Residual Risk from Abrasive Blasting Emissions: Particle Size and Metal Speciation

Final Report

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INTRODUCTION

Recently, there is a shift in regulatory emphasis from "emissions-based regulations" to "public health risk-based regulations" by the state and federal regulations. This is evidenced by the increased scrutiny of the health risks associated with air pollutant emissions resulting from shipyard operations. Based on the preliminary assessments, it appears that welding and blasting operations are driving the public health risks in the shipbuilding sector due to anticipated metal emissions and their associated toxicity. Welding emissions are relatively well studied compared to blasting emissions. Only recently, UNO studies published emission factors for TPM (total particulate matter) under a grant from EPA Region VI and the Office of Naval Research (ONR). However, due to limited resources and funding, particle size and metal speciation of blasting emissions could not be studied as part of the earlier UNO study. For health risk assessments, emission data (or emission factors) for inhalable particulate matter (typically PM_{10}, particulate matter less than 10 micron in size) and its chemical speciation is desired. Incorrect PM_{10} fraction and chemical speciation (e.g., metal fraction) can lead to incorrect calculated health risk that will be different from the true health risks. Health risk assessment process is illustrated in the following figure, Figure 1.

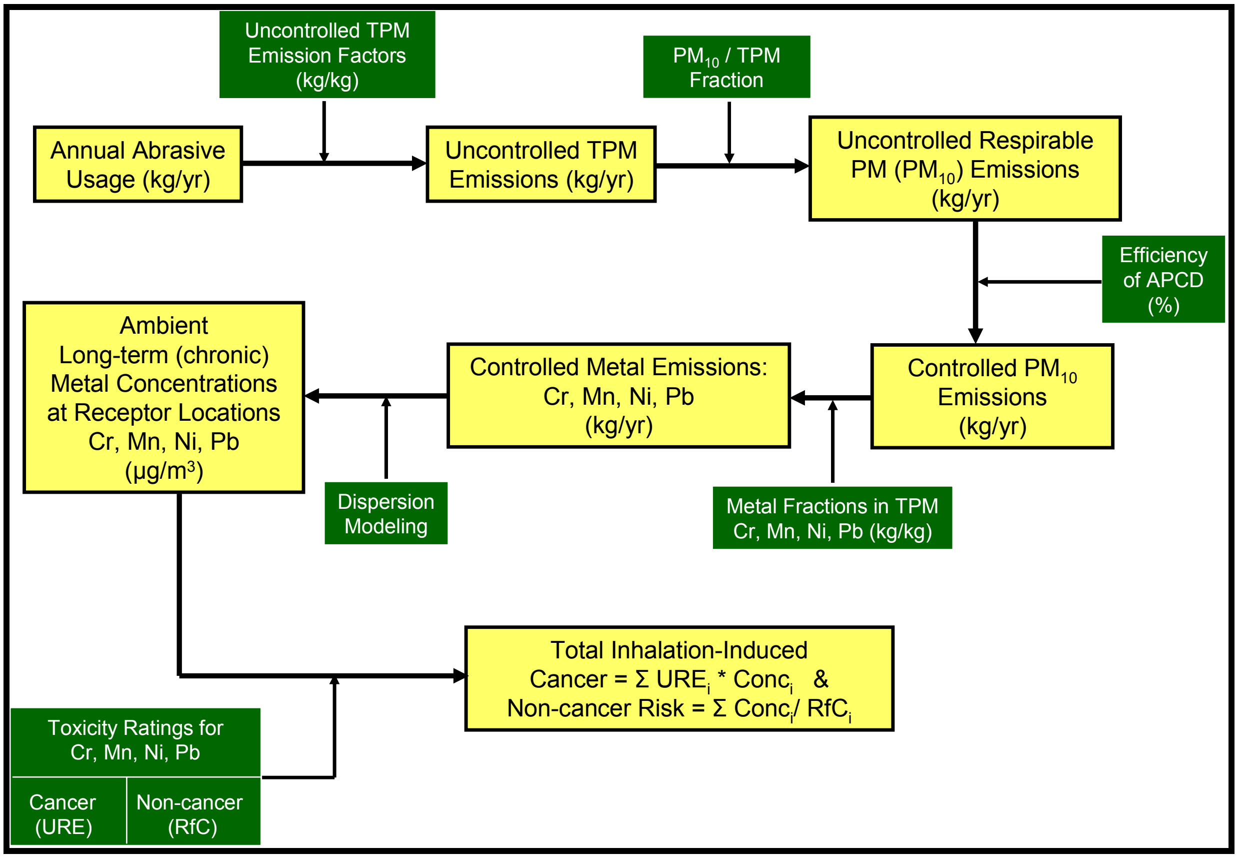


Figure 1a: Residual Risk Analysis for Dry Abrasive Blasting Process

Problem Statement

From Figure 1, it may be noted that PM_{10} fraction which is being considered as the inhalable/respirable fraction in residual risk assessment is an important input. EPA recognizes that only the PM_{10} fraction is of concern in residual risk analysis; higher PM10 fraction leads to higher potential public health risk

Similarly, it may be noted from Figure 1 that the metal fraction contained in the particulate matter emitted from dry abrasive blasting is another important input in calculating residual risk from dry abrasive blasting. These metals may include both, carcinogenic and non-carcinogenic metals. Chromium (Cr), lead (Pb), manganese (Mn), and nickel (Ni) are considered important in blasting emissions due to possible contamination or presence of these metals in abrasives and the base plate. Again, higher metal fraction within air emissions results in increased public health risks.

As it can be seen from Figure 1, respirable fraction (PM_{10} fraction of TPM) and the metal fraction have a multiplying effect on the calculated residual risk. There is a concern that the compiled literature data for PM_{10} and metal fractions to be applied in the health risk assessment are high and are not applicable to the shipbuilding industry as most of it came from different sources not relevant to the shipbuilding and ship repair industry sector. There is no reliable data on PM_{10} and metal fractions of airborne particulates resulting from dry abrasive blasting as this process was not studied well in the past. In order to estimate the true public health risk resulting from the blasting operations, more realistic data is required on (1) PM_{10} fraction of TPM emissions and (2) metal fractions of PM_{10} or TPM.

Scope of Work

Main objective of this project was to generate additional data on (1) PM_{10}/TPM fraction and (2) metal fractions of TPM for total chromium, manganese, nickel and lead. Filters with airborne particulate matter (PM) collected on them were available from earlier study titled, “Environmentally-friendly Abrasives” project for use in this project.

In the original proposal, Scanning Electron Microscope (SEM) was proposed for PM_{10}/TPM determination. SEM involves a two dimensional scanning/imaging which gives the area of a particle. Considering that all the particles are spheroids, volumes of the individual particles are calculated to finally arrive at mass fractions. Whereas, Interferometer technique involves scanning of particles at various heights to arrive at true volume of various sized particles which results in more accurate mass-based particle size distribution. As the Interferometer was available to the investigator for use in this project, Interferometer in combination with Micro Sieves was used to determine the particle size. Additionally, Single Particle Optical Sizing (SPOS) method was also used to determine the particle size.

