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Airborne Hexavalent Chromium During Welding and Thermal Metal Cutting

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PRODUCT DESCRIPTION

Welding and cutting chromium-containing metals may give rise to hexavalent chromium, or Cr(VI), exposure of workers. Since the passage in 2006 of a new U.S. Occupational Safety and Health Administration (OSHA) regulation governing Cr(VI) exposure levels, electric utilities have been conducting air monitoring studies to evaluate workers' exposures to Cr(VI). The 2006 OSHA regulation permits the use of objective and robust data in lieu of exposure monitoring. This report contains the results of an analysis of worker breathing zone air samples associated with Cr(VI) during welding and thermal cutting activities conducted at electric utility operations. Air sampling data from several electric utilities were gathered, verified, organized, and statistically evaluated. During a previous study, it was demonstrated that a large amount of data obtained did contain sufficient information about welding processes and the types of materials being welded. Based on the initial feasibility study, this larger scale study was conducted.

Results and Findings

During this study, more than 2000 air sampling results for Cr(VI) were reviewed, and a subset that contained useful details of the welding process, chromium content, and environmental conditions was entered into a database for further analysis. This database can be used to estimate likely airborne Cr(VI) concentrations, if one knows the types of welding consumables and the welding process and has a general idea of the environmental conditions that will be encountered. From this, the need for and type of exposure controls can be selected, and—for certain welding processes and types of welding consumable materials—this study can be an objective source for estimating airborne concentrations.

Challenges and Objectives

Regulations established in 2006 by OSHA require that employers conduct exposure assessments for Cr(VI). This assessment involves collecting and analyzing air samples to quantify exposures. Instead of collecting air samples from each potentially exposed worker, OSHA has permitted the use of objective data to assess exposures under the wide variety of conditions that may affect air sample results. Since the passage of the new OSHA regulation, electric utilities have been conducting air monitoring studies to evaluate worker exposure to Cr(VI). Following on these studies and OSHA's regulation allowing for the use of industry-wide studies, the Electric Power Research Institute (EPRI) initiated this project.

Applications, Value, and Use

The data collected in this study aid in quantifying exposures to Cr(VI) associated with welding and thermal metal cutting and could be used in future health evaluations, such as surveys of workers involved with various forms of welding. The compiled data can also assist companies working toward compliance with OSHA regulations established in 2006.

EPRI Perspective

By building a database from available utility data, this EPRI work results in a better understanding of exposures and factors that affect Cr(VI) fumes associated with welding activities across the electricity generating sector. Data for area air samples collected in the immediate vicinity of welding activities—representing the types of airborne Cr(VI) exposures that individuals other than welders might encounter—also could be classified and added to the database. The analysis of this welding and thermal cutting Cr(VI) air sampling data provides insight on the circumstances in which exposure controls are needed as well as the efficacy of engineering controls, such as local exhaust ventilation. Under many common welding conditions found at power generating plants, these data appear sufficient to predict airborne Cr(VI) exposures, satisfying the OSHA requirements for exposure assessment.

Approach

During this study, more than 2000 air sampling results for Cr(VI) were reviewed, and a subset that contained useful details of the welding process, chromium content, and environmental conditions was entered into a database for further analysis. Data gathered from EPRI and non-EPRI member electric utilities were examined to verify the availability of sufficient information. A simplified database was developed and organized by welding process, chromium content in the consumable, and environmental (ventilation) conditions. Summary statistics, such as the range and mean of the compiled data as well as a comparison to the OSHA action level and permissible exposure level (PEL), were compiled. Comparisons were made to help determine which variable had the most pronounced effect on the air sampling results. This database can be used to estimate likely airborne Cr(VI) concentrations, if one knows the types of welding consumables and the welding process and has a general idea of the environmental conditions that will be encountered. From this, the need for and type of exposure controls can be selected, and—for certain welding processes and types of welding consumable materials—the data is this study can serve as an objective source of airborne concentrations.

The 2006 OSHA regulations require that employers conduct exposure assessments, which includes the collection and analysis of air samples, to quantify exposures. These assessments are required whenever it is anticipated that airborne concentrations may exceed a value of 0.5 $\mu g/m^3$. However, rather than collecting air samples from each potentially exposed worker, the use of other objective data permits the assessment of exposures. *Objective data* are those from past exposure assessments and industrywide studies that are reasonable representations of the variety of conditions that a worker will encounter that result in hexavalent chromium exposures.

Keywords

Hexavalent chromium
Occupational exposure
Occupational Safety and Health Administration (OSHA)
Welders and welding

EXECUTIVE SUMMARY

This study contains the results of an analysis of worker breathing zone air samples associated with hexavalent chromium [Cr(VI)] during welding and thermal cutting activities conducted at electric utility operations. Almost all of these air samples were collected in field settings, such as in fossil fuel fired power plants. A limited number of samples were collected in welding shops. Hexavalent chromium is created during welding and thermal cutting of metals containing chromium. It is of particular interest because of its potential toxicity and the related regulations governing exposures to Cr(VI) established by the U.S. Occupational Safety and Health Administration (OSHA) in 2006 (OSHA 2006). Air sampling data previously gathered by several electric utilities was gathered, verified, organized and statistically evaluated. An earlier EPRI study demonstrated that a large amount of this data could be obtained, including data with sufficient information about welding processes and the types of materials being welded on. Based on the initial feasibility study, this larger scale study was conducted.

During this study, over 2000 air sampling results for Cr(VI) were reviewed, and a subset that contained useful details of the welding process, chromium content and environmental conditions were entered into a database for further analysis. This database can be used to estimate likely airborne Cr(VI) concentrations, in instances with known types of welding consumables, the welding process, and a general idea of the environmental conditions encountered. From this, the need for and type of exposure controls can be selected, and for certain welding processes and types of welding consumable materials, the data is this study can serve as an objective source of airborne concentrations.

The 2006 OSHA regulations require that employers conduct exposure assessments, which includes the collection and analysis of air samples, to quantify exposures. These required assessments occur whenever it is anticipated that airborne concentrations may exceed a value of 0.5 µg/m^3. However, instead of collecting air samples from each potentially exposed worker, OSHA permits the use of other objective data to assess exposures. Objective data are data from past exposure assessments and industry wide studies that are reasonable representations of the variety of conditions that a worker will encounter that results in hexavalent chromium exposures.

As a result of the evaluation, there appears to be a sufficient amount of objective data available to characterize typical exposures to Cr(VI) from shielded metal arc welding (SMAW), gas-tungsten arc welding (GTAW, also known as TIG) and arc gouging processes, on the typical and most common chromium containing metals present within the electric utility industry. Some information was gathered concerning gas metal arc welding (GMAW, also known as MIG), although the quantity of data was limited, restricting the type of analysis that could be conducted.

The analysis of welding and thermal cutting Cr(VI) air sampling data provides insight on the circumstances needing exposure controls, as well as the efficacy of engineering controls, such as local exhaust ventilation. Under many common welding conditions found at power generating plants, this data should be sufficient to predict airborne Cr(VI) exposures, satisfying the OSHA requirements for exposure assessment.

Even when air sampling results are organized based on welding process, the content of chromium in the consumable, and the degree of ventilation in the work area, there is considerable variation in airborne Cr(VI) concentrations. This occurs because there are many factors that will affect the concentration of airborne Cr(VI). One example is the orientation of the welder to the fume plume generated during welding or thermal cutting – in some circumstances, the worker must hover directly over the location where the fume is being generated, resulting in higher airborne concentrations. In other situations, the worker may be oriented such that the welding or cutting is somewhat above their breathing zone, which would result in significantly lower concentrations of fume within the worker's breathing zone. Another factor that was not captured in this data set remains the variation in the amount of arc time occurring. In some situations, the arc time is relatively high (e.g. upwards of 50% of the work day), while in other situations, the welder spends limited amount of the work shift physically welding (or cutting), spending more time in set-up, preparing the weld site, grinding or abrasive cutting, etc. Finally, as some welding tasks occurs in the immediate proximity of other welders, a single one individual may not be only generating welding fume, but may also be exposed to welding fume generated by another nearby welder.

The results of this analysis indicate that the most common welding process conducted on chromium bearing metals at power plants, which is where the majority of the air sampling data gathered during this study is from, is shielded metal arc welding (SMAW). This type of welding can give rise to airborne Cr(VI) concentrations in excess of the OSHA permissible exposure limit (PEL), especially when consumables contain more than 3% chromium (Cr). In those situations, 24 to 67% of the air samples exceed the PEL, depending on the type of ventilation used. Unfortunately, an inverse relationship between exposures and ventilation was not found (higher ventilation, including the use of LEV, should reduce exposure concentrations). Even with the use of LEV, a significant fraction of air samples exceed the current PEL, except when the consumable is less than 3% chromium and LEV is being used. The analysis of these welding fume results indicate that ventilation, including LEV, is not sufficient under many circumstances to keep airborne Cr(VI) concentrations below the OSHA PEL. This may be due to improper use of the ventilation equipment. During SMAW on chromium bearing metals conducted at electric utility operations, respirators should be used by welders – except in cases of low chromium content in the consumable (less than 3%) and with the use LEV.

Arc gouging consistently showed the highest Cr(VI) exposures, even when LEV is used. Therefore, respirators coupled with enhanced ventilation should always be used for this type of welding. Gas-tungsten arc welding (GTAW) is the second most common type of welding process used at electric utilities. None of the air samples collected during this welding process exceeded the PEL, regardless of the ventilation conditions or the chromium content of the consumable or of the base metal. The results indicate that there is no reason for additional exposure assessments for GTAW, when welding with consumables with chromium content up to approximately 25%. When possible, GTAW should be the welding process chosen to help limit airborne Cr(VI) concentrations. Limited amount of data was provided for GMAW. We were not able to collect a sufficient number of GMAW air samples for Cr(VI) needed to characterize or identify factors that may affect its presence and concentration.

Processes using a low (<3%) chromium content in the consumable had statistically lower airborne concentrations compared to those using consumables containing 3% chromium or more. There are often few options in terms of the chromium content that can be used for welding specific chromium bearing metals, thus substituting to a lower chromium content in the consumable may not be feasible. However, where these options do exist, it would be appropriate to select the welding consumable with the lowest chromium content.

When the choice of consumables and base metals are not available, the use of ventilation would appear to be a logical choice to reduce airborne Cr(VI) concentrations. However, during the analysis, a linear decrease in airborne Cr(VI) did not appear with increasing levels of ventilation, including when Local Exhaust Ventilation (LEV) is used. It is likely that this occurs due to the many factors that will affect the airborne concentration of Cr(VI) during welding (Blade 2007). For example, it is possible that LEV gets used most frequently when it is anticipated that high concentrations of welding fume will be encountered, such as in locations with poor ventilation or where the setting results in the accumulation of airborne fumes. Given this possibility, it cannot be categorically concluded that LEV is not an effective strategy to control fume exposures. Additional study of engineering controls is indicated, in part because some feedback from welders suggests that LEV systems may not be used in an optimum way. In some situations, welders are reluctant to use LEV because of concerns that it may have an adverse effect on weld quality by interfering with flux or shielding gases and their function of preventing the formation of oxides. Additionally, the use of LEV, which requires constant adjustment takes time, slowing down the welding process and productivity, resulting in higher welding costs.

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1
INTRODUCTION

Welding and thermal cutting on chromium bearing metals may result in the formation of Cr(VI) containing fumes (Castner 1998, Hewitt 1986). OSHA has had a long-standing permissible exposure limit for Cr(VI), but a comprehensive Cr(VI) standard was enacted in 2006. This new regulation considers Cr(VI) to be a potential respiratory carcinogen, mandating a variety of exposure monitoring and exposure control procedures. It is not known if workers' exposure to Cr(VI) from welding have an increased risk of developing cancer, and future health related surveys or epidemiological studies are possible.

1.1 OSHA Cr(VI) Regulations

OSHA promulgated regulations in 2006 for exposures to Cr(VI). These regulations include 29CFR1910.1026, Chromium (VI) in General Industry, and 29CFR1910.1126, Chromium (VI) in Construction. OSHA has also promulgated similar standards for shipyards and marine terminals addressed by separate standards. These new OSHA regulations lowered the permissible exposure limit (PEL) for an 8-hour time-weighted average exposure to Cr(VI) to 5.0 $\mu g/m^3$ (micrograms per cubic meter of air), and the regulation established an action level (AL) of 2.5 $\mu g/m^3$ (micrograms per cubic meter of air). If workers have the potential to be exposed above 0.5 $\mu g/m^3$, an exposure assessment including air sampling and analysis must be conducted. If airborne exposures exceed the action level, certain provisions, such as an increased frequency of exposure assessment, is triggered. If exposures exceed the PEL, exposure controls are required, including the use of engineering controls, such as ventilation, and if this is not completely successful, then personal protection such as respirators will be required in addition to ventilation controls.

In this regulation, OSHA allows for the use of historical monitoring data, and other objective data, in meeting the exposure assessment requirement. These are defined in the OSHA regulations as follows (OSHA 2006):

Historical monitoring data means data from chromium (VI) monitoring conducted prior to May 30, 2006, obtained during work operations conducted under workplace conditions closely resembling the processes, types of material, control methods, work practices, and environmental conditions in the employer's current operations.

Objective data means information such as air monitoring data from industry-wide surveys or calculations based on the composition or chemical and physical properties of a substance demonstrating the employee exposure to Cr (VI) associated with a particular product or material or a specific process, operation, or activity. The data must reflect workplace conditions closely resembling the processes, types of material, control methods, work practices, and environmental conditions in the employer's current operations.

This study presents data designed, in part, to meet the objective data definition, and is based on an industry-wide study in which air monitoring data collected since mid-2006 has been gathered, reviewed, qualified, and organized.

1.2 Factors Affecting the Presence of Cr(VI) During Welding and Thermal Cutting Operations

There are a number of factors that affect the presence and concentration of Cr(VI) in the work environment. During the welding process, both the consumable material (e.g. the welding rod or wire), as well as the base metal, are heated to the point where the solid metals become liquids. Some of these liquids then vaporize, followed by condensation and formation of welding fumes. The composition of the fumes is dominated by the composition of the welding consumables (i.e. welding rod or wire materials) (Moreton 1986). The type of welding or thermal cutting process is also known to have significant impacts on the quantity of fume that is generated (Dasch 2008, Fiore 2006). The type and use of ventilation will affect the concentration of fume present in worker's breathing zones. Factors anticipated to impact airborne Cr(VI) concentrations and worker exposures during welding include:

- The welding or metal cutting procedures or process;
- The amount of chromium present in the consumable (i.e. the rod, stick or welding wire);
- The amount of chromium in the base metal;
- The relative openness or confinement of the work area, which would affect the ability of the fume to accumulate or be dispersed;
- The degree of ventilation;
- The worker's orientation to the fume plume;
- The duration of time the welding process is conducted; and,
- The duration of the arc time or the duration of metal fume generation.

Efforts were made to collect as much detailed information as was possible concerning these issues, along with the measured airborne concentrations.

