Shipbuilding and Ship Repair - Residual Risk
Industry Meeting – January 25, 2005

1. Purpose and Objectives

The purpose of this January 2005 meeting is to review the process that we (EPA) used to develop the welding emission factors for several welding process/electrode (rod or wire) combinations and to respond to any questions you may have. The emission factors will be used to estimate HAP metal emissions from welding operations, which will then be used in the risk analysis for each individual shipyard. We have delayed the refined risk analysis calculation in response to the shipbuilding industry's request that EPA not complete the analysis until we first share with the shipbuilding and repair industry the emission factors we plan to use as input to the risk model. We have complied with that request, and unless there are serious issues with the process used by EPA, we plan to start the refined risk analysis after our meeting in January 2005.

When reviewing the shipyard questionnaire responses, we found that some shipyards used different emission factors (or assumptions) to calculate metal HAP emissions from welding operations. For example, some shipyards estimated that one percent of the electrode is emitted to the air and used the metal composition of the electrode to estimate metal emissions, while other shipyards identified several "generic" emission factors and selected the lowest factor to estimate emissions. Our analysis shows that the 12 shipyards responding to the 2003 questionnaire consumed 10.2 million pounds of welding electrodes in 1999. (Usage data for a 13th facility [Newport News Shipyard] was not included because EPA is still reviewing the facility's claim that all their data needs to be protected as confidential business information.) The breakdown by welding process is shielded metal arc welding (SMAW), 29.3 percent; gas metal arc welding (GMAW), 5.1 percent; flux core arc welding (FCAW), 54.5 percent; and submerged arc welding (SAW), 10.8 percent. All stainless steel electrodes combined account for approximately 1.3 percent of the reported welding usage (by mass).

The primary objectives of the meeting are to (1) present the information and procedures used to develop a set of welding emission factors to be used in the residual risk analysis, (2) allow shipbuilding industry representatives the opportunity to review and comment on the presented information and raise questions, and (3) document a final set of emission factors to be used in the residual risk analysis for all shipyard welding operations. The following write-up and attachments describe how we developed emission factors for the welding process/electrode (rod or wire) combinations. Several attachments are referenced throughout this summary and a listing of all attachments is provided at the end of this document.

2. Emission Rate Calculation

Knowledge of the emission rate and release characteristics is necessary for estimating pollutant fate and transport. Because emission measurements at the fenceline of a shipyard facility are generally <u>not</u> available, we are using emission factors to estimate the quantity of pollutants typically released to the atmosphere from welding and blasting operations.

3. Single Test Data

For the statistical computations that are discussed in the following sections, we used data for single test runs when that was available. However, we have taken a different approach for estimating emission factors for other welding material/process combinations for which we could not identify test data.

4. Sources of Emission Factor Data

In addition to the information related to welding emission factors provided by the shipyards in response to the 2003 questionnaire, we reviewed our emission inventories and contacted state and local air toxics agencies. To obtain data for individual test runs, we started by reviewing original references mentioned in Table 4-16 of EPA's AP-42 document [1]. The EPA AP-42 emission factors were published in 1995 and the test reports referenced in that document account for most of the emission factor information we have evaluated. The summary emission data listed in Table 4-16 provide candidate emission factors based on weighted average values from 12 references, which included test reports. The weighted averages are based on the number of replicate runs. Some of the references provided emission factors based on 1 test run; however, 3 to 6 replicate (repeat) runs were performed on average. In one case, the experimenters undertook more than 15 runs to generate an average emission factor. Table 4-16 of AP-42 did not include emission factors for stainless steel electrodes E309 (or several new alloy steels), which some of the shipyards indicated are now being used in significant quantities. Also, only 6 out of 34 process/electrode combinations in AP-42 included data on hexavalent chromium.

In addition to the AP-42 data, we identified four other sources of test data for welding emission factors: two National Shipbuilding Research Program (NSRP) reports [2, 3]; ESAB Welding and Cutting Products (ESAB) testing involving E309 electrodes and funded by the National Steel and Shipbuilding Company (NASSCO) in September 2000 [4]; and some recent welding emission testing funded by California Air Resources Board (CARB) and done by the Department of Civil and Environmental Engineering, University of California, Davis [5].