For metal fraction determination, X-Ray Fluorescence (XRF) Spectrometer was utilized. The project results will help eliminate errors in the residual risk assessment due to data-quality problems.

Brief Description of UNO's Environmentally-Friendly Abrasives Project

Because the "airborne PM collected on filters" came from UNO's study titled, Environmentally-friendly Abrasives, it was felt appropriate to include this section that describes the earlier study, its goals, the equipment used, and the research methodology adopted.

Goals

The main purpose of the UNO study was to rank six commonly used abrasives namely, barshot (hematite), coal slag, copper slag, garnet, steel grit/shot, and specialty sand based on (1) productivity (ft^2/hr), (2) abrasive consumption (lb/ft^2), (3) used-abrasive generation potential (lb/ft^2), and (4) particulate emission factors (lb/lb and/or lb/ft^2). The portion of the study that dealt with particulate emission factors is relevant to the current study which is described further in this section.

Influencing Parameters

Atmospheric particulate emissions from dry abrasive blasting are influenced by (a) blast pressure, (b) abrasive feed rate, (c) properties of abrasive (type, size, shape, and hardness), (d) number of reuses of the abrasive, (e) nozzle size, (f) angle between blast nozzle and base plate, (g) stand-off distance, (h) ventilation conditions / exhaust fan capacity in case of indoor blasting, (i) wind speed in case of outdoors, and (j) the expertise of the worker, (k) initial surface contamination (rust, paint, others), and (l) desired surface finish. UNO study involved varying, (1) abrasives (six abrasives were tested), (2) blast pressure (80, 100, 120 PSI), (3) abrasive feed rate (Schmidt feed valve #6 set at 3, 4, 5 turns). All other conditions were kept unchanged from experiment to experiment. Average exhaust fan capacity used was 3000 cfm. Emission factors reported were "uncontrolled emission factors for total particulate matter" as these emissions were measured before the particulate collection device.

Mild steel plates were used with two initial surface conditions, rusted and painted, were used. However, only the samples collected from the testing of painted panels were utilized in this current study. Plates were painted with a 1:1 volume mixture of Rust Oleum© Safety Yellow paint and thinner. Painting was carried out with spray gun and hand rollers with an average transfer efficiency of 50% and the average paint thickness was 0.73 mils.

Emissions Test Facility Design

Dry abrasive blasting operations were simulated within the UNO's Emissions Test Facility (ETF) of size 3.7 x 3 x 2.5 m (12 x 10 x 8 feet) in order to measure particulates emitted during blasting operations. Figure 1b shows ETF utilized for the Environmentally-friendly Abrasives project which provided filter samples for this current study. A 600 lbs (273 kg) capacity Abec© blast pot was used as the abrasive supply unit. For all blasting operations, a standard Bazooka #6 nozzle was used. A Schmidt feed valve fitted below the hopper of the blast pot was used to regulate the abrasive flow rate during the blasting experiments. Sullair Model 375H© and Ingersoll Rand© compressors capable of providing a maximum of 150 PSI fitted with appropriate pressure gauges and moisture traps were used to provide the compressed air. Mild steel plates, each of dimensions 2.5 x 1.5 m (8 x 5 feet) were mounted on steel carts for ease of movement in and out of the chamber. Both rusted and painted panels were tested using six abrasives namely, barshot (hematite), coal slag, copper slag, garnet, steel grit/shot, and specialty sand. However, it should be noted that only the samples collected from the painted panels were utilized in this study as those samples from rusted panels were not available.

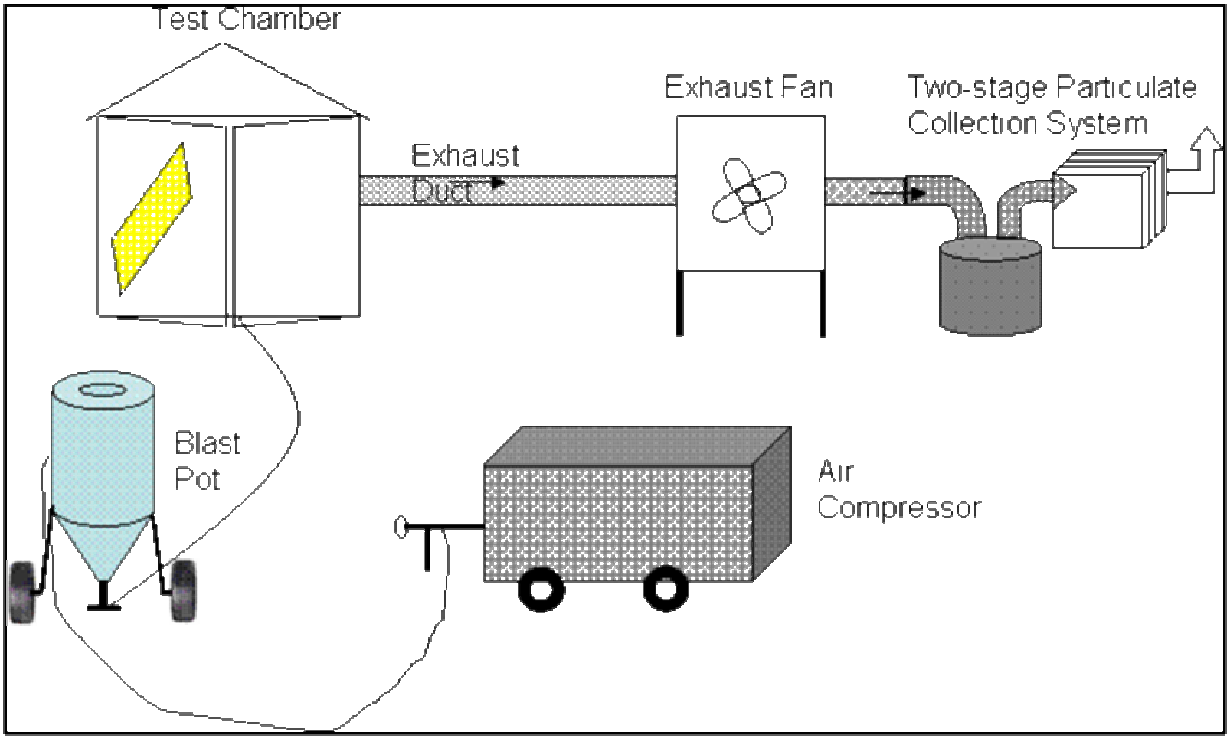


Figure 1b: UNO's Emissions Test Facility (ETF)

Exhaust Duct and Two-Stage Particle Collection System

A variable speed fan with 60 rpm was used to vent the particulates from the test chamber through an exhaust duct. The exhaust duct was designed to comply with the EPA guidelines for source monitoring. A straight, smooth circular duct of diameter 0.31 m (12 inches) was used. Sampling port was positioned at a downstream distance of 8 diameters from the air intake (flow disturbance) and 2 diameters upstream of the variable speed fan (flow disturbance) to minimize the flow turbulence. A two-stage particulate collection system was designed and installed downstream of the exhaust fan to collect the particles and prevent nuisance to the ambient environment. The first stage collected the coarse particles by changing the direction of the gas flow. The second stage collected fine particles by using a fabric filter. Since the sampling was carried out at upstream side of the particulate collection systems, the measured emission factors represent "uncontrolled total particulate emission factors."