1.3 Acronyms and Abbreviations

AL	Action Level
Cr(VI)	Hexavalent Chromium
EPRI	Electric Power Research Institute
FCAW	Flux-Cored Arc Welding
GMAW	Gas Metal Arc Welding
GTAW	Gas-Tungsten Arc Welding
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
SMAW	Shielded Metal Arc Welding
$\mu g/m^3$	Micrograms per cubic meter of air

2
STUDY METHODS

2.1 Data Gathering

Data was gathered by soliciting electric utilities in North America. Some efforts were made to gather similar information for non-electric utility companies expected to have workers who weld on chromium containing metals under similar workplace conditions. This contact included an explanation of the purpose of the study, a listing of the type of information and data requested, and a brief description of how the data was to be used.

2.2 Data Evaluation

Upon receipt of the data, verification of each data point was conducted to ensure high data quality and the presence of sufficient information. Minimum essential critical data required for inclusion in the data analysis and the air-sampling database included the following:

- Air samples were collected and analyzed by recognized methods for hexavalent chromium (e.g. OSHA method ID-215; NIOSH methods 7604 or 7600);
- The measured Cr(VI) air sample concentration;
- The location of the air sampler (e.g. filter located inside the welding hood, on the welder's shoulder or shirt label, or an area sample in the welding area, etc.);
- Information about the type of welding or thermal cutting process (e.g. SMAW, GTAW, GMAW, etc.);
- Information about the type of welding consumable (e.g. welding wire or rod type or description);
- Information about the composition of the base metal for thermal cutting (e.g. oxy-acetylene, plasma cutting or arc gouging);
- Information about general environmental conditions (e.g. general ventilation conditions, the use of local exhaust ventilation, etc.);and,
- Work location and task.

If this information was provided, the data and the air sampling results were entered into the database.

2.3 Database

A Microsoft Access database was created to store the data that had sufficient details about the welding task. Information was imported into the database from Excel spreadsheets or entered manually. Informational fields were created for certain parameters that could affect the exposure concentration such as the base metals, information on the consumables (e.g. rod or wire type), location of air sampling equipment (e.g. under the welding hood, or on the worker's shoulder), information about ventilation conditions, job description and work locations. Using Access, queries were developed to correlate exposures to types of welding processes, chromium content in the consumables and environmental (ventilation) conditions. The percentage of exposures exceeding the current PEL and AL could also be related to these parameters.

2.4 Data Analysis

Initially, the data was grouped by type of welding processes and summary statistics of the grouped data were computed, such as the range, arithmetic and geometric mean, and the percentage of air sample results that exceeded the OSHA PEL and AL. Concentrations were compared between different welding types or combinations of types of welding, location of the sampling equipment and location of the task. Next, the relationship between certain parameters and their effect on exposure was evaluated. The parameters chosen for additional study were the chromium content of the consumable and the ventilation conditions. Finally, statistical comparisons were made to help determine which variable had the most pronounced effect on the air sampling results.

3
RESULTS

This section presents the results of this data collection, processing and analysis project.

3.1 Data Gathering Results

Six electric utility companies provided Cr(VI) air sampling data. Although this type of data was also requested from other industries, ultimately only data from electric utilities was included. Spreadsheets or reports of the results of approximately 2,000 air samples for Cr(VI) were received. The data were reviewed to determine the level of detail provided, if insufficient, in some cases additional information was gathered by teleconference with the source utility. Data lacking critical information was excluded from the database. For example, some of the data provided very limited descriptions of the work activities and little or no information on the welding process or consumable (e.g. a data description of "welding on stainless steel" was judged insufficient and excluded).

In other cases, information about the type of welding rod or welding wire was provided, but the information did not include the chromium content of the specific consumable. This information was gathered by searching for welding consumable product specifications or material safety data sheets on the internet using the standard identification information provided for the consumable. In some cases, a range of possible chromium content data was provided, and these ranges were entered into the database.

Of the 2,000 data points submitted, 665 sampling results (33%) were deemed to have sufficient information and were entered into the database for additional analysis.

Most of the air samples were personal breathing zone samples collected under or within the welding hood. A small fraction of the data entered into the data base were personal air samples collected from welders, with the sample collected outside of the welding hood (i.e. on the shoulder). OSHA recommends that welding fume air sample be collected with the sampling media positioned inside of the welding hood. There were 24 samples (i.e. 4% of the total number of sample results in the database) collected outside of the welding hood that were included in the database, and they are designated as such. These samples were separately analyzed.

Samples were also categorized based on whether the welding occurred at an indoor or an outdoor setting. The majority of the welding fume samples came from work taken at indoor locations. We were interested in determining if there was a distinct influence on airborne Cr(VI) concentrations related to whether, the welding or thermal cutting was conducted indoors or outdoors.

3.2 Categorizing Chromium Content Information

The chromium content in consumable welding materials, such as welding rods used in SMAW, or welding wire used in GMAW, were categorized in a logical manner to simplify the analysis of their relative influence on the airborne concentration of Cr(VI). As there are dozens of common chromium-containing welding consumable types used in the electric utility industry, both the database and earlier experience in evaluating welding activities within the electric utility industry were used to develop categories of 'low', 'medium' and 'high' chromium content in the consumables. Table 3-1 shows the groupings that were developed.

Table 3-1
Chromium Content in the Consumables

Category	Chromium Content
Low	<3%
Medium	3–11%
High	>11%

These categories were selected based on common chromium bearing metals used in the electric utility industry, coupled with common definitions of corrosion resistive steels. P22 steel, that contains 2.25% chromium, is commonly used in fossil fuel boiler water wall tubes. These water wall tubes are routinely welded on at power plants. Therefore, 'low' chromium content was categorized as metals containing <3% chromium. Stainless steel is defined as containing more than 10.5% chromium (AISI) (i.e. 11% or more), and this was used as the low-end cut-off for 'high' chromium content. Some molybdenum-chromium alloys used at power generation facilities do have lower chromium content as compared to stainless steels, but higher than P22 steel, thus steel with 3 to 11% chromium was categorized as 'medium' chromium content. These categories were used in grouping and simplifying the analysis of airborne Cr(VI) during the using consumable metals based on the chromium content.

3.3 Categorizing Environmental Conditions

Certain environmental conditions directly influence the presence and concentration of welding fume in the breathing zone of welders, including relative work area size (degree of confinement) and amount of ventilation present. For some air samples, active forms of ventilation were in place, such as local exhaust ventilation (LEV) or dilution ventilation (e.g. the use of space fans to disperse airborne fumes). Table 3-2 shows the categories of ventilation that were developed.

Table 3-2
Categories of Ventilation

Degree of Ventilation	Description
Low	Confining work environment, low degree of ventilation
Medium	Open work areas with limited active ventilation but no obvious accumulation of airborne fumes
High	Active ventilation such as dilution ventilation and outdoor work (except in circumstances where the work area is confined)
Local Exhaust Ventilation	Highly localized exhaust ventilation systems to extract fume at the point of generation (often-called fume capture systems or fume scrubbers)

3.4 Air Sampling Results

A total of 665 air sampling results have been entered into the database. All of these samples included sufficient detail concerning the type of welding process, the chromium content in the consumable and the extent of ventilation. All of the analyzed data were limited to personal air sampling results. Of the 665 samples, 576 (86%) were taken inside welding hood during welding with one type of consumable and during a single type of welding or thermal cutting process; and, 24 samples (4%) were taken outside the welding hood (on shoulder). An additional 65 air samples (i.e. 10%) were collected during a combination of welding types. Table 3-3 presents a summary of the data points taken inside the welding hood within the database, divided by welding process.

Table 3-3
Sample Number, Welding and Thermal Cutting Types for Personal Air Sampling Data Points (collected inside the welding hood)

Welding or Cutting Process	Number of Samples	Percent of All Samples
SMAW (Stick)	362	63
GTAW (TIG)	92	16
GMAW (MIG)	40	7
FCAW	9	2
Plasma Torch Cutting	8	1
Flame Torch Cutting	6	1
Arc Gouging	59	10

This breakdown indicates that the most common type of welding or thermal cutting process used by electric utilities involving chromium-containing metals was shielded metal arc welding, followed by GTAW (or TIG), and by arc gouging. Table 3-4 provides summary statistics of airborne Cr(VI) concentrations for the most common welding or thermal cutting procedures. This includes the range, mean, geometric mean, as well as the relative fraction above the OSHA PEL or action level (AL).

Table 3-4
Summary Statistics for Hexavalent Chromium Air Samples by Welding Type (inside the Welding Hood)

Welding or Cutting Process	Number of Samples	Concentration Range (μ/m^3)	Mean	Geometric Mean	Percent Above Action Level	Percent Above Permissible Exposure Limit
SMAW (Stick)	362	<0.01-330	8.36	1.4	37	25
GMAW (MIG)	40	<0.04-52	5.04	1.29	33	28
GTAW (TIG)	92	<0.02-3.22	0.26	0.14	1	0
Arc Gouging	59	0.26-229	44.6	11.9	78	64

For all of the welding/cutting process categories, the geometric mean values appear substantially lower than the arithmetic mean values. This is an expected and common observation for air sampling data, since it is normal to find occasionally very high concentration values that skew the arithmetic mean. As previously mentioned, a very wide range appears in all of these welding or cutting process categories. This variation reflects the many factors affecting fume concentration. Appendix A-1 provides the individual data points for SMAW, GTAW and Arc Gouging.

A comparison to the OSHA PEL and AL show that more than one-third of the SMAW air samples within the database were above the AL, and one-quarter above the PEL. Similar percentages were observed for the GMAW samples. None of the GTAW samples exceeded the PEL, and only 1 out of 92 of these samples exceeded the AL (or 1%). Arc gouging (also known as carbon arc gouging), which produces a considerable amount of fume consistently, revealed the highest Cr(VI) concentrations, with 78% of the air samples exceeding the AL and 64% above the PEL.

Figure 3-1 presents a frequency histogram for Cr(VI) concentrations during SMAW welding, indicating that a limited number of samples occurred at relatively high concentrations. The red-dashed line indicates the PEL on this chart for general reference.

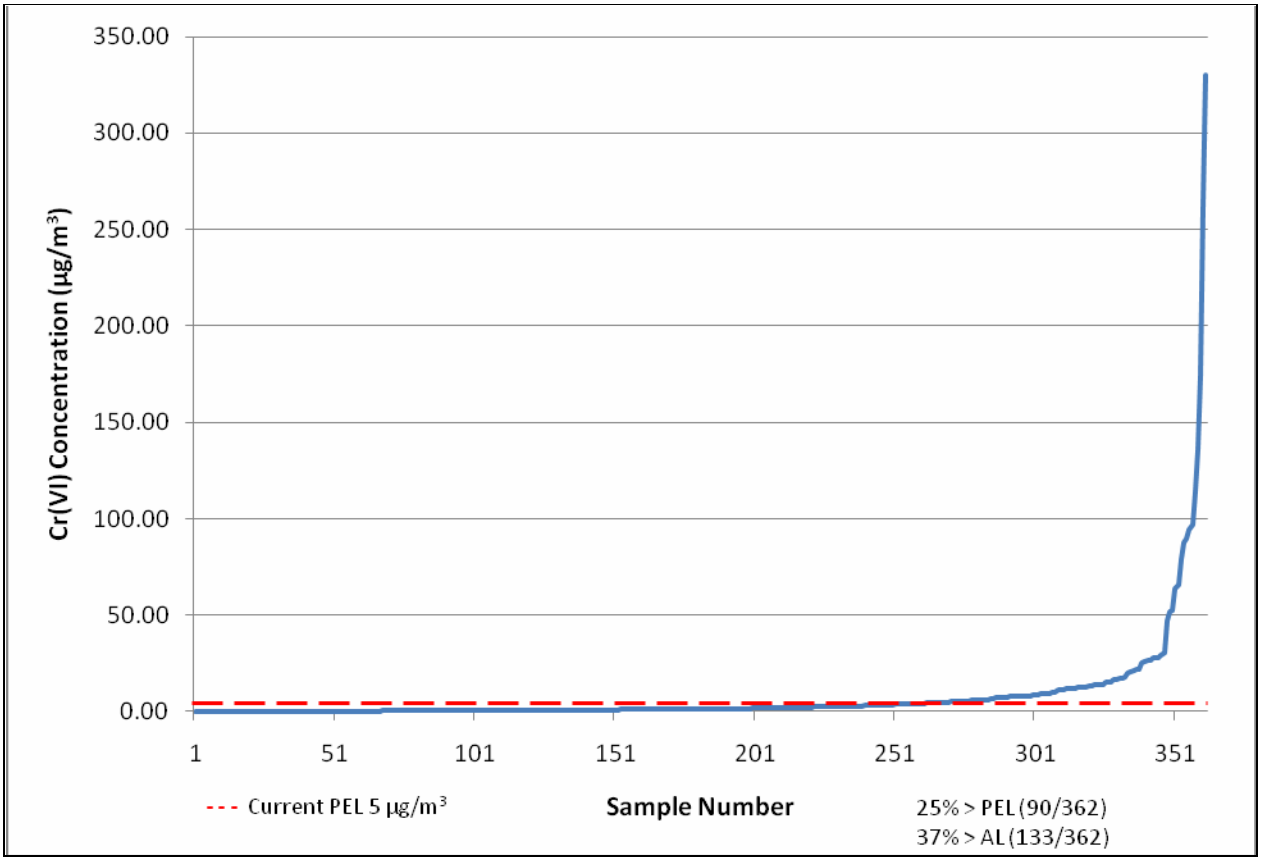

Figure 3-1
Frequency Distribution of Cr(VI) Airborne Concentrations During SMAW

The shape of the frequency distribution suggests that the data appears skewed due to a small number of high readings; therefore, further computation analysis was conducted on this data set. Using EPA ProUCL software (EPA 2008), which tests data sets for distribution patterns, the results for all of the personal air samples (collected inside the welding hood) from SMAW welding were evaluated. This analysis showed that the SMAW data has a lognormal distribution.

3.5 Exposures by Chromium Content, Ventilation Conditions, and Welding Processes

Figures 3-2 and 3-3 graphically present the differences between grouped welding types and demonstrate the effects of different chromium content in the consumable on airborne Cr(VI) concentrations. Figure 3-2 uses the arithmetic mean, and Figure 3-3 uses the geometric mean Cr(VI) concentrations.

