# Reduction of Weld Fume Risk in Naval and Commercial Shipyards

## Final Report

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## Abstract

In 2009 the American Conference of Governmental Industrial Hygienists (ACGIH) published a Notice of Intended Change (NIC) to revise the Threshold Limit Value (TLV) for Manganese (Mn). If adopted, this new occupational exposure limit would require new air monitoring methods for the measurement of Inhalable and Respirable particulate fractions of Mn in breathing zone air. Before this proposed change, the established OSHA Permissible Exposure Limit (PEL), and previous TLV's have always required the same air monitoring process for the measurement of "Total" Mn to evaluate compliance. Since Inhalable and Respirable Mn measurements have not been collected before in American industry, there is no basis of comparison to estimate what impact these proposed changes may have in the evaluation of workplace exposure previously evaluated by "Total" Mn. If implemented, the new TLV in combination with the PEL would in effect require employers to collect three different types of air samples for a single element to characterize representative exposure for all affected employees. This type of triplicate air monitoring burden for a single substance is unparalleled in previous occupational exposure standards.

The goal of this project was to perform side-by-side testing of Total, Respirable and Inhalable Mn exposure in operator breathing zones and general areas of shipyard welding operations to determine if air monitoring of representative tasks could be used to establish estimated or predictable ranges of exposure. This data would be beneficial to the industry to reduce both the labor and expense burden on individual shipyards and to provide a more timely impact analysis of these proposed changes. A total of 96 air samples were collected during actual production work in three US shipyards and one manufacturing facility for ship components, representing work during 7 different welding and metal-working processes. All air sampling results for total Mn were well below the OSHA PEL. The comparative relationship between Total, Inhalable and Respirable particulate sizes, however, did not follow any consistent or predictable pattern. These findings question the technical merits of this unvalidated testing process for the measurement of fractional sizes of Mn in welding fume. The wild variations seen in the relative comparisons of Total, Inhalable and Respirable Mn in this study make any predictive value assigned to these size-fractional test methods unsupportable at this time.

## Introduction

Controlling welding fume emission has been the subject of strict regulations, and the regulatory organizations (EPA, OSHA, ACGIH, and others) have kept increasing the scrutiny of more and more weld fume components while simultaneously lowering the exposure limits. In 2009 the American Conference of Governmental Industrial Hygienists (ACGIH) proposed a 10-fold reduction in their Threshold Limit Value (TLV) for Manganese (Mn) to 0.02 mg/m3 of air over an 8-hour period, and further complicating this rule by requiring new monitoring processes for particle sizes defined as "Respirable" and "Inhalable." Since that time, the new TLV for Mn has remained on the Notice of Intended Changes (NIC) for 2011. Previous exposure monitoring testing has collected "Total" airborne Mn. Unfortunately, there is no validated method to correlate previous testing for "Total" Mn to the newly proposed limits for Respirable and Inhalable Mn, therefore any evaluation to determine compliance will require new air monitoring in accordance with the appropriate methods. As a consequence of these changes, the baseline Mn exposure data for welding and other metalworking processes collected at shipyards and previous NSRP studies cannot provide a measure of how much “Respirable” or “Inhalable” Mn may be released during this work.

These changes proposed in the new TLV for Manganese require totally different air sampling methods from the historical OSHA compliance methods followed for several decades. At this time there is no valid means of comparison to determine what correlation may be drawn between previous air sampling data for Mn and compliance with the new and drastically lowered occupational exposure limit. In addition, no body of data has been identified which has previously studied this relationship, which may allow employers to determine if their previously “compliant” welding operations are operating above or below the new limits. This data gap requires field evaluation to determine what correlation, if any, may exist between historical air sampling data for Total Mn and new air sampling data for Inhalable and Respirable Mn.

**The concerns to be addressed in this project:**

- **Regulatory Impact:** Upcoming or suggested changes and their impact on worker health, productivity, and compliance costs
- **Type of Fume:** Total amount of Mn fume produced, and, where necessary, fume particle size distribution. Recent concerns with manganese fumes have prompted studies, but these have not looked at the occupational exposure to Inhalable or Respirable particle sizes in the broader range of welding processes commonly used in shipyards
- **Welding Process:** In the 90’s, newer, inverter-style power supplies showed dramatic reduction in total weld fume under certain conditions, but did not evaluate particle size, now of interest for compliance with changing Occupational Exposure Standards.
- **Welding Technology:** Newer “Green” welding technologies such as HLAW have shown the potential for a 90% reduction in fume generation and reduced power use at equivalent production rates – but need to be evaluated as to overall economy and ability to be implemented
- **“Outside the Fence” Issues:** With EPA looking at weld fume beyond the scope of employee exposure to include environmental releases, this project will evaluate weld fume emissions with actual in-process air monitoring data, which may provide a basis to offer a qualified technical rebuttal if inaccurate or questionable process-specific emission factors may be imposed. This project is essential “due diligence,” to know the anticipated level of exposure, and be able to take steps to assure a focused compliance response in a proactive manner.

## Technical Approach

### 1. Air Monitoring Procedures

#### A. On Site Air Monitoring during Representative Shipyard Welding Operations.

Testing conducted in each location will follow an identical process to ensure a valid comparison of results between each welding method and each respective location and operating condition.

Personal breathing zone (PBZ) and ambient area air samples will be collected in accordance with established protocol for exposure monitoring for Inhalable and Respirable Mn, using IOM Samplers and Cyclone inlets, as needed for the particle size separation. During each sampled event, a consistent sample collection and analysis process will be followed to ensure the most valid comparison of results between Total, Respirable or Inhalable Mn.

Air samples for Mn will be collected in accordance with three sampling methods:

(1.) Total Mn– Collection with 37mm MCE 0.8um filters in a closed-face mode, calibrated at approximately 2.0 lpm. Lab Analysis will comply with OSHA Method 125G, with ICP/MS.

(2.) Respirable Mn – SKC Aluminum cyclone sample inlet, with unweighed 37mm MCE 0.8um filters open-face mode, calibrated at approximately 2.5 lpm. Lab analysis will comply with OSHA Method 125G, with ICP/MS.

(3.) Inhalable Mn - IOM Sampling inlet with 25mm 0.8um MCE filter, calibrated at approximately 2.0 lpm. Lab analysis will comply with OSHA Method 125G, with ICP/MS.

The sampling plan will include two days of full-shift on site testing in each location.
Each day will include samples collected from 4 locations:

L1 = Welding Operator
L2 = Operator's Helper (or nearby observer)
L3 = Area Sample at nearest accessible point to arc and fume generation
L4 = Area Sample at point accessible to observers or passers by
Each sampling location will be tested for Inhalable (I), Respirable ( R ) and Total (T) Mn. As proposed, each day will generate 12 air samples (L1-I, L1-R, L1-T, etc…) with a total of 24 air samples being collected at the completion of the 2-day event. In addition, as required by sampling methods, laboratory and field blanks will be submitted for quality assurance. During air sampling operations, detailed field notes and process information will be recorded to document pertinent technical information on welding process performance such as run times, weld speeds, filler and base metals used, power use, weld gaps and other data necessary to effectively describe and base conclusions from this evaluation.

## B. Laboratory Analysis.

Following sample collection, air samples will be submitted to a laboratory that participates in the American Industrial Hygiene Association (AIHA) Industrial Hygiene Laboratory Accreditation Program (IHLAP). Samples will be analyzed on a routine turn-around basis, which means that results will typically be available 7 to 10 business days following the on-site air monitoring.

Air sampling results will be compared to applicable OSHA Permissible Exposure Limits (PEL) and the current and proposed ACGIH Threshold Limit Values (TLV) for Manganese (Mn). All project work will be performed under the technical direction of an American Board of Industrial Hygiene (ABIH) Certified Industrial Hygienist (CIH).