Stack Sampling Equipment

Stack sampling and velocity measurements were carried out as per EPA Source Test Methods 1 through 5 for total particulate matter. Figure 1c shows the stack monitoring in progress. An S-type pitot tube was used for taking velocity and flow measurements within the duct. A sampling train in accordance with EPA Method 4 was used for determining moisture content and evaluating the volumetric gas flow rate. EPA Method 5 sampling train consisting of a sampling nozzle, S-type pitot tube, temperature probe, dry gas meter, PM sampling filter holder, glass impingers, hot and cold bath was used in the study. The glass impingers were connected in series inside an ice bath to condense the water vapor. The first two impingers were filled with 100 ml of distilled water to allow the moisture to condense. The third impinger was left dry for further condensation. The fourth impinger contained known quantity of silica gel (adsorbent) to remove water vapor as the gas passed through it before entering the dry gas meter inlet.

Figure 1c: PM Emissions Monitoring in Progress Using Stack Testing Equipment

Stack Test Procedure

As per EPA Source Test Method 1, a total of eight traverse points were chosen for velocity and flow measurements in the circular exhaust duct used in this study. The traverse points were measured and marked on the sampling probe to ensure accuracy and ease of traverse. For ensuring isokinetic flow conditions inside the duct, a nozzle with inner diameter of 4.57 mm (0.018 inches) was used for particulate sampling during all the runs. Pilot tests were conducted to determine the nozzle diameter to obtain isokinetic sampling conditions. For carrying out the blasting operations, three persons were trained by professionals on the operating procedures and safety issues. A pre-weighed, known amount of medium grade abrasive was loaded into the blast pot through a sieve to remove any foreign material that may interfere with the smooth flow of the abrasive. The air flow was regulated at the compressor to provide required nozzle pressures (80, 100 and 120 PSI) and the Schmidt valve was opened to the required number of turns (3, 4, and 5 turns).

Leak checks were performed before and after sampling to ensure accuracy of flow rate and velocity measurements. Conditioned, pre-weighed Whatman No. 10 filter papers were used to collect the particulate emissions. While blasting was in progress inside the chamber, sampling was carried out at the sampling port by traversing the sampling probe unit through the duct. The necessary parameters for flow and velocity measurements namely velocity head, stack temperature, vacuum, DGM flow readings, hot and cold bath temperatures were recorded at the eight traverse points. The sampling time was two minutes at each traverse point and hence the total sampling time for each experiment was sixteen minutes. Blasting time varied from run to run and it was measured using a stopwatch. Blasting was carried out until all the material in blast pot was consumed. A near-white (SP 10) surface finish was achieved in all the runs and the personnel were trained to visually examine and ensure this finish. Once blasting was complete, the filter was conditioned in the dessicator and the final weight was recorded. The sampling probe was rinsed thoroughly with acetone thrice according to EPA method 5 to collect the particles on the probe walls. The wash off liquid was collected in a pre-weighed beaker and was later evaporated in a dessicator. The blasted area was measured using a measuring tape with appropriate approximations for non-quadrilateral geometries. Due care was taken to ensure isokinetic flow conditions for each sampling run.

After conditioning and weighting, filters with PM on them were stored in zip lock bags for future examination of particle size and metal analysis as the funding was not adequate at that time. These samples were used in the current study to evaluate particle size and the metal analysis.

METHODOLOGY

In order to reach the goals of the project, the following tasks were undertaken to analyze the PM_{10}/TPM fraction and the metal speciation. The methodology used for these tasks are briefly discussed in the following section.

Determination of Particles Size Using Interferometry

MicroXAM MP8, a vertical scanning interferometer (VSI) was used in this experiment which provides high (angstrom to nanometer-scale) vertical resolution, and a lateral resolution of 500 X 500 nanometer (with a Nikon 50X Mirau objective). Figure 2a is a photograph of the MicroXAM MP8 used and Figure 2b illustrates the white light VSI principle.

Saved samples from previous research project were utilized to analyze particle size using Interferometer. Because of the wide particle size (submicron to 400 micron), samples had to be separated into a narrow size range prior to using Interferometer. For separating the particles into narrow size ranges, micro sieves were used. Micro sieves employed in this exercise confirmed to the ASTM standard ASTM E 161 – 00.

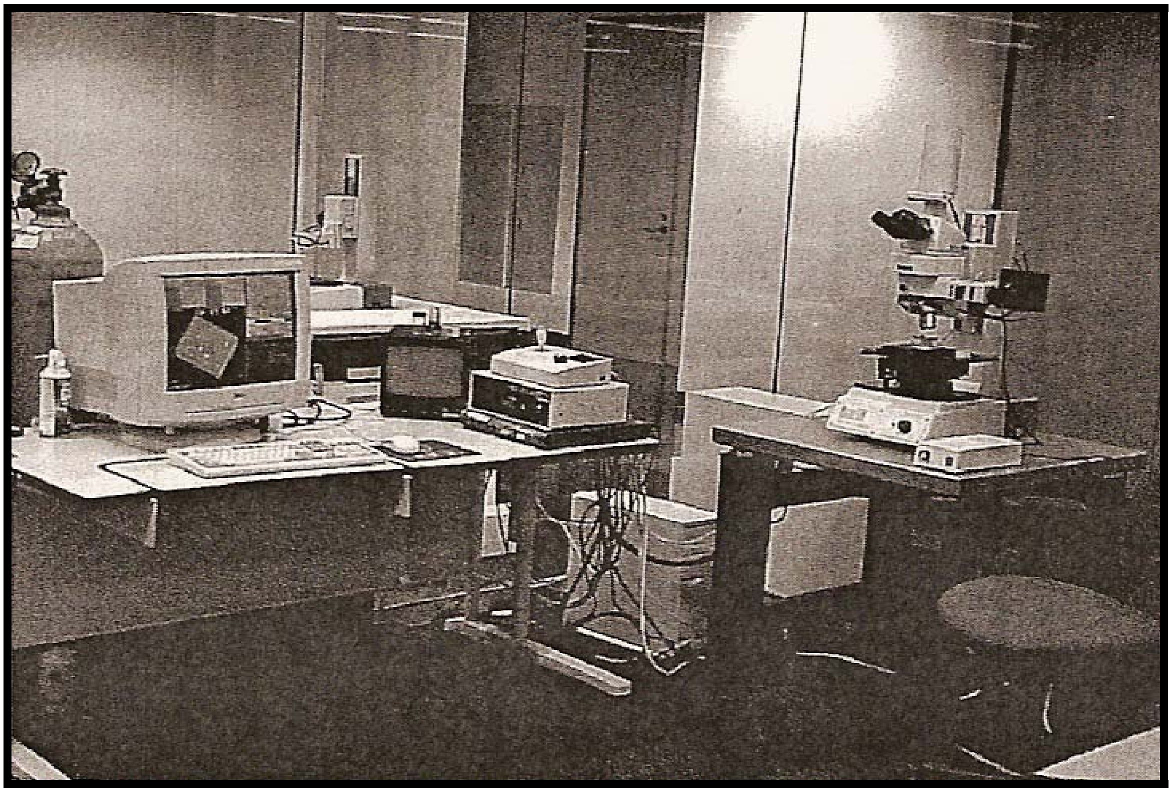


Fig 2a. MicroXAM MP8 Interferometer Positioned on an Anti-Vibration Air Table
Source: A. Luttge *et al.*