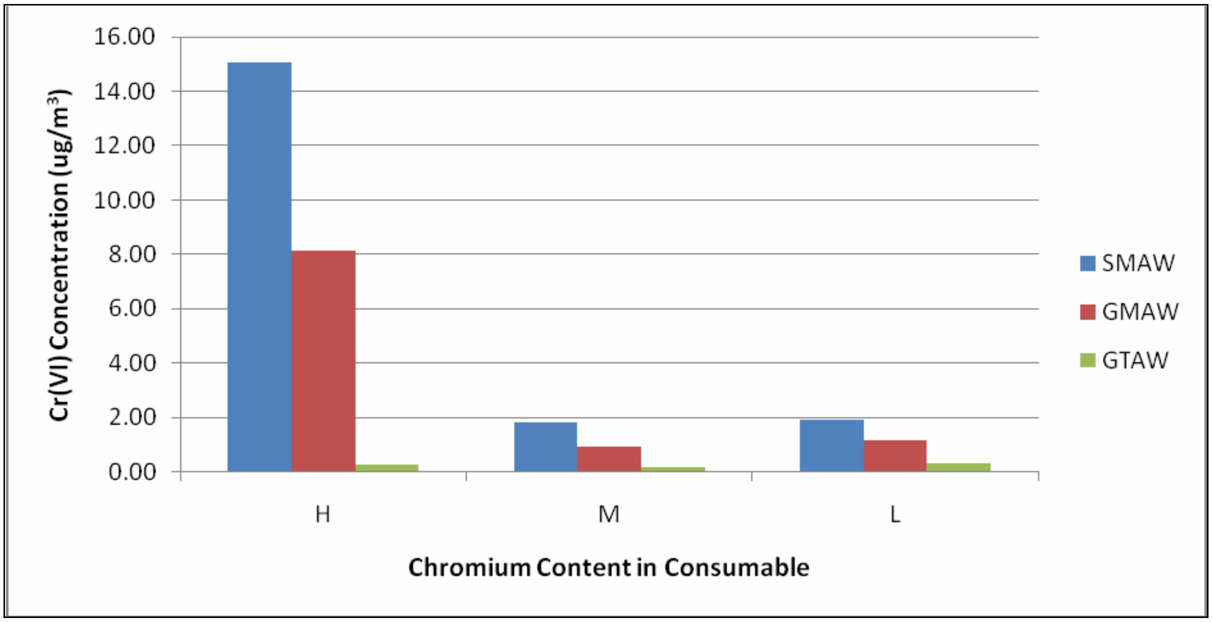

Figure 3-2
Arithmetic Mean of Cr(VI) Airborne Concentration Versus Chromium Content in Consumable

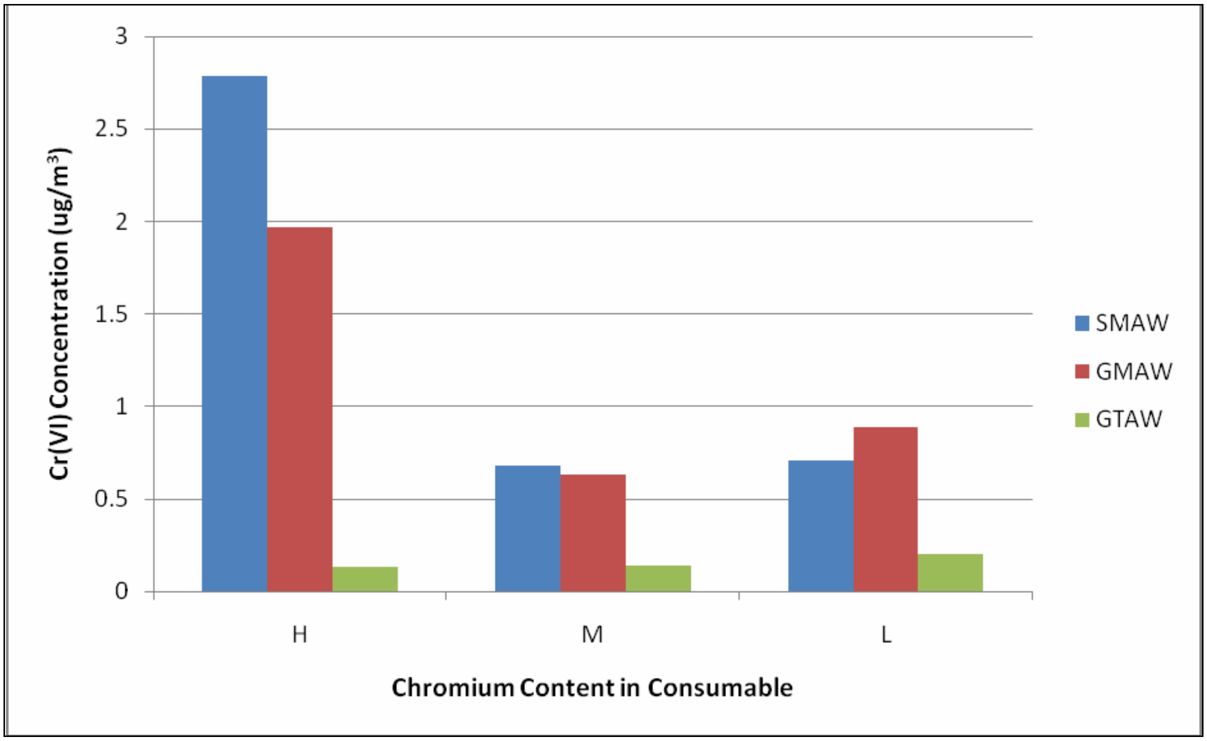

Figure 3-3
Geometric Mean of Cr(VI) Airborne Concentration Versus Chromium Content in Consumable

Both figures show a significant decrease in the airborne Cr(VI) with a decreasing chromium concentration in the consumable materials, particularly for SMAW samples. A less obvious decline appears for GTAW due to the relatively low airborne concentrations that occur, regardless of the chromium content in the consumable.

Figure 3-4 shows an analysis of geometric means based on the type of welding consumable, under different ventilation conditions. The three most common types of welding consumable used on chromium bearing metals were 9018 electrodes (0 to 5% chromium), 308 wire (18 to 22% chromium) and 309 wire (23.5% chromium). A difference appeared between the highest ventilation (LEV) and lowest ventilation conditions for the 308 and 309 wires, versus no significant differences for the 9018 welding rod. Clearly, the 308 and 309 wires, with a significantly higher level of chromium content as compared to the 9018 rods, had correspondingly higher Cr(VI) fume concentrations. Figure 3-5 shows the percentage of samples that exceeded the PEL by consumable and ventilation type.

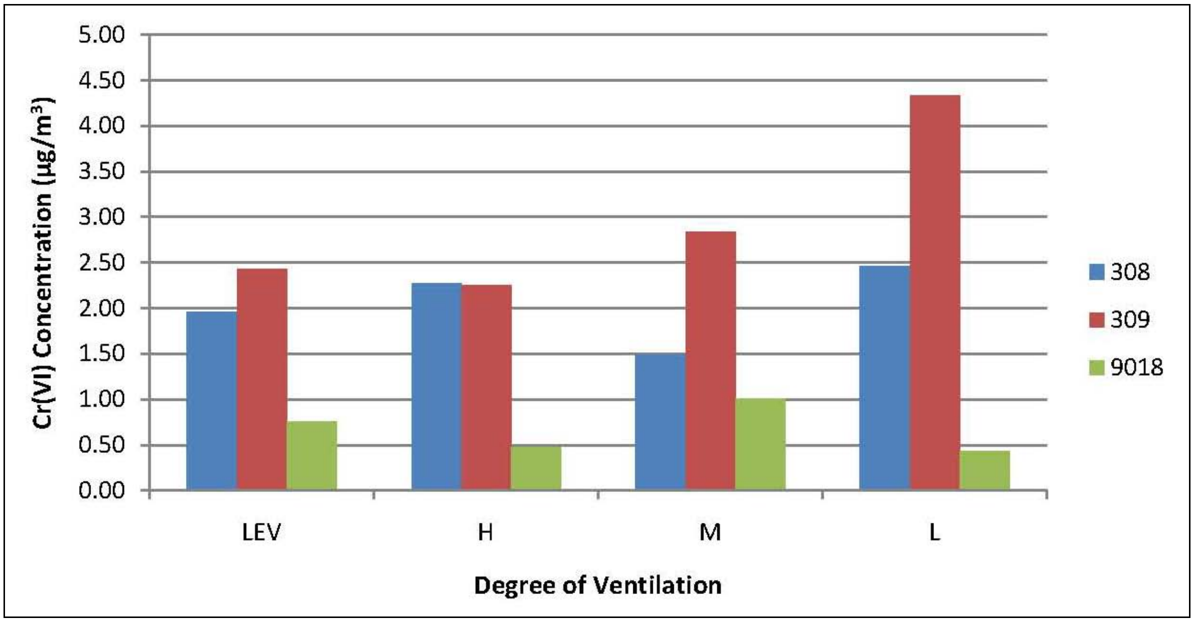

Figure 3-4
Popular Consumables: Geometric Mean Airborne Cr(VI) Versus Degree of Ventilation

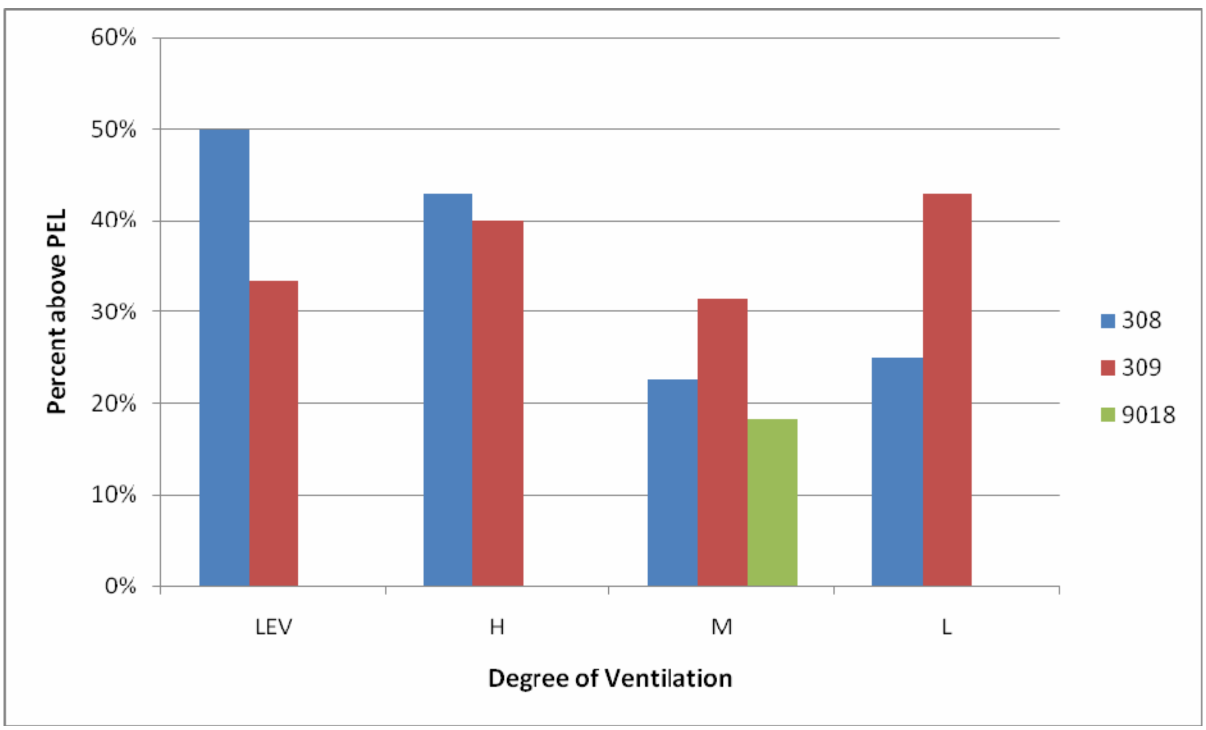

Figure 3-5
Popular Consumables: Percent Above PEL Versus Degree of Ventilation

Figure 3-5 shows that for the 308 and 309 welding wires with high chromium content, increasing ventilation was not sufficient to reduce airborne concentrations to levels consistently below the

PEL, as a significant number of samples even in the highest ventilation category had airborne concentrations exceeding this limit. Even the low chromium content welding rods, 9018, had a fraction of air samples exceeding the PEL for the medium ventilation category.

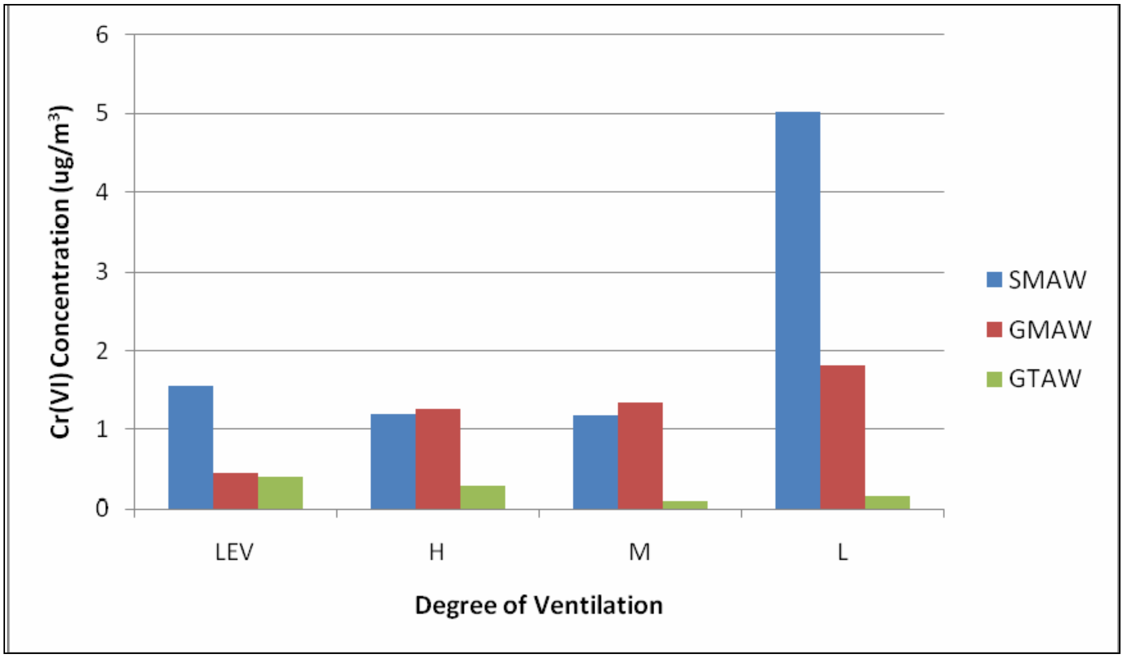

Figure 3-6
Effect of Ventilation on Airborne Geometric Mean Cr(VI) Concentrations by Welding Type

Figure 3-6 shows the relationship between the geometric mean of the Cr(VI) concentration and ventilation condition for various types of welding. Ventilation had an obvious impact on Cr(VI) fume concentrations inside of the welding hood. Cr(VI) concentrations during GTAW were not especially affected by conditions, which makes sense given that the Cr(VI) concentrations for this type of welding appeared consistently low. The effect of increasing ventilation on Cr(VI) concentrations with SMAW was not linear. Normally, it would be expected that LEV would lead to the lowest fume concentrations, but this did not occur for SMAW. Perhaps the use of LEV during activities expected to generate a very high fume concentrations (even with the LEV), skewed the results high for this category. In addition, it is also possible that LEV equipment was not used in an optimal fashion, as its effectiveness varies with how the welder positions the intake hood and the proximity of the hood to the welding site. There may be other variables affecting airborne concentrations even with the use of high ventilation, such as body position relative to the fume plume.