The NSRP information was taken from two separate reports: (1) "Shipyard Welding Emission Factor Development" (September 1999) and (2) "Emission Factors for Flux Core Rod Used in Gas Shielded Processes" (December 2000). The NSRP-0574 and ESAB reports only involved stainless steel electrodes. A box of supporting test data and information related to NSRP 0574 [2] and NSRP 0587 [3] was sent to EPA on April 16, 2004, by the shipyard industry. The documentation for NSRP 0574 refers to one study for two welding technologies (SMAW and SAW) and several stainless steel electrodes. Dave Reeves of RTI International documented the results of his review of the test data and information in a memo to EPA dated April 21, 2004 (Attachment 1).

We then reviewed the testing data documented in the ESAB and CARB reports. The ESAB study [4] was provided by Ms. Dina Torgerson of NASSCO on May 3, 2004. The study involved fume analysis testing of three welding processes (SMAW, GMAW, and FCAW carbon dioxide [CO_2] shielding) for E309 stainless steel welding with E309 filler material. The data show a comparison of the fume generation rates and the analysis of the weld fume. In follow-up correspondence, it was determined that the analytical laboratory split each of the test samples and ran two analytical tests. Because the analytical results for the two tests done on the same sample were very close, the test lab used the arithmetic average of the two analytical results for each of the metals reported.

The final CARB/University of California-Davis test report provided by Chris Halm of CARB [5] was received in August 2004. The study provided data for hexavalent chrome. Unfortunately, the data for the other metals (total chromium, manganese, nickel, and lead) were not available. The final report can be downloaded from the CARB web site: http://www.arb.ca.gov.

5. Confidence Level for Risk Assessment

The screening analysis residual risk test report published in May 2003 is posted on the EPA shipbuilding Web site. It was conducted using available data and health-protective assumptions to fill data gaps. The resulting risk estimates exceeded the ample margin of safety criteria set by the Clean Air Act (CAA), triggering a more complete refined risk assessment. To develop this new assessment, we collected more specific usage and modeling data to run a more refined risk analysis. We also developed new welding emission factors based on a 95 percent upper confidence limit on the mean (95% UCL). These factors were derived after considering data that were available to EPA through October 2004, as we explained in Section 4 above.

Section 112(f)(1) requires EPA to address "any uncertainties in risk assessment methodology or other health assessment technique," with a focus on uncertainty (degree of precision) in residual risk assessment. Several factors affect uncertainty in the risk assessment [6] and include

- Uncertainty in the structure of the models used to estimate risks (model uncertainty)

- Uncertainty in the input values used in the risk assessment models (parameter uncertainty).

Data (input value) uncertainty has to do with data quality or lack of knowledge of fundamental relationships [7]. This is different from data variability, which is an intrinsic property of the data being evaluated. The variability represents the degree of "heterogeneity" of an event or the population from which a sample was taken, and cannot be reduced by collecting more data.

With the shipbuilding industry's cooperation, we have now acquired much more detailed information on the types of welding rods and apparatus used, and the specific locations of welding operations in each of the shipyards. We will therefore be able to model individual welding sources using more realistic inputs for this assessment. Furthermore, EPA has developed an improved dispersion/exposure model since the initial screening assessment was done, which we will use as the basis of the risk estimates.

6. Confidence Level Regarding the Emission Factors

Welding emission factors are important input parameters that can influence the outcome of a risk assessment. The 1995 AP-42 document provided subjective quality ratings (A, B, C, D, and E) for the emission factors, based on a number of criteria. For example, an emission factor was rated "D" when there was a lack of thorough documentation or an insufficient number of replications. However, these weighted average emission factors in AP-42 were not meant to reflect data precision or to be used for a refined risk analysis. Thus, we will not be using them for that purpose, especially now that we have developed emission factors to which we have assigned a confidence level. A major benefit of the evaluation of uncertainty that we attempted here is to improve the information necessary for management of risk. The final outcome or decision will depend on the uncertainty associated with the determined level of risk and specific control options and their economic impacts.