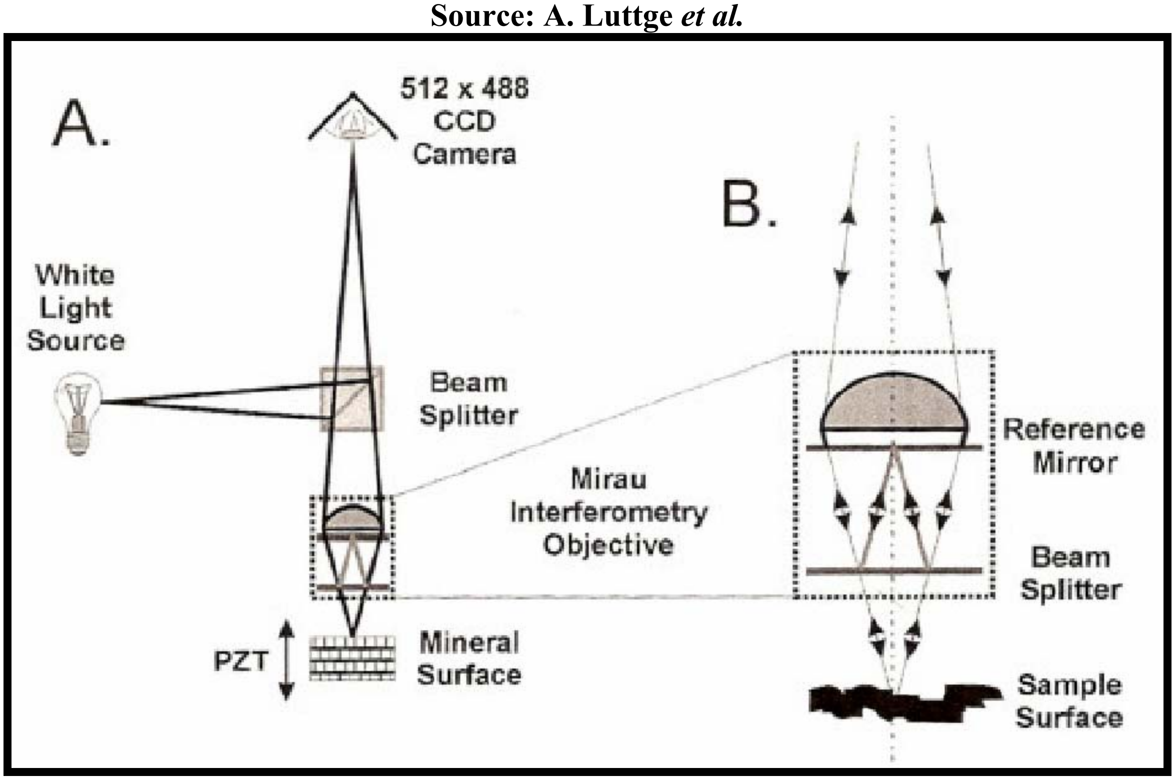


Fig 2b. Sketch of a Double-Beam Mirau Interferometer with CCD Camera
Source: A. Luttge *et al.*

The measured particles were imaged at randomly from the field of particles on the glass surface. Only the discrete particles, those that were not touching one another were chosen for measurement. This potential bias or error source would be common to all optical techniques.

The length, width, height, and volume of 100 particles were measured in each sample. Airborne particle samples from all six abrasives, viz. coal slag, specialty sand, garnet, copper slag, barshot (hematite), and steel grit were analyzed. The length, width, and height are given in microns. For irregularly shaped particles, the length and width are somewhat arbitrarily chosen. For the most part, longest dimensions of the particles were measured since these are the dimensions that didn't allow the particles to pass through the sieve. The height measurement is very arbitrary since any number of heights could be chosen from the array of pixels in the interferometry height map of each particle. Most representative height of the surface of the particle was measured, i.e. a plateau produced by many pixels of the same height. The volume of each particle is given in cubic nanometers. This was measured using the volume analysis tool provided as part of the ADE-Phase Shift software package that works in combination with the MicroXAM interferometer. Each particle was isolated using a data masking tool and if the resulting image subset had any bad pixels, they were filled using nearest neighbor approximations. Each image was also "flattened" before the volume analysis tool was employed. A horizontal plane representing the glass slide was chosen and the volume analysis tool provided the volume of each particle by calculating the volume of the pixels that rose above the plane of the glass. The error associated with this volume measurement, both, in terms of repeatability and bad or missing pixels was not considered to be higher than 10%. The volume measured in this way is much more precise and accurate than the length, width, and height measurements since it maps the height of each pixel for the entire 2D area of the particle. Therefore this volume measurement should be considered the primary number assigned to each particle. The particles were sorted in the spreadsheet according to the shortest length or width dimension.

Information obtained from the micro sieve analysis and the Interferometry were combined to obtain the particle size distribution from sub micron to 30 micron. Particles between 30 and 400 micron were lumped to one category, though there were a few particles that were larger than 400 micron. Size of these large particles (which were very few) could not be determined. However, their mass was included in calculation so there is no error in determining the mass percentages of various size fractions.

Determination of Particle Size Using Single Particle Optical Sizing (SPOC)

Single Particle Optical Sizing (SPOC) method involves the following procedure. Particles flow into illuminated view volume one at a time as illustrated in the Figure 2c. Detector picks up the decrease in light transmission due to particle obstruction. Decrease in light transmission corresponds to particle size/volume which is measured using a calibration curve. Each pass through the view volume produces a pulse which is counted.