**Project Statement of Work:**

**<u>Task 1: Complete Literature Search and Develop Field Testing Plan</u>**

- Finalize project team to include operational breadth (new construction and repair) and
- technological breadth (existing and emerging welding processes)
- Work with shipyard team to refine project goals and finalize tasking
- Review available literature to take advantage of prior work and avoid duplication
- Define scope and methodology for fume sampling and analysis

. **<u>Task 2: Field Testing and Analysis</u>**

- Perform side-by-side fume measurement for Total, Respirable and Inhalable Mn during selected shipyard welding processes, such as SMAW, SubArc, FCAW, and MMAW
- Evaluate HLAW as a "Green Shipyard" option for reduced energy consumption, less waste and lower emissions
- Review results to determine need for additional testing in focused areas

**<u>Task 3: Prepare Draft Report</u>**

- Consolidate results with a "snapshot" of existing conditions and results
- Establish recommendations of the team for path to compliance, submittal of comments to regulatory agencies and any need for future work
- Circulate DRAFT report to the Panel for review and comment

**<u>Task 4: Final Report</u>**

- Deliver a report that documents existing welding methods and exposure profiles, and provides guidelines for implementation of methods to reduce employee and environmental exposure to weld fume in accordance with new occupational exposure limits.
- The data collected and recommendations will be available for use by all shipyards and ship repair activities. Project progress reports will be made to appropriate panels of the NSRP during and at the completion of the project. Reports will be disseminated via "nsrp.org" and other media. A workshop will be held at Ship-Tech or other venue that is well-attended by the shipbuilding community.

**Results and Discussion**

**Task 1: Complete Literature Search and Develop Field Testing Plan:** During Task 1 of this project, several sources were examined to determine if any data is available from previous studies that may be applied to better define what predictable relationship may exist, if any, between the Total, Inhalable and Respirable particulate components of the Mn found in welding fume as measured in the breathing zone of the welding operator using exposure monitoring collection and analysis methods accepted in American industry. This evaluation has demonstrated that no conclusive body of data is known to exist which answers this question.

Sources examined during this evaluation have included:

- Review of the Navy Occupational Exposure Database (NOED) historical air monitoring data for occupational exposure to Manganese during "hot work" to determine if any particle-size data exists for comparison to the newly-proposed limits. This assessment included the review of 3866 air sample entries collected between 1982 and 2007. No particle-size data for Manganese in welding was found.

- Review of OSHA's historical air monitoring data in their Integrated Management Information System (IMIS) for occupational exposure to Manganese to determine if any particle-size data exists for comparison to the newly proposed limits. This assessment included the review of 1248 air sample results for Manganese fume collected in shipyard industry locations between 1984 and 2009. No particle-size data for Manganese in welding was found.

- Review of technical reports and discussions with National Institute for Occupational Safety and Health (NIOSH) researchers Dr. James Antonini and Dr. Martin Harper. Each researcher has been involved with multi-year studies on welding fume and particle-size measurements, respectively. Neither researcher could provide any historical particle-size air sampling data for Mn in welding operations.

- Review of the ACGIH TLV Documentation for Manganese and Inorganic Compounds (2010). This report states the basis for the recommendation of a 10-fold lowering of the TLV and the adoption of newly proposed sampling methods to measure Inhalable and Respirable Mn. It is an 18-page document prepared by their Chemical Substances Committee, citing 90 technical references. No references could be identified, and none of the text cited any comparative air sampling data to demonstrate that the proposed Mn particle-size ratios have ever been verified in American industry using US-validated air sampling collection and analysis methods and equipment. The only reference cited as a field-testing validation of the 10-fold lowering of the TLV was a single 2003 paper from Norway (Ellingsen, 2003). The Ellingsen paper describes three days of air monitoring in a Norwegian alloy-producing plant with sample collection using a variety of international equipment and with laboratory analysis using "a novel four-step chemical fractionation procedure developed to characterize workroom aerosols in Mn alloy producing plants." These methods are not consistent with American occupational exposure measurement procedures and they have not been reproduced or validated in accordance with established US quality control standards, such as the American Industrial Hygiene Association Industrial Hygiene Proficiency Analytical Testing (IHPAT) Program.

- Discussion and correspondence with the American Conference of Governmental Industrial Hygienists (ACGIH), including the Chair of the TLV-Chemical Substances Committee, Dr. Terry Gordon, and the ACGIH Staff Science and Education Manager, Ryan Peltier. They have reported that ACGIH TLV-Chemical Substances Committee does not have any side-by-side air monitoring data comparing total, inhalable and respirable size fractions on Mn in welding fume.

- Review of extensive technical literature including previous NSRP studies and research published by the American Welding Society has not identified any historical particle-size air monitoring data responsive to the current research objectives. Although there is extensive research on particle-sizing of welding fume, including evaluation of manganese, none of the published literature found to this point has collected or analyzed the air samples using methods accepted for the measurement of personal breathing zone levels required to determine compliance with the newly proposed occupational exposure limit. With the drastically different sample collection and analysis methods, there is no known pathway to correlate results to overcome the differences in sampler placement, collection times, air flow rates, dimensions and porosity of sample collection media, lab analysis techniques and independent quality control standards.

**Task 2: Field Testing and Analysis** During Task 2 of the Project, field testing was conducted in three shipyards and one commercial production facility in order to meet the following objectives:

1. Perform side-by-side fume measurement for Total, Respirable and Inhalable Mn during selected shipyard welding processes, such as SMAW, SubArc, FCAW, and GMAW.
2. Evaluate Hybrid Laser Arc Welding (HLAW) as a "Green Shipyard" option for reduced energy consumption, less waste and lower emissions.
3. Review results to determine need for additional testing in focused areas.

Air monitoring was conducted during welding operations in the following locations:

**a.** BAE Systems Southeast Shipyards, Jacksonville, FL; April 12-14, 2011
**b.** Bath Iron Works, Bath, ME; April 25-27, 2011
**c.** Norfolk Naval Shipyard, Portsmouth, VA; May 2-4, 2011
**d.** Applied Thermal Sciences, Inc. production facility, Sanford, ME; June 8-10, 2011

This air monitoring was conducted during real production work, not as part of a staged demonstration.
Personal breathing zone air monitoring and area monitoring was conducted in accordance with the current validated occupational exposure method for Metals (OSHA ID 125).

The field testing was successful in collecting samples during 7 welding and metal working processes. Processes tested included:

- Flux-Cored Arc Welding
- Gas Tungsten Arc Welding
- Shielded Metal Arc Welding
- Gas Metal Arc Welding-Pulse-Arc
- Carbon Arc Gouging
- Grinding
- Hybrid Laser Arc Welding

## 1. Air Monitoring During Shipyard Welding Processes

### A. On Site Air Monitoring During Representative Shipyard Welding Operations.

Testing conducted in each location followed an identical process to ensure a valid comparison of results between each welding method and each respective location and operating condition. Personal breathing zone (PBZ) and ambient area air samples were collected in accordance with established protocol for exposure monitoring for Total, Inhalable and Respirable Mn, as needed for the particle size separation. During each sampled event, a consistent sample collection and analysis process was followed to ensure the most valid comparison of results between Total, Respirable or Inhalable Mn.

Air samples for Mn were collected in accordance with three sampling methods:

1. Total Mn– Collection with 37mm MCE 0.8um filters in a closed-face mode, calibrated at approximately 2.0 liters of air per minute (lpm). Lab Analysis by OSHA Method 125G, with ICP/MS.
2. Respirable Mn – SKC Aluminum cyclone sample inlet, with unweighed 37mm MCE 0.8um filters open-face mode, calibrated at approximately 2.5 liters of air per minute (lpm). Lab analysis by OSHA Method 125G, with ICP/MS.
3. Inhalable Mn - IOM Sampling inlet with 25mm 0.8um MCE filter, calibrated at approximately 2.0 liters of air per minute (lpm). Lab analysis by OSHA Method 125G, with ICP/MS.

