sup>VI</sup> [0.05]		0.245 0.020	4.9	boiler burner	indoors	40	50%	out
NO <sub>2</sub> [5.6]		6 0.5	1.0713	boiler burner	indoors	40	50%	out		
OAC	Mild Steel	Fume [5]	1	43 26.9	8.6	windboxburner	indoors/ vent	300	50%	in
			2	31 7.75	6.2	boiler bottom	indoors	120	50%	in
			3	7.8 6.825	1.56	rotary dump	outdoors	135	50%	out

*Note: Table continued on the following page.*

### Thermal Cutting Highest Air Contaminant Concentration Exposures

**Table V.A.2.7.2 (Continued)**

Process	Metal	Analyte	#	AC TWA	AC/ OEL	Plant System	Location	Time	Arc- on%	In/out Hood
OAC	Low Alloy	Fume [5]	1	23.7 20.9	4.74	boiler tubes in boiler	indoors	424	75%	in
			2	16.8 15.1	3.36	boiler tubes in boiler	indoors	430	75%	in
			3	14.2 13.9	2.84	boiler tubes in boiler	indoors	470	75%	in
	High Alloy	Fume [5]	1	13.4 6.14	2.68	boiler bottom	indoors	220	90%	out
			2	10.2 8.394	2.04	boiler bottom	indoors	395	70%	out

**Legend)** [ ] = OEL in mg/m<sup>3</sup> (ACGIH TLV or OSHA PEL\* - whichever is more stringent)

# = rank order of air contaminant concentration exposures from highest

AC = air contaminant concentration TWA; TWA = 8-hr TWA; AC/OEL = ratio of AC divided by OEL

System: Piping /valves, Boiler tubes, Boiler skin, Coal mill, Coal conveyor, Structural steel

Location: CS = Confined space; vent = local exhaust ventilation; ES = enclosed space

Time = exposure time in minutes

Arc-on% = estimate of percent of sampling time welding/cutting arc (or flame) was on

In/out Hood = location of sampling device

### **2.7.3 Profiles for Welding/Thermal Cutting on Toxic Surface Coatings Air Contaminant Concentrations Exceeding OELs**

#### Thermal Cutting/Welding on Toxic Paint Highest Air Contaminant Concentration Exposures

**Table V.A.2.7.3**

Process	Metal %	Analyte	#	AC TWA	AC/ OEL	Plant System	Location	Time
OAC	11.3	Pb[0.05*]	1	0.78 0.146	15.6	structural steel	outdoors	90
ACAC	9.027		2	0.5849 0.1279	11.7	archway inside boiler	indoors	105
ACAC	to be analyzed		3	0.32 0.2867	6.4	inside boiler penthouse	indoors	430
OAC	17.21		4	0.298 0.0826	5.96	cooling tower; supply piping	outdoors	133
OAC	9.027		5	0.261 0.0516	5.22	structural steel	outdoors	95
ACAC	9.027		6	0.1557 0.0723	3.11	inside boiler, structural	indoors	220
OAC	9.027		7	0.198 0.0136	3.96	structural steel	outdoors	33
OAC	9.027		8	0.198 0.0136	3.96	CS	indoors	195
ACAC	to be analyzed		9	0.198 0.13	3.96	inside boiler penthouse	indoors	210
OAC	17.21		10	0.1908 0.0886	3.82	piping/valves	outdoors	223

*Note: Table continued on the following page.*

**Thermal Cutting/Welding on Toxic Paint  
Highest Air Contaminant Concentration Exposures**

**Table V.A.2.7.3 (Continued)**

Process	Metal %	Analyte	#	AC TWA	AC/OEL	Plant System	Location	Time	
ACAC	9.027		1 1	0.164 0.12	3.28	inside boiler, structural	indoors	215	
OAC	not available		1 5	0.15 0.018	3	structural steel	indoors	58	
OAC	9.027		1 2	0.148 0.0067	2.96	CS	indoors	22	
SMAW	9.027		1 3	0.146 0.0107	2.92	CS	indoors	236	
OAC	9.027		1 4	0.146 0.041	2.92	boiler skin	outdoors	135	
PAC	5.57		1 6	0.13 0.03656	2.6	coal conveyor	indoors	135	
ACAC	9.027		1 7	0.1222 0.1107	2.44	archway CO	indoors	435	
SMAW	2.8		1 8	0.114 0.0449	2.28	structural steel	indoors	189	
OAC	9.027		1 9	0.111 0.0141	2.22	CS	indoors	61	
ACAC	to be analyzed		2 0	0.091 0.13	1.82	inside boiler penthouse	indoors	225	
PAC	1.36		ZnCro <sub>4</sub> [0.010]	1	0.078 0.02194	7.8	coal conveyor	indoors	135
SMAW	0.265			2	0.0458 0.00114	4.58	turbine boiler feed pump	indoors	12
ACAC	<0.005			3	0.045 0.04	4.5	dewatering bin	outdoors	427
ACAC	0.08			4	0.043 0.03322	4.3	dewatering bin	outdoors	200*
ACAC	0.081			5	0.043 0.0038	4.3	dumper	outdoors	31
ACAC	<0.005			6	0.041 0.004	4.1	dewatering bin	indoors	47
ACAC	0.4			7	0.04 0.034	4	inside boiler penthouse	indoors	225*
SMAW	0.4			8	0.04 0.0006	4	tack welds	indoors	7
ACAC	<0.005			9	0.035 0.0332	3.5	dewatering bin	outdoors	210*
ACAC	to be analyzed			1 0	0.035 0.0314	3.5	inside boiler penthouse	indoors	430
ACAC	0.4		1 1	0.034 0.034	3.4	inside boiler penthouse	indoors	210*	
ACAC	0.081		1 2	0.032 0.0032	3.2	dumper	indoors	48	
SMAW	4.45		1 3	0.0314 0.00163	3.14	F mill pyrite bottle	indoors	25	
SMAW	9.027		1 4	0.0257 0.0039	2.57	CS	indoors	236	
OAC	9.027		1 5	0.0253 0.0006	2.53	CS	indoors	195	

*Note: Table continued on the following page*

**Thermal Cutting/Welding on Toxic Paint  
Highest Air Contaminant Concentration Exposures**

*Table V.A.2.7.3 (Continued)*

Process	Metal %	Analyte	#	AC TWA	AC/OEL	Plant System	Location	Time
OAC	9.027	ZnCrO <sub>4</sub> [0.010]	1	0.0253	2.53	structural steel	outdoors	135
			6	0.0071				
ACAC	0.081		1	0.023	2.3	coal rotary dumper	outdoors	82
			7	0.0039				
	NA	Fume [5] in mg	1	850	170	inside boiler penthouse	indoors	210
			2	400	80	inside boiler penthouse	indoors	210
			3	261	52	inside boiler penthouse	indoors	400
			4	229	45.8	inside boiler penthouse	indoors	430
			5	195	39	inside boiler penthouse	indoors	225
			6	139	27.8	inside boiler penthouse	indoors	225
ACAC			7	146	29.2	archway inside boiler	indoors	215 *
			8	104	20.8	inside boiler penthouse	indoors	180
			9	55.5	11.1	inside boiler penthouse	indoors	320
			10	52.5	10.5	inside boiler penthouse	indoors	325
ACAC			1	41.5	8.3	boiler bottom	indoors	220 *
			1	23.6				
ACAC			1	32.1	6.42	archway plating	indoors	250 *
			2	82.1				
ACAC			1	25.8	5.16	archway inside boiler	indoors	215
			3	17.14				
OAC			1	22	4.4	bolts on condenser water box	indoors	70
			4	3.2				
ACAC			1	21	4.2	on boiler bottom	indoors	135
			5	5.9				
ACAC		1	20	4	on boiler bottom	indoors	460	
		6	19.2					
OAC		1	13.4	2.68	on boiler bottom	indoors	220	
		7	6.14					
ACAC		1	13.3	2.66	on boiler bottom	indoors	165 *	
		8	23.6					
ACAC		1	11.4	2.28	inside boiler, structural	indoors	235	
		9	17.14					
OAC		2	10.2	2.04	on boiler bottom	indoors	395	
		0	8.39					
OAC		2	9.7	1.94	guard rails	indoors	73	
		1	1.48					

**Legend)** [ ] = OEL in mg/m<sup>3</sup> (ACGIH TLV or OSHA PEL\* - whichever is more stringent)

# = rank order of air contaminant concentration exposures from highest

AC = air contaminant concentration TWA; TWA = 8-hr TWA; AC/OEL = ratio of AC divided by OEL

System: Piping /valves, Boiler, Coal mill, Coal conveyor, Structural steel

Location: CS = Confined space; vent = local exhaust ventilation; ES = enclosed space

Time = exposure time in minutes

Shaded areas represent samples affected by fly ash, which may influence gravimetric welding fume results

## **2.8 Eight-Hour TWA Exposure Summary Statistical Measures**

Eight-hour TWA exposure summary statistics were calculated for each welding process sampled, by base metal/consumable. Individual air contaminant statistics for each of these strata include:

- sample size TWA (n)
- OEL (TLV/PEL\*)
- highest exposure (High)
- arithmetic mean (AM)
- geometric mean (GM)
- percent of n less than or equal to the action level ( $\%n \leq AL$ )
- percent of n greater than the AL, but less than or equal to the OEL ( $AL < \%n \leq OEL$ )
- percent of n greater than the OEL ( $\%n > OEL$ ).

For the purposes of this study, the AL was defined as half of the OEL.

### **2.8.1 Welding 8-Hour TWA Exposure Summary Statistical Measures**

*Tables V.A.2.8.1.a-j*, at the end of this section, provide summary statistics for the welding processes sampled. The order of presentation is as follows:

<i>Table V.A.2.8.1.a</i>	SMAW-Mild Steel
<i>Table V.A.2.8.1.b</i>	SMAW-Low Alloy Steel
<i>Table V.A.2.8.1.c</i>	SMAW-Medium Alloy Steel
<i>Table V.A.2.8.1.d</i>	SMAW-High Alloy Steel
<i>Table V.A.2.8.1.e</i>	GTAW-Mild Steel
<i>Table V.A.2.8.1.f</i>	GTAW-Low Alloy Steel
<i>Table V.A.2.8.1.g</i>	GTAW-High Alloy Steel
<i>Table V.A.2.8.1.h</i>	FCAW-Mild Steel
<i>Table V.A.2.8.1.i</i>	FCAW-High Alloy Steel
<i>Table V.A.2.8.1.j</i>	GMAW-Mild Steel

## 2.8.2 Thermal Cutting 8-Hour TWA Exposure Summary Statistical Measures

Tables V.A.2.8.2.a-i, at the end of this section, provide summary statistics for the thermal cutting processes sampled. The order of presentation is as follows:

Table V.A.2.8.2.a	ACAC-Mild Steel
Table V.A.2.8.2.b	ACAC-Low Alloy Steel
Table V.A.2.8.2.c	ACAC-High Alloy Steel
Table V.A.2.8.2.d	PAC-Mild Steel
Table V.A.2.8.2.e	PAC-Low Alloy Steel
Table V.A.2.8.2.f	PAC-High Alloy Steel
Table V.A.2.8.2.g	OAC-Mild Steel
Table V.A.2.8.2.h	OAC-Low Alloy Steel
Table V.A.2.8.2.i	OAC-High Alloy Steel

### Shielded Metal Arc Welding (SMAW)

Table V.A.2.8.1.a

Mild Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	17	5	4.3	1.40863	0.97922	88%	12%	0%
Al	16	5	0.0609	0.01519	0.00848	100%	0%	0%
Be	24	0.002*	0.0005	0.00014	0.0001	100%	0%	0%
Cd	24	0.005*	0.00025	0.00011	0.00009	100%	0%	0%
Co	16	0.02	0.001	0.00022	0.00017	100%	0%	0%
Cr	38	0.5	0.0192	0.00144	0.00075	100%	0%	0%
Cr VI	N/A	0.05	-	-	-	-	-	-
Cu	38	0.1*	0.0123	0.00283	0.00175	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	38	5	1.59	0.35887	0.16984	100%	0%	0%
MgO	24	10	0.0148	0.00438	0.00302	100%	0%	0%
Mn	38	0.2	0.149	0.02481	0.01377	97.37%	2.63%	0%
Ni	38	0.2	0.0034	0.00067	0.00048	100%	0%	0%
ZnO	34	5	0.246	0.01791	0.00511	100%	0%	0%
Fluorides	7	1	0.18	0.107	0.0517	100%	0%	0%
-particles	8	2.5*	0.16	0.0645	0.0338	100%	0%	0%
-gaseous	7	2.45*	0.02	0.0073	0.0039	100%	0%	0%
NO <sub>2</sub>	6	5.6	0.13	0.0738	0.0648	100%	0%	0%
Ozone	8	0.2	0.016	0.007	0.005	100%	0%	0%

**Legend:** TWA (n) = 8-hour time-weighted average sample size;

OEL = Occupational Exposure Limit (ACGIH TLV/OSHA PEL\*, whichever is more stringent); AL = Action Level (1/2 of the OEL);

High = Highest 8-hour TWA exposure; AM = Arithmetic Mean; GM = Geometric Mean

% n≤AL = Percent of 8-hour TWA exposures less than or equal to the AL; AL<% n≤OEL = Percent of 8-hour TWA exposures greater than the AL, but less than or equal to the OEL; % n> OEL = Percent of 8-hour TWA exposures greater than the OEL

## Shielded Metal Arc Welding (SMAW)

**Table V.A.2.8.1.b**

Low Alloy								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	12	5	4.27313	1.03359	0.65764	92%	8%	0%
Al	2	5	0.0061	0.0043	0.00391	100%	0%	0%
Be	7	0.002*	0.0001	0.0001	0.0001	100%	0%	0%
Cd	7	0.005*	0.00012	0.0001	0.0001	100%	0%	0%
Co	2	0.02	0.00115	0.00063	0.00034	100%	0%	0%
Cr	7	0.5	0.0061	0.00187	0.00129	100%	0%	0%
Cr VI	10	0.05	0.0016	0.0008	0.0006	100%	0%	0%
Cu	7	0.1*	0.004	0.00176	0.00123	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	7	5	0.39	0.19757	0.14286	100%	0%	0%
MgO	2	10	0.0041	0.0037	0.00368	100%	0%	0%
Mn	7	0.2	0.03	0.01187	0.00906	100%	0%	0%
Ni	7	0.2	0.006	0.00116	0.00046	100%	0%	0%
ZnO	7	5	0.014	0.00647	0.00404	100%	0%	0%
Fluorides	1	1	0.0249	0.0249	0.0249	100%	0%	0%
-particles	1	2.5*	0.0184	0.0184	0.0184	100%	0%	0%
-gaseous	1	2.45*	0.0031	0.0031	0.0031	100%	0%	0%
NO <sub>2</sub>	3	5.6	0.039	0.0295	0.0282	100%	0%	0%
Ozone	5	0.2	0.045	0.025	0.023	100%	0%	0%