3.6 Airborne Concentrations During SMAW Considering Chromium Content and Ventilation Conditions

Since SMAW appears as the most common type of welding process on chromium bearing metals within electric utilities, the database contains a large number of air samples during this type of welding. This allowed for a further analysis by the chromium content in the welding consumable material (categorized as high, medium and low) and by the type of ventilation that was present (categorized as LEV, high, medium and low). Table 3-5 presents results of this categorical segregation of the air samples. Two categories had an insufficient number of samples to provide meaningful summary statistics (i.e. only two air sample results available: medium chromium content, high ventilation; and medium chromium content, low ventilation conditions).

Table 3-5
Analysis of SMAW Air Sampling Results

Cr Content in Consumable	Ventilation Conditions	Number of Samples	Range (μg/m^3)	Mean (μg/m^3)	Geometric Mean (μg/m^3)	Percent Above AL	Percent Above PEL
H	LEV	21	<0.09 – 87.4	11.18	2.76	57%	43%
H	H	41	<0.10- 330	19.22	2.74	51%	39%
H	M	82	<0.06- 174	9.06	2.23	48%	27%
H	L	29	0.05-261	30.51	6.99	72%	66%
M	LEV	6	0.24-2.97	0.77	0.47	17%	0%
M	H	2	0.06-1.08	0.57	0.25	0%	0%
M	M	18	<0.04-12.6	2.47	0.89	22%	11%
M	L	2	0.17-0.49	0.33	0.29	0%	0%
L	LEV	13	<0.07-2.01	0.93	0.63	0%	0%
L	H	21	<0.01-17.0	2.04	0.47	10%	10%
L	M	105	<0.01-13.3	2.06	0.79	27%	14%
L	L	4	0.20-1.84	0.79	0.53	0%	0%

This breakdown demonstrates that the chromium content in the consumable plays a significant effect on the concentration of Cr(VI) in the air sample results, and on the percentage of samples that exceed the PEL and AL. More than half of all samples with a medium and high consumable chromium content exceeded the AL (46% - 76%) and of these air sample results for these categories, most exceeded the PEL (24-67%). This contrasts with the low chromium consumable content category that had zero to 25% of the samples exceeding the AL and zero to 13% exceeding the PEL.

Figure 3-7 provides a graphical representation of this segregation of the air sampling results, based on the computed geometric means for each category.

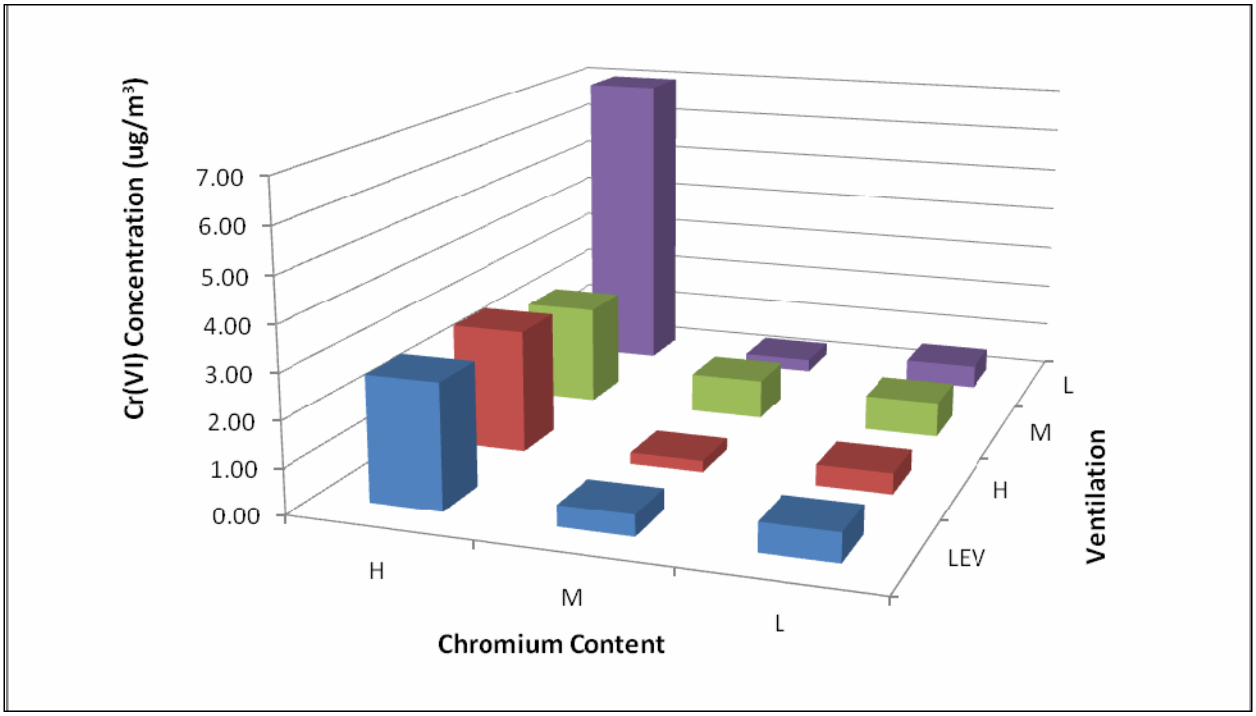

Figure 3-7
SMAW: Effect of Consumable Chromium Content Ventilation on Geometric Mean Airborne CR(VI)

This figure demonstrates a clear relationship between chromium content of the welding consumable and the Cr(VI) airborne concentrations. There appears to be a relationship between elevated Cr(VI) concentrations with ventilation conditions in the presence of a high chromium content consumable, but this relationship remains unclear when the consumable chromium content is in the low or medium categories.

Figures 3-8 and 3-9 depict the percentage of SMAW air samples that exceed the AL and PEL based on chromium content in the consumable and the ventilation conditions. Again, an obvious relationship appears between chromium content and airborne concentrations (based on the fraction of samples that exceed the action level or permissible exposure limit) but not relative to ventilation.

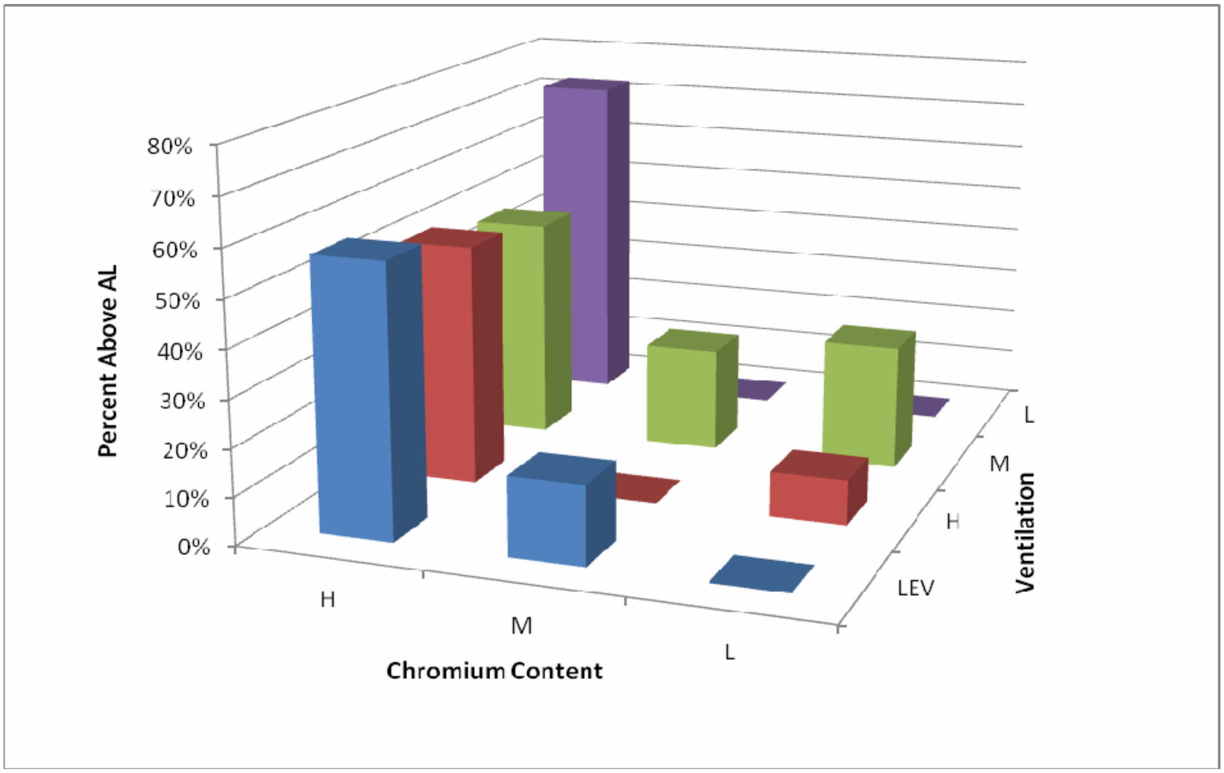

Figure 3-8
SMAW: Effect of Consumable Cr Content and Ventilation on Percent Above AL

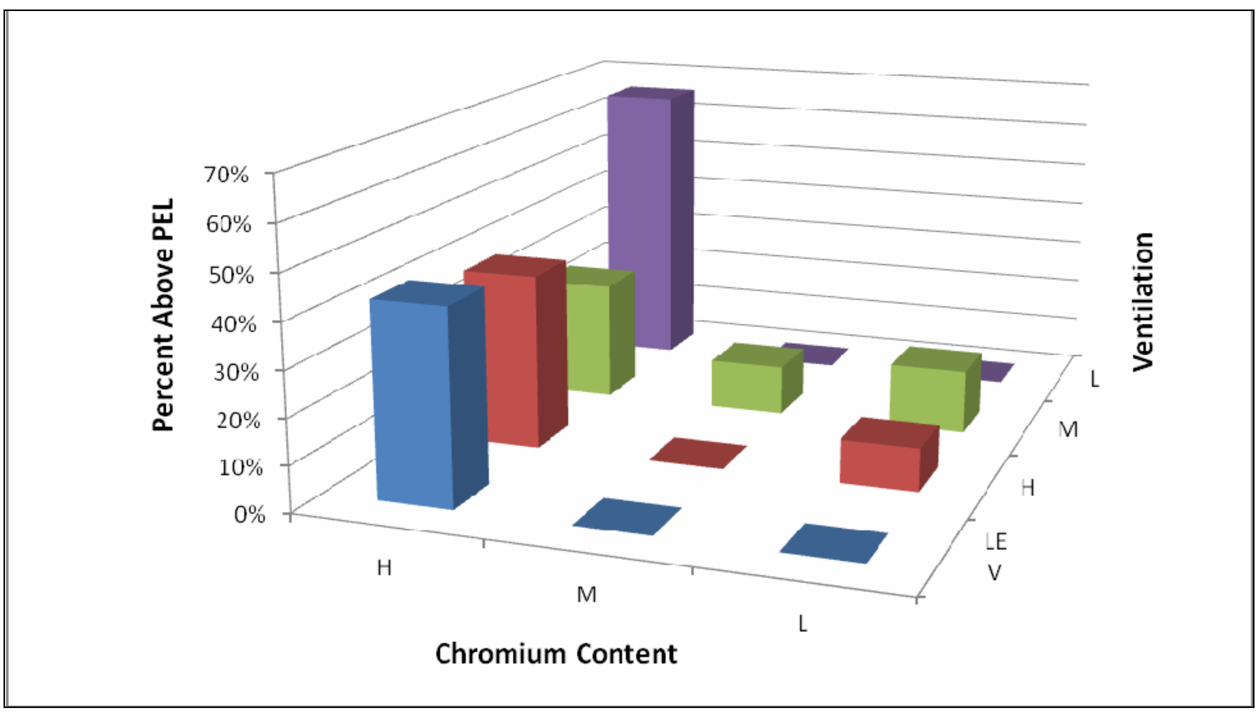

Figure 3-9
SMAW: Effect of Consumable Cr Content and Ventilation on Percent Above PEL

Figure 3-10 depicts similar comparisons of SMAW exposures to the three categories of chromium content in the consumable (low, medium and high). Airborne concentrations related to the high chromium content category appear significantly higher than those concentrations related to the "low" and "medium" chromium content categories ($p<0.05$).

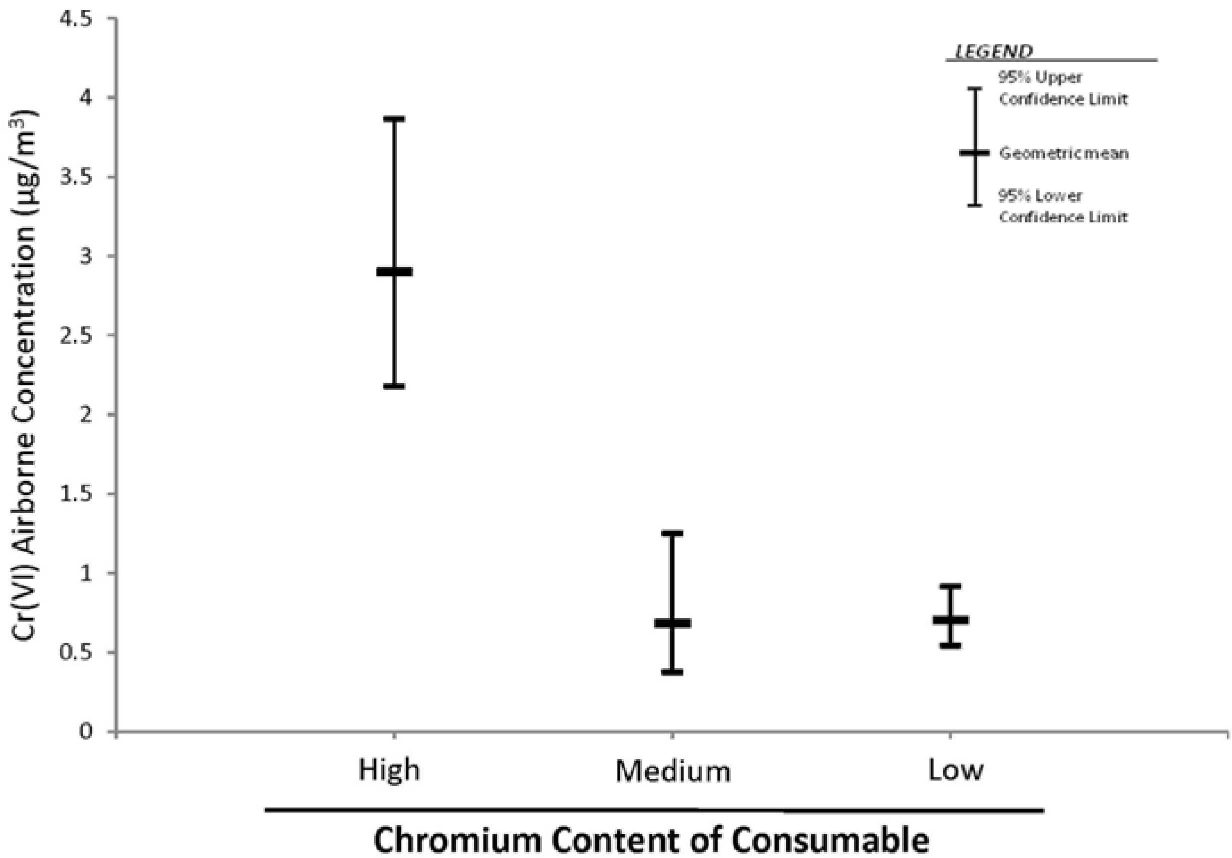

Figure 3-10
Comparisons of Cr(VI) Airborne Concentrations by Chromium Content of the Consumable

Figure 3-11 presents statistical comparisons of SMAW exposures related to the four ventilation categories (LEV, high, medium and low). Airborne concentrations appeared significantly higher for low degree of ventilation as compared to medium or high ventilation ($p<0.05$). The airborne concentrations from LEV ventilation categories were not significantly different from other ventilation levels.