A picture of the air sample configuration for personal air samples is provided as Figure 1.

Figure 1 – Personal Air Sampling for Total, Inhalable and Respirable Manganese

A picture of the air sample configuration for area air samples is provided as Figure 2.

Figure 2 – Area Air Sampling for Total, Inhalable and Respirable Manganese

The sampling plan included two days of full-shift on site testing in each location.
Each day included samples collected from 4 locations, such as:

L1 = Welding Operator
L2 = Operator's Helper (or nearby observer)
L3 = Area Sample at nearest accessible point to arc and fume generation
L4 = Area Sample at point accessible to observers or passers by

Each sampling location was tested for Inhalable (I), Respirable (R) and Total (T) Mn. Each day generated 12 air samples (L1-I, L1-R, L1-T, etc…) with a total of 24 air samples being collected at the completion of the 2-day event. In addition, as required by sampling methods, laboratory and field blanks were submitted to the laboratory for quality assurance.

During air sampling operations, detailed field notes and process information were recorded to document pertinent technical information on welding process performance such as run times, weld speeds, filler and base metals used, power use, weld gaps and other data necessary to effectively describe and base conclusions from this evaluation.

**Laboratory Analysis:** Following sample collection, air samples were submitted to Galson Laboratories in Buffalo, NY. This laboratory successfully participates in the American Industrial Hygiene Association (AIHA) Industrial Hygiene Laboratory Accreditation Program (IHLAP).

Air sampling results have been compared to applicable OSHA Permissible Exposure Limits (PEL) and the current and proposed ACGIH Threshold Limit Values (TLV) for Manganese (Mn). All project work was performed under the technical direction of an American Board of Industrial Hygiene (ABIH) Certified Industrial Hygienist (CIH) and all air samples were collected by a CIH.

**Air Sample Results** Air sample results are summarized below in Table 1- Air Monitoring Results for Mn in Air.

| | | | | Total | | | Inhalable | | | | Respirable | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | Total | Process | Sample Type Personal (P) Area (A) | Minutes | Result (Mn, mg/m$^3$) | 8-HR TWA | | Minutes | Result (Mn, mg/m$^3$) | 8-HR TWA | | Minutes | Result (Mn, mg/m$^3$) | 8-HR TWA |
| T1 | Total(2) | FCAW | P | 439 | 0.60 | 0.549 | Inhal(IM459) | 376 | 0.52 | 0.407 | Resp(21) | – | – | |
| T2 | Total(10) | FCAW | P | x | – | – | Inhal(IM408) | x | – | – | Resp(26) | x | – | |
| T3 | Total(4) | FCAW | A | 399 | 0.41 | 0.341 | Inhal(IM401) | 399 | 0.31 | 0.258 | Resp(24) | 398 | 0.46 | 0.381 |
| T4 | Total(5) | FCAW | A | 390 | 0.58 | 0.471 | Inhal(IM475) | 391 | 0.87 | 0.709 | Resp(13) | 391 | 0.58 | 0.472 |
| T5 | Total(19) | Grinding | P | 374 | 0.23 | 0.179 | Inhal(IM504) | 374 | 0.24 | 0.187 | Resp(17) | 272 | 0.13 | * |
| T6 | Total(11) | FCAW | P | 368 | 0.47 | 0.360 | Inhal(IM405) | 153 | 0.52 | * | Resp(30) | 359 | 0.49 | 0.366 |
| T7 | Total(7) | Grinding | A | 304 | 0.32 | 0.203 | Inhal(IM385) | 303 | 0.11 | 0.069 | Resp(20) | 304 | 0.30 | 0.190 |
| T8 | Total(16) | FCAW | A | 320 | 0.50 | 0.333 | Inhal(IM076) | 320 | 0.62 | 0.413 | Resp(23) | 185 | 0.40 | * |
| T9 | Total(15) | MIG PulseArc | P | 466 | 0.39 | 0.379 | Inhal(IM357) | 390 | 0.37 | 0.301 | Resp(14) | 243 | 0.17 | * |
| T10 | Total(11) | MIG/CAG | A | 398 | 0.55 | 0.456 | Inhal(IM332) | 303 | 0.21 | 0.133 | Resp(7) | 461 | 0.68 | 0.653 |
| T11 | Total(4) | Carbon ArcGouging | P | 415 | 0.22 | 0.190 | Inhal(IM478) | x | – | – | Resp(13) | 94 | 0.18 | * |
| T12 | Total(3) | MIG/CAG | A | 448 | 0.044 | 0.041 | Inhal(IM435) | 448 | 0.028 | 0.026 | Resp(9) | 448 | 0.037 | 0.035 |
| T13 | Total(10) | MIG PulseArc | P | 459 | 0.013 | 0.012 | Inhal(IM319) | 459 | 0.012 | 0.011 | Resp(L21209-1) | 459 | 0.0082 | 0.008 |
| T14 | Total(TW-1) | MIG PulseArc | A | 446 | 0.0056 | 0.005 | Inhal(IM041) | 446 | 0.0063 | 0.006 | Resp(L21209-13) | 446 | 0.0049 | 0.005 |
| T15 | Total(12) | FCAW | P | 173 | 2.50 | * | Inhal(IM422) | 90 | 2.2 | * | Resp(L21209-7) | 137 | 3.0 | * |
| T16 | Total(5) | FCAW | A | 169 | 0.098 | * | Inhal(IM353) | 169 | 0.090 | * | Resp(L21209-9) | 169 | 0.083 | * |
| T17 | Total(6) | SMAW | P | 189 | 0.86 | * | Inhal(IM497) | 113 | 0.41 | * | Resp(11) | 275 | 0.53 | * |
| T18 | Total(3) | SMAW | A | 399 | 0.033 | 0.027 | Inhal(IM458) | 399 | 0.027 | 0.022 | Resp(23) | 399 | 0.029 | 0.024 |
| T19 | Total(14) | TIG Stainless | P | 275 | 0.027 | * | Inhal(IM329) | 174 | 0.022 | * | Resp(4) | 275 | 0.011 | * |
| T20 | Total(25) | TIG Stainless | A | 345 | 0.0022 | 0.002 | Inhal(IM482) | 345 | 0.0026 | 0.002 | Resp(20) | 345 | 0.0020 | 0.001 |
| T21 | Total(17) | SMAW | P | 286 | 0.13 | 0.077 | Inhal(IM512) | 286 | 0.14 | * | Resp(21) | 286 | 0.12 | * |
| T22 | Total(18) | SMAW | A | 390 | 0.046 | * | Inhal(IM372) | 390 | 0.051 | 0.041 | Resp(24) | 390 | 0.043 | 0.035 |
| T23 | Total(7) | TIG Stainless | P | 295 | 0.0060 | * | Inhal(IM320) | 295 | 0.0078 | * | Resp(8) | 295 | 0.0058 | * |
| T24 | Total(22) | TIG Stainless | A | 360 | 0.0015 | 0.001 | Inhal(IM385) | 360 | 0.0015 | 0.001 | Resp(15) | 300 | 0.0013 | 0.001 |
| T25 | Total(13) | HLAW | P | 477 | 0.010 | | Inhal(IM392) | 477 | 0.0091 | | Resp(12) | 322 | 0.011 | |
| T26 | Total(4) | HLAW | A | 477 | 0.0075 | | Inhal(IM315) | 477 | 0.0083 | | Resp(2) | 477 | 0.0076 | |
| T27 | Total(5) | HLAW | P | 58 | 0.19 | | Inhal(IM060) | 58 | 0.20 | | Resp(3) | 58 | 0.22 | |
| T28 | Total(8) | TIG | P | 460 | 0.010 | | Inhal(IM161) | 460 | 0.010 | | Resp(1) | 460 | 0.0091 | |
| T29 | Total(25) | Grinding | P | 360 | 0.0020 | | Inhal(IM507) | 149 | 0.0061 | | Resp(20) | 360 | 0.00048 | |
| T30 | Total(22) | Grinding | A | 345 | 0.00084 | | Inhal(IM041) | 345 | 0.00089 | | Resp(16) | 345 | 0.00044 | |
| T31 | Total(21) | Grinding | P | 355 | 0.0025 | | Inhal(IM510) | 355 | 0.0066 | | Resp(23) | 355 | 0.0020 | |
| T32 | Total(26) | HLAW | P | 110 | 0.091 | | Inhal(IM489) | 110 | 0.095 | | Resp(24) | 110 | 0.091 | |
| *Specific task-related sample. Does not represent an 8-hr TWA | | | | | | | | | | | | | | |