Data validation and evaluation is an important step in the risk assessment process and is a necessary step used to support decision-making. One question that often arises is whether the sample size is sufficient to produce meaningful statistical results. Sample size is important when there is great variability in a data set. Also, when the UCL exceeds the range of the values detected, the maximum value of a small data set may be a last resort option [8]. The larger the sample size, the more precisely it represents the population. Hence, for a given confidence level, the larger the sample size, the smaller the confidence interval, though the relationship does not change linearly.

We selected the 95% UCL of the unknown population arithmetic mean (mean) as our measure of precision, which is often used by EPA to support risk assessment applications and determine the attainment of cleanup standards.

To determine the 95% UCL of the unknown population mean, we computed several parametric UCLs, based on a normal, lognormal, and gamma distribution. In these tests, we are assuming that the sample is represented by the assumed distribution; hence that the mean, standard deviation, and other computed parameters of the distribution are valid. We also computed UCLs for several nonparametric methods. These include bootstrap procedures and Chebyshev Inequality. For the nonparametric methods, we did not have to assume a distribution. The parametric and nonparametric methods used and a brief explanation of the methods are shown in Attachment 2, and the values chosen as "recommended" are based on the criteria in Attachment 3, which have a theoretical foundation – based on the standard deviation of the log-transformed data [9]. For example, the information in Attachment 3 indicates that if the data are normally distributed, then the one-sided 95% UCL should be computed using Students' statistics. When the data set is moderately to highly skewed, the t-statistics will fail, especially when the data set is around 10 or fewer data points. However, if the sample size is large, the mean will be normally distributed, according to the Cental Limit Theorem. This is true even if the data sample is highly skewed, has outliers, or represents more than one population. For lognormally distributed data sets, use of the Chebyshev minimum-variance unbiased estimator (MVUE) for the mean and variance is recommended to obtain a UCL. This approach is preferred to the Land's Method when the underlying distribution is lognormal. Numerical illustrations of some of the methods discussed here are given in reference [9].

Attachment 4 provides a summary of UCL calculation methods. For our analysis, the following statistical procedure was used to evaluate the data distributions associated with the welding emission factor test data and information:

A. Test for normality, lognormality, and Gamma distribution of the data:
– Graphical Q-Q plot and Histogram
– Shapiro-Wilk test (sample size, n, < or = 50)
– Lillieforth test (n < 50), a generalization of K-S test.

B. If the data set was determined not to have normal, lognormal, or gamma distribution, we selected nonparametric statistical methods:
– Bootstrap-t
– Bootstrap (percentile)
– Bootstrap Hall's
– Modified-t
– Modified Chebyshev (Mean, SD).

7. Development of New EPA Welding Emission Factors

Attachment 5 contains a summary of the new welding emission factors for different types of electrodes (e.g., stainless steel, mild steel, and alloy steel), covering four welding processes:

- Shielded Metal Arc Welding (SMAW)
- Gas Metal Arc Welding (GMAW)
- Flux Core Arc Welding (FCAW)
- Submerged Arc Welding (SAW).

SAW is primarily a flat position welding process, and significant amounts of SAW with mild steel electrodes were reported by two shipyards. However, there are limited emission data for SAW except for a few comparisons with SMAW, such as " SAW has significantly lower fume generation rates than does SMAW." We documented the available information (Attachment 6) and recommended HAP metal emission factors for SAW equal to 10 percent of SMAW emission factors.

Alloy steel electrodes have higher manganese, chromium, or nickel contents and are generally used in small quantities. However, there were very limited test data or emission factors for any of the alloy steel electrodes. Therefore, we developed a methodology and default emission factors for all of the alloy steel electrodes using fume generation rates for the different welding processes and the percentage of metal in the welding fumes (Attachment 7).

8. Statistical Analysis of Welding Emission Test Data

This section describes the statistical analysis of the test data for stainless steel and mild steel electrodes and the resulting emission factors. A summary of all the test data is included as Attachment 8. (Please note that the information is compiled in Excel spreadsheets and is organized as follows: stainless steel - 8A; mild steel - 8B; and alloy steel - 8C). In this effort, we have grouped emission factors that both came from single test runs and were generated using laboratory test set-ups that represent variations of the "Laboratory Method for Measuring Fume Generation Rates and Total Fume Emissions of Welding and Allied Processes," AWS F1.2:1999) [10]. We compiled the single test run data for total chromium, hexavalent chromium, manganese, nickel, and lead from the documents identified in Section 4.