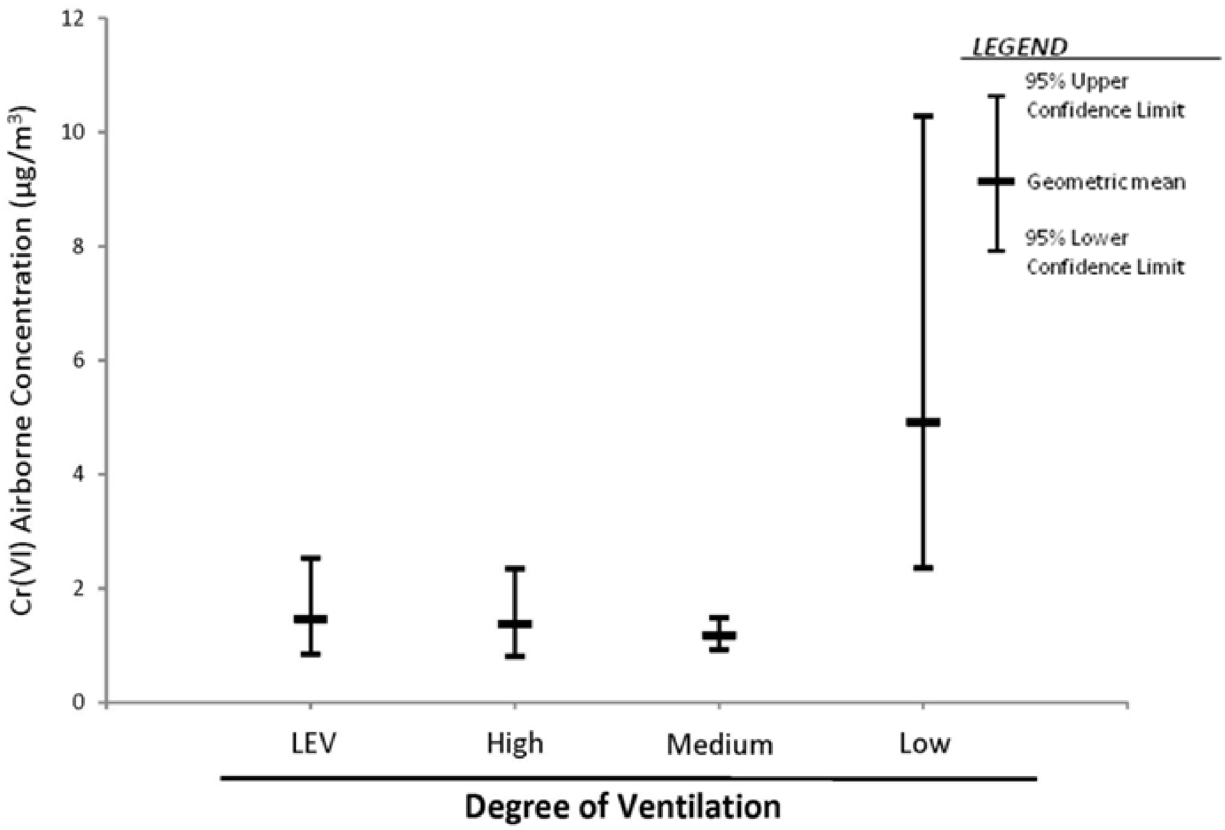

Figure 3-11
Comparisons of Cr(VI) Airborne Concentrations by Degree of Ventilation

Only two types of welding processes were monitored with the sample collection media located outside of the welding hood (SMAW and GTAW). These samples are summarized in Table 3-6.

Table 3-6
Summary Statistics for Hexavalent Chromium Air Samples by Welding Type (Outside of the Welding Hood)

Welding Process	Number of Samples	Concentration Range (µ/m^3)	Mean	Geometric Mean	Percent Above Action Level	Percent Above Permissible Exposure Limit
SMAW	22	<0.05-32	3.97	0.32	23	14
GTAW	2	<0.05-0.47	0.26	0.15	0	0

These results demonstrate that even with the sampling media outside of the welding hood, GTAW welding on chromium bearing metals does not result in airborne concentrations above the PEL (and for these samples, the AL as well). In contrast, a significant fraction of the SMAW samples collected outside of the welding hood was above the AL, with a subset of these above the PEL.

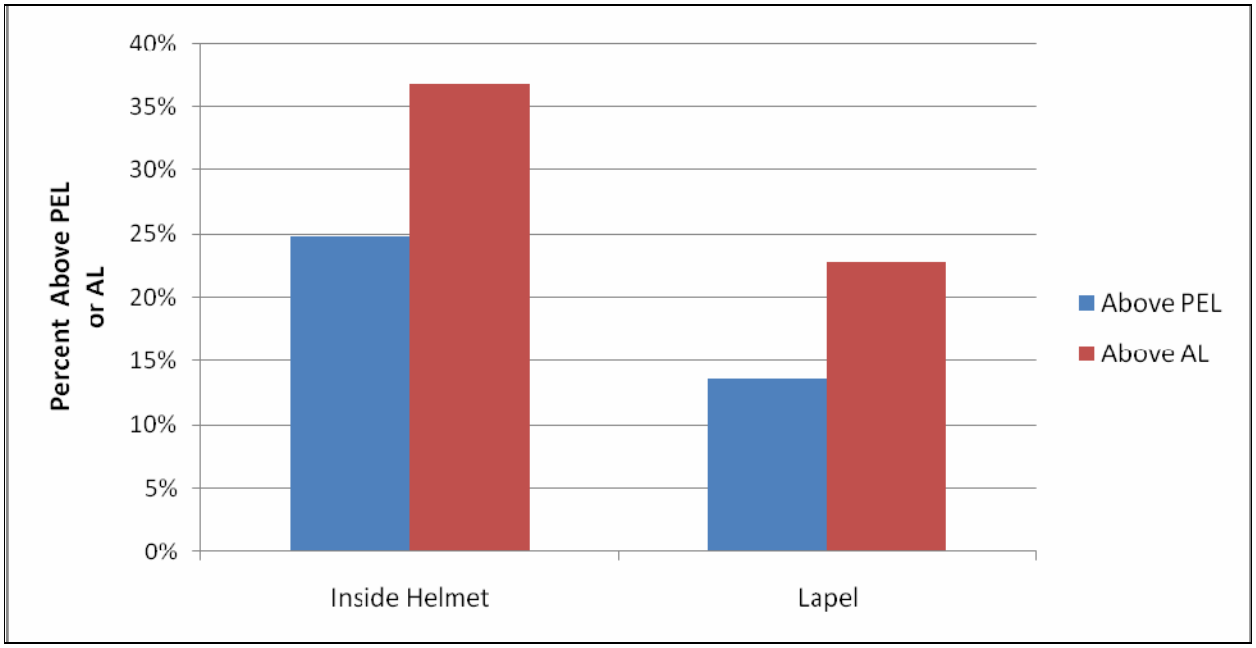

Figure 3-12
Percent of Samples Above Cr(VI) PEL and AL: Inside Versus Outside Hood

Figure 3-12 suggests that samples taken inside the hood were higher than those taken outside the hood (i.e. on the worker's lapel), although the differences do not appear large. Nevertheless, these were not paired samples, so this limits a direct comparison between these sets of data. These data do suggest only a limited difference between air samples collected inside versus outside of the welding hood. However, the number of samples taken inside the hood (N=362) far exceeds the number of samples taken on the lapel (N=24), limiting the power to determine a consistent relationship.

3.7 Combination Welding

Common welding tasks conducted within the electric utility industry, especially at power plants during maintenance outages, involve individual welders conducting a combination of welding and thermal cutting tasks within the same work shift. A portion of the data provided contained such combinations, including arc gouging combined with SMAW, or GTAW combined with SMAW. In some cases, the combinations involved the use of two different types of consumables during the same work shift. These combinations were uniquely marked and entered into the database. A total of 65 Cr(VI) air samples taken inside the welding hood and containing combinations of welding (and thermal cutting in some cases) were analyzed. Table 3-7 summarizes these samples. Figure 3-13 shows the percentage of samples exceeding the PEL and AL for these combination samples.

Table 3-7
Summary Statistics for Cr(VI) Air Samples by Combinations of Welding Processes

Welding or Cutting Process	Number of Samples	Concentration Range (μ/m³)	Mean	Geometric Mean	Percent Above Action Level	Percent Above Permissible Exposure Limit
Arc Gouging and SMAW	16	<0.296--94	8.69	2.80	50	19
GTAW and SMAW	34	<0.05-60.7	7.39	1.06	26	21
SMAW and Flame cutting	5	<1.27-23.3	10.24	6.20	80	60
SMAW and SMAW	10	0.26-7.3	1.29	0.68	0	10

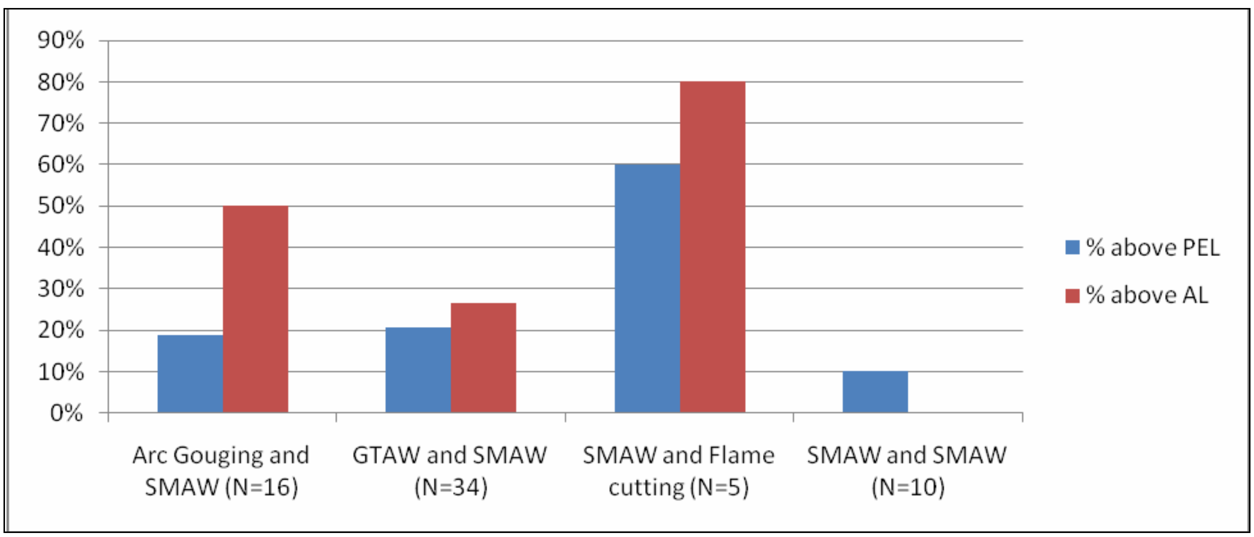

Figure 3-13
Combination Welding: Percentage of Samples Above PEL and AL

3.8 Outdoor Versus Indoor Samples

A total of 34 samples were taken during SMAW and GTAW tasks conducted outdoors, as compared to 457 samples collected from indoor locations. These two types of welding were the only ones with a sufficient number of samples in the data set. Figure 3-14 presents the geometric mean values for these groups, broken down by welding type. There were no significant differences between indoor and outdoor air sampling results for these two welding types.

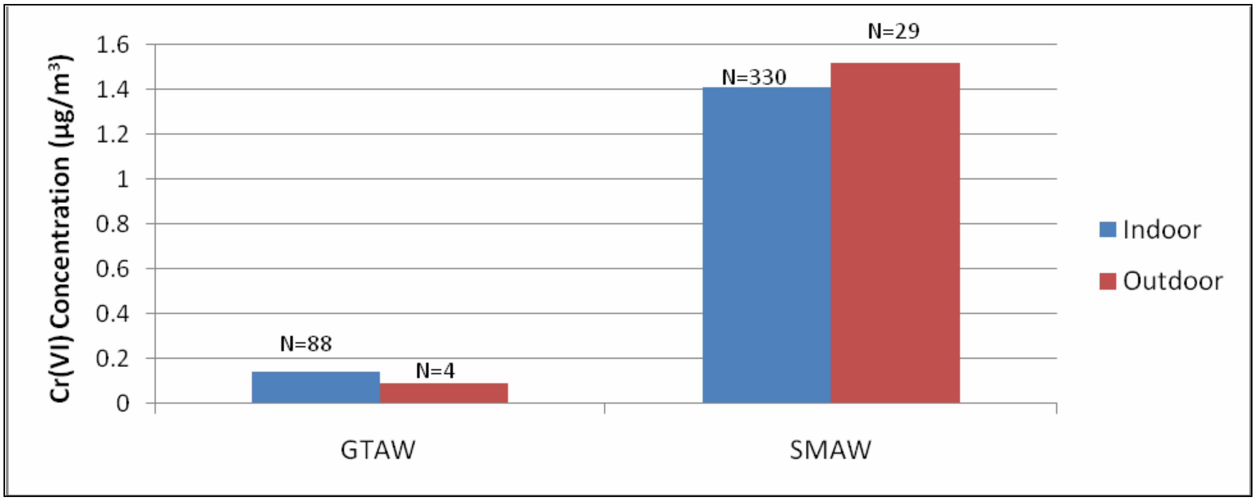

Figure 3-14
Geometric Mean Cr(VI): Indoor Versus Outdoor

4
DISCUSSION AND CONCLUSIONS

The database developed during this project has a sufficient number of samples to indicate the range and average airborne concentrations of common welding and thermal cutting processes conducted on chromium bearing metals at electric utility operations. The welding and thermal cutting processes in which there is sufficient data are SMAW, GTAW and Arc Gouging. The air sampling data represent a variety of ventilation conditions, and chromium content within the consumable (for welding) or base metal (for arc gouging). The data associated with these processes represent approximately 80 to 90% of welding types and conditions that could generate airborne Cr(VI) commonly performed at electric utility facilities. Almost all of the data comes from field settings, with a small fraction from work conducted in welding or fabrication shops. Therefore, this data should be appropriate to satisfy OSHA air monitoring conditions for objective data during similar welding processes, environmental conditions and consumable chromium content.