**Table V.A.2.8.1.c**

Medium (9% Chromium) Alloy Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	6	5	4.14	1.68167	1.22266	67%	33%	0%
Al	2	5	0.043	0.0239	0.01437	100%	0%	0%
Be	2	0.002*	1.5E-5	0.00001	8.7E-6	100%	0%	0%
Cd	2	0.005*	4.5E-5	2.5E-5	1.5E-5	100%	0%	0%
Co	0	0.02	-	-	-	-	-	-
Cr	2	0.5	0.061	0.03095	0.00740	100%	0%	0%
Cr VI	6	0.05	0.016	0.00402	0.00221	100%	0%	0%
Cu	2	0.1*	0.0059	0.0033	0.00203	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	2	5	0.805	0.4245	0.18820	100%	0%	0%
MgO	0	10	-	-	-	-	-	-
Mn	2	0.2	0.043	0.0226	0.00973	100%	0%	0%
Ni	2	0.2	0.004	0.00225	0.00141	100%	0%	0%
ZnO	2	5	0.014	0.0085	0.00648	100%	0%	0%
Fluorides	0	1	-	-	-	-	-	-
-particles	0	2.5*	-	-	-	-	-	-
-gaseous	0	2.45*	-	-	-	-	-	-
NO <sub>2</sub>	0	5.6	-	-	-	-	-	-
Ozone	0	0.2	-	-	-	-	-	-

**Legend:** TWA (n) = 8-hour time-weighted average sample size;

OEL = Occupational Exposure Limit (ACGIH TLV/OSHA PEL\*, whichever is more stringent); AL = Action Level (1/2 of the OEL);

High = Highest 8-hour TWA exposure; AM = Arithmetic Mean; GM = Geometric Mean

% n≤AL = Percent of 8-hour TWA exposures less than or equal to the AL; AL<% n≤OEL = Percent of 8-hour TWA exposures greater than the AL, but less than or equal to the OEL; % n> OEL = Percent of 8-hour TWA exposures greater than the OEL

## Shielded Metal Arc Welding (SMAW)

Table V.A.2.8.1.d

High Alloy Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	24	5	15.6	3.37210	1.97140	66.667%	16.667%	16.667%
Al	4	5	0.0453	0.02237	0.01846	100%	0%	0%
Be	12	0.002*	0.00035	0.00015	0.00012	100%	0%	0%
Cd	12	0.005*	0.00025	0.00013	0.00011	100%	0%	0%
Co	3	0.02	0.00035	0.00025	0.00024	100%	0%	0%
Cr	15	0.5	0.165	0.02150	0.00545	100%	0%	0%
Cr VI	17	0.05	0.22	0.04761	0.00985	71%	0%	29%
Cu	13	0.1*	0.0321	0.00460	0.00229	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	15	5	0.875	0.17788	0.09359	100%	0%	0%
MgO	5	10	0.0131	0.00698	0.00438	100%	0%	0%
Mn	15	0.2	0.13	0.02456	0.01299	93.33%	6.67%	0%
Ni	15	0.2	0.016	0.00571	0.00412	100%	0%	0%
ZnO	13	5	0.032	0.01191	0.0064	100%	0%	0%
Fluorides	0	1	-	-	-	-	-	-
-particles	0	2.5*	-	-	-	-	-	-
-gaseous	0	2.45*	-	-	-	-	-	-
NO <sub>2</sub>	1	5.6	0.052	0.052	0.052	100%	0%	0%
Ozone	4	0.2	0.036	0.017	0.013	100%	0%	0%

## Gas Tungsten Arc Welding (GTAW)

Table V.A.2.8.1.e

Mild Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	0	5	-	-	-	-	-	-
Al	0	5	-	-	-	-	-	-
Be	0	0.002*	-	-	-	-	-	-
Cd	0	0.005*	-	-	-	-	-	-
Co	0	0.02	-	-	-	-	-	-
Cr	2	0.5	0.005	0.0004	0.00039	100%	0%	0%
Cr VI	N/A	0.05	-	-	-	-	-	-
Cu	1	0.1*	0.0005	0.0005	0.0005	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	2	5	0.0515	0.0284	0.01652	100%	0%	0%
MgO	2	10	0.0005	0.00045	0.00045	100%	0%	0%
Mn	2	0.2	0.0032	0.00175	0.00098	100%	0%	0%
Ni	0	0.2	-	-	-	-	-	-
ZnO	2	5	0.0004	0.00035	0.00035	100%	0%	0%
Fluorides	N/A	1	-	-	-	-	-	-
-particles	N/A	2.5*	-	-	-	-	-	-
-gaseous	N/A	2.45*	-	-	-	-	-	-
NO <sub>2</sub>	0	5.6	-	-	-	-	-	-
Ozone	0	0.2	-	-	-	-	-	-

**Legend:** TWA (n) = 8-hour time-weighted average sample size;  
 OEL = Occupational Exposure Limit (ACGIH TLV/OSHA PEL\*, whichever is more stringent); AL = Action Level (1/2 of the OEL);  
 High = Highest 8-hour TWA exposure; AM = Arithmetic Mean; GM = Geometric Mean  
 % n≤AL = Percent of 8-hour TWA exposures less than or equal to the AL; AL<% n≤OEL = Percent of 8-hour TWA exposures greater than the AL, but less than or equal to the OEL; % n> OEL = Percent of 8-hour TWA exposures greater than the OEL

## Gas Tungsten Arc Welding (GTAW)

**Table V.A.2.8.1.f**

Low Alloy Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	5	5	3.96	1.8144	1.17886	80%	20%	0%
Al	4	5	0.071	0.04125	0.0369	100%	0%	0%
Be	5	0.002*	0.0001	0.00005	0.00004	100%	0%	0%
Cd	5	0.005*	0.0001	0.00006	0.00006	100%	0%	0%
Co	0	0.02	-	-	-	-	-	-
Cr	5	0.5	0.0077	0.00342	0.00242	100%	0%	0%
Cr VI	5	0.05	0.0009	0.00054	0.0005	100%	0%	0%
Cu	5	0.1*	0.0052	0.00356	0.00345	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	5	5	0.336	0.1436	0.10799	100%	0%	0%
MgO	0	10	-	-	-	-	-	-
Mn	5	0.2	0.015	0.00786	0.00600	100%	0%	0%
Ni	5	0.2	0.0011	0.00048	0.00036	100%	0%	0%
ZnO	5	5	0.114	0.06356	0.03494	100%	0%	0%
Fluorides	N/A	1	-	-	-	-	-	-
-particles	N/A	2.5*	-	-	-	-	-	-
-gaseous	N/A	2.45*	-	-	-	-	-	-
NO <sub>2</sub>	1	5.6	0.036	0.036	0.036	100%	0%	0%
Ozone	1	0.2	0.032	0.032	0.032	100%	0%	0%

**Table V.A.2.8.1.g**

High Alloy Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	1	5	0.6539	0.6539	0.6539	100%	0%	0%
Al	3	5	0.0245	0.0109	0.00561	100%	0%	0%
Be	3	0.002*	0.0002	0.00015	0.00012	100%	0%	0%
Cd	3	0.005*	0.0002	0.00011	0.00009	100%	0%	0%
Co	3	0.02	0.0002	0.00015	0.00014	100%	0%	0%
Cr	4	0.5	0.0277	0.00713	0.00073	100%	0%	0%
Cr VI	4	0.05	0.0004	0.00017	0.00012	100%	0%	0%
Cu	1	0.1*	0.0103	0.0103	0.0103	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	4	5	0.06254	0.02029	0.00568	100%	0%	0%
MgO	3	10	0.007	0.00373	0.00178	100%	0%	0%
Mn	3	0.2	0.0087	0.003	0.00056	100%	0%	0%
Ni	4	0.2	0.038	0.00965	0.00071	100%	0%	0%
ZnO	3	5	0.00158	0.00093	0.00056	100%	0%	0%
Fluorides	N/A	1	-	-	-	-	-	-
-particles	N/A	2.5*	-	-	-	-	-	-
-gaseous	N/A	2.45*	-	-	-	-	-	-
NO <sub>2</sub>	5	5.6	0.036	0.0174	0.015	100%	0%	0%
Ozone	8	0.2	0.133	0.042	0.031	87.5%	12.5%	0%

**Legend:** TWA (n) = 8-hour time-weighted average sample size;

OEL = Occupational Exposure Limit (ACGIH TLV/OSHA PEL\*, whichever is more stringent); AL = Action Level (1/2 of the OEL);

High = Highest 8-hour TWA exposure; AM = Arithmetic Mean; GM = Geometric Mean

% n≤AL = Percent of 8-hour TWA exposures less than or equal to the AL; AL<% n≤OEL = Percent of 8-hour TWA exposures greater than the AL, but less than or equal to the OEL; % n> OEL = Percent of 8-hour TWA exposures greater than the OEL

## Flux-Cored Arc Welding (FCAW)

**Table V.A.2.8.1.h**

Mild Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	13	5	5.67	2.07718	1.37738	69%	23%	8%
Al	14	5	0.1	0.01504	0.00432	100%	0%	0%
Be	14	0.002*	0.0121	0.00101	0.00014	93%	0%	7%
Cd	14	0.005*	0.00035	0.00016	0.00014	100%	0%	0%
Co	12	0.02	0.00075	0.00026	0.0002	100%	0%	0%
Cr	16	0.5	0.0013	0.00061	0.00045	100%	0%	0%
Cr VI	N/A	0.05	-	-	-	-	-	-
Cu	14	0.1*	0.0062	0.00145	0.00058	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	16	5	1.46	0.48408	0.19481	100%	0%	0%
MgO	16	10	0.29	0.07049	0.02023	100%	0%	0%
Mn	16	0.2	0.32	0.10299	0.03433	62.5%	12.5%	25%
Ni	16	0.2	0.001	0.00036	0.00031	100%	0%	0%
ZnO	14	5	0.0165	0.00406	0.00236	100%	0%	0%
Fluorides	2	1	0.009	0.007	0.0067	100%	0%	0%
-particles	4	2.5*	0.225	0.076	0.0368	100%	0%	0%
-gaseous	2	2.45*	0.0045	0.0043	0.0042	100%	0%	0%
NO <sub>2</sub>	0	5.6	-	-	-	-	-	-
Ozone	0	0.2	-	-	-	-	-	-

**Table V.A.2.8.1.i**

High Alloy Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	8	5	7.16344	1.99281	1.40830	75%	12.5%	12.5%
Al	3	5	0.024	0.0172	0.01655	100%	0%	0%
Be	3	0.002*	0.0002	0.00011	0.00007	100%	0%	0%
Cd	3	0.005*	0.001	0.00043	0.00027	100%	0%	0%
Co	1	0.02	0.0001	0.0001	0.0001	100%	0%	0%
Cr	3	0.5	0.034	0.02793	0.02748	100%	0%	0%
Cr VI	5	0.05	0.01654	0.00589	0.00344	100%	0%	0%
Cu	1	0.1*	0.0001	0.0001	0.0001	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	3	5	0.1833	0.11543	0.08388	100%	0%	0%
MgO	3	10	0.0149	0.01297	0.01278	100%	0%	0%
Mn	3	0.2	0.06	0.0426	0.03919	100%	0%	0%
Ni	3	0.2	0.0078	0.00483	0.0032	100%	0%	0%
ZnO	0	5	-	-	-	-	-	-
Fluorides	0	1	-	-	-	-	-	-
-particles	1	2.5*	0.064	0.064	0.064	100%	0%	0%
-gaseous	0	2.45*	-	-	-	-	-	-
NO <sub>2</sub>	0	5.6	-	-	-	-	-	-
Ozone	3	0.2	0.039	0.021	0.018	100%	0%	0%

**Legend:** TWA (n) = 8-hour time-weighted average sample size;

OEL = Occupational Exposure Limit (ACGIH TLV/OSHA PEL\*, whichever is more stringent); AL = Action Level (1/2 of the OEL);

High = Highest 8-hour TWA exposure; AM = Arithmetic Mean; GM = Geometric Mean

% n≤AL = Percent of 8-hour TWA exposures less than or equal to the AL; AL<% n≤OEL = Percent of 8-hour TWA exposures greater than the AL, but less than or equal to the OEL; % n> OEL = Percent of 8-hour TWA exposures greater than the OEL

## Gas Metal Arc Welding (GMAW)

Table V.A.2.8.1.j

Mild Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	0	5	-	-	-	-	-	-
Al	0	5	-	-	-	-	-	-
Be	0	0.002*	-	-	-	-	-	-
Cd	0	0.005*	-	-	-	-	-	-
Co	0	0.02	-	-	-	-	-	-
Cr	1	0.5	0.0002	0.0002	0.0002	100%	0%	0%
Cr VI	N/A	0.05	-	-	-	-	-	-
Cu	1	0.1*	0.0002	0.0002	0.0002	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	1	5	0.0016	0.0016	0.0016	100%	0%	0%
MgO	0	10	-	-	-	-	-	-
Mn	1	0.2	0.0002	0.0002	0.0002	100%	0%	0%
Ni	0	0.2	-	-	-	-	-	-
ZnO	0	5	-	-	-	-	-	-
Fluorides	N/A	1	-	-	-	-	-	-
-particles	N/A	2.5*	-	-	-	-	-	-
-gaseous	N/A	2.45*	-	-	-	-	-	-
NO <sub>2</sub>	2	5.6	0.16	0.1525	0.1523	100%	0%	0%
Ozone	1	0.2	0.029	0.029	0.029	100%	0%	0%

## Air Carbon Arc Cutting (ACAC)

Table V.A.2.8.2.a

Mild Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	12	5	123.4	30.8327	15.1031	8.3%	16.7%	75%
Al	8	5	0.96	0.28095	0.11324	100%	0%	0%
Be	10	0.002*	0.0003	0.00013	0.00010	100%	0%	0%
Cd	11	0.005*	0.0011	0.00038	0.00025	91%	9%	0%
Co	8	0.02	0.01733	0.00299	0.00058	87.5%	12.5%	0%
Cr	10	0.5	0.057	0.01265	0.00368	100%	0%	0%
Cr VI	N/A	0.05	-	-	-	-	-	-
Cu	12	0.1*	0.448	0.06871	0.02313	75%	8%	17%
Fe <sub>2</sub> O <sub>3</sub>	12	5	34.75	4.62543	1.69819	67%	25%	8%
MgO	8	10	0.27	0.09231	0.04282	100%	0%	0%
Mn	12	0.2	0.424	0.06460	0.03107	91.7%	0%	8.3%
Ni	11	0.2	0.0878	0.01342	0.00206	100%	0%	0%
ZnO	11	5	0.058	0.02139	0.01294	100%	0%	0%
Fluorides	N/A	1	-	-	-	-	-	-
-particles	N/A	2.5*	-	-	-	-	-	-
-gaseous	N/A	2.45*	-	-	-	-	-	-
NO <sub>2</sub>	4	5.6	0.138	0.0835	0.0733	100%	0%	0%
Ozone	2	0.2	0.037	0.025	0.022	100%	0%	0%

**Legend:** TWA (n) = 8-hour time-weighted average sample size;

OEL = Occupational Exposure Limit (ACGIH TLV/OSHA PEL\*, whichever is more stringent); AL = Action Level (1/2 of the OEL);

High = Highest 8-hour TWA exposure; AM = Arithmetic Mean; GM = Geometric Mean

%n≤AL = Percent of 8-hour TWA exposures less than or equal to the AL; AL<%n≤OEL = Percent of 8-hour TWA exposures greater than the AL, but less than or equal to the OEL; %n>OEL = Percent of 8-hour TWA exposures greater than the OEL