Table 1- Air Monitoring Results for Mn in Air

**Data Analysis:** A total of 91 results were obtained from the collection of 96 samples, for a 95% completion rate. The complete data represent 31 samples for Total Mn, 30 samples for Inhalable Mn and 30 samples for Respirable Mn. The 5 samples lost were personal breathing zone samples which could not be retrieved due to destruction of the paper sample filter or plastic cassette housing during the day's production work. Four of the five samples lost were damaged during shipboard welding work requiring extensive climbing, crawling and fitting into tight spaces below deck.

The air sampling data presented in Table 1 is receiving statistical analysis at the Navy and Marine Corps Public Health Center as part of Task 3, Preparation of Draft Report. This analysis will determine what trends and patterns may be presented as supportable conclusions. During Task 3, Applied Thermal Sciences will be reviewing more detailed welding process information collected during the field testing. This information includes weld speeds, filler and base metals used, power use, weld gaps, work area configuration and ventilation use.

An initial summary of the data reveals:

1. There is a wide variation in airborne Mn concentrations found in shipyard welding and metalworking processes. Results ranged from 3.0 mg/m3 to 0.00044 mg/m3 of air, for a greater than 6800-fold difference.
2. All results were well below the OSHA Permissible Exposure Limit for Manganese of 5.0 mg/m3 of air, expressed as a Ceiling value.

3. Only TIG (Gas Tungsten Arc Welding) was observed to be consistently below the ACGIH Notice of Intended Changes TLV for Mn of 0.02 mg/m3 as Respirable particulate. All other processes tested provided results which exceeded this limit.
4. The relationship between Total, Inhalable and Respirable Mn does not follow any regular or predictable pattern. Side by side air samples will often yield results with smaller size fractions exceeding Total Mn concentration or Respirable Mn greater than Inhalable Mn. These finding raise questions about the technical merits of the proposed testing process, especially when evaluation requires a 3-fold increase in labor, equipment and laboratory resources.

## 2 Review of Hybrid Laser Arc Welding as a "Green Shipyard" Option

During the course of the field testing, one of the welding methods evaluated was Hybrid Laser Arc Welding (HLAW). HLAW has received considerable attention in recent years because of many potential benefits over conventional welding processes due to:

- Highly automated and precise welds – whereas manual and semi-automatic processes are prone to overwelding, and traditional mechanization equipment is not controllable and thus tends to make welds larger than necessary;
- Reduced operator exposure time to airborne fume – The operator stands at a control station during the entire weld cycle, many feet away from the actual weld zone, in contrast to tradition welding, in which the welder must be positioned within 1-2 feet of the arc for sufficient visibility;
- HLAW system design - to reduce fume exposure by means of a powerful "air knife" is positioned to blow smoke and sparks away from the operator's station;
- Reduced time of generation of fume - since the HLAW process works at 5-10 times faster than conventional processes, the actual time of fume generation for a given weld is much shorter;
- Smaller weld sizes – the deep penetration offered by the laser allows the designer to switch from partial-penetration fillet welds to full-penetration welds;
- Reduced use of filler metal the smaller weld sizes noted above allow reduction in actual weld deposit volume by factors as high as 50%; and
- Consistent results and fewer failures – thus less rework is required, with concomitant savings in energy and reductions in fume.

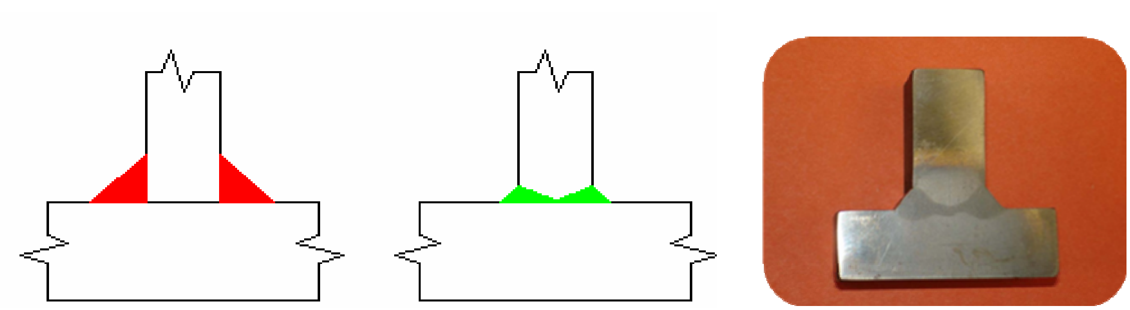

Figure 3. Comparison of conventional and HLAW weld tee-joints; macro of HLAW joint (right)
3/8" Double fillet weld (left) Full-pen HLAW weld with 1/8" fillet reinforcement (center)
Weight of fillet = 0.578lb/ft Weight of fillet = 0.144 lb/ft; 75% Reduction in weld

As noted above in Figure 3, a tee-joint requiring a 0.375-inch partial penetration double fillet weld can be replaced by a full-penetration HLAW tee-joint with only a 0.125-inch fillet required by Navy and AWS joint design manuals. This represents a significant (75%) reduction in the amount of filler metal transferred across the arc, and thus much, much lower levels of welding fume.

These operating factors are consistent with the goals of reduced energy use and lower emissions commonly referred to as “green” technology.

Manganese fume data collected during HLAW as shown in Table 1 can be compared to the emissions for the other welding processes. In virtually every case, HLAW clearly offers measureable benefits in fume reduction. Air sampling conducted during HLAW on June 9 and 10, 2011 shows that almost all Mn fume concentrations are an order of magnitude lower than those of FCAW or SMAW. GMAW-P values were close to HLAW readings, and in a few cases were actually better, although the average values were higher. GTAW results were the lowest of all. Note that GTAW is a low-productivity process, and thus would be expected to exhibit lower fume concentrations. Averages of test data are shown below in Figure 4.