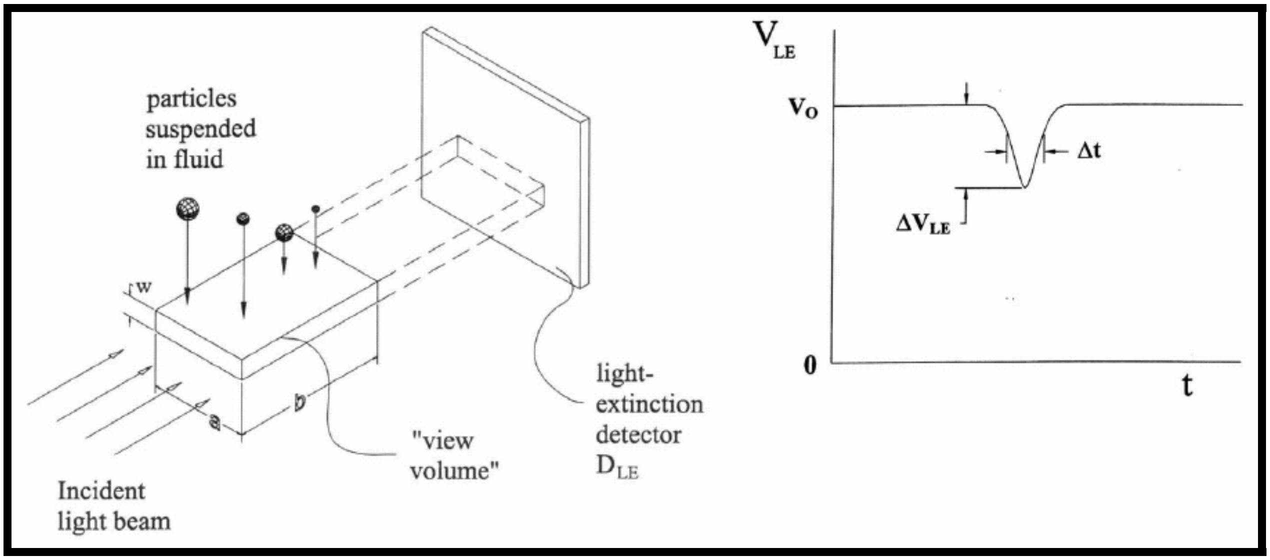


Fig 2c. Principle of SPOC Measurement Method

Sample preparation method involved taking each sample into particle free container then adding Triton-X, a non-ionic surfactant. To this sample, about 20 ml of distilled water was added. Particles were allowed to disperse uniformly by manual shaking and with the aid of sonic bath for five minutes. Sample was shook vigorously before an aliquot was injected into the Accusizer. Measurements were made with two thresholds; one set at 0.5 micron and one at 2 micron and the data was combined to obtain consolidated particle size distribution.

Determination of Metal Fraction of Airborne TPM Using XRF Spectrometry

This task involved analysis of filters containing particulate emissions from abrasive blasting to determine metal content (Cr, Mn, Ni, and Pb) using XRF Spectrometer. Metals analyzed in this study are elemental metals and not their compounds. Also, the chromium reported is total chromium not hexavalent chromium. XRF method, measurement principle, advantages are briefly described in the following section.

XRF Spectrometry method is used to identify elements in a substance and quantify the amount of those elements present to ultimately determine the elemental composition of a material. An element is identified by its characteristic X-ray emission wavelength (λ) or energy (E). The amount of an element present is quantified by measuring the intensity (I) of its characteristic emission. XRF Spectrometry identifies and quantifies elements over a wide dynamic concentration range, from PPM levels up to virtually 100% by weight.

In XRF Spectrometry, the primary interference is from other specific elements in a substance that can influence (matrix effects) the analysis of the element(s) of interest. However, these interferences are well known and documented; and, instrumentation advancements and mathematical corrections in the system's software easily and quickly correct for them. In certain cases, the geometry of the sample can affect XRF analysis, but this is easily compensated for by selecting the optimum sampling area, grinding or polishing the sample, or by pressing a pellet or making glass beads.

Quantitative elemental analysis for XRF Spectrometry is typically performed using Empirical Methods (calibration curves using standards similar in property to the unknown) or Fundamental Parameters (FP). FP is frequently preferred because it allows elemental analysis to be performed without standards or calibration curves. The capabilities of modern computers allow the use of this no-standard mathematical analysis, FP, accompanied by stored libraries of known materials, to determine not only the elemental composition of an unknown material quickly and easily, but even to identify the unknown material itself. XRF analytical procedure is illustrated in Figure 2d below.

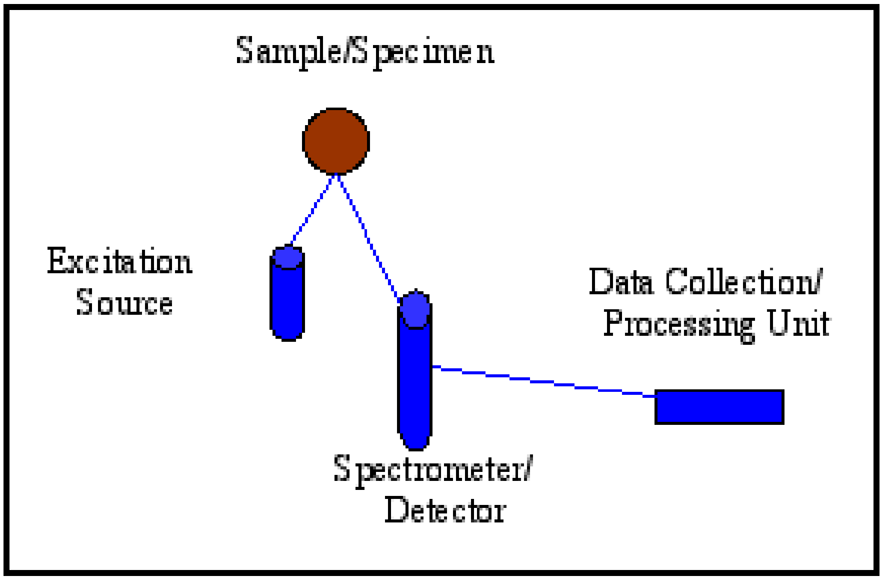


Fig 2d. XRF Spectrometry for Metal Analysis

RESULTS

Final, processed results are organized into various tables and figures for convenient use which are briefly discussed in this section. In lieu of long explanation of results, care was taken to prepare these tables and figures efficiently so that they are self-explanatory to the reader. Necessary particle size data and metal concentration data for six abrasives can be extracted from the results presented in this section for ready use in the residual risk analysis.