## Air Carbon Arc Cutting (ACAC)

**Table V.A.2.8.2.b**

Low Alloy Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	3	5	26.2	14.5563	9.6674	33%	0%	67%
Al	0	5	-	-	-	-	-	-
Be	0	0.002*	-	-	-	-	-	-
Cd	0	0.005*	-	-	-	-	-	-
Co	0	0.02	-	-	-	-	-	-
Cr	3	0.5	0.001	0.001	0.001	100%	0%	0%
Cr VI	3	0.05	0.0064	0.0031	0.00226	100%	0%	0%
Cu	3	0.1*	0.001	0.001	0.001	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	3	5	0.5762	0.31633	0.26995	100%	0%	0%
MgO	3	10	0.006	0.003	0.00229	100%	0%	0%
Mn	3	0.2	0.042	0.023	0.01970	100%	0%	0%
Ni	3	0.2	0.0003	0.00023	0.00021	100%	0%	0%
ZnO	3	5	0.002	0.00133	0.00126	100%	0%	0%
Fluorides	N/A	1	-	-	-	-	-	-
-particles	N/A	2.5*	-	-	-	-	-	-
-gaseous	N/A	2.45*	-	-	-	-	-	-
NO <sub>2</sub>	0	5.6	-	-	-	-	-	-
Ozone	3	0.2	0.03	0.025	0.024	100%	0%	0%

**Table V.A.2.8.2.c**

High Alloy Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	4	5	23.6	14.5325	9.32638	25%	0%	75%
Al	0	5	-	-	-	-	-	-
Be	1	0.002*	0.0001	0.0001	0.0001	100%	0%	0%
Cd	1	0.005*	0.0001	0.0001	0.0001	100%	0%	0%
Co	0	0.02	-	-	-	-	-	-
Cr	1	0.5	0.0033	0.0033	0.0033	100%	0%	0%
Cr VI	4	0.05	0.022	0.01158	0.00546	100%	0%	0%
Cu	1	0.1*	0.002	0.002	0.002	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	1	5	0.073	0.073	0.073	100%	0%	0%
MgO	0	10	-	-	-	-	-	-
Mn	1	0.2	0.0044	0.0044	0.0044	100%	0%	0%
Ni	1	0.2	0.0013	0.0013	0.0013	100%	0%	0%
ZnO	1	5	0.0035	0.0035	0.0035	100%	0%	0%
Fluorides	N/A	1	-	-	-	-	-	-
-particles	N/A	2.5*	-	-	-	-	-	-
-gaseous	N/A	2.45*	-	-	-	-	-	-
NO <sub>2</sub>	0	5.6	-	-	-	-	-	-
Ozone	2	0.2	0.029	0.026	0.025	100%	0%	0%

**Legend:** TWA (n) = 8-hour time-weighted average sample size;

OEL = Occupational Exposure Limit (ACGIH TLV/OSHA PEL\*, whichever is more stringent); AL = Action Level (1/2 of the OEL);

High = Highest 8-hour TWA exposure; AM = Arithmetic Mean; GM = Geometric Mean

% n≤AL = Percent of 8-hour TWA exposures less than or equal to the AL; AL<% n≤OEL = Percent of 8-hour TWA exposures greater than the AL, but less than or equal to the OEL; % n> OEL = Percent of 8-hour TWA exposures greater than the OEL

## Plasma Arc Cutting (PAC)

**Table V.A.2.8.2.d**

Mild Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	1	5	10.5	10.5	10.5	0%	0%	100%
Al	1	5	0.214	0.214	0.214	100%	0%	0%
Be	0	0.002*	-	-	-	-	-	-
Cd	0	0.005*	-	-	-	-	-	-
Co	1	0.02	0.0006	0.0006	0.0006	100%	0%	0%
Cr	2	0.5	0.015	0.0078	0.003	100%	0%	0%
Cr VI	N/A	0.05	-	-	-	-	-	-
Cu	2	0.1*	0.035	0.0178	0.00458	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	2	5	4.12	2.1059	0.61499	50%	50%	0%
MgO	1	10	0.083	0.083	0.083	100%	0%	0%
Mn	2	0.2	0.018	0.01135	0.00920	100%	0%	0%
Ni	2	0.2	0.01	0.00513	0.00158	100%	0%	0%
ZnO	1	5	0.004	0.004	0.004	100%	0%	0%
Fluorides	N/A	1	-	-	-	-	-	-
-particles	N/A	2.5*	-	-	-	-	-	-
-gaseous	N/A	2.45*	-	-	-	-	-	-
NO <sub>2</sub>	1	5.6	0.57	0.57	0.57	100%	0%	0%
Ozone	N/A	0.2	-	-	-	-	-	-

**Table V.A.2.8.2.e**

Low Alloy Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	1	5	6.6	6.6	6.6	0%	0%	100%
Al	0	5	-	-	-	-	-	-
Be	1	0.002*	0.0002	0.0002	0.0002	100%	0%	0%
Cd	1	0.005*	0.0004	0.0004	0.0004	100%	0%	0%
Co	0	0.02	-	-	-	-	-	-
Cr	1	0.5	0.002	0.002	0.002	100%	0%	0%
Cr VI	1	0.05	0.0003	0.0003	0.0003	100%	0%	0%
Cu	1	0.1*	0.0076	0.0076	0.0076	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	1	5	1.08	1.08	1.08	100%	0%	0%
MgO	0	10	-	-	-	-	-	-
Mn	1	0.2	0.013	0.013	0.013	100%	0%	0%
Ni	1	0.2	0.0011	0.0011	0.0011	100%	0%	0%
ZnO	1	5	0.022	0.022	0.022	100%	0%	0%
Fluorides	N/A	1	-	-	-	-	-	-
-particles	N/A	2.5*	-	-	-	-	-	-
-gaseous	N/A	2.45*	-	-	-	-	-	-
NO <sub>2</sub>	0	5.6	-	-	-	-	-	-
Ozone	0	0.2	-	-	-	-	-	-

**Legend:** TWA (n) = 8-hour time-weighted average sample size;

OEL = Occupational Exposure Limit (ACGIH TLV/OSHA PEL\*, whichever is more stringent); AL = Action Level (1/2 of the OEL);

High = Highest 8-hour TWA exposure; AM = Arithmetic Mean; GM = Geometric Mean

% n≤AL = Percent of 8-hour TWA exposures less than or equal to the AL; AL<% n≤OEL = Percent of 8-hour TWA exposures greater than the AL, but less than or equal to the OEL; % n> OEL = Percent of 8-hour TWA exposures greater than the OEL

## Plasma Arc Cutting (PAC)

Table V.A.2.8.2.f

High Alloy Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	4	5	8.25	4.51167	3.65289	25%	25%	50%
Al	0	5	-	-	-	-	-	-
Be	0	0.002*	-	-	-	-	-	-
Cd	0	0.005*	-	-	-	-	-	-
Co	0	0.02	-	-	-	-	-	-
Cr	0	0.5	-	-	-	-	-	-
Cr VI	4	0.05	0.02042	0.00103	0.00715	100%	0%	0%
Cu	0	0.1*	-	-	-	-	-	-
Fe <sub>2</sub> O <sub>3</sub>	0	5	-	-	-	-	-	-
MgO	0	10	-	-	-	-	-	-
Mn	0	0.2	-	-	-	-	-	-
Ni	0	0.2	-	-	-	-	-	-
ZnO	0	5	-	-	-	-	-	-
Fluorides	N/A	1	-	-	-	-	-	-
-particles	N/A	2.5*	-	-	-	-	-	-
-gaseous	N/A	2.45*	-	-	-	-	-	-
NO <sub>2</sub>	2	5.6	0.83	0.665	0.6442	100%	0%	0%
Ozone	1	0.2	0.019	0.019	0.019	100%	0%	0%

## Oxyacetylene Cutting (OAC)

Table V.A.2.8.2.g

Mild Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	3	5	26.9	13.825	11.2474	0%	0%	100%
Al	1	5	0.01575	0.01575	0.01575	100%	0%	0%
Be	3	0.002*	0.00015	9.8E-05	8.7E-05	100%	0%	0%
Cd	3	0.005*	0.00015	0.00013	0.00013	100%	0%	0%
Co	1	0.02	0.00044	0.00044	0.00044	100%	0%	0%
Cr	3	0.5	0.08	0.03247	0.01563	100%	0%	0%
Cr VI	N/A	0.05	-	-	-	-	-	-
Cu	5	0.1*	0.03	0.01020	0.00700	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	5	5	2.765	1.133	0.80453	80%	20%	0%
MgO	3	10	0.043	0.025	0.02150	100%	0%	0%
Mn	5	0.2	0.03	0.01715	0.01375	100%	0%	0%
Ni	5	0.2	0.02	0.01048	0.00369	100%	0%	0%
ZnO	5	5	0.03	0.01418	0.00877	100%	0%	0%
Fluorides	N/A	1	-	-	-	-	-	-
-particles	N/A	2.5*	-	-	-	-	-	-
-gaseous	N/A	2.45*	-	-	-	-	-	-
NO <sub>2</sub>	5	5.6	0.24	0.1338	0.0793	100%	0%	0%
Ozone	N/A	0.2	-	-	-	-	-	-

**Legend:** TWA (n) = 8-hour time-weighted average sample size;

OEL = Occupational Exposure Limit (ACGIH TLV/OSHA PEL\*, whichever is more stringent); AL = Action Level (1/2 of the OEL);

High = Highest 8-hour TWA exposure; AM = Arithmetic Mean; GM = Geometric Mean

% n≤AL = Percent of 8-hour TWA exposures less than or equal to the AL; AL<% n≤OEL = Percent of 8-hour TWA exposures greater than the AL, but less than or equal to the OEL; % n> OEL = Percent of 8-hour TWA exposures greater than the OEL

## Oxyacetylene Cutting (OAC)

Table V.A.2.8.2.h

Low Alloy Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	3	5	20.9	16.6333	16.3699	0%	0%	100%
Al	0	5	-	-	-	-	-	-
Be	3	0.002*	0.0003	0.0002	0.00019	100%	0%	0%
Cd	3	0.005*	0.0004	0.0003	0.00028	100%	0%	0%
Co	0	0.02	-	-	-	-	-	-
Cr	3	0.5	0.02	0.01233	0.00684	100%	0%	0%
Cr VI	5	0.05	0.0016	0.00102	0.00096	100%	0%	0%
Cu	3	0.1*	0.05	0.037	0.03593	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	3	5	1.07	0.90333	0.8916	100%	0%	0%
MgO	0	10	-	-	-	-	-	-
Mn	3	0.2	0.0147	0.01157	0.01133	100%	0%	0%
Ni	3	0.2	0.012	0.0074	0.00678	100%	0%	0%
ZnO	3	5	0.166	0.11567	0.11059	100%	0%	0%
Fluorides	N/A	1	-	-	-	-	-	-
-particles	N/A	2.5*	-	-	-	-	-	-
-gaseous	N/A	2.45*	-	-	-	-	-	-
NO <sub>2</sub>	0	5.6	-	-	-	-	-	-
Ozone	0	0.2	-	-	-	-	-	-

Table V.A.2.8.2.i

High Alloy Steel								
Analyte	TWA (n)	TLV/PEL* (mg/M <sup>3</sup> )	High (mg/M <sup>3</sup> )	AM (mg/M <sup>3</sup> )	GM (mg/M <sup>3</sup> )	%n≤AL	AL<%n≤OEL	%n>OEL
Fume	2	5	8.394	7.268	7.18024	0%	0%	100%
Al	2	5	0.179	0.1234	0.11016	100%	0%	0%
Be	0	0.002*	-	-	-	-	-	-
Cd	2	0.005*	0.00015	0.0001	0.00008	100%	0%	0%
Co	2	0.02	0.0009	0.00073	0.0007	100%	0%	0%
Cr	2	0.5	0.018	0.01633	0.01625	100%	0%	0%
Cr VI	0	0.05	-	-	-	-	-	-
Cu	2	0.1*	0.0257	0.02085	0.02028	100%	0%	0%
Fe <sub>2</sub> O <sub>3</sub>	2	5	2.62	2.387	2.3756	50%	50%	0%
MgO	2	10	0.064	0.04919	0.0469	100%	0%	0%
Mn	2	0.2	0.032	0.02906	0.02891	100%	0%	0%
Ni	2	0.2	0.043	0.0309	0.02843	100%	0%	0%
ZnO	2	5	0.215	0.181	0.17778	100%	0%	0%
Fluorides	N/A	1	-	-	-	-	-	-
-particles	N/A	2.5*	-	-	-	-	-	-
-gaseous	N/A	2.45*	-	-	-	-	-	-
NO <sub>2</sub>	0	5.6	-	-	-	-	-	-
Ozone	0	0.2	-	-	-	-	-	-

Legend: TWA (n) = 8-hour time-weighted average sample size:

OEL = Occupational Exposure Limit (ACGIH TLV/OSHA PEL\*, whichever is more stringent); AL = Action Level (1/2 of the OEL);

High = Highest 8-hour TWA exposure; AM = Arithmetic Mean; GM = Geometric Mean

% n≤AL = Percent of 8-hour TWA exposures less than or equal to the AL; AL<% n≤OEL = Percent of 8-hour TWA exposures greater than the AL, but less than or equal to the OEL; % n> OEL = Percent of 8-hour TWA exposures greater than the OEL

**CHAPTER V**  
**RESULTS AND DISCUSSION**  
**PART B - PULMONARY FUNCTION STUDY**

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## CHAPTER V

### RESULTS AND DISCUSSION

#### **B. Pulmonary Function Study**

A longitudinal pulmonary function (spirometry) study was conducted on power plant welders employed by a utility company. The spirometric indices forced expiratory volume in one second ( $FEV_1$ ) and forced vital capacity (FVC) were evaluated longitudinally for the group of welders as a whole, to estimate mean annual change. A number of independent variables were examined for their effect on annual change in  $FEV_1$  and FVC over time.

##### **1. Longitudinal Study Design for Chronic Occupational Respiratory Disease**

A longitudinal design was selected for the study. There are several reasons for and benefits of this approach, including:

- to estimate the annual change in  $FEV_1$  and FVC for the study group
- to determine if the subjects' pulmonary functions in terms of  $FEV_1$  and FVC appear to be declining at a rate in excess of that expected for aging alone
- to distinguish more subtle changes over time, allowing for early detection of trends and appropriate response measures

- to better ascertain the types, magnitudes, frequencies, and temporal sequences of exposures versus health outcomes
- to better verify spirometric testing procedures and surveillance procedures

A purely prospective study is ideal for a study such as this because prospective studies present the opportunity for total design and control of the measurement and evaluation of exposure and the health outcome. In this case, the exposure assessment, while conducted over a limited portion of the span of the study, was designed and controlled by the study investigators. The health outcome measurement protocol and documentation was not, and was partially retrospective. It is more difficult to verify the accuracy of information under the latter circumstance, but the considerable time span and resources were not available in this case to conduct a purely prospective study.

## **2. Scope and Duration**

The scope of the pulmonary function study consisted of collection, tabulation, and statistical analysis of spirometric test data by years of welding, smoking status, packyears, years of asbestos exposure, age, change in weight, years of follow-up, and number of tests per subject. The spirometric test data and other medical surveillance information had been obtained on a periodic basis, from 43 welders working in nine electric utility power plants. There were 195 total spirometric observations each for FEV<sub>1</sub> and FVC, resulting in an average of 4.54 observations per welder. The vast majority of the spirometry testing and administration of medical surveillance questionnaires was

conducted during the time span of 1990-2000, with a range of 1981-2000. The average follow-up period was 7.6 (SD 3.1) years, with a range of 1.7-17.9 years.