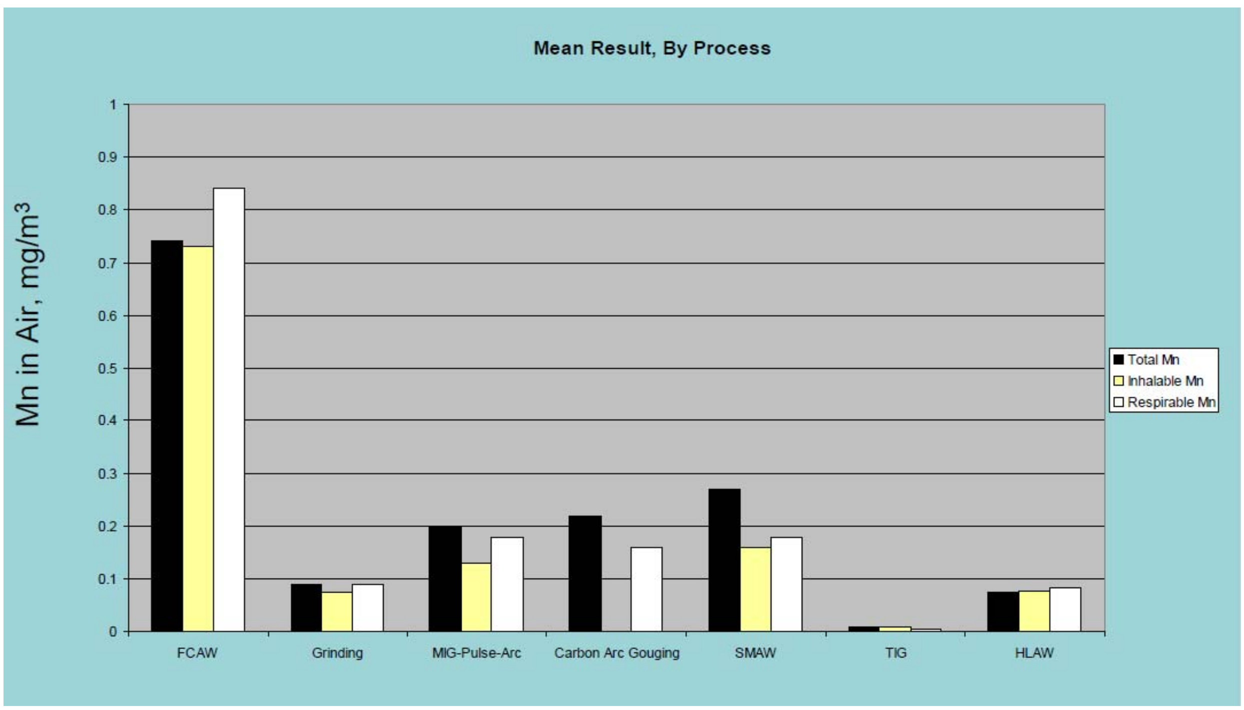


Figure 4. Averages of Mn fume values from field tests by process.

## Further Analysis of Mn Fume Data

The Navy and Marine Corps Public Health Center Industrial Hygiene Department participated in this study during field data collection and completion of a detailed statistical analysis of the results. The graphs and data tables prepared during this analysis are attached to this report as Appendix A.

Their analysis and findings may be summarized as follows:

1. It was difficult to calculate Confidence Limits for the air sample results since no previous work had determined validated Coefficients of Variation (CVT) for the analysis of Inhalable or Respirable particle-size fractions of Manganese.
2. Actual period sample results for matching sample period durations, not TWA calculations, should be used as the best data source for comparison of the findings for evaluation of percentage fractions of Total Mn which may be found as Inhalable or Respirable mass.
3. Equivalent sample run times, in minutes, provide the best basis of comparison of side-by-side samples for Total, Inhalable and Respirable Mn.
4. Potential sources of variability in sample placement, collection and analysis process are significant factors to consider in the future analysis of comparative data for Total, Inhalable and Respirable Mn. All data collected in this study was collected by the same industrial hygienist and the same analytical laboratory was used throughout the project to ensure consistency of methods.
5. Detailed statistical analysis for 3 data sets of FCAW results (T3, T4, T16) found three different rankings of Total, Inhalable and Respirable particulate. These data sets were selected for detailed analysis because they demonstrated the best match of sample duration times across all three air sampling methods combined with the highest Mn concentrations with significantly measureable variability. Data set T3 demonstrates greater Respirable mass than Total or Inhalable. Data set T4 demonstrates greater Inhalable mass than Total. Only data set T16 demonstrated the expected ranking of Total, Inhalable and Respirable Mn in air.
6. It is not physically possible for Respirable or Inhalable Mn to exceed Total Mn in a side-by-side sample set. The findings of this study raise questions, which remain unanswered, about the validity of particle-size sampling as an accurate measure of exposure for Mn in welding fume.

## Conclusions

From the foregoing, the following conclusions can be made:

- There is a wide variation in airborne Mn concentrations found in shipyard welding and metalworking processes. Results ranged from 3.0 mg/m3 to 0.00044 mg/m3 of air, for a greater than 6800-fold difference.
- All results were well below the OSHA Permissible Exposure Limit for Manganese of 5.0 mg/m3 of air, expressed as a Ceiling value.
- Only TIG (Gas Tungsten Arc Welding) was observed to be consistently below the ACGIH Notice of Intended Changes TLV for Mn of 0.02 mg/m3 as Respirable particulate. All other processes tested provided results which exceeded this limit.
- The relationship between Total, Inhalable and Respirable Mn does not follow any regular or predictable pattern. Side by side air samples will often yield results with smaller size fractions exceeding Total Mn concentration or Respirable Mn greater than Inhalable Mn. These finding raise questions about the technical merits of the proposed testing process, especially when evaluation requires a 3-fold increase in labor, equipment and laboratory resources.
- Clearly, more work will be required in the area of test equipment design and methods validation in order to provide meaningful and relevant data on which to base future standards and compliance activities.

## Summary

The results of this study demonstrate that the air sampling methods currently available for evaluation of the Inhalable and Respirable particulate sizes of Mn found in welding fume do not correlate with the established and accepted historical air sampling method for Total Mn. In the absence of a demonstrated and reproducible validation study to demonstrate a credible means of measurement, a new TLV for Mn based upon Inhalable and Respirable particle sizes lacks sufficient scientific methodology to determine compliance. The wildly unpredictable variations seen here and now known to exist in the measurements for Mn welding fume particle sizes in welders’ work zones make any predictive value assigned to these test methods totally unsupportable at this time.