We determined the 95% UCL of the mean, in Attachment 8, using the methods discussed in Section 6. Although the use of single test runs instead of averages or weighted averages increased the data points for the statistical analysis, there were many instances where we had fewer than five data points for a process/electrode combination, or even no data. Therefore, we made several judgement calls for combining the single data points for all electrodes under a process. More data points helped to increase the data pool before we computed the 95 % UCL and expanded the applicability of the emission factor to other electrodes of similar composition.

A. Attachment 8A, Worksheet for Stainless Steel Data

1. Chromium. The data for SMAW/308 and SMAW/316 electrodes were combined (14 data points) before computing the 95% UCL. We determined the UCL for SMAW/E309 as a separate data set (7 data points), since electrode E309 can be used to weld both stainless steel and mild steel materials (substrates). We were aware that the stainless steel substrate can contribute chromium to the fumes, up to 10 percent (by mass). The level of chromium in stainless steel can exceed 20 percent of the rod mass, whereas it is less than 1 percent in mild steel.

The 95% UCL values for electrodes E308/E316 and E309 were reasonably close (~0.89 and ~0.81 g/kg, respectively). We ended up combining all of the data for electrodes E308, E309, and E316 and computing a new 95% UCL (~ 0.81 g/kg) using the 21 data points. The combined data followed a normal distribution, as was the case for the individual data sets. We therefore conclude that this emission factor can be used for all stainless steels that have the same range of chromium content. Because the welding operational factors (e.g., current, voltage, shielding type) used to generate the individual test data compiled here are generally not documented in the original references, we have no way of determining if the spread in the values of the emission factors for a process/electrode combination is due to variability in the process or the electrode properties, or simply analytical errors. We have no way of making that distinction with any level of confidence using the information at hand.

Concerning chromium for both GMAW and FCAW processes, we did not have enough data points to generate meaningful UCLs for these process/rod combinations. We combined the data, ending up with a data set for GMAW and another for FCAW. We also recommend the use of the new factor for those stainless steel electrodes that have levels of chromium similar to those in this study. We have included additional comments in the work sheet for stainless steel (see "Notes" portion of Attachment 8A).

We could not explain why the total chromium results for GMAW/309 NSRP are so much different than the emission factor data we collected for this process/electrode combination. A shielding gas was used, the test was conducted at the same time as the other tests in that NSRP report, and the air volume, test length, and mass of electrode used appear to be consistent with the other tests.

2. Nickel. In the case of nickel in stainless steels, the statistical analysis resulted in a 95% UCL value greater than the amount of material in the electrode. We generated a default UCL using three pieces of data: (1) the metal composition of the electrode, (2) the data curves from Appendix A in AP-42 to determine the average metal content of the welding fumes, and (3) the maximum fume (PM/TSP) formation rates from Table 4-15 in AP-42.

We used the highest fume formation rate from any of the electrodes that were reported by the shipyards in the project database. The same approach was used for all alloy steel rods where we did not have any test data or emission factors. We selected this approach instead of the using the metal content (percent by mass) of the electrode as the default 95 % UCL.

3. Lead. We recommended a default emission values for lead in stainless steel based on the lead value for mild steels, considering that lead is a trace contaminant in these electrodes. Hence, we are proposing to use 0.215 g/kg for both stainless steel and mild steel.

B. Attachment 8B, Worksheet for Mild Steel Data

1. Chromium. We had very little data for chromium. Mild steels have a total chromium content less than 0.05 percent, as compared to stainless steels (e.g., 304, 308, 309, 310, 316, and 347) which have total chromium contents ranging from 16 to 25 percent. We adjusted for data gaps and unusually high or low values. For example, we used the average chromium ranges for SMAW, GMAW, and FCAW [11] to generate factors for estimating chromium in mild steel, based on the percentage of the chromium in the welding electrode. The procedure is explained for SMAW in the "Notes" portion of Attachment 8B.