Particle Size Using Interferometry

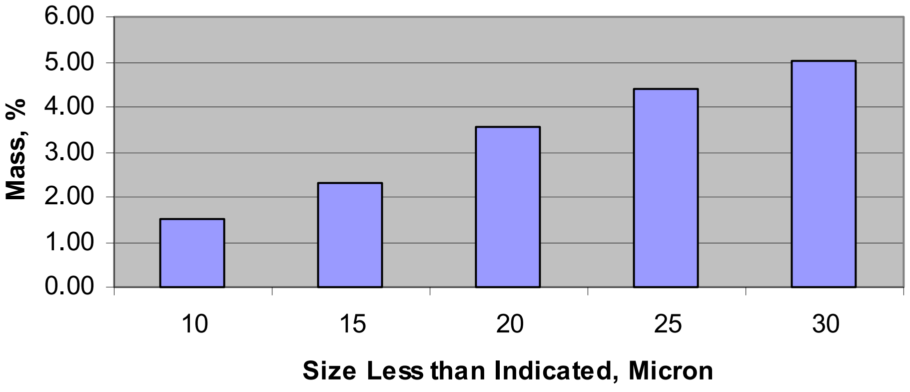
Table 1 includes the particle size data obtained using the combination of micro sieving and Interferometer. Table 1 includes average particle size distribution (PSD) of airborne particulate matter (PM) emitted from dry abrasive blasting using six different abrasives. These six abrasives are garnet (GA), coal slag (CO), copper slag (CU), garnet (GA), steel grit (SG), and specialty sand (SS).

Table 1: Size Distribution of Airborne Particles from Dry Abrasive Blasting

Particle Size, Micron	Cumulative Mass % (all particles less than the size indicated)					
	Barshot	Coal Slag	Copper Slag	Garnet	Steel Grit	Specialty Sand
10	1.52	0.73	0.03	0.36	0.00	0.20
15	2.29	0.92	0.10	0.49	0.00	0.27
20	3.57	1.16	0.29	0.93	0.00	0.39
25	4.39	1.45	0.61	1.61	0.00	0.62
30	5.03	1.62	1.15	2.20	0.91	0.65
400	100.00	100.00	100.00	100.00	100.00	100.00

Figures 3 through 8 illustrate the size distribution of airborne particles for each of the six abrasives studied. Airborne particles were collected on filter media in a previous study that involved blasting on painted panels using Bazooka blast nozzle number 6 in an enclosed test chamber. Blasting pressure used ranged from 80 to 120 psi at the tip of the nozzle. All abrasives used in the study were of medium grade. Specialty sand refers to sand that is washed and graded to reduce the dust emissions and improve its abrasive properties.

Fig 3. PSD of Airborne PM - Barshot Blasting



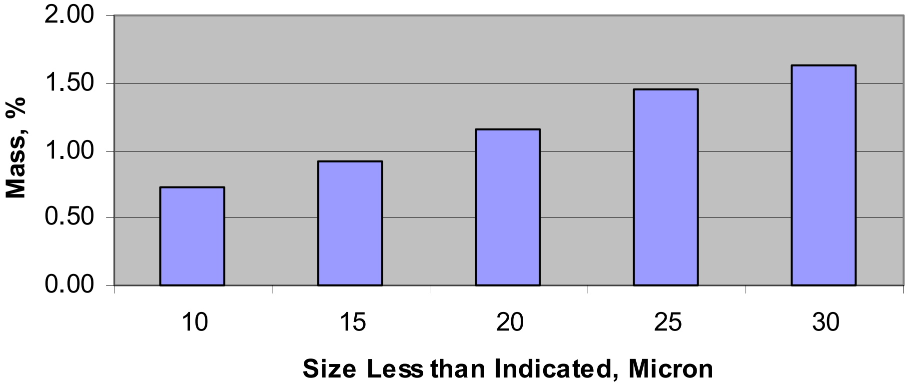


Fig 4. PSD of Airborne PM - Coal Slag Blasting

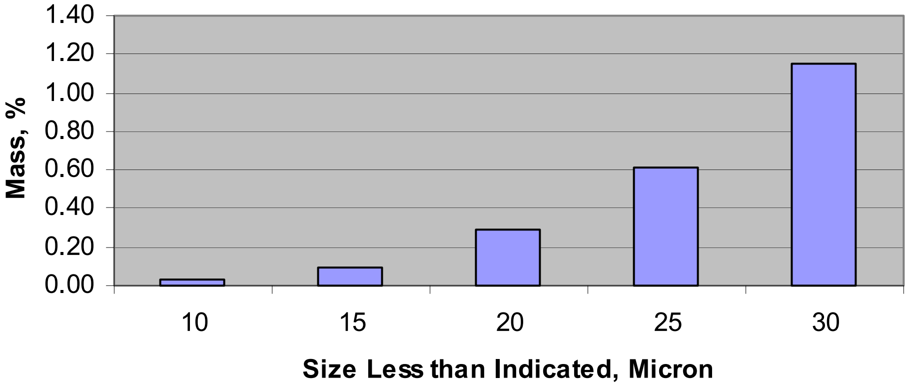


Fig 5. PSD of Airborne PM - Copper Slag Blasting

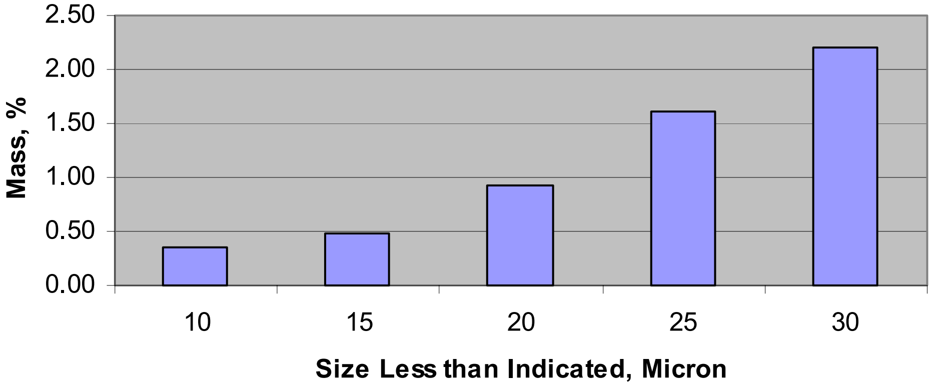
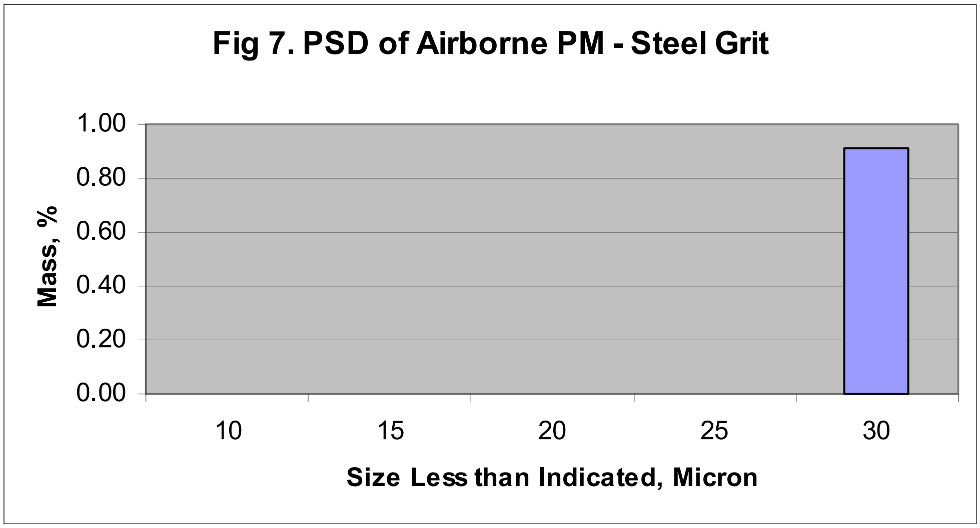
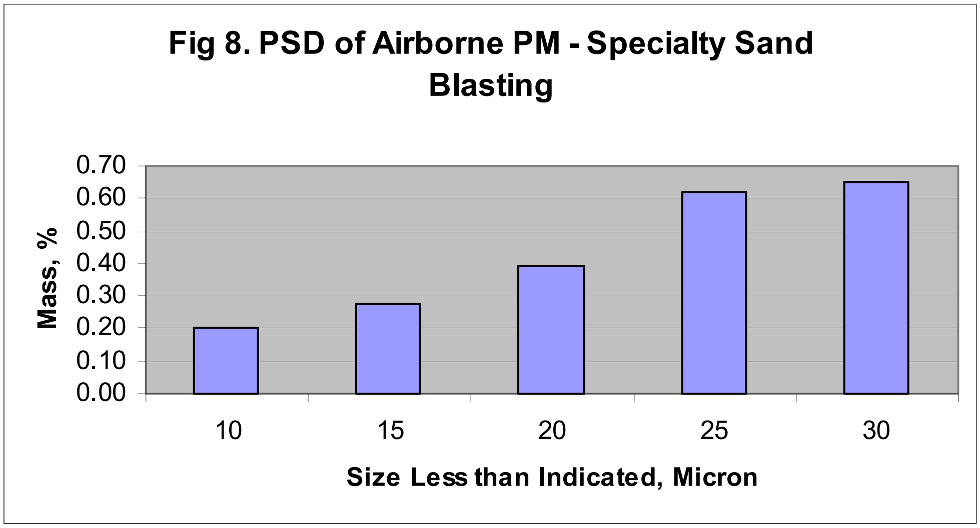