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# Appendix A

# Statistical Analysis of Results

## Figure A-1

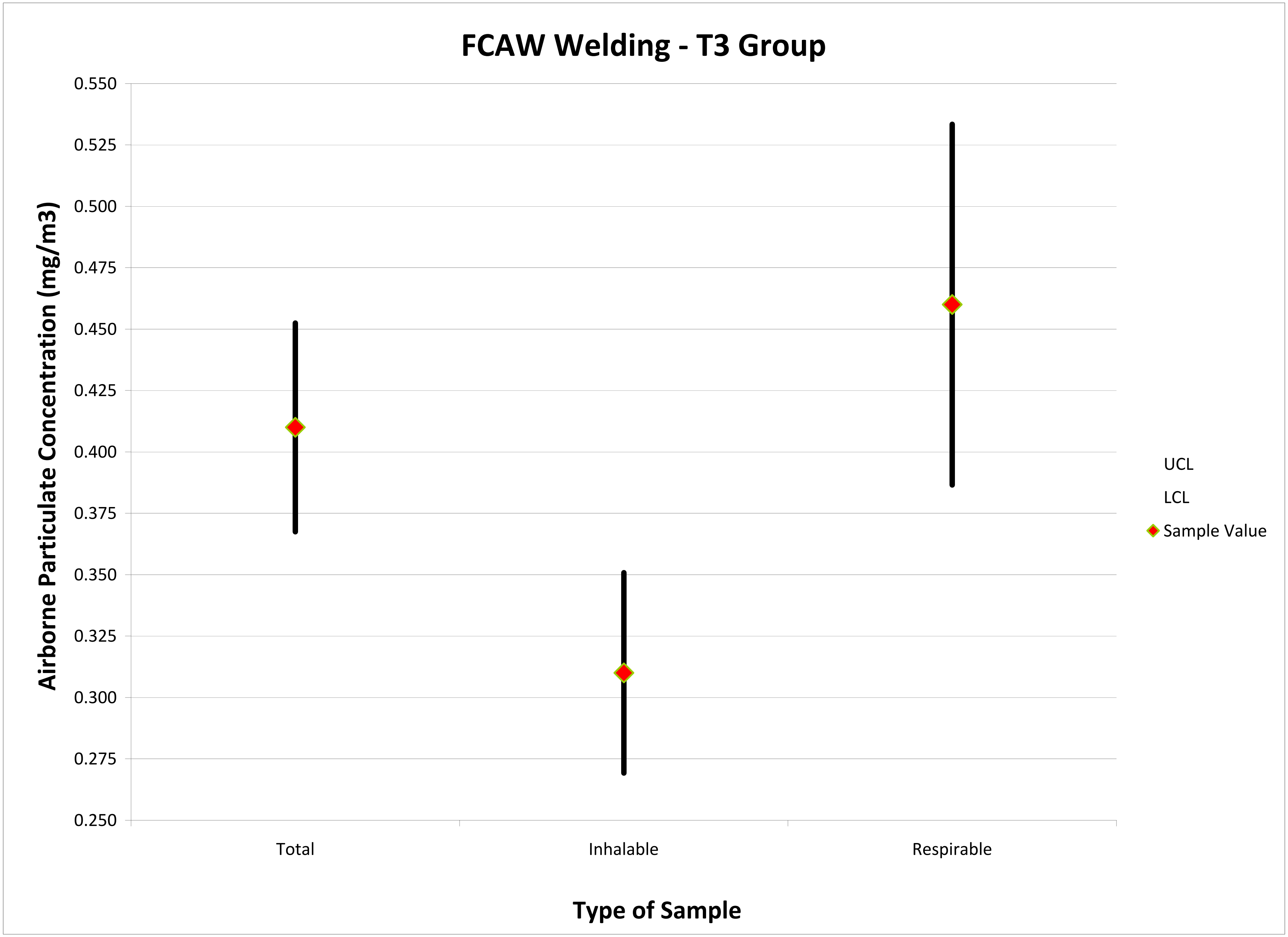
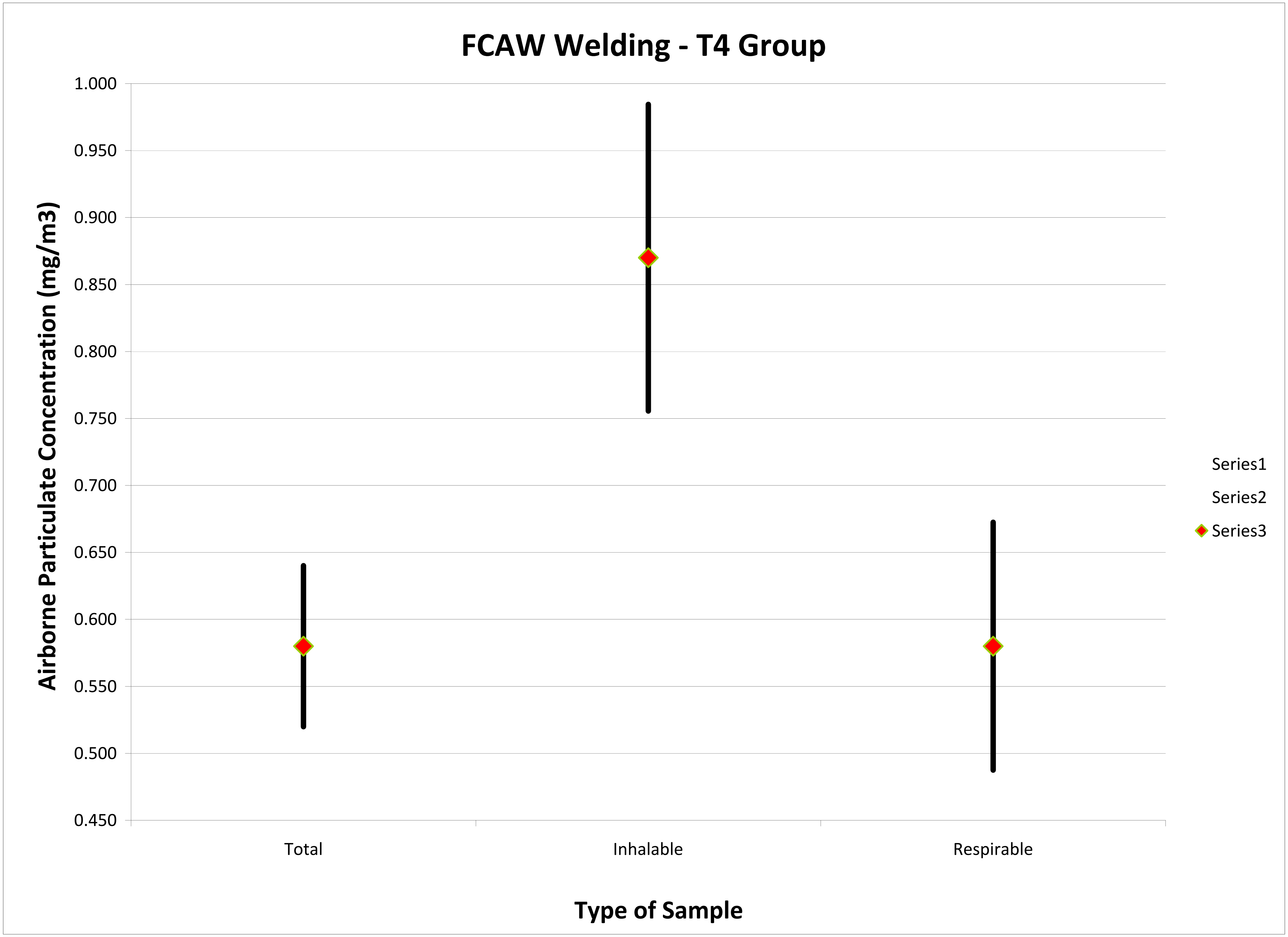
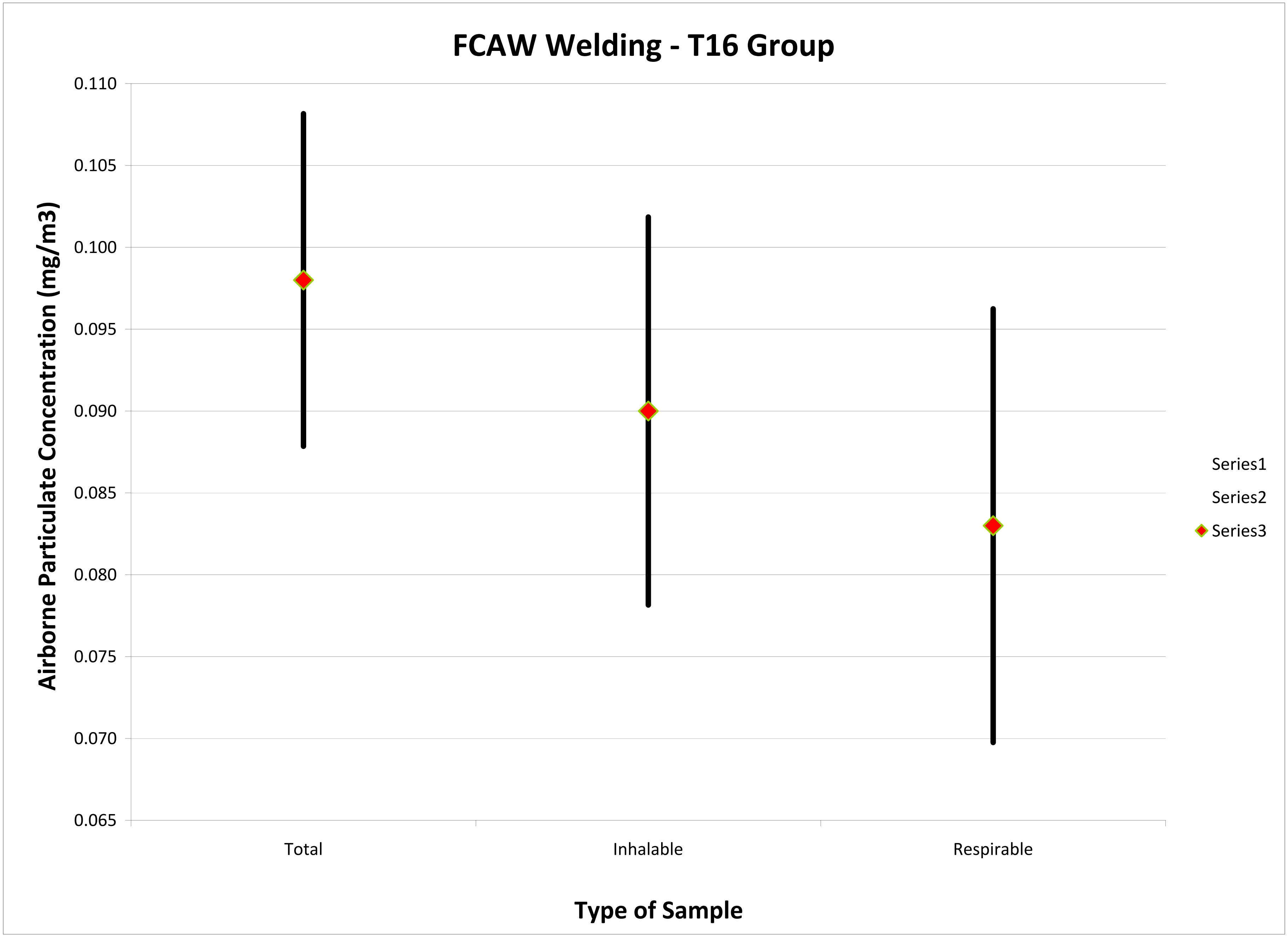