There are considerable variations in Cr(VI) concentrations during welding and thermal cutting. Even when the analysis of air sampling data focused on specific welding procedures, under similar ventilation conditions and chromium content in the consumables, considerable variation remained, potentially explained by the many variables ultimately affecting the airborne concentrations within the welding hood.

The data permits prediction of the type of airborne fume controls necessary to insure that welder's exposures remain below the PEL. During GTAW on chromium bearing metals (up to approximately 25% chromium), no ventilation or other controls appear needed to maintain airborne concentrations below the PEL. Furthermore, there should be no reason to conduct additional exposure assessments for this type of welding. When feasible, this type of welding should be selected to help reduce airborne exposures to Cr(VI). During SMAW on chromium bearing metals, feasible ventilation controls should always be used, as well as use of appropriate respirators types, the exception being applications using consumables with chromium content under 3% and local exhaust ventilation. During arc gouging on any type of chromium bearing metal, feasible ventilation controls and respirators should be used under all conditions.

For SMAW, the chromium content in the consumable had a noticeable effect on the airborne Cr(VI) concentrations for the high and medium chromium content categories. The effect of ventilation on airborne concentrations of Cr(VI) appears less apparent relative to the effect of consumable chromium content. Additionally, it appears likely that LEV systems are not being used to an optimal effect. The exhaust hood on these LEV systems requires constant adjustments as the welding site moves, thereby slowing the welding process. In fieldwork observations, it appeared that many welders are prone to keep the exhaust hood some distance from the weld site, likely due to concerns with weld quality (potential for adverse affect). Unfortunately, a study to determine methods to improve the LEV effectiveness has never been conducted. Given the difficulty of obtaining welder compliance to wear respirators, especially for extended periods and while wearing a welding hood, evaluating interventions on how to optimize use of LEV systems seems important. Optimizing the use of LEV should be able to keep Cr(VI) fumes to airborne concentrations below the PEL.

The results for GMAW appear to be similar to SMAW, but the database contains a limited quantity of air sampling results from this type of welding process. Therefore, it was not possible to conduct a detailed analysis of GMAW to determine the role of multiple conditions, such as variations in both ventilation and chromium content in consumable materials. More GMAW data is required before additional conclusions can be reached concerning this type of welding process.

5
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A
SUPPORTING MATERIAL

Exponent, under contract to EPRI, is gathering air sampling data related to hexavalent chromium (Cr(VI) associated with welding and metal torch cutting. This data will be held confidentially, and the identities of the participating companies will not be revealed. Please verify that any data provided does not provide private information such as social security numbers, or any medial related data. Listed below is the type of information we would like. Even if the data does not contain all of the requested detail, please submit your data to be considered for our study.

Table A-1
Hexavalent Chromium Air Sampling Data Request Form

Topic	Response
1. Air Sampling and Analytical Method (e.g. OSHA method ID-215)	
2. Duration and Volume of Air Sample	
3. Hexavalent Chromium results (mg/m^3 or $\mu g/m^3$)	
4. Location of sampling cassette	
a. Personal - inside welding hood	
b. Personal - on welder's or other workers shoulder or other breathing zone location	
c. Area - near welding activity (specify distance)	
5. Type of welding/cutting process	
a. Shielded metal arc welding (SMAW or stick arc)	
b. Gas Tungsten arc welding (GTAW or TIG)	
c. Gas Metal arc welding (GMAW or MIG)	
d. Flux Cored arc welding (FCAW)	
e. Submerged arc welding	
f. Plasma torch cutting	
g. Gas torch cutting	
h. Arc gouging	
i. Other (define)	

Table A-1 (continued)
Hexavalent Chromium Air Sampling Data Request Form

Topic	Response
6. Base Metal Chromium Content	
a. Base metal designation (e.g. SAE designation, such as 316)	
b. None	
c. Low (<1 to 5%)	
d. Medium (>5 to 20%)	
e. High (>20 to 30%)	
f. Very High (>30%)	
7. Consumable Material Chromium Content	
a. Consumable (e.g. wire or rod designation)	
b. None	
c. Low (<1 to 3%)	
d. Medium (3 to 11%)	
e. High (>11%)	
8. Is the base material painted or otherwise coated?	
a. If yes, what is the chromium content, if known?	
9. Environmental Conditions	
a. Outdoor with no ventilation restrictions	
b. Local exhaust ventilation (LEV) to capture fume from the welding site is in use	
c. Good ventilation (e.g. active dilution ventilation with fans or a wind is blowing in the work area actively dispersing the generated fumes)	
d. Moderate ventilation (e.g. indoor, no special ventilation, some fume may linger in the work area)	
e. Poor ventilation (e.g. fume linger and accumulates inside the work area)	
f. Unknown	

Table A-1 (continued)
Hexavalent Chromium Air Sampling Data Request Form

Topic	Response
10. Worker Orientation to the Fume Plume	
a. Hot work is below the worker's waist level	
b. Hot work is above the worker's waist level	
11. Information about the sampled worker	
a. Job description (e.g. welder, helper, inspector)	
b. General description of work location	
c. Distance of stationary samples from hot work location	
d. Are there other workers present in the area	
12. Arc time (duration arc or active hot work is conducted during the air sampling)	
13. Voltage (voltage used for arc welding process	
14. Other relevant information	

Table A-2
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc $\mu g/m^3$
Stainless steel	H	19-22	308	Indoor	LEV	LEV	P		21.7
Stainless steel	H	19-22	308	Indoor	LEV	LEV	P		25.6
T-22	H	16.5%	16-8-2	Indoor	LEV	LEV	P		1.7
T-22	H	16.5%	16-8-2	Indoor	LEV	LEV	P		2.42
T-22	H	16.5%	16-8-2	Indoor	LEV	LEV	P		4.98
T-22	H	16.5%	16-9-2	Indoor	LEV	LEV	P		2.62
304 Stainless steel	H	16.5	16-8-2	Indoor	LEV	LEV	P		0.129
U	H	16.5	16-8-2	Indoor	LEV	LEV	P		1.39
U	H	16.5	16-8-2	Indoor	LEV	LEV	P		12
Stainless steel	H	19	316	Indoor		LEV	P		0.838
Stainless steel	H	23.5	309	Indoor	LEV	LEV	P		1.3
316 Stainless steel	H	19	316SS	Indoor		LEV	P		26.7
316 Stainless steel	H	19	316SS	Indoor		LEV	P		87.4
U	H	30-35	707	Indoor		LEV	P		<0.09
U	H	30-35	707	Indoor		LEV	P		5.66

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc μg/m^3
material XXH SA4796R304 and pipe 80 SA106	H	23.5	E309, E7018 and E3008	Indoor		LEV	P		0.226
ER308	H	23.5	309	Indoor	LEV	LEV	P	Inside hood	3.8
304L	H	23.5	309	Indoor	LEV	LEV	P	Inside Hood	16.4
304L	H	23.5	309	Indoor	LEV	LEV	P	Inside Hood	12.4
ER308	H	23.5	316 & 308 & 309	Indoor	LEV	LEV	P	Inside hood	1.69
U	H	19.5 - 22	308	Indoor	LEV	LEV	P	Inside Hood	5.72
Stainless steel	H	23.5	309	Indoor		H	P		<0.1
U	H	16.5	16-8-2	Indoor		H	P		5.41
309 Stainless	H	23.5	309	Indoor		H	P		8.34
309 Stainless	H	23.5	309	Indoor		H	P		0.33
316 Stainless steel	H	19	316	Indoor		H	P		0.169
T-22	H	20	918	Indoor	Natural	H	P	Inside hood	0.12
U	H	19.5 - 22	308	Outdoor	Natural	H	P	Inside Hood	0.12

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m³
U	H	19.5 - 22	308	Outdoor	Natural	H	P	Inside Hood	0.14
U	H	19.5 - 22	308	Outdoor	Natural	H	P	Inside Hood	2.4
U	H	19.5 - 22	308	Outdoor	Natural	H	P	Inside Hood	8.9
U	H	19.5 - 22	308	Outdoor	Natural	H	P	Inside hood	114
U	H	19.5 - 22	308	Outdoor	Natural	H	P	Inside hood	7.8
U	H	19.5 - 22	308	Outdoor	Natural	H	P	Inside hood	11
U	H	19.5 - 22	308	Outdoor	Natural	H	P	Inside hood	29
U	H	19.5 - 22	308	Outdoor	Natural	H	P	Inside hood	0.53
U	H	19.5 - 22	308	Outdoor	Natural	H	P	Inside hood	0.12
U	H	20.7	NA	Indoor	Natural	H	P	Inside hood	64
U	H	20.7	NA	Indoor	Natural	H	P	Inside hood	<0.35
	H	23.5	309	Indoor	Dilution Vent	H	P	Inside hood	94.5

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m³
	H	23.5	309	Indoor	Dilution Vent	H	P	Inside hood	16.6
	H	23.5	309	Indoor	Dilution Vent	H	P	Inside hood	9.38
U	H	24.7	NA	Indoor	Natural	H	P	Inside hood	330
	H	23.5	309	Indoor	Natural	H	P	Inside hood	1.05
Stainless Steel	H	23.5	309	Indoor	Natural	H	P	Inside hood	1.6
Stainless Steel	H	23.5	309	Indoor	Natural	H	P	Inside hood	6.5
Stainless Steel	H	23.5	309	Indoor	Natural	H	P	Inside hood	2.52
Stainless Steel	H	23.5	309	Indoor	Exhaust Ventilation	H	P	Inside hood	1.64
316	H	23.5	309	Indoor	Dilution Vent	H	P	Inside hood	1.92
316	H	23.5	309	Indoor	Dilution Vent	H	P	Inside hood	0.796
304L	H	15 - 30	ESAB 309L	Outdoor	Natural	H	P	Inside Hood	1.67
	H	11.1	NA	Indoor	Natural	H	P	Inside hood	<0.34

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m^3
U	H	13.4	NA	Indoor	Natural	H	P	Inside hood	13.6
U	H	13.4	NA	Indoor	Natural	H	P	Inside hood	<0.34
U	H	13.4	NA	Indoor	Natural	H	P	Inside hood	<0.36
U	H	13.9	NA	Indoor	Natural	H	P	Inside hood	28
317 LMN Alloy SS	H	16.5	C276	Indoor	Natural	H	P	Inside hood	3.6
U	H	19	316	Outdoor	Natural	H	P	Inside Hood	3.23
U	H	19	316	Outdoor	Natural	H	P	Inside Hood	7.66
316 Stainless steel	H	16-18	ESAB E316L	Outdoor	Natural	H	P	Inside Hood	4.15
304SS	H	19	316L	Indoor	Dilution Vent	H	P	Inside hood	4.17
316	H	19.5 - 22	308	Outdoor	Natural	H	P	Inside Hood	1.58
Stainless steel	H	23.5	309	Indoor		M	P		4.61
308 Stainless steel	H	18-21	308	Outdoor		M	P		1.52

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m^3
304 Stainless steel	H	18-21	308	Indoor		M	P		15.2
304 Stainless steel	H	18-21	308	Indoor		M	p		11.9
316 Stainless steel	H	19.5 - 22	308	Indoor		M	P		4.49
316 Stainless steel	H	19.5 - 22	308	Indoor		M	P		4.42
316 Stainless steel	H	19.5 - 22	308	Indoor		M	P		3.73
316 Stainless steel	H	19.5 - 22	308	Indoor		M	P		1.41
P-22 steel	H	19.5 - 22	308	Outdoor		M	P		0.529
304H	H	16.5%	16-8-2	Indoor		M	P		8.5
Stainless to mild base	H	23.5	309	Indoor		M	P		4.48
Stainless to mild base	H	23.5	309	Indoor		M	P		3.32
SA213TP 304H	H	19.5 - 22	308	Indoor		M	P		0.973
SA213TP 304H	H	19.5 - 22	308	Indoor		M	P		0.801
Hardox 600 base	H	29.0	E312-16	Indoor		M	P		3.99
Stainless steel	H	23.5	309	Indoor		M	P		1.04

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc $\mu g/m^3$
Stainless steel	H	23.5	309	Indoor		M	P		2.62
Stainless steel and carbon	H	23.5	309	Outdoor		M	P		27.9
Stainless steel	H	23.5	309	Indoor		M	P		0.83
316 Stainless steel	H	19	E316L	Outdoor		M	P		15.4
Stainless steel	H	23.5	309	Indoor		M	P		2.65
Stainless steel	H	23.5	309	Indoor		M	P		7.86
Stainless steel	H	23.5	309	Indoor		M	P		78.8
Stainless steel	H	23.5	309	Indoor		M	P		1.3
Alloy pipe and stainless	H	23.5	309	Indoor		M	P		2.28
Stainless steel	H	23.5	309	Indoor		M	P		14.2
Stainless steel (347)	H	19.5 - 22	308	Indoor		M	P		3.4
	H	23.5	309	Indoor		M	P		3.2
316 Stainless steel	H	19	316	Indoor		M	P		0.169
316 Stainless steel	H	19	316	Indoor		M	P		5.58
Stainless steel	H	23.5	309	Indoor		M	P		14.2

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc $\mu g/m^3$
Stainless steel	H	19	316	Outdoor		M	P		5.58
Stainless steel	H	19	316	Indoor		M	P		0.152
Stainless steel	H	19	316	Indoor		M	P		0.837
308	H	19.5-22	308	Indoor		M	P		27.7
308	H	19.5-22	308	Indoor		M	P		12.8
316 Stainless steel	H	19	316	Outdoor		M	P		2.5
Stainless steel	H	23.5	309	Indoor		M	P		0.7
Stainless steel	H	23.5	309	Indoor		M	P		0.23
Stainless steel	H	23.5	309	Indoor		M	P		1.4
SA106 pipe	H	23.5	309 and 7018	Indoor		M	P		<0.06
carbon steel	H	23.5	E309	Outdoor		M	P		0.408
carbon steel	H	23.5	E309	Outdoor		M	P		0.519
U	H	18-20	E307/309L-16	Indoor		M	P		21.2
U	H	19.5 - 22	308	Indoor	U	M	P	Inside Hood	0.44
U	H	19.5 - 22	308	Indoor	U	M	P	Inside Hood	174
U	H	19.5 - 22	308	Indoor	Natural	M	P	Inside Hood	0.78