### **3. Selection of Subjects**

The entire population of welders employed at the nine power plants as of 1994 was enrolled as subjects in the study.

### **4. Selection of Controls**

The exposed study group served as their own controls, as the longitudinal study involved repeated measures (FEV<sub>1</sub> and FVC) on the same subjects over time. This approach is preferred for longitudinal studies of pulmonary function, because of the benefit of eliminating interpersonal variability, which may be considerable for pulmonary function. In addition, this eliminated other problems pertaining to the comparability of subjects and controls that could introduce bias, such as smoking history, other exposures, age, height, weight, etc.

### **5. Study Agent Exposure Estimation**

A comprehensive exposure characterization was conducted and covered in *Part A Exposure Assessment*. This information was very useful. However, due to the large number of combinations of welding and thermal cutting processes conducted with various base metals and consumables, a quantitative cumulative exposure estimate was not practical as a variable in the statistical model. Instead, a surrogate measure of exposure was used in the model – years as a welder. The rationale for this also includes the

assumption that, for the study group, the welders' exposures are roughly equivalent in terms of air contaminant types and concentrations. This assumption was considered to be justifiable, based on two factors. First, was the consistency of responses obtained, during seven years of interviews, with regard to the types and proportions of work pertaining to processes conducted, materials worked with, environmental conditions, and other variables that influence welding exposures. Second, was that work assignments tended to be allocated in a random fashion, based on worker availability. The fact that welders' exposures were deemed to be fairly equivalent in terms of air contaminant types and concentrations precludes looking for a dose-response effect in these terms.

The exposure evaluation was based on information collected during the period 1994-2000. It was assumed, based on numerous industrial hygiene survey worker interviews conducted from 1994 to 2000, that the exposures were likely to be very similar for the time period prior to 1994. The interviews that provided information on the types and relative proportions of work, materials used, and conditions could have been subject to inaccurate recall and responses; however, the large numbers of interviews over time with various experts produced consistent responses. It was recognized that welders' exposures may vary between individuals during the same time period; however, the fact that work was largely randomly assigned, and the uniformity of responses obtained during interviews, rationalized the decision to assume a large degree of comparability. However, variability does exist in terms of exposure duration, and was addressed by including "years of welding" in the model. It is possible that years of welding could have been subject to recall bias. However, the potential for recall bias should have been somewhat

controlled, as once again, subjects were asked to fill out questionnaires on a regular basis (usually at least every two years) during the period of spirometric testing. The comprehensive exposure information obtained by observations, interviews, sample size and exposure evaluation was unprecedented compared with previous welder respiratory health studies.

## **6. Expected Annual Decline in FEV<sub>1</sub> and FVC**

Previous studies and other authoritative references have reported that the average rate of aging-related decline expected for FEV<sub>1</sub> and FVC is 25-30 ml per year.

## **7. Variables Included in the Statistical Analysis**

The variables included in the analysis are specified and discussed below.

### **7.1 Dependent Variables**

Dependent variables included in the model were as follows.

- A) Annual change in height-adjusted FEV<sub>1</sub> (ml per year)
- B) Annual change in height-adjusted FVC (ml per year)

Height was recognized initially to be a potential confounder. Therefore, FEV<sub>1</sub> and FVC were adjusted by height using a standard methodology to remove its confounding effect. The procedure involved adjusting FEV<sub>1</sub> and FVC for each test by multiplying by the squared ratio of the average height of all subjects divided by the average height for that subject (1). Inspection of plots of height-adjusted FEV<sub>1</sub> and FVC by age indicated a

linear decline with age. Linear regression analysis was used to estimate the annual change in height-adjusted FEV<sub>1</sub> and FVC as described in *Section 8*.

## **7.2 Independent Variables**

Independent variables included in the model were as follows.

- A) Welding exposure
- B) Smoking history
- C) Asbestos exposure
- D) Age at spirometry
- E) Annual change in weight
- F) Follow-up years
- G) Number of tests per subject

Multiple linear regression was used to estimate the effect of the above independent variables on annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC.

### **7.2.1 Welding Exposure**

As mentioned, the metric for welding exposure was years as a welder. Welding years for each subject was calculated by taking the average of the welding years coinciding with each of their spirometry test dates.

### **7.2.2 Smoking History**

Smoking history was included in the model as both a categorical and a continuous variable. First, smoking status was included as a categorical variable in the form of never smoker and smoker, the latter including both current and former smokers. Smoking status was not significant as a variable in the model. Using the Means Procedure, subjects were then stratified into four values of smoking status, consisting of: never smoker, former smoker who quit prior to enrollment in the study, former smoker who quit during the study, and current smoker. The mean annual changes in FEV<sub>1</sub> and FVC were examined for each of the groups. Smoking history was also quantified as a continuous variable in the model using packyears (packs smoked per day times number of years smoking). Packyears for each subject was calculated by taking the average of the packyears coinciding with each of their spirometry test dates.

### **7.2.3 Asbestos Exposure**

Asbestos exposure was included in the model as a continuous variable, asbestos years, which was the number of years worked in a plant containing asbestos thermal system insulation. Asbestos exposure years for each subject were calculated by taking the average of the years of asbestos exposure coinciding with each of their spirometry test dates.

Power plants constructed prior to the 1980's often contain asbestos thermal system insulation. Asbestos thermal system insulation is a more friable form of asbestos, more subject to damage or deterioration, and thus, more likely to result in exposure. The

much-publicized asbestos hazard generated significant concern in the company during the 1980's and many power plant workers, including most welders, were enrolled in the asbestos medical surveillance program during this time. This was more often done at employee request in response to their concerns, rather than for documented exposure reasons, although some welders did perform limited asbestos work. Since this time, most welders have voluntarily discontinued participation in asbestos medical surveillance. In general, it is believed, based on interviews, that welders were perceived and treated as a more skilled craft than others assigned to maintenance such as insulators, laborers, or mechanics. As such, welders would normally have been preferentially reserved for and assigned to welding work rather than asbestos removal. However, it is possible that some welders may have had exposure to asbestos, some more so than others. If significant asbestos exposure did occur, it is probably more likely that it occurred in older plants containing thermal system insulation. In addition, asbestos hazard awareness and training have increased over the years and asbestos regulations have become more stringent. Therefore, it is more probable that older welders have had more asbestos exposure. Significant asbestos exposure could have an effect on pulmonary function manifested as decrements in FVC. Significant exposure from smoking and/or welding fumes would be expected to be manifested more likely as decrements in FEV<sub>1</sub>. Historical asbestos exposure information on individual welders was not available for the study. In lieu of this, a surrogate for asbestos exposure was used, the number of years worked in a plant containing asbestos thermal system insulation.

#### **7.2.4 Age at Spirometry**

Age is a common confounder, and was expected to be related to spirometric performance. When the subjects' FEV<sub>1</sub> and FVC test values were initially plotted versus age, a linear relationship was observed for both indices. The use of change in FEV<sub>1</sub> and FVC per year as the response variables took into account the decline of spirometric measures with age. Thus, a linear regression analysis was used to adjust the spirometric measures for age. Even though age was adjusted via linear regression, age was still allowed to be a potential predictor or effect modifier in the model. Age for each subject was calculated by taking the average of the ages coinciding with each of the spirometry test dates. Multiple linear regression was used to estimate the effect of age on annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC.

#### **7.2.5 Change in Body Weight**

Annual change in body weight (pounds) was included as in the model, as some previous studies have indicated that weight gain was significantly associated with decline in FEV<sub>1</sub> and FVC. Each subject's annual change in weight was determined by simple linear regression analysis of all his recorded weights. Weight had previously been self-reported and recorded on respiratory medical surveillance questionnaires at intervals coinciding with each spirometric test. Multiple linear regression was used to estimate the effect of weight change on annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC.

Increases in weight, often also associated with aging and sometimes also associated with reduced physical fitness, may be inversely related to spirometric performance. Weight

(provided by the subject) was recorded on medical surveillance questionnaires and also during testing; recognizing that actual measurement would have been more accurate.

#### **7.2.6 Follow-up Years**

The number of years of follow-up for each subject differed. Thus, follow-up years was included as a covariate in the model for each subject to determine if there was an association between number of years of follow-up and annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC.

#### **7.2.7 Number of Tests Per Subject**

Since the number of spirometry tests per subject differed, This factor was included as a covariate in the model for each subject to determine if there was an association between number of spirometry tests per subject and annual change in height-adjusted FEV<sub>1</sub> and FVC.

### **8. Statistical Methods Utilized**

The appropriateness of using simple and multiple linear regression in evaluating the effect of the independent variables, including age, follow-up years, and annual change in weight on height-adjusted FEV<sub>1</sub> and FVC, was examined by use of regression diagnostics (e.g., residual plots). Inspection of the residual plots indicated that a) a linear relationship was apparent; b) the normality assumption was justified; and, c) the variance appeared to be constant. Thus, linear and multiple linear regression were deemed appropriate as methods of analysis.

A two-step process was used in the analysis to determine the group mean annual change in height-adjusted FEV<sub>1</sub> and FVC. First, simple linear regression was used to determine each subject's mean annual change for of all the spirometric data points available for that subject. Second, the group mean for the subjects' individual mean annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC was calculated.

Last, stepwise multiple linear regression was used to analyze the effects of the independent variables (years of welding, years of asbestos, smoking status, packyears, age, weight change, time, and number of tests) on changes in pulmonary function. Models were constructed for annual change in height-adjusted FEV<sub>1</sub> and for height-adjusted FVC. The stepwise multiple linear regression process is explained as follows (2). The computer program is instructed to enter the one variable with the strongest association with the dependent variable. After this, the second variable is entered with the next strongest association with the dependent variable. The explanatory strength of the variable entered ( $r^2$ ) changes as each new variable is entered. The stepping continues until none of the remaining independent variables meets the predetermined criterion for being entered (e.g.,  $p \leq 0.1$  or the increase in  $r^2$  is  $\geq 0.01$ ) or until all of the variables have been entered. Once variables are entered, they can also be removed at subsequent steps if they are determined not to be significant. When the stepping stops, the analysis is complete. In addition to watching for the statistical significance of the overall equation and of each variable entered, the investigator keeps a close watch on the overall  $r^2$  for each step, which is the proportion of variation the model has explained so far. In multiple

regression equations that are statistically significant, the  $r^2$  indicates how much of the variation is being explained by all the variables in the model.

The parameter estimates for each independent variable in the model describe how much change there is in the dependent variable when the independent variable changes by one unit and the other independent variables are held constant. The key hypothesis is whether the estimate is equal to zero. If the estimate is not statistically significant, the corresponding independent variable would probably be dropped from the model because there is no linear relationship between that independent variable and the dependent variable once the other independent variables are taken into account (3). The SAS system was used for all statistical analyses.

## **9. Study Analysis Results and Discussion**

The study analysis consisted of: calculating descriptive statistics for the study group; linear regression to estimate mean annual change in height-adjusted FEV<sub>1</sub>, height-adjusted FVC, and body weight; and multiple linear regression both to examine the effect of variables on annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC; and to determine the best model for predicting annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC.

### **9.1 Study Group Descriptive Characteristics for First and Last Test**

Pulmonary function tests had been administered to 43 Caucasian male welders. The welders had participated in an average of 4.54 tests each, with a range of from 2 to 9 tests.

The average follow-up period was 7.6 (SD 3.1) years, with a range of 1.7-17.9 years. Descriptive statistics for the 43 welders, pertaining to the first and last spirometry test, are provided in *Tables V.B.9.1a,b*. *Table V.B.9.1a* contains the categorical descriptors and variables: number of subjects, sex, race, smoking status – expressed as never, former, current, and asbestos exposure in terms of yes or no. *Table V.B.9.1b* contains the continuous descriptors and variables: age in years, packyears (smoking), asbestos exposure years, weight in pounds, height in inches, welding years, FEV<sub>1</sub>, height-adjusted FEV<sub>1</sub>, FVC, and height-adjusted FVC at initial test, FEV<sub>1</sub>, height-adjusted FEV<sub>1</sub>, FVC, and height-adjusted FVC at final test, and follow-up time in years.

**Descriptive Statistics of Study Population (n = 43) for Categorical Variables**  
*Table V.B.9.1a*

<b>Characteristic</b>	<b>Initial Test (mean)</b>	<b>Final Test (mean)</b>
Number of subjects	43	43
Sex (% male)	100	100
Race (% Caucasian)	100	100
Smoke		
Never (%)	48.9	48.9
Former (%)	34.9	46.5
Current (%)	16.3	4.7
Asbestos_exposure		
Yes (%)	81.4	81.4
No (%)	18.6	18.6
Time (years)		7.6

**Descriptive Statistics of Study Population (n = 43) for Continuous Variables***Table V.B.9.1b*

Characteristic	Initial Test (mean)	SD	Min	Max	Final Test (mean)	SD	Min	Max
Age in years	38.6	7	21.8	55.1	46.2	5.8	35.6	57.9
Packyears	12.8	20.3	0	82	13.8	20.8	0	82
Asbestos years	10.6	7.5	0	25.4	16.9	9.6	0	33.1
Weight (pounds)	192.1	29.1	145	270	198.1	31.4	150	300
Height (inches)	70.4	2.6	64	77	70.3	2.6	63	77
Welding years	11.6	5.8	0	25.2	19.0	5.3	6	30.5
FEV <sub>1</sub> (ml)	4258	701	2430	6490	3832	736	2220	6320
Height-adjusted FEV <sub>1</sub> (ml)	4258	651	2386	5698	3831	617	2180	5277
FVC (ml)	5502	882	4190	8310	4930	869	3500	7820
Height-adjusted FVC (ml)	5498	781	4115	7025	4926	674	3437	6530
Follow-up time (years)					7.6	3.1	1.7	17.9

**9.2 Annual Changes in Height-Adjusted FEV<sub>1</sub> and Height-Adjusted FVC**

The Means Procedure (SAS) was used to calculate the descriptive statistics for annual change in FEV<sub>1</sub> and FVC (Table V.B.9.2). The mean annual change in height-adjusted FEV<sub>1</sub> for the group during the average 7.6-year follow-up was a decline of 49.4 (SD 87.4) ml. The range was a decline of 204.9 ml per year to an increase of 384.1 ml. A 95 percent confidence interval (CI) was calculated with the following equation (1):

$$95\% \text{ CI} = \text{mean annual change in height-adjusted FEV}_1 \pm \text{standard error} \times 1.96$$

$$95\% \text{ CI} = 49.4 \pm 13.3 \times 1.96 = 49.4 \pm 26.1 = 23.3 - 75.5$$

The mean annual change in height-adjusted FVC for the group during the average 7.6-year follow-up was a decline of 70.8 (SD 101.3) ml. The range was a decline of 256.8 ml per year to an increase of 384.1 ml. A 95% CI was calculated with the following equation:

$$95\% \text{ CI} = \text{mean annual change in height-adjusted FVC} \pm \text{standard error} \times 1.96$$

$$95\% \text{ CI} = 70.8 \pm 15.5 \times 1.96 = 70.8 \pm 30.4 = 40.4 - 101.2$$

**Descriptive Statistics for Annual Change in Height-Adjusted FEV<sub>1</sub> and Height-Adjusted FVC**

*Table V.B.9.2*

<b>Variable</b>	<b>N</b>	<b>Mean</b>	<b>Std Deviation</b>	<b>Std Error</b>	<b>Minimum</b>	<b>Maximum</b>
Change in FEV <sub>1</sub>	43	-49.4	87.4	13.3	-204.9	384.1
Change in FVC	43	-70.8	101.3	15.5	-256.8	384.1

**9.3 Regression with All Independent Variables in the Model**

Regression analysis was conducted with all independent variables included in the models predicting annual change in height-adjusted FEV<sub>1</sub> and annual change in height-adjusted FVC. The only significant association at the 95 percent confidence level (CL) with annual change in height-adjusted FEV<sub>1</sub> was with annual change in weight ( $P$ -value = 0.0148). The only significant association at the 95% CL with annual change in height-adjusted FVC was with annual change in weight ( $P$ -value = 0.0101). The  $P$ -values for the height-adjusted FEV<sub>1</sub> model and the height-adjusted FVC model were 0.2624 and 0.3193. There was a large discrepancy for the FEV<sub>1</sub> model between the R-square (0.2384) and the adjusted R-square (0.0591), and also for the FVC model between the R-square (0.2225) and the adjusted R-square (0.0396). This indicated that there was redundant information in the model that was not useful. Therefore, the analysis proceeded utilizing stepwise multiple linear regression. The information generated in the analysis with all independent variables in the model is provided for annual change in height-adjusted FEV<sub>1</sub> in *Table V.B.9.3a*, and annual change in height-adjusted FVC in *Table V.B.9.3b*.