FCAW Welding - T3 Group
Airborne Particulate Concentration (mg/m3)
0.550
0.525
0.500
0.475
0.450
0.425
0.400
0.375
0.350
0.325
0.300
0.275
0.250
Total
Inhalable
Respirable
Type of Sample
UCL
LCL
Sample Value

**Figure A-2**



FCAW Welding - T4 Group
Airborne Particulate Concentration (mg/m3)
1.000
0.950
0.900
0.850
0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.450
Total
Inhalable
Respirable
Type of Sample
Series1
Series2
Series3

**Figure A-3**



FCAW Welding - T16 Group
Airborne Particulate Concentration (mg/m3)
0.110
0.105
0.100
0.095
0.090
0.085
0.080
0.075
0.070
0.065
Total
Inhalable
Respirable
Type of Sample
Series1
Series2
Series3

## Table A-1

| | | | | Total | | | Inhalable | | | | Respirable | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total** | **Total** | **Process** | **Sample Type Personal (P) Area (A)** | **Minutes** | **Result (Mn, mg/m$^3$)** | **TWA** | | **Minutes** | **Result (Mn, mg/m$^3$)** | **TWA** | | **Minutes** | **Result (Mn, mg/m$^3$)** | **TWA** |
| T1 | Total(2) | FCAW | P | 439 | 0.60 | | Inhal(IM459) | 376 | 0.52 | | Resp(21) | – | – | |
| T2 | Total(10) | FCAW | P | x | – | | Inhal(IM408) | x | – | | Resp(26) | x | – | |
| T3 | Total(4) | FCAW | A | 399 | 0.41 | | Inhal(IM401) | 399 | 0.31 | | Resp(24) | 398 | 0.46 | |
| T4 | Total(5) | FCAW | A | 390 | 0.58 | | Inhal(IM475) | 391 | 0.87 | | Resp(13) | 391 | 0.58 | |
| T6 | Total(11) | FCAW | P | 368 | 0.47 | | Inhal(IM405) | 153 | 0.52 | | Resp(30) | 359 | 0.49 | |
| T8 | Total(16) | FCAW | A | 320 | 0.50 | | Inhal(IM076) | 320 | 0.62 | | Resp(23) | 185 | 0.40 | |
| T15 | Total(12) | FCAW | P | 173 | 2.50 | | Inhal(IM422) | 90 | 2.20 | | Resp(L21209-7) | 137 | 3.00 | |
| T16 | Total(5) | FCAW | A | 169 | 0.098 | | Inhal(IM353) | 169 | 0.090 | | Resp(L21209-9) | 169 | 0.083 | |
| *Specific task-related sample. Does not represent an 8-hr TWA | | | | | | | | | | | | | | |

## Table A-2

| | | | Total | | | | Inhalable | | | | Respirable | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | Process | Sample Type Personal (P) Area (A) | Total | Minutes | Result (Mn, mg/m$^3$) | 8-HR TWA | | Minutes | Result (Mn, mg/m$^3$) | 8-HR TWA | | Minutes | Result (Mn, mg/m$^3$) | 8-HR TWA |
| T17 | SMAW | P | Total(6) | 189 | 0.86 | | Inhal(IM497) | 113 | 0.41 | | Resp(11) | 275 | 0.53 | |
| T18 | SMAW | A | Total(3) | 399 | 0.033 | | Inhal(IM458) | 399 | 0.027 | | Resp(23) | 399 | 0.029 | |
| T21 | SMAW | P | Total(17) | 286 | 0.13 | | Inhal(IM512) | 286 | 0.14 | | Resp(21) | 286 | 0.12 | |
| T22 | SMAW | A | Total(18) | 390 | 0.046 | | Inhal(IM372) | 390 | 0.051 | | Resp(24) | 390 | 0.043 | |
| *Specific task-related sample. Does not represent an 8-hr TWA | | | | | | | | | | | | | | |

**Table A-3**

| | | | Total | | | | Inhalable | | | | Respirable | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | Process | Sample Type Personal (P) Area (A) | Total | Minutes | Result (Mn, mg/m$^3$) | 8-HR TWA | | Minutes | Result (Mn, mg/m$^3$) | 8-HR TWA | | Minutes | Result (Mn, mg/m$^3$) | 8-HR TWA |
| T9 | MIG PulseArc | P | Total(15) | 466 | 0.39 | | Inhal(IM357) | 390 | 0.37 | | Resp(14) | 243 | 0.17 | |
| T13 | MIG PulseArc | P | Total(10) | 459 | 0.013 | | Inhal(IM319) | 459 | 0.012 | | Resp(L21209-1) | 459 | 0.0082 | |
| T14 | MIG PulseArc | A | Total(TW-1) | 446 | 0.0056 | | Inhal(IM041) | 446 | 0.0063 | | Resp(L21209-13) | 446 | 0.0049 | |
| *Specific task-related sample. Does not represent an 8-hr TWA | | | | | | | | | | | | | | |

## Table A-4

| | | | | Total | | | Inhalable | | | | Respirable | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | Process | Sample Type Personal (P) Area (A) | Total | Minutes | Result (Mn, mg/m$^3$) | 8-HR TWA | | Minutes | Result (Mn, mg/m$^3$) | 8-HR TWA | | Minutes | Result (Mn, mg/m$^3$) | 8-HR TWA |
| T19 | TIG Stainless | P | Total(14) | 275 | 0.027 | * | Inhal(IM329) | 174 | 0.022 | * | Resp(4) | 275 | 0.011 | * |
| T20 | TIG Stainless | A | Total(25) | 345 | 0.0022 | 0.002 | Inhal(IM482) | 345 | 0.0026 | 0.002 | Resp(20) | 345 | 0.0020 | 0.001 |
| T23 | TIG Stainless | P | Total(7) | 295 | 0.0060 | * | Inhal(IM320) | 295 | 0.0078 | * | Resp(8) | 295 | 0.0058 | * |
| T24 | TIG Stainless | A | Total(22) | 360 | 0.0015 | 0.001 | Inhal(IM385) | 360 | 0.0015 | 0.001 | Resp(15) | 300 | 0.0013 | 0.001 |
| *Specific task-related sample. Does not represent an 8-hr TWA | | | | | | | | | | | | | | |