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc μg/m³
U	H	19.5 - 22	308	Indoor	Natural	M	P	Inside Hood	4.8
	H	19.5 - 22	308	Indoor	Natural	M	P	Inside hood	0.5
	H	19.5 - 22	308	Indoor	Natural	M	P	Inside hood	0.4
U	H	19.5 - 22	308	Indoor	Natural	M	P	Inside hood	3.46
U	H	19.5 - 22	308	Indoor	Natural	M	P	Inside hood	0.163
U	H	19.5 - 22	308	Indoor	Natural	M	P	Inside hood	8.18
U	H	19.5 - 22	308	Indoor	Natural	M	P	Inside hood	97
	H	17-30%	ESAB 316	Indoor	Natural	M	P	Inside Hood	0.1
U	H	18-21	308	Indoor	Natural	M	P	Inside Hood	0.061
U	H	23.5	309	Indoor	Natural	M	P	Inside Hood	0.13
308	H	18-21	308	Indoor	Natural	M	P	Inside Hood	17.6
308	H	18-21	308	Indoor	Natural	M	P	Inside Hood	0.692

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m^3
U	H	19.5 - 22	308, 309, 316	Indoor	Natural	M	P	Inside Hood	0.573
U	H	23.5	309	Indoor	Natural	M	P	Inside hood	52.2
U	H	23.5	309	Indoor	Natural	M	P	Inside hood	11.9
304L	H	23.5	309	Indoor	Natural	M	P	Inside Hood	1.95
304L	H	23.5	309	Indoor	Natural	M	P	Inside Hood	1.55
316 Stainless steel	H	19	316	Indoor	Natural	M	P	Inside Hood	0.561
410SS	H	23.5	309	Indoor	Natural	M	P	Inside Hood	3.74
310SS	H	19.5 - 22	308	Indoor	Natural	M	P	Inside Hood	1.37
310SS	H	19.5 - 22	308	Indoor	Natural	M	P	Inside Hood	0.429
310SS	H	19.5 - 22	308	Indoor	Natural	M	P	Inside Hood	0.459
310SS	H	19.5 - 22	308	Indoor	Natural	M	P	Inside Hood	1.05
310SS	H	19.5 - 22	308	Indoor	Natural	M	P	Inside Hood	1.45

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m³
U	H	23.5	309	Indoor	Natural	M	P	Inside Hood	4.8
U	H	26	310	Indoor	Natural	M	P	Inside hood	2.71
U	H	26	310	Indoor	Natural	M	P	Inside hood	0.584
U	H	17??	ENICR Fe3	Indoor	Natural	M	P	Inside Hood	<0.1
U	H	23.5	309	Indoor	Natural	M	P	Inside hood	0.244
U	H	23.5	309	Indoor	Natural	M	P	Inside hood	0.98
U	H	19.5 - 22	308	Indoor	Natural	M	P	Inside Hood	7
U	H	19.5 - 22	308	Indoor	Natural	M	P	Inside Hood	0.73
U	H	19.5 - 22	308	Indoor	Natural	M	P	Inside hood	0.409
U	H	19.5 - 22	308	Indoor	Natural	M	P	Inside hood	11.1
304	H	19.5 - 22	308	Indoor	Natural	M	P	Inside Hood	3.16
Carbon and stainless steel	H	16.5	16-8-2 & 7018	Indoor		L	P		15.2

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc μg/m^3
Carbon and stainless steel	H	16.5	16-8-2 & 7018	Indoor		L	P		<0.4
Carbon and stainless steel	H	16.5	16-8-2 & 7018	Indoor		L	P		30.7
Carbon and stainless steel	H	16.5	16-8-2 & 7018	Indoor		L	P		12.9
Carbon and stainless steel	H	16.5	16-8-2/7018	Indoor		L	P		51.8
Carbon and stainless steel	H	16.5	16-8-2 & 7018	Indoor		L	P		0.403
319 Stinless	H	19	316L	Indoor		L	P		1.8
319 Stinless	H	19	316L	Indoor		L	P		25
316 Stainless steel	H	19	316	Indoor		L	P		26.8
316 Stainless steel	H	19	316	Indoor		L	P		20.8
Stainless steel	H	19.5-22	308	Indoor		L	P		1.22
308	H	19.5 - 22	308	Indoor	Natural	L	P	Inside hood	136
U	H	10-25%	E2209-16	Indoor	Natural	L	P	Inside Hood	10.2
U	H	10-25%	E2209-16	Indoor	Natural	L	P	Inside Hood	6.4

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc μg/m³
U	H	17-20%	2209	Indoor	Natural	L	P	Inside Hood	<0.7
U	H	23	309	Indoor	Natural	L	P	Inside Hood	5
U	H	23	309	Indoor	Natural	L	P	Inside Hood	4.7
U	H	23	309	Indoor	Natural	L	P	Inside Hood	66
U	H	20-23	ENiCrMo-3	Indoor	Natural	L	P	Inside Hood	261.6
U	H	20-23	ENiCrMo-3	Indoor	Natural	L	P	Inside Hood	46.8
SA213TP304	H	15-25	16-8-2 & 9018	Indoor	Natural	L	P	Inside hood	1.32
U	H	23.5	309	Indoor	Natural	L	P	Inside Hood	20
U	H	26	310	Indoor	Natural	L	P	Inside Hood	89.6
U	H	26	310	Indoor	Natural	L	P	Inside hood	11.8
U	H	26	310	Indoor	Natural	L	P	Inside hood	8.93
Cast Iron	H	23.5	309	Indoor	Natural	L	P	Inside hood	21.74

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m³
316 Stainless steel	H	19	316	Indoor	Natural	L	P	Inside hood	6
U	H	23.5	309	Indoor	Natural	L	P	Inside Hood	0.85
U	H	23.5	309	Indoor	Natural	L	P	Inside Hood	0.05
	M	<5	9018	Indoor	LEV	LEV	P		2.97
	M	<5	9018	Indoor	LEV	LEV	P		0.467
U	M	<5	9018	Indoor		LEV	P		0.254
U	M	<5	9018	Indoor		LEV	P		0.241
U	M	<5	9018	Indoor		LEV	P		0.45
U	M	<5	9018	Indoor		LEV	P		0.266
U	M	<5	9018	Indoor		H	P		<0.06
	M	<5	9018	Indoor		H	P		1.08
P22 Cr	M	<5	9018	Indoor		M	P		<0.04
P22 Cr	M	<5	9018	Indoor		M	P		<0.04
U	M	8-10.5	8015	Indoor		M	P		1.28
U	M	8-10.5	8015	Indoor		M	P		0.931
	M	<5	9018	Indoor		M	P		4.26
	M	<5	9018	Indoor		M	P		2.49

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc $\mu g/m^3$
	M	<5	9018	Indoor		M	P		3.66
U	M	<5	9018	Indoor		M	P		0.629
U	M	<5	9018	Indoor		M	P		9.82
U	M	<5	9018	Indoor		M	P		1.53
U	M	<5	9018	Indoor		M	P		12.6
213T22 and 213-TP321H	M	<5	9018	Indoor		M	P		0.486
T-2	M	<5	9018	Indoor	Natural	M	P	Inside hood	<0.04
T-2	M	<5	9018	Indoor	Natural	M	P	Inside Hood	1.08
F22	M	<5	9018	Indoor	Natural	M	P	Inside hood	0.746
F22	M	<5	9018	Indoor	Natural	M	P	Inside hood	0.757
F22	M	<5	9018	Indoor	Natural	M	P	Inside hood	2.41
F22	M	<5	9018	Indoor	Natural	M	P	Inside hood	1.71
T11 and T22	M	<5	9018	Indoor		L	P		0.494
SA335	M	<5	9018	Indoor		L	P		0.17
T-22	L	0.0	9018	Indoor	LEV	LEV	P		1.1

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m³
T-22	L	0.0	9018	Indoor	LEV	LEV	P		1.73
T-22	L	0.0	9018	Indoor	LEV	LEV	P		2.01
T-22	L	0.0	9018	Indoor	LEV	LEV	P		1.52
U	L	0.0	9018	Outdoor	LEV	LEV	P		0.853
U	L	0.0	9018	Indoor	LEV	LEV	P		1.37
U	L	0.0	9018	Indoor	LEV	LEV	P		1.2
	L	0.0	9018	Indoor	LEV	LEV	P		0.339
Stainless steel	L	0.0	7018	Indoor		LEV	P		<0.07
Carbon steel	L	0.0	7018	Indoor	LEV	LEV	P		0.93
Carbon steel	L	0.0	7018	Indoor	LEV	LEV	P		0.27
Stainless steel (SA-335-P11)	L	1.0	8018-B2	Indoor	LEV	LEV	P		<0.09
	L	0.0	9018	Indoor		LEV	P		0.602
Carbon Steel	L	0.0	8018-C3	Outdoor	Directed	H	P		0.777
Carbon Steel	L	0.0	8018-C3	Outdoor	Directed	H	P		0.386
309 Stainless	L	0.0	E9018	Indoor		H	P		0.125
309 Stainless	L	0.0	E9018	Indoor		H	P		0.0859
309 Stainless	L	0.0	E9018	Indoor		H	P		0.141
309 Stainless	L	0.0	E9018	Indoor		H	P		0.389

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc μg/m³
Stainless steel (SA387)	L	0.0	9018	Indoor		H	P		0.496
U	L	0	7018	Outdoor		H	P		<0.01
U	L	0	7018	Outdoor		H	P		<0.01
Carbon Steel	L	0.0	8018	Indoor	Natural	H	P	Inside hood	0.82
U	L	0.04	NA	Indoor	Natural	H	P	Under Hood	0.63
	L	0.5	8018-B3L	Indoor	Natural	H	P	Inside hood	2.13
U	L	1.11	NA	Indoor	Natural	H	P	Inside hood	<0.37
U	L	1.2	NA	Indoor	Natural	H	P	Inside hood	14
U	L	1.2	NA	Indoor	Natural	H	P	Inside hood	17
U	L	0.0	9018	Indoor	Exhaust Ventilation	H	P	Inside hood	1.16
U	L	0.0	9018	Indoor	Exhaust Ventilation	H	P	Inside hood	0.609
U	L	0.0	9018	Indoor	Exhaust Ventilation	H	P	Inside hood	0.596
Carbon Steel	L	0.0	7018	Indoor	Exhaust Ventilation	H	P	Inside hood	0.304

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m³
21/4 Chrome Pipe	L	<1	9018	Indoor	Natural	H	P	Inside hood	0.42
Carbon Steel	L	0.0	8018	Indoor	Exhaust Ventilation	H	P	Inside hood	2.28
Carbon Steel	L	0.0	8018-C3	Indoor		M	P		<0.1
Mild Steel	L	0.0	8018	Indoor		M	P		0.0895
U	L	0.0	8018	Indoor		M	P		1.84
	L	0.0	9018	Indoor		M	P		6.96
SA213-T-11	L	1.0	8018-B2	Indoor		M	P		1.18
SA213-T-11	L	1.0	8018-B2	Indoor		M	P		0.997
T-22	L	0.0	9018	Indoor		M	P		0.362
U	L	0.0	9018	Indoor		M	P		2.52
U	L	0.0	9018	Indoor		M	P		12.5
U	L	0.0	9018	Indoor		M	P		3.44
U	L	0.0	9018	Indoor		M	P		1.28
U	L	0.0	9018	Outdoor		M	P		3.77
U	L	0.0	9018	Indoor		M	P		5.7
U	L	0.0	7018	Indoor		M	P		0.81
Carbon steel	L	0.0	8018	Indoor		M	P		0.196
Carbon steel	L	0.0	7018	Indoor		M	P		0.23

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc μg/m^3
Stainless steel (SA213T2)	L	1.0	8018-B2	Indoor		M	P		<0.04
Stainless steel (SA213T2)	L	1.0	8018-B2	Indoor		M	P		<0.04
Stainless steel (SA213T2)	L	1.0	8018-B2	Indoor		M	P		<0.05
Stainless steel (SA213T2)	L	1.0	8018-B2	Indoor		M	P		0.586
Stainless Steel (SA213T2)	L	1.0	8018-B2	Indoor		M	P		5.05
Stainless Steel (SA213T2)	L	1.0	8018-B2	Indoor		M	P		4.24
U	L	1	7010A1 and 8018-B2	Indoor		M	P		1.16
U	L	1	7010A1 and 8018-B2	Indoor		M	P		0.266
U	L	0	7010A1 and 8018-B2	Indoor		M	P		1.16
Stainless steel (SA213T2)	L	0	7010A1 and 8018-B2	Indoor		M	P		0.266
Stainless steel (SA213T2)	L	0	7010A1 and 8018-B2	Indoor		M	P		0.638
Stainless steel (SA213T2)	L	0	7010A1 and 8018-B2	Indoor		M	P		1.42

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m^3
Stainless steel (SA213T2)	L	0	7010A1 and 8018-B2	Indoor		M	P		1.87
Stainless steel (SA213T2)	L	0	7010A1 and 8018-B2	Indoor		M	P		7.34
Stainless steel (SA213T2)	L	0	7010A1 and 8018-B2	Indoor		M	P		0.948
	L	0.0	9018	Indoor		M	P		0.298
Cr alloy (80 pipe SA335 P11)	L	0	8018-B2	Indoor		M	P		0.904
Cr alloy (80 pipe SA335 P11)	L	0	8018-B2	Indoor		M	P		0.328
Cr alloy	L	0	8018-B2	Indoor		M	P		<0.01
Cr alloy (80 pipe SA335 P11)	L	0	8018-B2	Indoor		M	P		<0.01
	L	0	8018	Indoor		M	P		2.12
	L	0	8018	Indoor		M	P		2.78
	L	0	8018	Indoor		M	P		1.41
	L	0	8018	Indoor		M	P		9.1
	L	0	8018	Indoor		M	P		1.31
	L	0	8018	Indoor		M	P		1.92
Stainless steel (304)	L	0	7018	Indoor		M	P		3.69

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m^3
Stainless steel (SA213T2)	L	0	7010A1 and 8018-B2	Indoor		M	P		<0.1
Stainless steel (SA213T2)	L	0	7010A1 and 8018-B2	Indoor		M	P		1.11
Stainless steel (SA213T2)	L	0	7010A1 and 8018-B2	Indoor		M	P		1.41
Cr carbide and carbon steel	L	0	7018	Indoor		M	P		2.5
SA213(2.25%) and INCOCLAD 671/800H (48%)	L	0	E9018-B	Indoor		M	P		0.168
SA213(2.25%) and INCOCLAD 671/800H (48%)	L	0	E9018-B	Indoor		M	P		0.71
Carbon steel	L	0	6010 and 7018	Indoor		M	P		1.26
U	L	0	7018	Indoor		M	P		3.16
U	L	0	7018	Indoor		M	P		3.04
213T22 and 213-TP321H	L	2.25	9018	Indoor		M	P		1.84
213T22 and 213-TP321H	L	2.25	9018	Indoor		M	P		3.41
	L	0.0	9018	Indoor		M	P		13.3
	L	0.0	9018	Indoor		M	P		8.07