**Regression Model with All Independent Variables  
for Annual Change in Height-Adjusted FEV<sub>1</sub> as the Dependent Variable  
Analysis of Variance**

*Table V.B.9.3a*

Source	DF	Sum of Squares	Mean Square	F Value	p-value
Model	8	76506	9563.24626	1.33	0.2624
Error	34	244466	7190.18269		
Corrected total	42	320972			

Root MSE	84.79494	R-square	0.2384
Dependent mean	-49.40839	Adjusted	0.0591
Coefficient of variation	-171.62055	R-Square	

Variable	DF	Parameter Estimate	Std Error	t Value	p-value
Intercept	1	127.23416	151.49813	0.84	0.4069
Age	1	-3.21560	3.74986	-0.83	0.3972
Welding years	1	1.41590	3.82672	0.37	0.7137
Packyears	1	0.60536	0.98981	0.61	0.5449
Asbestos years	1	1.27209	1.89513	0.67	0.5066
Follow-up years	1	-4.73298	7.02414	-0.67	0.5050
Smoke	1	4.33800	33.37064	0.13	0.8973
Weight change (annual)	1	-19.14550	7.45617	-2.57	0.0148
Number of tests	1	-8.49878	13.93002	-0.61	0.5458

**Regression Model with All Independent Variables  
for Annual Change in Height-Adjusted FVC as the Dependent Variable  
Analysis of Variance**

*Table V.B.9.3b*

Source	DF	Sum of Squares	Mean Square	F Value	p-value
Model	8	95962	11995	1.22	0.3193
Error	34	335333	9862.74165		
Corrected total	42	431295			

Root MSE	99.31134	R-square	0.2225
Dependent mean	-70.79129	Adjusted	0.0396
Coefficient of variation	-140.28750	R-Square	

Variable	DF	Parameter Estimate	Std Error	t Value	p-value
Intercept	1	67.17296	177.43372	0.38	0.7074
Age	1	-2.21241	4.39181	-0.50	0.6177
Welding years	1	-0.49785	4.48183	-0.11	0.9122
Packyears	1	0.00150	1.15926	0.00	0.9990
Asbestos years	1	1.23323	2.21957	0.56	0.5821
Follow-up years	1	-3.31579	8.22663	-0.40	0.6894
Smoke	1	15.62923	39.08349	0.40	0.6917
Weight change (annual)	1	-23.79443	8.73262	-2.72	0.0101
Number of tests	1	-3.90790	16.31476	-0.24	0.8121

#### **9.4 Stepwise Regression to Determine the Best Models for Annual Change in Height-Adjusted FEV<sub>1</sub> and Height-Adjusted FVC**

Stepwise regression analysis was conducted with the independent variables included in the models predicting annual change in height-adjusted FEV<sub>1</sub> and annual change in height-adjusted FVC. The single independent variable with the greatest association with annual change in height-adjusted FEV<sub>1</sub> was annual change in weight. The F statistic for testing whether there is a significant straight line regression with only annual change in weight in the model is 6.65, which has a *P*-value of 0.0136, significant at the 95% CL. The R-square (0.1396) indicates that almost 14% of the variability in annual change in height-adjusted FEV<sub>1</sub> is explained by only annual change in weight in the model. The parameter estimate for annual change in body weight (-17.55183) indicates that for every annual increase of one pound in weight, FEV<sub>1</sub> can be expected to decline annually almost 18 ml. The next single independent variable with the greatest association with annual change in height-adjusted FEV<sub>1</sub>, after including annual change in weight in the model, was follow-up years. The F statistic for testing whether there is a significant straight line regression with annual change in weight and follow-up years in the model is 5.16, which has a *P*-value of 0.0102, significant at the 95% CL. The R-square (0.2051) indicates that almost 21% of the variability in annual change in height-adjusted FEV<sub>1</sub> is explained by annual change in weight and follow-up years in the model. The partial F test assesses whether the addition of an independent variable (follow-up years) contributes significantly to the linear prediction of the dependent variable (annual change in height-adjusted FEV<sub>1</sub>) (4). The partial F statistic is 3.3, which has a *P*-value of 0.077, not significant at the 95% CL, but significant at the 90% CL. Although follow-up years was

not significant at the 95% CL, examination of the partial R-square for time (.0655) indicates that, by itself, it explains almost 7% of the variability in annual change in height-adjusted FEV<sub>1</sub>. The parameter estimate for annual change in weight (-17.95426) with follow-up years in the model again indicates that for every annual increase of one pound in weight, FEV<sub>1</sub> can be expected to decline annually almost 18 ml. No other variable met the 0.15 significance level for entry into the model.

The single independent variable with the greatest association with annual change in height-adjusted FVC was also annual change in weight. The F statistic for testing whether there is a significant straight line regression with only annual change in weight in the model is 9.68, which has a *P*-value of 0.0034. The R-square (0.1909) indicates that approximately 19% of the variability in annual change in height-adjusted FVC is explained by annual change in weight. The parameter estimate for annual change in weight (-23.79699) indicates that for every annual increase of one pound in weight, FVC can be expected to decline annually almost 24 ml. No other variable met the 0.15 significance level for entry into the model. The information generated in the analysis is provided for annual change in height-adjusted FEV<sub>1</sub> in *Tables V.B.9.4a,b,c* and annual change in height-adjusted FVC in *Tables V.B.9.4d,e*.

**Stepwise Regression Model**

**Annual Change in Weight as the Independent Variable**

**Annual Change in Height-Adjusted FEV<sub>1</sub> as the Dependent Variable**

**Analysis of Variance**

*Table V.B.9.4a*

Source	DF	Sum of Squares	Mean Square	F Value	<i>p</i> -value
Model	1	44800	44800	6.65	0.0136
Error	41	276172	6735.90987		
Corrected total	42	320972			

Variable	Parameter Estimate	Std Error	Type II SS	F Value	p-value
Intercept	-35.83359	13.57777	46916	6.97	0.0117
Weight change (annual)	-17.55183	6.80585	44800	6.65	0.0136

### Stepwise Selection: Step 2

Variable Follow-up Years Entered: R-Square = 0.2051 and C(p) = -1.5143

### Analysis of Variance

Table V.B.9.4b

Source	DF	Sum of Squares	Mean Square	F Value	p-value
Model	2	65823	32912	5.16	0.0102
Error	40	2255149	6378.72094		
Corrected total	42	320972			

Variable	Parameter Estimate	Std Error	Type II SS	F Value	p-value
Intercept	19.35310	33.14567	2174.60837	0.34	0.5626
Follow-up years	-7.20866	3.97072	21023	3.30	0.0770
Weight change (annual)	-17.95426	6.62665	46825	7.34	0.0099

Bounds on condition number: 1.0011, 4.0045

All variables left in the model are significant at the 0.15 level. No other variable met the 0.15 significance level for entry into the model.

### Summary of Stepwise Selection

Table V.B.9.4c

Step	Variable Entered	Variable Removed	# Variables In	Partial R <sup>2</sup>	Model R <sup>2</sup>	C(p)	F Value	p-value
1	Weight change (annual)		1	0.1396	0.1396	-0.5904	6.65	0.0136
2	Follow-up years		2	0.0655	0.2051	-1.5143	3.30	0.0770

### Stepwise Regression Model

Annual Weight Change as the Independent Variable

Annual Change in Height-Adjusted FVC as the Dependent Variable

### Analysis of Variance

Table V.B.9.4d

Source	DF	Sum of Squares	Mean Square	F Value	p-value
Model	1	82352	82352	9.68	0.0034
Error	41	348943	8510.80788		
Corrected total	42	431295			

Variable	Parameter Estimate	Std Error	Type II SS	F Value	p-value
Intercept	-52.38642	15.26215	100271	11.78	0.0014
Weight change (annual)	-23.79699	7.65014	82352	9.68	0.0034

Bounds on condition number: 1, 1

All variables left in the model are significant at the 0.15 level. No other variable met the 0.15 significance level for entry into the model.

### Summary of Stepwise Selection

Table V.B.9.4e

Step	Variable Entered	Variable Removed	# Variables In	Partial R <sup>2</sup>	Model R <sup>2</sup>	C(p)	F Value	p-value
1	Weight change (annual)		1	0.1909	0.1909	-3.6201	9.68	0.0034

## 9.5 Welding Exposure

The metric for welding exposure was years as a welder. The average number of years as a welder at initial test was 11.6 years, with a standard deviation (SD) of 5.8 years. The range was 0 to 25.2 years. The average number of years as a welder at final test was 19 (SD 5.3) years, with a range of 6 to 30.5 years.

The Means Procedure (SAS) was used to calculate the descriptive statistics for welding years for the group (Table V.B.9.5). Note: due to the weighting process used, these values may differ somewhat from those provided above.

### Descriptive Statistics for Welding Years

Table V.B.9.5

Variable	N	Mean	Std Deviation	Std Error	Minimum	Maximum
Welding years	43	15.6	5.2	0.8	3.7	26.6

Multiple linear regression was used to estimate the effect of years of welding on annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC. Years of welding was not significant as a predictor variable in the model.

## **9.6 Smoking History**

The percentage of smokers decreased from 16.3% at the time of the initial test to 4.7% at the time of the final test. The percentage of former smokers increased from 34.9% at initial test to 46.5% at final test. The percentage of never smokers was 48.9% at both initial test and final test (*Table V.B.9.1a*).

Smoking status was included as a categorical variable in the form of never smoker and smoker, the latter including both current and former smokers. Using the Means Procedure, subjects were then stratified into four subgroups for smoking status, consisting of: never smoker, former smoker that quit prior to enrollment in the study, former smoker that quit during the study, and current smoker. Smoking has been implicated as a significant cause of accelerated decline in FEV<sub>1</sub>. However, there was no relationship between annual change in FEV<sub>1</sub> and smoking history in terms of either smoking status or packyears. This could have been influenced by the small sample size for current smokers (n = 2). When smoking groups were stratified, the greatest to least mean annual declines in FEV<sub>1</sub> occurred, respectively in:

- 1) Former smokers who quit smoking after the first spirometry test  
(n = 7; mean packyears = 32.3; mean annual decline = 72 ml)
- 2) Current smokers  
(n = 2; mean packyears = 23.5; mean annual decline = 63 ml)
- 3) Nonsmokers  
(n = 21; 0 packyears; mean annual decline = 59 ml)
- 4) Former smokers who quit smoking prior to the first spirometry test

(n = 13; mean packyears = 21.4; mean annual decline = 20 ml)

The former smokers who quit smoking after the first spirometry test had a larger mean annual decline in FEV<sub>1</sub> than did the current smokers and the former smokers who quit prior to the first spirometry test. However, they had a larger mean packyears than did the other subgroups. The nonsmokers had a larger mean annual decline than the former smokers who quit prior to the first spirometry test.

The descriptive statistics for annual changes in height-adjusted FEV<sub>1</sub> and height-adjusted FVC for each of the groups are presented in *Table V.B.9.6a*.

**Annual Change in Height-Adjusted FEV<sub>1</sub> and Height-Adjusted FVC by Smoking Status**  
*Table V.B.9.6a*

Smoke Group	N	Variable	Mean	Std Deviation	Minimum	Maximum
Nonsmokers	21	FEV <sub>1</sub> change	-58.9	46.4	-138.9	47.4
		FVC change	-75.2	60.5	-165.1	74.9
Former (quit before first test)	13	FEV <sub>1</sub> change	-19.7	134.0	-204.9	384.1
		FVC change	-53.8	153.8	-256.8	384.1
Former (quit after first test)	7	FEV <sub>1</sub> change	-72.2	84.8	-183.2	91.0
		FVC change	-97.9	97.2	-252.5	56.8
Current	2	FEV <sub>1</sub> change	-63.1	47.1	-96.4	-29.9
		FVC change	-39.6	79.4	-95.8	16.5

Smoking history was also quantified as a continuous variable in the model in units of packyears. The descriptive statistics for packyears are presented in *Table V.B.9.6b*

**Descriptive Statistics for Packyears**  
*Table V.B.9.6b*

Variable	N	Mean	Std Deviation	Std Error	Minimum	Maximum
Packyears	43	12.8	20.3	3.1	0	82.0

Multiple linear regression was used to estimate the effect of smoking status and packyears on annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC. Neither

smoking status, consisting of either 2 or 4 levels, nor packyears was significant as a predictor variable in the model.

### 9.7 Asbestos Exposure

The fraction of welders who had worked in a plant containing asbestos thermal system insulation was 35 of 43 (81.4%). Those welders assigned to plants that either did or did not contain asbestos thermal system insulation did not have their assignments change during the course of the study. For the study group as a whole, the mean years of asbestos exposure at initial test was 10.6 (SD 7.5) years, with a range of 0-25.5 years. The mean years of asbestos exposure at final test was 16.9 (SD 9.6) years, with a range of 0-33.1 years. The Means Procedure (SAS) was used to calculate the descriptive statistics for years of asbestos exposure for the group as a whole during the span of the follow-up (Table V.B.9.7).

**Descriptive Statistics for Years of Asbestos Exposure**

*Table V.B.9.7*

Variable	N	Mean	Std Deviation	Std Error	Minimum	Maximum
Asbestos years	43	14.0	8.4	1.3	0	28.7

Multiple linear regression was used to estimate the effect of years of asbestos exposure on annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC. Years of asbestos exposure was not significant as a predictor variable in the model.

### 9.8 Age at Spirometry

Average age at time of the initial test was 38.6 (SD 7), with a minimum and maximum age of 21.8 and 55.1, respectively. Average age at time of the final test was 46.2 (SD

5.8), with a minimum and maximum age of 35.6 and 57.9, respectively. The Means Procedure (SAS) was used to calculate the descriptive statistics for age for the group as a whole during the span of the follow-up (*Table V.B.9.8*).