Fig 6. PSD of Airborne PM - Garnet Blasting





Particle Size Using Single Particle Optical Scanning (SPOS)

Table 2 presents the particle size data of airborne particles emitted from dry abrasive blasting using six different abrasives. Figures 9 through 14 illustrate the PSD trends.

Table 2: Size Distribution of Airborne Particles from Dry Abrasive Blasting
Single Particle Optical Scanning (SPOS) Method

Particle Size, Micron	Cumulative Mass % (all particles less than the size indicated)					
	Barshot	Coal Slag	Copper Slag	Garnet	Steel Grit	Sp. Sand
1.01	0.16	0.19	0.22	0.16	0.33	0.17
2.46	0.37	0.63	0.54	0.37	0.92	0.57
3.93	0.56	1.28	0.85	0.56	1.56	1.13
6.99	1.16	3.89	2.42	1.16	4.56	3.06
10.07	2.11	8.87	7.27	2.11	9.92	6.19
15.29	4.09	18.74	21.47	4.09	17.62	12.00
19.86	6.02	25.59	30.62	6.02	23.15	16.30
24.47	8.46	31.13	36.18	8.46	28.82	20.67
30.16	12.54	36.62	40.98	12.54	35.94	26.89
400	100.00	100.00	100.00	100.00	100.00	100.00

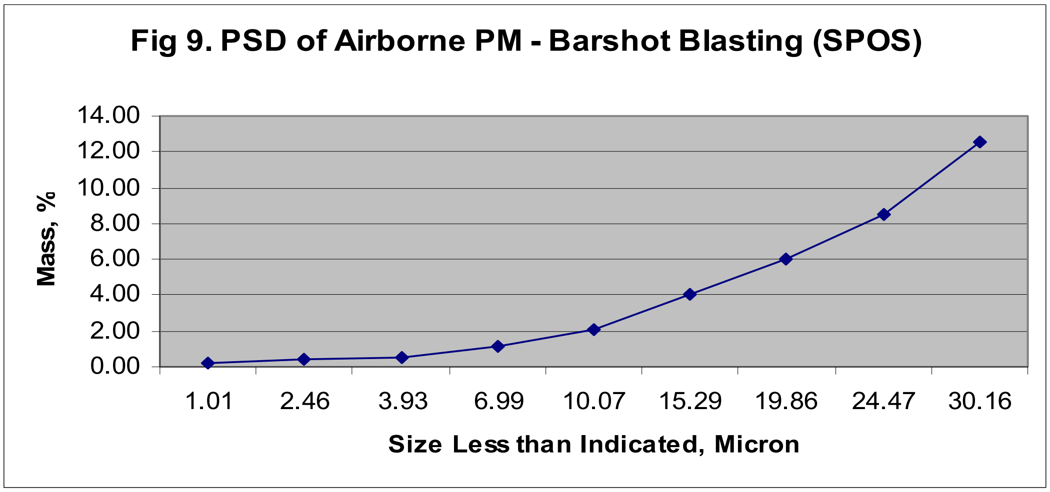


Fig 9. PSD of Airborne PM - Barshot Blasting (SPOS)

Fig 10. PSD of Airborne PM - Coal Slag Blasting (SPOS)

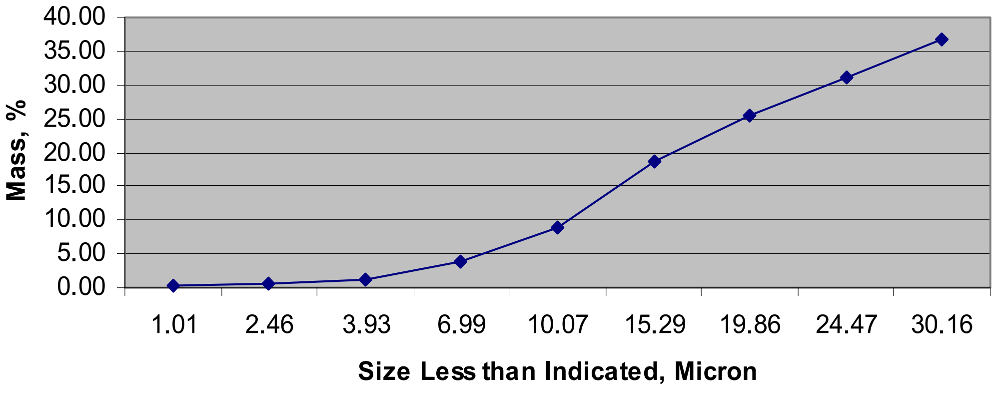


Fig 11. PSD of Airborne PM - Copper Slag (SPOS)