## Table A-5

| | | | | Total | | | Inhalable | | | | Respirable | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | Process | Sample Type Personal (P) Area (A) | Total | Minutes | Result (Mn, mg/m$^3$) | 8-HR TWA | | Minutes | Result (Mn, mg/m$^3$) | 8-HR TWA | | Minutes | Result (Mn, mg/m$^3$) | 8-HR TWA |
| T25 | HLAW | P | Total(13) | 477 | 0.010 | | Inhal(IM392) | 477 | 0.0091 | | Resp(12) | 322 | 0.011 | |
| T26 | HLAW | A | Total(4) | 477 | 0.0075 | | Inhal(IM315) | 477 | 0.0083 | | Resp(2) | 477 | 0.0076 | |
| T27 | HLAW | P | Total(5) | 58 | 0.19 | | Inhal(IM060) | 58 | 0.20 | | Resp(3) | 58 | 0.22 | |
| T32 | HLAW | P | Total(26) | 110 | 0.091 | | Inhal(IM489) | 110 | 0.095 | | Resp(24) | 110 | 0.091 | |
| *Specific task-related sample. Does not represent an 8-hr TWA | | | | | | | | | | | | | | |

## Table A-6

| | | | | Total | | | Inhalable | | | | Respirable | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total** | **Total** | **Process** | **Sample Type Personal (P) Area (A)** | **Minutes** | **Result (Mn, mg/m$^3$)** | **8-HR TWA** | | **Minutes** | **Result (Mn, mg/m$^3$)** | **8-HR TWA** | | **Minutes** | **Result (Mn, mg/m$^3$)** | **8-HR TWA** |
| T1 | Total(2) | FCAW | P | 439 | 0.60 | 0.549 | Inhal(IM459) | 376 | 0.52 | 0.407 | Resp(21) | – | – | |
| T2 | Total(10) | FCAW | P | x | – | – | Inhal(IM408) | x | – | – | Resp(26) | x | – | |
| T3 | Total(4) | FCAW | A | 399 | 0.41 | 0.341 | Inhal(IM401) | 399 | 0.31 | 0.258 | Resp(24) | 398 | 0.46 | 0.381 |
| T4 | Total(5) | FCAW | A | 390 | 0.58 | 0.471 | Inhal(IM475) | 391 | 0.87 | 0.709 | Resp(13) | 391 | 0.58 | 0.472 |
| T5 | Total(19) | Grinding | P | 374 | 0.23 | 0.179 | Inhal(IM504) | 374 | 0.24 | 0.187 | Resp(17) | 272 | 0.13 | * |
| T6 | Total(11) | FCAW | P | 368 | 0.47 | 0.360 | Inhal(IM405) | 153 | 0.52 | * | Resp(30) | 359 | 0.49 | 0.366 |
| T7 | Total(7) | Grinding | A | 304 | 0.32 | 0.203 | Inhal(IM385) | 303 | 0.11 | 0.069 | Resp(20) | 304 | 0.30 | 0.190 |
| T8 | Total(16) | FCAW | A | 320 | 0.50 | 0.333 | Inhal(IM076) | 320 | 0.62 | 0.413 | Resp(23) | 185 | 0.40 | * |
| T9 | Total(15) | MIG PulseArc | P | 466 | 0.39 | 0.379 | Inhal(IM357) | 390 | 0.37 | 0.301 | Resp(14) | 243 | 0.17 | * |
| T10 | Total(11) | MIG/CAG | A | 398 | 0.55 | 0.456 | Inhal(IM332) | 303 | 0.21 | 0.133 | Resp(7) | 461 | 0.68 | 0.653 |
| T11 | Total(4) | Carbon ArcGouging | P | 415 | 0.22 | 0.190 | Inhal(IM478) | x | – | – | Resp(13) | 94 | 0.18 | * |
| T12 | Total(3) | MIG/CAG | A | 448 | 0.044 | 0.041 | Inhal(IM435) | 448 | 0.028 | 0.026 | Resp(9) | 448 | 0.037 | 0.035 |
| T13 | Total(10) | MIG PulseArc | P | 459 | 0.013 | 0.012 | Inhal(IM319) | 459 | 0.012 | 0.011 | Resp(L21209-1) | 459 | 0.0082 | 0.008 |
| T14 | Total(TW-1) | MIG PulseArc | A | 446 | 0.0056 | 0.005 | Inhal(IM041) | 446 | 0.0063 | 0.006 | Resp(L21209-13) | 446 | 0.0049 | 0.005 |
| T15 | Total(12) | FCAW | P | 173 | 2.50 | * | Inhal(IM422) | 90 | 2.2 | * | Resp(L21209-7) | 137 | 3.0 | * |
| T16 | Total(5) | FCAW | A | 169 | 0.098 | * | Inhal(IM353) | 169 | 0.090 | * | Resp(L21209-9) | 169 | 0.083 | * |
| T17 | Total(6) | SMAW | P | 189 | 0.86 | * | Inhal(IM497) | 113 | 0.41 | * | Resp(11) | 275 | 0.53 | * |
| T18 | Total(3) | SMAW | A | 399 | 0.033 | 0.027 | Inhal(IM458) | 399 | 0.027 | 0.022 | Resp(23) | 399 | 0.029 | 0.024 |
| T19 | Total(14) | TIG Stainless | P | 275 | 0.027 | * | Inhal(IM329) | 174 | 0.022 | * | Resp(4) | 275 | 0.011 | * |
| T20 | Total(25) | TIG Stainless | A | 345 | 0.0022 | 0.002 | Inhal(IM482) | 345 | 0.0026 | 0.002 | Resp(20) | 345 | 0.0020 | 0.001 |
| T21 | Total(17) | SMAW | P | 286 | 0.13 | 0.077 | Inhal(IM512) | 286 | 0.14 | * | Resp(21) | 286 | 0.12 | * |
| T22 | Total(18) | SMAW | A | 390 | 0.046 | * | Inhal(IM372) | 390 | 0.051 | 0.041 | Resp(24) | 390 | 0.043 | 0.035 |
| T23 | Total(7) | TIG Stainless | P | 295 | 0.0060 | * | Inhal(IM320) | 295 | 0.0078 | * | Resp(8) | 295 | 0.0058 | * |
| T24 | Total(22) | TIG Stainless | A | 360 | 0.0015 | 0.001 | Inhal(IM385) | 360 | 0.0015 | 0.001 | Resp(15) | 300 | 0.0013 | 0.001 |
| T25 | Total(13) | HLAW | P | 477 | 0.010 | | Inhal(IM392) | 477 | 0.0091 | | Resp(12) | 322 | 0.011 | |
| T26 | Total(4) | HLAW | A | 477 | 0.0075 | | Inhal(IM315) | 477 | 0.0083 | | Resp(2) | 477 | 0.0076 | |
| T27 | Total(5) | HLAW | P | 58 | 0.19 | | Inhal(IM060) | 58 | 0.20 | | Resp(3) | 58 | 0.22 | |
| T28 | Total(8) | TIG | P | 460 | 0.010 | | Inhal(IM161) | 460 | 0.010 | | Resp(1) | 460 | 0.0091 | |
| T29 | Total(25) | Grinding | P | 360 | 0.0020 | | Inhal(IM507) | 149 | 0.0061 | | Resp(20) | 360 | 0.00048 | |
| T30 | Total(22) | Grinding | A | 345 | 0.00084 | | Inhal(IM041) | 345 | 0.00089 | | Resp(16) | 345 | 0.00044 | |
| T31 | Total(21) | Grinding | P | 355 | 0.0025 | | Inhal(IM510) | 355 | 0.0066 | | Resp(23) | 355 | 0.0020 | |
| T32 | Total(26) | HLAW | P | 110 | 0.091 | | Inhal(IM489) | 110 | 0.095 | | Resp(24) | 110 | 0.091 | |
| *Specific task-related sample. Does not represent an 8-hr TWA | | | | | | | | | | | | | | |