**Descriptive Statistics for Age**

*Table V.B.9.8*

Variable	N	Mean	Std Deviation	Std Error	Minimum	Maximum
Age at spirometry	43	42.7	6.0	0.9	30.6	56.5

Age had been adjusted for by converting the dependent variables, consisting of change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC, into units of ml per year. Multiple linear regression was used to estimate the effect of age on annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC. No significant association was found.

### **9.9 Change in Body Weight**

The average weight at time of initial test was 192.1 (SD 29.1) pounds, with a range of 145 to 270 pounds. The average weight at time of final test was 198.1 (SD 31.4) pounds, with a range of 150 to 300 pounds. The Means Procedure (SAS) was used to calculate the descriptive statistics for annual change in weight for the group as a whole during the span of the follow-up (*Table V.B.9.9*).

**Descriptive Statistics for Annual Change in Weight**

*Table V.B.9.9*

Variable	N	Mean	Std Deviation	Std Error	Minimum	Maximum
Weight change (lbs.)	43	0.77	1.86	0.28	-5.77	5.03

A 95% CI was calculated with the following equation:

$$95\% \text{ CI} = \text{mean annual change in weight} \pm \text{Standard Error} \times 1.96$$

$$95\% \text{ CI} = 0.7734119 \pm 0.2837639 \times 1.96 = 0.7734119 \pm 0.5561772 = 0.2172347 - 1.3295891 = 0.22 - 1.33$$

Multiple linear regression was used to estimate the effect of change in weight on annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC. Regression analysis was conducted with all independent variables included in the models predicting annual change in height-adjusted FEV<sub>1</sub> and annual change in height-adjusted FVC. The only significant association at the 95% CL with annual change in height-adjusted FEV<sub>1</sub> was with annual change in weight (*P*-value = 0.0148). The only significant association at the 95% CL with annual change in height-adjusted FVC was with annual change in weight (*P*-value = 0.0101). The F statistic for testing whether there is a significant straight line regression with only annual change in weight in the model is 6.65, which has a *P*-value of 0.0136, significant at the 95% CL. The R-square (0.1396) indicates that almost 14% of the variability in annual change in height-adjusted FEV<sub>1</sub> is explained by only annual change in weight in the model. The parameter estimate for annual change in weight (-17.55183) indicates that for every annual increase of one pound in weight, FEV<sub>1</sub> can be expected to decline annually almost 18 ml. The next single independent variable with the greatest association with annual change in height-adjusted FEV<sub>1</sub>, after including annual change in weight in the model, was follow-up years. The F statistic for testing whether there is a significant straight line regression with annual change in weight and follow-up years in the model is 5.16, which has a *P*-value of 0.0102, significant at the 95% CL. The R-square (0.2051) indicates that almost 21% of the variability in annual change in height-

adjusted FEV<sub>1</sub> is explained by annual change in weight and follow-up years in the model. The partial F test assesses whether the addition of an independent variable (follow-up years) contributes significantly to the linear prediction of the dependent variable (annual change in height-adjusted FEV<sub>1</sub>) (4). The partial F statistic is 3.3, which has a *P*-value of 0.077, not significant at the 95% CL, but significant at the 90% CL. Although follow-up years was not significant at the 95% CL, examination of the partial R-square for time (0.0655) indicates that, by itself, it explains almost 7% of the variability in annual change in height-adjusted FEV<sub>1</sub>. The parameter estimate for annual change in weight (-17.95426) with follow-up years in the model again indicates that for every annual increase of one pound in weight, FEV<sub>1</sub> can be expected to decline annually almost 18 ml. No other variable met the 0.15 significance level for entry into the model. The single independent variable with the greatest association with annual change in height-adjusted FVC was also annual change in weight. The F statistic for testing whether there is a significant straight line regression with only annual change in weight in the model is 9.68, which has a *P*-value of 0.0034. The R-square (0.1909) indicates that approximately 19% of the variability in annual change in height-adjusted FVC is explained by annual change in weight. The parameter estimate for annual change in weight (-23.79699) indicates that for every annual increase of one pound in weight, FVC can be expected to decline annually almost 24 ml.

### 9.10 Follow-up years

The Means Procedure (SAS) was used to calculate the descriptive statistics for follow-up years for the group as a whole (*Table V.B.9.10*).

**Descriptive Statistics for Follow-up Years**

*Table V.B.9.10*

Variable	N	Mean	Std Deviation	Std Error	Minimum	Maximum
Follow-up years	43	7.6	3.1	0.5	1.7	17.9

Multiple linear regression was used to estimate the effect of follow-up years on annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC. No significant association was found.

### 9.11 Number of Tests Per Subject

The number of tests per subject was included in the model to determine if the number of tests a subject was associated with annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC. The Means Procedure (SAS) was used to calculate the descriptive statistics for number of tests per subject for the group as a whole during the span of the follow-up (*Table V.B.9.11*).

**Descriptive Statistics for Number of Tests Per Subject**

*Table V.B.9.11*

Variable	N	Mean	Std Deviation	Std Error	Minimum	Maximum
Tests	43	4.54	1.70	0.26	2	9

Multiple linear regression was used to estimate the effect of number of tests per subject on annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC. No significant association was found.

## 10. Precision

Issues pertaining to study precision are discussed in the following section.

### 10.1 Sample Sizes for Subjects and Health Outcome Measurements

Compared with previous welder respiratory health studies, this was not a large sample size in terms of number of subjects (43); however, it was a large sample size in terms of number of observations (spirometric tests) on the subjects over time. There were 195 total observations, resulting in an average of 4.54 observations per welder. The distribution of the number of observations by number of subjects is presented in *Table V.B.10.1*.

**Number of Observations by Number of Welders**

*Table V.B.10.1*

<b># Observations</b>	2	3	4	5	6	7	8	9
<b># Welders</b>	6	7	7	11	8	2	1	1

## 11. Validity

Issues pertaining to study validity are discussed in the following section.

### 11.1 Selection Bias

Selection bias is a concern in the form of subject self-selection and the healthy worker effect. These two forms of selection bias are discussed below.

### **11.1.1 Subject Self-Selection Regarding Health Outcome Status**

The utility company had a policy of administering respiratory health questionnaires and requiring spirometric testing for welders every two years during most of the time span of the study. At times, this schedule was not enforced for various reasons. For example, at times, some welders missed scheduled spirometry testing and were either never rescheduled or failed to attend follow-up testing. Tests may have been missed for reasons due to illness, vacation, work emergency maintenance projects, or intentional absence. Therefore, over the span of the study some welders accumulated more spirometry test data than others. This could potentially have some effect on results in the form of self-selection bias if welders that were more health conscious were more responsive to testing and accumulated more test data points. It would be expected that more data (greater sample size) would lead to less error due to random variability for those welders. If these welders through self-selection had more spirometric testing and better spirometric performance, which is effort dependent, this could bias results toward the null hypothesis. In addition, if welders with more data points were more health conscious and used ventilation or respiratory protection more than others, the potential exists for this reduced exposure to result in a reduced decline (after accounting for aging) in spirometric values; which could bias results toward the null hypothesis. In response to these issues, a covariate was introduced in the model to determine if the number of observations on a subject is a significant independent variable. Results indicated no significant differences.

### **11.1.2 Healthy Worker Effect**

It was possible that there was a higher proportion of individuals healthier than the average among the subjects, reflected as higher than average spirometric values. However, a cross-sectional study would be more subject to selection bias in the form of the healthy worker effect than a longitudinal study such as this (1). Even if workers started out initially with higher than average spirometric values, a longitudinal study such as this detects more subtle change over time. Thus, a longitudinal study may determine that even while workers may not be "abnormal" due previous exposures by the endpoint of a study, they may be trending towards dysfunction at a rate accelerated over that expected for aging alone.

### **11.2 Information Bias**

Information bias involves misclassification of the study subjects with respect to disease or exposure status. It is customary to consider two types of misclassification: nondifferential and differential misclassification. Nondifferential information bias occurs when the likelihood of misclassification is the same for both groups compared. This can occur if exposed and nonexposed persons are equally likely to be misclassified according to exposure. Nondifferential misclassification will bias the effect estimate toward the null value. Hence, it is of particular concern in studies that show no association between exposure and disease. Differential information bias occurs when the likelihood of misclassification of exposure is different in diseased and nondiseased persons or the likelihood of misclassification of disease is different in exposed and nonexposed persons. This can bias the observed effect estimate either toward or away from the null value (5).

Information bias is a concern in the form of instrumentation/recorder bias and subject/respondent bias. These two forms of information bias are discussed below.

#### **11.2.1 Instrumentation/Recorder Bias**

Instrumentation/recorder bias would be considered a form of information bias. In measuring and recording spirometry tests, instrument or recorder bias could occur. The proper interpretation of longitudinal or follow-up studies requires the ability to distinguish lung function changes due to disease from other sources of variability. Adherence to recommended spirometry standards should minimize the variability due to inconsistent technique, fluctuating patient effort, or instrument inaccuracy (6). The calibration records were available for a portion, but not all of the past spirometric testing. The medical director and testing technicians stated that to the best of their knowledge, the spirometers had been properly calibrated. When spirometric test results and other relevant information was collected and tabulated, the process was repeated several times for each subject, in order to reduce the likelihood of errors.

#### **11.2.2 Subject/Respondent Bias**

Subject/respondent bias would be considered a form of information bias. Two types of subject/respondent bias would include recall bias and reporting bias (7). Welding years, smoking, and weight change are examples of exposures that could be affected by this bias.

Smoking history could have been subject to recall bias or inaccurate responses, leading to misclassification. However, the potential for recall bias should have been somewhat controlled, as subjects were asked to fill out questionnaires on a regular basis (usually at least every two years) during the period of spirometric testing. It was commonly understood that medical surveillance information was kept confidential. This may have somewhat alleviated the potential for individuals' concerns pertaining to revealing smoking status accurately.

Weight could also have been subject to inaccurate responses as weight was self-reported at the time of each spirometry test. However, if weight gain were inaccurate, it may be more likely that it would be underestimated. Despite this, a significant association was found between annual decline in the spirometric indices and annual gain in weight.

### **11.3 Confounding**

Confounding is a systematic error (or bias) which may or may not be present in a particular study. Confounding is a distortion in an effect measure that results from the effect of another variable that is associated with the exposure under study. A confounding factor must: 1) be a risk factor for the disease among the nonexposed; 2) be associated with the exposure variable in the population from which the cases derive; and 3) not be an intermediate step in the causal path between the exposure and the disease (8). Thus, concomitant exposures to other agents (in addition to the agent under study) should also be identified and, if possible, quantified because they can be confounders if they are asymmetrically distributed across study groups. Variables with the potential to be

confounding factors were included and adjusted for in the analysis. This was done to determine if in fact accelerated decline was present, whether it was related to welding exposures, another variable, or multiple factors. Those variables included years of welding, smoking status, packyears, years of asbestos exposure, age, height, weight change, follow-up years, and number of tests per subject. No evidence during the analysis indicated that confounding was an issue.

## **12. Effect Modification**

Effect modification is defined as the effect of an exposure varying with a third variable (9). Interactions of the independent variables were included in the model in order to determine if effect modification was present. Interactions of the variables were examined during the analysis and were determined to be not significant. Therefore effect modification was not present.

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**CHAPTER VI  
SUMMARY AND CONCLUSIONS  
PART A - EXPOSURE ASSESSMENT STUDY**

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## **CHAPTER VI**

### **SUMMARY AND CONCLUSIONS**

#### **A. Exposure Assessment Study**

Chapter VI Part A contains the summary and conclusions of the exposure assessment study.

#### **1. Welding Industrial Hygiene Surveys**

The following sections summarize the findings of the welding industrial hygiene surveys.

##### **1.1 Welder Average Task/Time Allocation**

The average number of exposure days per year and the average daily exposure time were estimated. In-house welders may work more than 8-hour shifts and 40-hour weeks. Although variable during the year, the average may be closer to 45-hour work weeks, factoring in two days of overtime per month of extra shifts unplanned emergency maintenance. A typical power plant welder may perform welding work an average of 47 weeks per year, considering leave, training, etc. Potential exposure work time within a normal 8-hour shift would be close to 6 hours and 45 minutes; however, actual long-term average exposure time is probably significantly less. Daily tasks and thus exposure time may vary significantly due to the non-repetitive nature of maintenance work. The long-

term average proportions of total work time spent on typical work tasks were welding 50%, related nonexposure activities 40%, thermal cutting 5%, and grinding 5%.

## **1.2 Power Plant Systems Worked On**

The power plant worked on, from greatest to least amount of work, included:

- piping and valves (40%);
- boiler and boiler tubes (20%);
- coal conveyors (10%);
- coal pulverizers (20%);
- structural steel (10%).

## **1.3 Welding Environmental Locations/Ventilation Use**

The relative proportions of work by location, and by use of local exhaust ventilation were estimated as follows:

- inside the plant (without mechanical ventilation), 60%;
- inside the welding shop (with local exhaust ventilation), 20%;
- outdoors (no mechanical ventilation, but subject to air movement from wind), 15%;
- confined or enclosed spaces, with and without local exhaust ventilation, 5%.

## **1.4 Welding and Thermal Cutting Processes Used**

The welding processes used in order of greatest to least proportion of work were:

- shielded metal arc welding (SMAW), 80%;

- gas tungsten arc welding (GTAW), 10%;
- flux-cored arc welding (FCAW), 10%;
- gas metal arc welding (GMAW), < 1%.

The cutting processes used in order of greatest to least proportion of work were:

- oxyacetylene cutting (OAC), 60%;
- air carbon arc cutting (ACAC), 35%;
- plasma arc cutting (PAC), 5%.

### **1.5 Base Metals/Consumables by Estimated Fraction of Welding Work**

The main base metals/consumables worked with in order of greatest to least proportion of work were categorized as:

- "mild steel", also referred to as carbon steel (80%);
- "low alloy", containing either 1.25% chromium (Cr) / 0.5% Molybdenum (Mo) or 2.25% Cr / 1% Mo (15%);
- "high alloy", comprised of either stainless steel, containing 18-25% Cr / 8-14% nickel (Ni); or hardsurfacing, containing 27% Cr (5%);
- "medium alloy", containing 9% Cr / 1% Mo (< 1%);
- or "other", consisting of other metals (aluminum), alloys (inconel, monel), or cladding (galvanized, cadmium) (< 1%).

## **1.6 Welding/Cutting on Painted Steel**

It was estimated that 10-20% of steel to be welded or cut was painted, the vast majority of which was mild steel. Of the painted steel, it was estimated in the year 2000 that 90% of the time, it was stripped back first, mostly by using abrasive methods such as grinders or needle scalers with attached HEPA vacuums, and occasionally by vacuum blasting. Smaller surface areas were sometimes stripped by caustic paste. The remaining 10% of the time, it was burned off during welding or cutting. Historically (pre-1993, previous to the influence of the OSHA Lead in Construction Standard), the paint was reportedly burned off a higher proportion of the time. It was estimated that during this time period, 60-70% of paint was stripped back prior to welding or cutting by using grinders without attached HEPA vacuums. For some smaller jobs, methylene chloride strippers, since substituted by caustic paste, would have been used. Respiratory protection probably was worn on a discretionary basis. Numerous paint bulk samples had been collected from steel surfaces. Lead and zinc chromate were frequently found, either in combination or alone. Occasionally, lead as lead chromate was detected. On only two occasions cadmium was identified, once on coal chutes, and once on handrails. A random sample survey of 300 of the paint bulk sample records in some larger power plants indicated that a very high proportion of painted surfaces contained lead and/or zinc chromate.