2. Nomenclature. Mild steel electrodes E-70T and E70S (11 percent by mass), E-71T (45 percent), E7018 (12 percent), E6011 (4 percent), E7024 (10 percent), and EM12K (6 percent) constitute a large portion of the mild steels used by the 13 shipyards in our database. Electrodes E70T-1 and E71T-1 both contain less than 0.05 percent (by mass) chromium and approximately 1.3 percent manganese, and 0.01 percent nickel. Other mild steels ER70S-2 and ER70S-3 have a manganese content of 0.9 to 1.4 percent, and ER70S-6 has a manganese content of 1.4 to 1.85 percent (while nickel and chromium are considered "residual elements" and shall not exceed 0.05 percent). The NSRP report provided test data for electrode E-770. However, we believe that the rod is TM-770 by Tri-Mark, equivalent to AWS E71T-1M, E71T-12MJ (ref. www.hobartbrothers.com). We are proposing separate emission factors for the

E70/E71 series and the series containing the letter "M," until we can understand the reason the factors are several order of magnitude higher in the M series.

9. References

1. EPA's Compilation of Air Pollutant Emission Factors: Development of Particulate and Hazardous Emission Factors for Electric Arc Welding (AP-42, Section 12.19), Revised Final Report, May 1994.

2. "Shipyard Welding Emission Factor Development," National Shipbuilding Research Program (NSRP 0574), N1-98-2, September 1, 1999.

3. "Emission Factors for Flux Core Rod Used in Gas Shielded Processes," National Shipbuilding Research Program (NSRP 0587), N1-98-1 Subtask 43, December 18, 2000.

4. "Welding Fume Analysis Study" by ESAB Welding Products & Cutting Products for National Steel and Shipbuilding Company (NASSCO),

5. "Improving Welding Toxic Metal Emission Estimates in California," Department of Civil & Environmental Engineering, University of California, Davis for California Air Resources Board (CARB), Final Report, August 2004.

6. Residual Risk Report to Congress, US Environmetal Protection Agency, Office of Air Quality Planning And Standards, Research Triangle Park, EPA-453/R-99-001, May 1999.

7. Residual Risk Report to Congress, US Environmetal Protection Agency, Office of Air Quality Planning And Standards, Research Triangle Park, EPA-453/R-99-001, May 1999.

8. Calculating Upper Confidence Limits for Exposure Limits For Exposure Point Concentrations at Hazardous Waste Sites, Office of Emergency and Remedial Responses US Environmental Protection Agency, Washington, D.C., OSWER 9285.6-10, December 2002, p 20.

9. Calculating Upper Confidence Limits for Exposure Limits For Exposure Point Concentrations at Hazardous Waste Sites, Office of Emergency and Remedial Responses US Environmental Protection Agency, Washington, D.C., OSWER 9285.6-10, December 2002, p 20.

10. "Laboratory Method for Measuring Fume Generation Rates and Total Fume Emissions of Welding and Allied Processes, " **AWS** F1.2:1999.

11. "Chromium in Stainless Steel Welding Fumes," The Chromium File from the International Chromium Development Association, Issue No. 9, April 2002. (Available at http:// www.chromium-asoc.com/publications/crfile9apr02.htm)

10. List of Attachments

Attachment 1 -	Memo from D. Reeves, RTI International, to M. Serageldin, EPA, documenting results of technical review of test data related to NSRP 0574 and NSRP 0587. April 21, 2004.
Attachment 2 -	Parametric and Nonparametric Methods Evaluated (Excel table)
Attachment 3 -	UCL Method Flow Chart (shown as "Figure1")
Attachment 4 -	Summary of UCL Calculation Methods (shown as "Exhibit 14")
Attachment 5 -	Summary of New Welding Emission Factors (Excel table)
Attachment 6 -	Memo from D. Reeves, RTI International, to M. Serageldin, EPA, "Recommended Emission Factors for Submerged Arc Welding (SAW)." October 12, 2004.
Attachment 7 -	Memo from D. Reeves, RTI International, to M. Serageldin, EPA, "Recommended Default Welding Emission Factors for Alloy Steels." November 18, 2004.
Attachment 8 -	Summary Excel spreadsheets with statistical analysis of welding test data and emission factors based on 95% UCL. 8A - Stainless Steel Electrode Data 8B - Mild Steel Electrode Data 8C - Alloy Steel Electrode Data