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m³
	L	0.0	9018	Indoor		M	P		7.86
	L	0.0	E9018	Indoor	Natural	M	P	Inside hood	6.04
	L	0	E8018	Indoor	Natural	M	P	Inside hood	0.424
	L	0.0	E9018	Indoor	Natural	M	P	Inside hood	7.78
U	L	0.0	E7010	Indoor	Natural	M	P	Inside Hood	0.056
U	L	0.0	E7010	Indoor	Natural	M	P	Inside Hood	0.062
Carbon Steel	L	0.0	8018	Indoor	Natural	M	P	Inside hood	1.6
	L	0.0	9018	Indoor	Natural	M	P	Inside hood	8
	L	0.0	9018	Indoor	Natural	M	P	Inside hood	0.48
	L	0.0	9018	Indoor	Natural	M	P	Inside hood	7.36
	L	0.0	9018	Indoor	Natural	M	P	Inside hood	1.2
	L	0.0	9018	Indoor	Natural	M	P	Inside hood	1.12

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc $\mu g/m^3$
	L	0.0	9018	Indoor	Natural	M	P	Inside hood	0.42
	L	0.0	9018	Indoor	Natural	M	P	Inside hood	0.96
U	L	0.0	7010	Indoor	Natural	M	P	Inside Hood	0.2
U	L	0.0	7010	Indoor	Natural	M	P	Inside Hood	<0.2
U	L	0.0	7010	Indoor	Natural	M	P	Inside Hood	0.1
U	L	0.0	8018	Indoor	Natural	M	P	Inside Hood	8.84
U	L	0.0	8018	Indoor	Natural	M	P	Inside Hood	0.545
U	L	0.0	8018	Indoor	Natural	M	P	Inside Hood	0.286
U	L	0.0	8018	Indoor	Natural	M	P	Inside Hood	1.83
U	L	0.0	8018	Indoor	Natural	M	P	Inside Hood	1.29
U	L	0.0	8018	Indoor	Natural	M	P	Inside Hood	2.63
	L	0.0	9018	Indoor	Natural	M	P	Inside hood	0.66

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m³
U	L	0.0	9018	Indoor	Natural	M	P	Inside hood	5.14
U	L	0.0	9018	Indoor	Natural	M	P	Inside hood	0.284
U	L	0.0	9018	Indoor	Natural	M	P	Inside hood	0.364
U	L	0.0	9018	Indoor	Natural	M	P	Inside hood	0.687
304 Stainless steel	L	0.0	9018	Indoor	Natural	M	P	Inside hood	0.663
U	L	0.0	9018	Indoor	Natural	M	P	Inside hood	1.31
U	L	0.0	9018	Indoor	Natural	M	P	Inside hood	0.214
Carbon Steel	L	0.0	7018	Indoor	Natural	M	P	Inside hood	0.18
U	L	1.0	8018-B2	Indoor	Natural	M	P	Inside Hood	<0.06
F22 tube metal	L	0.0	9018	Indoor	Natural	M	P	Inside hood	0.2
F22 tube metal	L	0.0	9018	Indoor	Natural	M	P	Inside hood	0.5
U	L	0.0	9018	Indoor	Natural	M	P	Inside hood	2.81

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc μg/m³
U	L	0.0	9018	Indoor	Natural	M	P	Inside hood	0.206
T22 tube metal	L	0.0	9018	Indoor	Natural	M	P	Inside Hood	0.0677
T22 tube metal	L	0.0	9018	Indoor	Natural	M	P	Inside Hood	0.187
T22 tube metal	L	0.0	9018	Indoor	Natural	M	P	Inside hood	0.295
P22	L	0.0	9018	Indoor	Natural	M	P	Inside hood	1.9
P22	L	0.0	9018	Indoor	Natural	M	P	Inside hood	0.603
P22 & T22	L	0.0	9018	Indoor	Natural	M	P	Inside hood	0.167
P22 & T22	L	0.0	9018	Indoor	Natural	M	P	Inside Hood	<0.1
Hardox 450	L	0.25	NA	Indoor	Natural	M	P	Inside hood	4.75
Hardox 450	L	0.25	NA	Indoor	Natural	M	P	Inside hood	0.402
F22	L	0.0	9018	Indoor	Natural	M	P	Inside hood	1.54
F22	L	0.0	9018	Indoor	Natural	M	P	Inside hood	0.105

Table A-2 (continued)
CR(VI) Results for Personal Samples, SMAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m³
F22	L	0.0	9018	Indoor	Natural	M	P	Inside Hood	2.54
2.25 Cr and 304 Stainless steel	L	0.0	7018-A1	Indoor		L	P		0.884
2.25 Cr and 304 Stainless steel	L	0.0	7018-A1	Indoor		L	P		0.236
SA182-F2	L	2.25	9018	Indoor		L	P		1.84
U	L	1.0	8018-B2	Indoor	Natural	L	P	Inside Hood	<0.2

Table A-3
CR(VI) Results for Personal Samples, GTAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m³
	H	19.5 - 22	308	Indoor	LEV	LEV	P		1.1
	H	19.5 - 22	308	Indoor	LEV	LEV	P		0.53
	H	19.5 - 22	308	Indoor	LEV	LEV	P		<0.03
U	H	18.2??	ENICR-3	Indoor	LEV	LEV	P		3.22
U	H	18.2??	ENICR-3	Indoor	LEV	LEV	P		1.51
304 Stainless steel	H	19	316	Outdoor		H	P		0.153
Stainless steel	H	19.5 - 22	308	Indoor		H	P		0.339
U	H	20.1	NA	Indoor	Natural	H	P		<0.4
U	H	20.26	NA	Indoor	Natural	H	P		<0.36
U	H	23.9	NA	Indoor	Natural	H	P		<0.35
U	H	19.5	NA	Indoor	Natural	H	P		<0.36
U	H	19.5	NA	Indoor	Natural	H	P		<0.36
Stainless steel	H	19.5 - 22	308/316	Outdoor		M	P		0.116
Stainless steel	H	19.5 - 22	308/316	Outdoor		M	P		0.0598
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		0.092

Table A-3 (continued)
CR(VI) Results for Personal Samples, GTAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m^3
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		<0.04
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		0.12
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		0.14
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		<0.09
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		0.071
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		<0.03
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		<0.03
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		<0.06
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		<0.03
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		0.12
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		<0.04
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		0.047

Table A-3 (continued)
CR(VI) Results for Personal Samples, GTAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m^3
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		0.046
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		0.069
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		0.052
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		0.053
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		<0.03
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		0.047
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		<0.03
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		<0.03
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		0.069
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		0.058
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		0.042
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		<0.04

Table A-3 (continued)
CR(VI) Results for Personal Samples, GTAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc μg/m^3
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		<0.04
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		0.045
SA213TP 304H	H	19.5-22.0	ER308	Indoor		M	P		<0.03
394L base	H	20-22%	E308H	Indoor		M	P		0.161
304 Stainless steel	H	19.5 - 22	308	Indoor		M	P		0.297
Stainless steel (304)	H	19.5 - 22	308	Indoor		M	P		0.144
316 Stainless steel	H	19	316L	Indoor		M	P		0.319
316 Stainless steel	H	19.5 - 22.0	308	Indoor		M	P		0.662
316 Stainless steel	H	19.5 - 22.0	308	Indoor		M	P		<0.06
Stainless steel	H	16.5	16-8-2	Indoor		M	P		<0.2
Stainless steel	H	16.5	16-8-2	Indoor		M	P		<0.2

Table A-3 (continued)
CR(VI) Results for Personal Samples, GTAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m³
332 Stainless	H	19 - 23	NA	Indoor	Natural	M	P		0.173
U	H	19.5-22.0	ER308L	Indoor	Natural	M	P		0.15
U	H	19.5-22.0	ER308L	Indoor	Natural	M	P		0.34
U	H	19.5-22.0	ER308L	Indoor	Natural	M	P		<0.02
U	H	19.5-22.0	ER308L	Indoor	Natural	M	P		0.1
U	H	23.5	ER309	Indoor	Natural	M	P		<0.8
308H	H	19.5 - 22	308	Indoor	Natural	M	P		0.484
U	H	19.5 - 22	308	Indoor	Natural	M	P		<0.1
304SS	H	19-23	90SB3 308H	Indoor	Natural	M	P		0.193
	H	23.5	309	Indoor	Natural	M	P		0.324
304	H	19.5 - 22	308	Indoor	Natural	M	P		<0.09
	H	19.5-22.0	ER308	Indoor	Natural	M	P		0.202
304	H	19.5 - 22	308	Indoor	Vent Hood	M	P		<0.6
	H	15.5	INCO3	Indoor	Natural	M	P		0.7
308H	H	15.5	INCO3	Indoor	Natural	M	P		0.482
308H	H	15.5	INCO4	Indoor	Natural	M	P		0.661
U	H	19.5-22.0	ER308L	Indoor	Natural	L	P		0.1
U	H	19.5-22.0	ER308L	Indoor	Natural	L	P		0.15

Table A-3 (continued)
CR(VI) Results for Personal Samples, GTAW

Base Metal Cr Content	Consumable Cr Content (Relative)	Consumable Cr Content (%)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc μg/m³
U	H	19.5-22.0	ER308L	Indoor	Natural	L	P		0.042
U	H	19.5-22.0	ER308L	Indoor	Natural	L	P		0.095
304SS	H	19.5 - 22	308	Indoor	Natural	L	P		0.395
304SS	H	19.5 - 22	308	Indoor	Natural	L	P		0.558
U	M	3.25	80ES	Indoor	Natural	M	P		0.171
U	M	4.25	80ES	Indoor	Natural	M	P		0.0711
U	M	<5	9018	Indoor		L	P		0.224
	L	1.25	NA	Indoor	LEV	LEV	P		<0.08
U	L	0.0	8018	Indoor	LEV	LEV	P		0.52
	L	0.0	E8018-B2	Indoor	LEV	LEV	P		0.38
Mild steel	L	0.0	7018 and 9018	Outdoor		H			<0.06
U	L	0.15	NA	Indoor	Natural	H	P		<0.36
U	L	1.4	NA	Indoor	Natural	H	P		<0.35
U	L	1.25	80ES	Indoor	Natural	M	P		0.0852
U	L	2.25	80ES	Indoor	Natural	M	P		0.121
T-22 and T-22	L	2.4	90SB3	Indoor		L	P		1.1
U	L	2.4	90SB3	Indoor	Natural	L	P		<0.05
U	L	2.4	90SB3	Indoor	Natural	L	P	Inside hood	0.298

Table A-4
Arc Gouging Air Sampling Results

Base Metal Cr Content	Consumable Cr Content (%)	Consumable Cr Content (Relative)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m³
Stainless steel	NA	NA	NA	Indoor	LEV	LEV	P		5.97
Stainless steel	NA	NA	NA	Indoor	LEV	LEV	P		2.41
304 Stainless steel	NA	NA	NA	Indoor	LEV	LEV	P		18.6
304 Stainless steel	NA	NA	NA	Indoor	LEV	LEV	P		16.3
	NA	NA	NA	Indoor	LEV	LEV	P		1.54
Carbon steel	NA	NA	NA	Indoor	LEV	LEV	P		4.3
Carbon steel	NA	NA	NA	Indoor	LEV	LEV	P		6.9
Carbon steel	NA	NA	NA	Indoor	LEV	LEV	P		<0.7
309 Stainless	NA	NA	NA	Indoor	LEV	LEV	P		10.6
	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	105
	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	84.3
	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	120
	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	208

Table A-4 (continued)
Arc Gouging Air Sampling Results

Base Metal Cr Content	Consumable Cr Content (%)	Consumable Cr Content (Relative)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m³
	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	119
	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	148
	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	223
	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	161
U	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	119
U	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	194
U	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	61.4
U	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	86.2
U	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	229
U	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	139
	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	2.51
	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	1.56

Table A-4 (continued)
Arc Gouging Air Sampling Results

Base Metal Cr Content	Consumable Cr Content (%)	Consumable Cr Content (Relative)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m³
	NA	NA	NA	Indoor	LEV	LEV	P	Inside Hood	1.4
Stainless steel	NA	NA	NA	Indoor		LEV	P		18.2
Stainless steel	NA	NA	NA	Indoor		LEV	P		5.54
carbon steel	30-60	H	Ultra Met Cr carbide electrodes	Indoor		LEV	P		38
316L Stainless steel	NA	NA	NA	Outdoor		H	P		5.36
U	NA	NA	Copperclad pointed electrodes	Outdoor		H	P		1.92
U	NA	NA	Copperclad pointed electrodes	Outdoor		H	P		1.52
U	NA	NA	Copperclad pointed electrodes	Outdoor		H	P		4.76
U	NA	NA	Copperclad pointed electrodes	Outdoor		H	P		6.06

Table A-4 (continued)
Arc Gouging Air Sampling Results

Base Metal Cr Content	Consumable Cr Content (%)	Consumable Cr Content (Relative)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc µg/m^3
stoddy hardsurface 31	NA	NA	NA	Indoor		H	P		0.63
Mild steel	NA	NA	NA	Indoor		H	P		7
stoddy hardsurface 31	NA	NA	NA	Indoor		H	P		0.26
stoddy hardsurface 31	NA	NA	NA	Indoor		H	P		5.2
	NA	NA	NA	Indoor	Dilution Vent	H	P	Inside Hood	6.3
	NA	NA	NA	Indoor	Dilution Vent	H	P	Inside Hood	84.2
	NA	NA	NA	Indoor	Dilution Vent	H	P	Inside Hood	80.2
	NA	NA	NA	Indoor	Dilution Vent	H	P	Inside Hood	38.6
	NA	NA	NA	Indoor	Dilution Vent	H	P	Inside Hood	76.6
	NA	NA	NA	Indoor	Dilution Vent	H	P	Inside Hood	69.3
	NA	NA	NA	Indoor	Dilution Vent	H	P	Inside Hood	9.75

Table A-4 (continued)
Arc Gouging Air Sampling Results

Base Metal Cr Content	Consumable Cr Content (%)	Consumable Cr Content (Relative)	Consumable Code	General Location: In/Outdoor	Ventilation Type	Ventilation Conditions	Personal or Area Sample	Location of Sample	Task Conc μg/m³
	NA	NA	NA	Indoor	Dilution Vent	H	P	Inside Hood	8.38
	NA	NA	NA	Indoor	Dilution Vent	H	P	Inside Hood	2.62
	NA	NA	NA	Outdoor	Natural	H	P	Inside Hood	10
	NA	NA	NA	Outdoor	Natural	H	P	Inside Hood	4.68
Alloy plate	NA	NA	NA	Indoor		M	P		3.99
Alloy plate	NA	NA	NA	Indoor		M	P		1.1
Cr Carbide panels	NA	NA	Copper clad arcing rods	Indoor		M	P		12
	NA	NA	NA	Indoor		M	P		2.96
	NA	NA	NA	Indoor		M	P		4.03
	NA	NA	NA	Indoor	Natural	M	P	Inside Hood	1.81
	NA	NA	NA	Indoor	Natural	M	P	Inside Hood	0.947
	NA	NA	NA	Indoor	Natural	M	P	Inside Hood	1.36
	NA	NA	NA	Indoor	Natural	M	P	Inside Hood	34.1
	NA	NA	NA	Indoor	Natural	M	P	Inside Hood	13

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