## **1.7 Welder Hazard Perception and Respiratory Protection/Ventilation Practices**

Welders were frequently unaware of the types and hazards of the air contaminants they may be exposed to. Especially in the case of contract welders, had the company not intervened and stripped paint or required appropriate respiratory protection, lead and zinc

chromate-painted surfaces would likely have been frequently subjected to hot work by unprotected personnel. With regard to welding/cutting on unpainted steel, respiratory protection was worn rarely by in-house welders, except at times in confined spaces, and more rarely by contractor welders. Respiratory protection was often perceived as a hindrance to conducting welding. Ventilation was often perceived as unwieldy and impractical for most plant work locations, except for inside the welding shops, where fixed local exhaust ventilation with hanging flexible ducts was installed.

## **2. Welder Exposure Monitoring and Evaluation**

The following sections summarize the findings of the welder exposure monitoring and evaluation.

### **2.1 Welding 8-Hour TWA Exposures Exceeding OELS**

Welding air contaminants with 8-hour TWA exposures that exceeded OELs are identified in *Table VI.A.2.1*, for each welding process stratified by base metal/consumable, respectively. Exposure-related information for those air contaminants is discussed in more detail in section 2.2.

## Welding 8-Hour TWA Exposures Exceeding OELs

Table VI.A.2.1

Main Base Metal Classifications		Overexposures by Welding Processes Utilized (fraction of 8-hr TWA samples exceeding OEL)			
Base Metal	Alloy Type	SMAW (80%)	GTAW (10%)	FCAW (10%)	GMAW (<1%)
Mild Steel (80%)	NA	no OELs exceeded	no OELs exceeded	Manganese (4/16) Welding fume (1/13) Beryllium (1/14)	no OELs exceeded (n=2)
Low Alloy Steel (15%)	Chromium-molybdenum 1.25-2.25% Cr	no OELs exceeded	no OELs exceeded	not used	not used
Medium Alloy Steel (<1%)	Chromium-molybdenum 9% Cr	no OELs exceeded	not sampled	not used	not used
High Alloy Steel (5%)	Stainless 18-24%Cr; 8-12% Ni Hardsurfacing xx%Cr	Chromium <sup>VI</sup> (5/17)*  Welding fume (4/24)	no OELs exceeded	Welding fume (1/8)	not used

\* In comparison, applying the OSHA PEL (ceiling) for hexavalent chromium instead of the ACGIH TLV (8-hr. TWA) would have yielded a fraction of 6/17 samples exceeding the PEL. The current OSHA PEL for hexavalent chromium is a ceiling value of 0.1 mg/m<sup>3</sup>, measured as chromium anhydride (CrO<sub>3</sub>). The amount of chromium<sup>VI</sup> in the compound equates to a PEL of 0.052 mg/m<sup>3</sup>. This ceiling limit applies to all forms of chromium.

## 2.2 Significant Welding Air Contaminants

In the following subsection, individual air contaminant 8-hour TWA welding exposures that exceeded OELs are summarized.

### 2.2.1 Hexavalent Chromium

Eight-hour TWA exposures over the OEL (ACGIH TLV 0.05 mg/m<sup>3</sup> (soluble)) to hexavalent chromium occurred only during shielded metal arc welding (SMAW) in 5 of 17 samples (29.4%). The highest exposure (0.22 mg/m<sup>3</sup>) at 4.4 times the OEL (along with the second (0.207 mg/m<sup>3</sup>), third (0.1348 mg/m<sup>3</sup>) and fifth highest (0.0631 mg/m<sup>3</sup>)) was a coal mill overlay. Hard surfacing electrodes (27% Cr) were applied to increase wear resistance on the inside of coal mills; work in the coal mills constitutes a confined

space exposure. Local exhaust ventilation was used during the highest exposure, along with the third and fifth highest exposures. The fourth highest exposure ( $0.121 \text{ mg/m}^3$ ) involved welding on the boiler wet bottom seal inside the boiler bottom, an enclosed space with limited general ventilation, with stainless steel electrodes. This latter exposure was only sampled for 255 minutes due to logistical problems. In addition, the estimated arc-on percent time on this job was only 50%. It is estimated, hypothetically, that if the above-mentioned job was sampled for the full 8-hour shift (allowing for a typical exposure time of 6 hours and 45 minutes) at that air concentration ( $0.227 \text{ mg/m}^3$ ), the resultant 8-hr TWA exposure would have been  $0.192 \text{ mg/m}^3$ .

If the OSHA threshold ( $0.052 \text{ mg/m}^3$  ceiling) is applied, exposures over the PEL to hexavalent chromium occurred only during shielded metal arc welding (SMAW), in 6 of 17 jobs sampled (35.3%). The highest hexavalent chromium air concentrations on these jobs occurred during welding: 1) inside coal mills during hard surfacing ( $0.621$ ,  $0.457$ ,  $0.255$ ,  $0.231$ , and  $0.082 \text{ mg/m}^3$ ) at 11.9, 8.9, 4.9, 4.4, and 1.6 times the OSHA ceiling, respectively; 2) on the boiler wet bottom seal inside the boiler bottom ( $0.227 \text{ mg/m}^3$ ) at 4.4 times the OSHA ceiling; and 3) on boiler tube shields ( $0.06 \text{ mg/m}^3$ ) at 1.2 times the OSHA ceiling.

All hexavalent chromium samples were collected outside the welding hood, to allow sufficient space for respiratory protection.

If a new OSHA PEL for hexavalent chromium of  $0.0005 \text{ mg/m}^3$  was to be adopted, exposures from all of the welding processes conducted in this study could exceed this threshold whenever low or high alloy steels are worked on, based on both 8-hour TWA exposures and sample air concentration projections.

### **2.2.2 Manganese**

Eight-hour TWA overexposures (ACGIH TLV  $0.2 \text{ mg/m}^3$ ) to manganese occurred during flux-cored arc welding (FCAW) and air carbon arc cutting (ACAC) on mild steel. Overexposures resulted during FCAW in 4 of 16 samples (25%). The highest exposure ( $0.32 \text{ mg/m}^3$ ) was 1.6 times the TLV. The four overexposures had estimated arc-on percent times of 50% for the three highest and 60% for the fourth highest, indicating the potential for higher exposures given greater arc-on percent times. All manganese samples were collected inside the welding hood.

### **2.2.3 Welding Fumes (Total)**

Eight-hour TWA exposures over the ACGIH TLV  $5 \text{ mg/m}^3$  to welding fume occurred during shielded metal arc welding (SMAW) and flux-cored arc welding (FCAW). Overexposures occurred during SMAW only welding with high alloy metal in 4 of 24 samples (16.7%). These four jobs involved coal mill overlays, using hard surfacing electrodes on the insides of coal mills. The highest two exposures ( $15.6$  and  $12.7 \text{ mg/m}^3$ ) occurred on jobs without the use of local exhaust ventilation, the third and fourth highest exposures ( $8.56$  and  $8.17 \text{ mg/m}^3$ ) occurred with local exhaust ventilation. The only other

welding overexposure to welding fume occurred during FCAW in 1 (5.67 mg/m<sup>3</sup>) of 13 samples (7.7%).

#### **2.2.4 Beryllium**

Beryllium was present, inside the hood, in 1 sample of 14 samples (7.1%) at a level above the analytical limit of detection (LOD), during FCAW on structural mild steel with an estimated arc-on time of 50%. It may be an occasional contaminant in the steel making process. The 8-hour TWA was 0.012 with an average air concentration for 200 minutes of 0.029, versus an OSHA PEL/ACGIH TLV of 0.002 mg/m<sup>3</sup>. In the 1999 ACGIH TLVs, beryllium was placed on the List of Intended Changes for the year 2000, with a proposed TLV of 0.0002 mg/m<sup>3</sup>.

### **2.3 Thermal Cutting 8-Hour TWA Exposures Exceeding the OELS**

Thermal cutting air contaminants with 8-hour TWA exposures that exceeded the OELs are identified in *Table VI.A.2.3*, for each cutting process stratified by base metal/consumable, respectively. Exposure-related information for those air contaminants is discussed in more detail in section 2.4.

## Thermal Cutting 8-Hour TWA Exposures Exceeding OELs

Table VI.A.2.3

Main Base Metal Classifications		Overexposures by Thermal Cutting Processes Utilized (fraction of 8-hr TWA samples exceeding OEL)		
Base Metal	Alloy Type	ACAC (35%)	PAC (5%)	OAC (60%)
Mild Steel (80%)	NA	Welding fume (9/12) Copper (2/12) Iron oxide (1/12) Manganese (1/12)	Welding fume (1/1)	Welding fume (3/3)
Low Alloy Steel (15%)	Chromium-molybdenum 1.25-2.25% Cr	Welding fume (2/3)	Welding fume (1/1)	Welding fume (3/3)
High Alloy Steel (5%)	Stainless 18-24%Cr, 8-12%Ni Hardsurfacing 27%Cr	Welding fume (3/4)	Welding fume (2/4) Chromium <sup>VI</sup> (1/1)*	Welding fume (2/2)

\* In comparison, applying the OSHA PEL (ceiling) for hexavalent chromium instead of the ACGIH TLV (8-hr. TWA) would have yielded a fraction of 1/1 sample exceeding the PEL. The current OSHA PEL for hexavalent chromium is a ceiling value of 0.1 mg/m<sup>3</sup>, measured as chromium anhydride (CrO<sub>3</sub>). The amount of chromium<sup>VI</sup> in the compound equates to a PEL of 0.052 mg/m<sup>3</sup>. This ceiling limit applies to all forms of chromium.

### 2.4 Significant Thermal Cutting Air Contaminants

In the following subsection, individual air contaminant 8-hour TWA thermal cutting exposures that exceeded OELs are summarized.

#### 2.4.1 Welding Fumes (Total)

Most thermal cutting samples indicated eight-hour TWA exposures over the ACGIH TLV (5 mg/m<sup>3</sup>) to welding fume. Overexposures occurred during all thermal cutting processes, and with all types of metals. Overexposures occurred in 14 of 19 samples (73.7%) for air carbon arc cutting (ACAC), 4 of 6 plasma arc cutting (PAC) samples (66.7%), and 8 of 8 oxyacetylene cutting (OAC) samples (100%). The highest exposures occurred during the most heavily sampled process, ACAC. The four highest values for ACAC were 123.4, 96.8, 68.15, and 65.8 mg/m<sup>3</sup>. These values were, respectively, 24.68, 19.36, 13.63, and 13.16 times the TLV, and were in excess of the NIOSH assigned

protection factor of 10 for a half face respirator. The next highest exposure processes were OAC with a high value of 26.9, and PAC at 10.5 mg/m<sup>3</sup>.

#### **2.4.2 Copper**

The only process with significant air concentrations of copper was ACAC. Copper was present, inside the hood, in excess of the OSHA PEL in 2 of 12 (16.7%) 8-hour TWA samples collected. The source was likely the copper arc-gouging rod. The work was on mild steel boiler bottoms. The highest sample had an 8-hour TWA of 0.448 with an air concentration for 130 minutes of 0.659 versus the OSHA PEL of 0.1 mg/m<sup>3</sup>.

#### **2.4.3 Manganese**

The only 8-hour TWA overexposure to manganese in thermal cutting (0.424 mg/m<sup>3</sup>), at 2.12 times the TLV, was experienced during ACAC in 1 of 12 samples (8.3%). However, this ACAC sample was only the ninth highest with regard to total welding fume. All manganese samples were collected inside the welding hood.

#### **2.4.4 Iron Oxide**

The highest levels of iron oxide were found in ACAC on mild steel. Iron oxide was an overexposure in 1 of 12 ACAC jobs sampled (8.3%) on mild steel. The 8-hour TWA, inside the hood, was 34.75 mg/m<sup>3</sup> with an air concentration of 57.5 mg/m<sup>3</sup> for 130 minutes, and an arc-on time of 75%. This sample corresponded to the third highest welding fume sample for ACAC (68.15 mg/m<sup>3</sup>). In three additional boiler bottom samples, air concentrations exceeded the ACGIH TLV of 5 mg/m<sup>3</sup>, but lacked sufficient

exposure time to exceed the 8-hour TWA TLV. These air concentrations were 18.1, 17.6, and 9.22 mg/m<sup>3</sup>. Sampling was conducted inside the hood for the 8-hour TWA overexposure and the two highest air concentration samples. An air concentration of 5.4 mg/m<sup>3</sup> inside the hood was detected during PAC on low alloy metal in the boiler water wall outdoors for 96 minutes. The 8-hour TWA was 1.08 mg/m<sup>3</sup>.

#### **2.4.5 Hexavalent Chromium**

An air concentration (0.245 mg/m<sup>3</sup>) 4.9 times the ACGIH TLV of 0.05 mg/m<sup>3</sup> for soluble hexavalent chromium was detected in 1 of 4 samples (25%) of PAC on high alloy (stainless) steel. The work was inside the plant on a boiler burner, but lasted only 40 minutes, with an arc-on time of 50%, and was sampled outside the hood. The eight-hour TWA was 0.020 mg/m<sup>3</sup>. The air concentration (0.245 mg/m<sup>3</sup>) was 4.7 times the OSHA ceiling.

If a new OSHA PEL of 0.0005 mg/m<sup>3</sup> was adopted, exposures from all of the thermal cutting processes conducted in this study could potentially exceed this threshold, whenever low or high alloy steels are worked on, based on both 8-hour TWA exposures and sample air concentration projections.

#### **2.5 Surface Coating Hot Work 8-Hour TWA Exposures Exceeding OELs**

Numerous 8-hour TWA exposures over the OSHA PEL for lead (0.050 mg/m<sup>3</sup>) and the ACGIH TLV for zinc chromate (0.010 mg/m<sup>3</sup>) occurred during welding and thermal cutting on painted steel.

## **2.6 Significant Surface Coating Hot Work Air Contaminants**

Significant air contaminants that were generated during surface coating hot work are summarized below.

### **2.6.1 Lead**

The highest 8-hour TWA exposure ( $0.287 \text{ mg/m}^3$ ) was from ACAC on paint containing approximately 12% lead. The highest air concentration ( $0.780 \text{ mg/m}^3$ ) was obtained during OAC on 11% lead-based paint.

### **2.6.2 Zinc Chromate**

The highest 8-hour TWA exposure ( $0.04 \text{ mg/m}^3$ ) was from ACAC on paint containing approximately 0.08% zinc chromate. The highest air concentration ( $0.078 \text{ mg/m}^3$ ) was obtained during PAC on 1.36% zinc chromate-based paint. Notably, there was a much higher percentage of zinc chromate present in paint on several jobs (up to 9%); however, exposure levels were lower due to use of ventilation.

### **2.6.3 Welding Fumes (Total)**

The highest 8-hour TWA exposure ( $463 \text{ mg/m}^3$ ) was from ACAC on paint inside a boiler penthouse that had been opened up (semi-enclosed), subject to windy conditions. The highest air concentration ( $850 \text{ mg/m}^3$ ) was obtained during ACAC on the same job.

## **2.7 Major Variables that Influenced Air Contaminant Exposures**

Major variables that influenced the generation or concentration of air contaminants are summarized in the following subsection.

### **2.7.1 Process**

Of the welding processes, the highest welding fume and manganese concentrations and 8-hour TWA exposures occurred in FCAW, with SMAW not far behind. GTAW air concentrations and 8-hour TWA exposures were far lower than the previous two processes. GMAW, a rarely conducted process, was not sampled adequately to make a determination. However, the literature indicates that in terms of fume levels, it would be significantly higher than GTAW, but lower than SMAW. FCAW produced higher air concentrations and 8-hour TWA exposures of manganese, probably due to the higher production rate of this wire-fed process.

All three thermal cutting processes utilized - air carbon arc cutting (ACAC), plasma arc cutting (PAC), and oxyacetylene cutting (OAC) - resulted in 8-hour TWA air contaminant exposures over the OELs. Most samples of cutting yielded overexposures to welding fume. The sample sizes for PAC and OAC were small. The most heavily sampled process, ACAC on mild steel, also produced overexposures to copper in 2 of 12 samples (16.7%), and to manganese and iron oxide in 1 of 12 samples (8.3%) each.

### **2.7.2 Base Metals/Consumables**

With regard to the specific air contaminants generated, hexavalent chromium was only present in significant concentrations in fume from high alloy steel. Manganese was only present in significant concentrations in mild steel FCAW, but this was believed to be due to the fact that the heaviest FCAW jobs with the most arc-on time were conducted on mild steel.

For thermal cutting, there was no reason to believe that the metal type in itself influenced the level of total fume generation, except that the heaviest exposure jobs were probably conducted on mild steel. PAC and ACAC on high alloy steel did produce hexavalent chromium, but air concentrations and 8-hour TWA exposures were below the ACGIH TLV, with one exception. PAC on stainless steel (the only sample collected) produced an air concentration of hexavalent chromium approximately 5 times the ACGIH TLV of 0.05 mg/m<sup>3</sup>. However, due to the short job duration, this was not an 8-hour TWA overexposure. OAC on high alloy steel was not sampled. A limitation to drawing conclusions on hexavalent chromium exposures during cutting on high alloy steel was the small sample sizes (n = 4, 4, and 0, for PAC, ACAC, and OAC, respectively).

### **2.7.3 Environmental Conditions**

As expected, confined/enclosed spaces allowed fumes to accumulate, resulting in much higher exposure levels, at times despite the application of local exhaust ventilation. For example, for the SMAW process, the highest welding fume and hexavalent chromium concentrations and 8-hour TWA exposures over the OELs occurred inside coal mills

during hardsurfacing overlays and inside boiler bottoms welding on the stainless steel seal trough or refractory hangers.

Welding and thermal cutting outdoors reduced exposure levels through dispersion by air movement. The highest exposure concentrations, and most of the exposures over the OELs occurred indoors without ventilation. Nonetheless, exposures over OELs did occur during work outdoors. For example, lead and zinc chromate 8-hour TWA overexposures occurred during thermal cutting on painted surfaces outdoors. Fume 8-hour TWA exposures over the OEL also resulted from thermal cutting on unpainted steel outdoors.

Local exhaust ventilation reduced exposure levels when properly applied. However, overexposures did result at times when ventilation was either insufficient (some of the confined space coal mill jobs), or not kept close enough.

### **3. Conclusions**

In the electric utility power plant welding environment, maintenance welder exposures over OELs are likely, especially the ACGIH TLVs. However, it is likely that the overexposures occur on an intermittent rather than a routine basis. The thermal cutting processes would be expected to produce air concentrations of fume that exceed OELs, with a strong potential for 8-hour TWA overexposures, subject to exposure time within an 8-hour shift. In particular, ACAC produces extremely high fume and individual air contaminant exposures. Hexavalent chromium may be produced during thermal cutting on stainless steels. For the welding processes, 8-hour TWA exposures over the ACGIH

TLV for may be expected periodically for manganese and for fume during FCAW. Periodic exposures over the ACGIH TLV for soluble hexavalent chromium would be likely during SMAW on high alloy steels (stainless steels or hard surfacing), particularly in confined spaces or conditions of inadequate airflow. It is hypothesized (but not verified in this study due to small sample size) that FCAW on high alloy steels may also produce hexavalent chromium overexposures. Welding or thermal cutting on painted steel would be expected to produce high levels of lead, zinc chromate, or other metal pigments present in addition to pyrolysis products.

#### **4. Generalizability**

It is hypothesized that this study has good generalizability to the population of electric utility power plant maintenance welders in the U.S., and potentially elsewhere, assuming workshifts, processes, materials, and working conditions are similar.

#### **5. Recommendations**

Welders, supervisors, project managers, planner/schedulers should be educated as to the health hazards of air contaminants associated with the specific processes, tasks, and materials worked with. Knowledge of which processes are the more hazardous in terms of air contaminant generation may allow for substitution of a less hazardous process (e.g., stripping back paint prior to cutting versus cutting on painted steel with respiratory protection). Prejob briefings should be conducted to discuss the hazards of specific jobs.

Exposure assessment should be conducted in a manner that is process/task/material/condition-specific. Because of the large number of above-mentioned variables, exposure assessment may be a considerable undertaking. Sample sizes may need to be large due to variability. Information pertaining to hexavalent chromium exposures in the various thermal cutting procedures on high alloy steel would be useful.

The use of local exhaust ventilation should be encouraged to reduce exposures. Because most jobs are conducted in locations other than the welding shop, where fixed local exhaust ventilation may be provided, portable local exhaust ventilation should be made readily available with adequate time allowed for set up. The duct should be kept near the point of fume generation for adequate capture. A device that showed some promise in the study utilized a magnet attached to the flexible duct to allow for convenient movement toward the point of fume generation, as the work progresses.

Local exhaust ventilation may not always be sufficient to adequately reduce exposure levels (e.g., thermal cutting on lead-painted steel), or may be impractical in others. Thus, respiratory protection will continue to be necessary at times. Therefore, welders need to be: 1) evaluated for fitness to wear a respirator by a qualified medical professional on a routine schedule; 2) trained in respiratory protection; 3) provided respiratory protection selected to the level of the specific air contaminants; and 4) fit-tested on the respirators selected. Respiratory protection should also be made available for voluntary use, even at below OELs, for those welders who may wish to minimize their exposures to as low an extent as reasonably achievable.

## References

1. U.S. Department of Labor, Occupational Safety and Health Administration. OSHA Unified Agenda Long Term Actions: *1967. Occupational exposure to hexavalent chromium (preventing occupational illness: chromium)*. OSHA website, Nov. 11, 2000.

**CHAPTER VI**  
**SUMMARY AND CONCLUSIONS**  
**PART B - PULMONARY FUNCTION STUDY**

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## CHAPTER VI

### SUMMARY AND CONCLUSIONS

#### **B. Pulmonary Function Study**

Chapter VI Part B contains the summary and conclusions for the welder pulmonary function study.

##### **1. Summary of Study Results**

The study analysis consisted of: calculating descriptive statistics for the study group; linear regression to estimate mean annual change in height-adjusted FEV<sub>1</sub>, height-adjusted FVC, and weight; and multiple linear regression, both to examine the effect of variables on annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC, and to determine the best model for predicting annual change in height-adjusted FEV<sub>1</sub> and height-adjusted FVC.

##### **1.1 Annual Changes in FEV<sub>1</sub> and FVC**

The mean annual change in height-adjusted FEV<sub>1</sub> for the group during the average 7.6-year follow-up was a decline of 49.4 (SD 87.4) ml per year. The range was a decline of 204.9 ml per year to an increase of 384.1 ml. The 95% CI was a decline of 23.3 - 75.5 ml per year.

The mean annual change in height-adjusted FVC for the group during the average 7.6-year follow-up was a decline of 70.8 (SD 101.3) ml per year. The range was a decline of 256.8 ml per year to an increase of 384.1 ml. The 95% CI was 40.4 - 101.2 ml per year.

Previous studies and other authoritative references have reported that the average rate of aging-related decline in the general population expected for both FEV<sub>1</sub> and FVC is approximately 25-30 ml per year. The welders in this study, as a whole, had a greater decline in FEV<sub>1</sub> and FVC.

### **1.2 Regression with All Independent Variables in the Model**

Regression analysis was conducted with all independent variables included in the models predicting annual change in height-adjusted FEV<sub>1</sub> and annual change in height-adjusted FVC. The only significant association at the 95% CL with annual change in height-adjusted FEV<sub>1</sub> was with annual change in weight ( $P$ -value = 0.0148). The only significant association at the 95% CL with annual change in height-adjusted FVC was with annual change in weight ( $P$ -value = 0.0101). The  $P$ -value for the model was 0.3193. There was a large discrepancy between the R-square (0.2225) and the adjusted R-square (0.0396). This indicated there was redundant information in the model that was not useful. Therefore, the analysis proceeded utilizing stepwise multiple linear regression.

### **1.3 Stepwise Regression to Determine the Best Models for Annual Change in Height-Adjusted FEV<sub>1</sub> and Height-Adjusted FVC**

Stepwise regression analysis was conducted with the independent variables included in the models predicting annual change in height-adjusted FEV<sub>1</sub> and annual change in height-adjusted FVC. The single independent variable with the greatest association with annual change in height-adjusted FEV<sub>1</sub> was annual change in weight (*P*-value of 0.0136), significant at the 95% CL. The R-square (0.1396) indicated that almost 14% of the variability in annual change in height-adjusted FEV<sub>1</sub> was explained by only annual change in weight in the model. The parameter estimate for annual change in weight (-17.6) indicated that for every annual increase of one pound in weight, FEV<sub>1</sub> could be expected to decline annually almost 18 ml. The next single independent variable with the greatest association with annual change in height-adjusted FEV<sub>1</sub>, after including annual change in weight in the model, was follow-up years (*P*-value of 0.0102), significant at the 95% CL. The R-square (0.2051) indicated that almost 21% of the variability in annual change in height-adjusted FEV<sub>1</sub> was explained by annual change in weight and follow-up years in the model. The partial F test for whether the addition of follow-up years contributed significantly to the linear prediction of annual change in height-adjusted FEV<sub>1</sub> had a *P*-value of 0.077, not significant at the 95% CL, but significant at the 90% CL. Although follow-up years was not significant at the 95% CL, examination of the partial R-square for time (0.0655) indicated that, by itself, it explained almost 7% of the variability in annual change in height-adjusted FEV<sub>1</sub>. The parameter estimate for annual change in weight (-18.0) with follow-up years in the model again indicated that for every

annual increase of one pound in weight, FEV<sub>1</sub> could be expected to decline annually almost 18 ml. No other variable met the 0.15 significance level for entry into the model.

The single independent variable with the greatest association with annual change in height-adjusted FVC was also annual change in weight (*P*-value of 0.0034). The R-square (0.1909) indicated that approximately 19% of the variability in annual change in height-adjusted FVC was explained by annual change in weight. The parameter estimate for annual change in weight (-23.8) indicated that for every annual increase of one pound in weight, FVC could be expected to decline annually almost 24 ml. No other variable met the 0.15 significance level for entry into the model.

## **2. Conclusions**

It appeared the rate of annual decline estimated in this study group could be larger than the rate expected from aging alone, based on estimates derived from cross-sectional studies. This is a somewhat controversial issue, because there have not been sufficient longitudinal studies of the population to develop a good basis for comparison. Also, it is possible that the rate expected from aging alone may differ by region due to, as of yet, unexplained factors.

The only significant associations found with annual change in height-adjusted FEV<sub>1</sub> and FVC were with annual change in weight. Annual change in weight, by itself in the models, only explained 14% of the variability in annual change in height-adjusted FEV<sub>1</sub> and 19% of the variability in annual change in FVC.

Years of welding were not a significant predictor of annual change in either height-adjusted FEV<sub>1</sub> or FVC. It may be possible that a decline could result from an occupational exposure without regard to cumulative exposure. However, based on the exposure assessment, the welders were not exposed at levels higher than the occupational exposure limits on a regular basis. Exposures that exceeded the OELs occurred on an intermittent, but not frequent, basis.

Smoking has been implicated as a significant cause of accelerated decline in FEV<sub>1</sub>. However, there was no relationship between annual change in FEV<sub>1</sub> and smoking history in terms of either smoking status or packyears. However, the sample size for current smokers was very small (n = 2). When smoking groups were stratified, the greatest to least mean annual declines in FEV<sub>1</sub> occurred, respectively in: former smokers who quit smoking after the first spirometry test, current smokers, nonsmokers, and former smokers who quit smoking prior to the first spirometry test. The former smokers who quit smoking after the first spirometry test had a larger mean annual decline in FEV<sub>1</sub> than did the current smokers and the former smokers who quit prior to the first spirometry test. However, they had a larger mean for packyears than did the other subgroups. The nonsmokers had a larger mean annual decline than the former smokers who quit prior to the first spirometry test.

Asbestos exposure has similarly been implicated as a potential cause for decline in FVC, and possibly FEV<sub>1</sub> also. Years of asbestos exposure, determined as years welding in a

power plant that contained asbestos thermal system insulation, were not associated with annual change in either height-adjusted FEV<sub>1</sub> or FVC.

### **3. Recommendations**

Although the results are far from conclusive, it would seem prudent, based on the estimated rates of decline in FEV<sub>1</sub> and FVC, to keep this study group and other similar populations under surveillance. More information should be obtained until answers become apparent as to what is an accelerated longitudinal decline, and what factors common to welders are associated with accelerated longitudinal decline.

Additional studies under tightly controlled conditions are needed to elucidate the health effects of welding in this and other industries. Prospective cohort studies are recommended because this design allows meticulous planning and prompt quality assurance verification of spirometric testing measurement and calibration. The use of a separate control group may also be useful in elucidating whether what appears to be an accelerated decline is really unusual for that geographic region or location. It appears to be a common practice in industry to record self-reported weight and height at time of test. However, for the purpose of epidemiology studies, accurate measurements are recommended to remove this as a source of variability. Another benefit of the prospective study design is the more accurate ascertainment of startpoints, endpoints, and temporal sequence of exposure and effect. Numerous spirometry measurements are probably needed over a sufficient period of time on numerous subjects to distinguish true change from "noise".

Increases in body weight have been associated in previous studies with decline in FEV<sub>1</sub> and FVC. Conversely, loss of excess weight may result in a reduction in the rate of decline. Personal fitness and attention to weight may be an opportunity to positively influence the rate of decline in lung function on an individual basis.

Although there was not a significant association with smoking in this study, smoking has been implicated in excessive loss in lung function in previous studies of welders, either by itself, or in interaction with other exposures. Smoking cessation should also be recommended as the most significant opportunity for an individual positive influence on respiratory health.

Because the potential for exposures over the occupational exposure levels continues in this industry, efforts are needed in the areas of exposure assessment, health hazard awareness and exposure control in welding. Exposure assessment is needed to characterize exposures by processes, materials, and conditions. Welders, supervisors, and management need to be educated as to the associated air contaminants, exposure levels, and health hazards. Exposure controls should be required for applicable processes and their use verified. Local exhaust needs to be made available, be practical of design, and encouraged in use. Respiratory protection will at times continue to be necessary. Thus, welders must be medically qualified, trained and fit tested, and properly selected equipment must be worn.