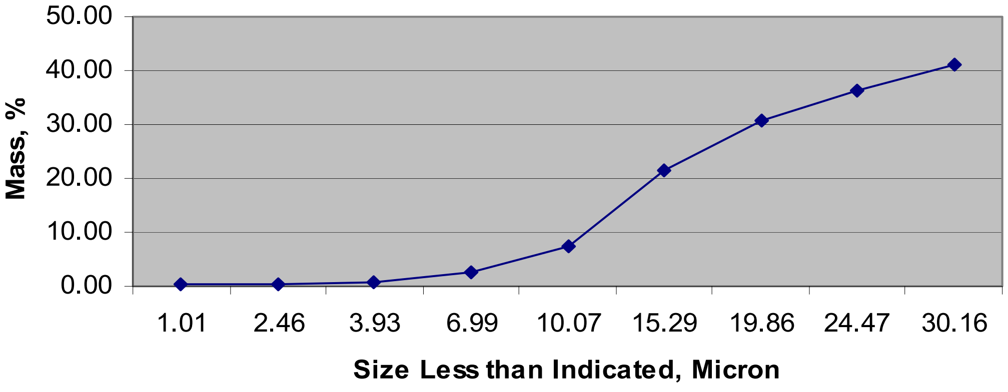
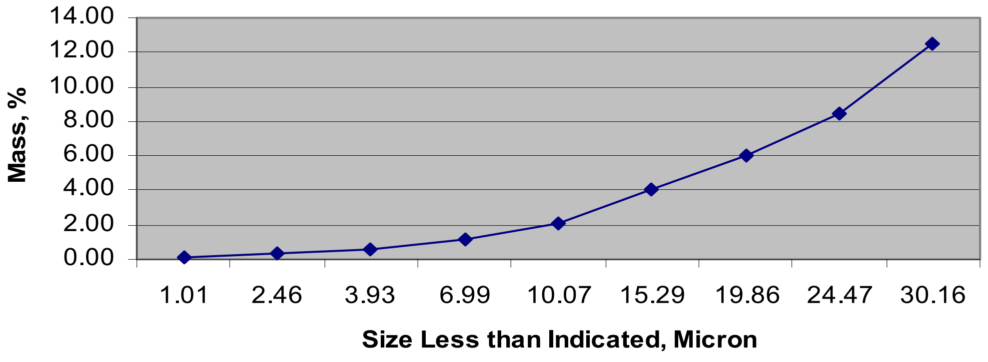
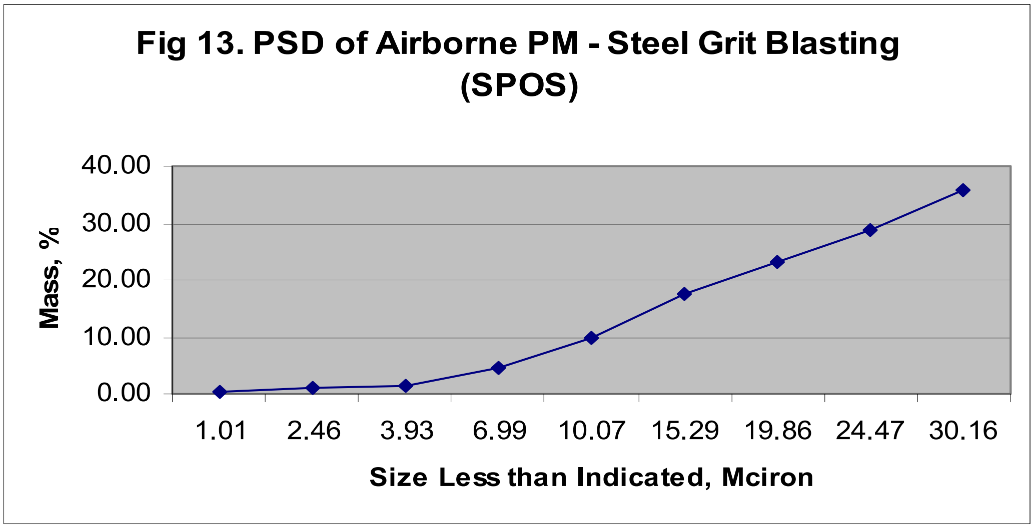
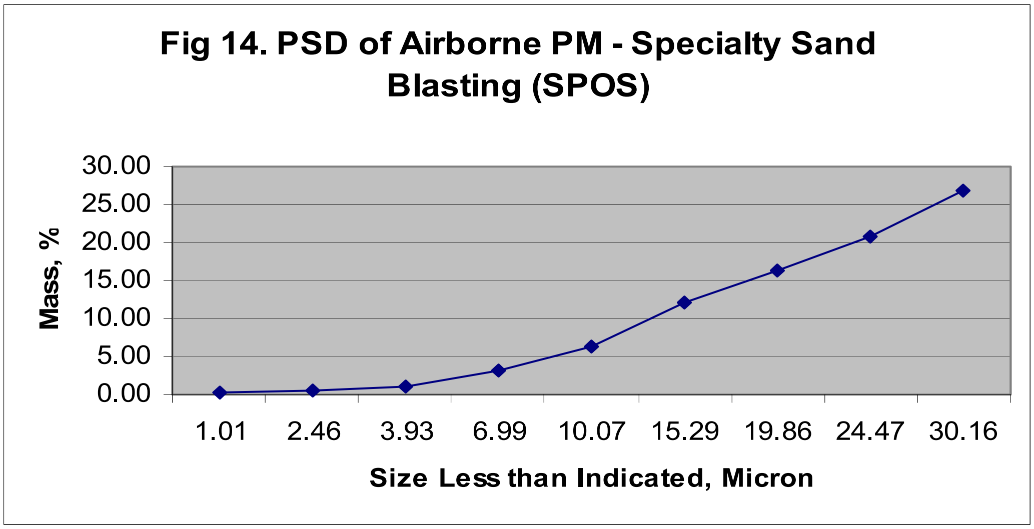


Fig 12. PSD of Airborne PM - Garnet Blasting (SPOS)







Metal Fraction of Airborne TPM Using XRF Spectroscopy

Original scope included analysis of only four metals, Cr, Mn, Ni, and Pb. However, all metals that were possible to be analyzed using XRF were analyzed and included in the results. Table 3 includes the summary of metals analyzed, EPA's classification - if it is carcinogen or non-carcinogen, respective toxicity values, and the specific health effects. It is important to note that the toxicity values given in Table 3 are for various metal compounds. Whereas, the results presented in Table 4 and 5 represent the elemental metals. In case of chromium the results presented are total chromium, not hexavalent chromium. Due care should be taken when calculating various input data for the risk assessment of emissions from dry abrasive blasting. Cancer toxicity values are indicated by the unit risk estimate (URE) and the non-cancer toxicity values are indicated by the reference concentrations (RfC) values. URE and RfC are defined as follows:

Unit Risk Estimate (URE)

The URE is defined as the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 μg/m^3 in air. A higher URE value indicates that the air pollutant has high potential for inducing caner in exposed individuals.

Reference Concentration (RfC)

The RfC is an estimate of a concentration in air to which a human population might be exposed (including sensitive subgroups) that is likely to be without appreciable risks of deleterious effects during a lifetime. A lower RfC value indicates that the air pollutant has high potential for inducing a specific health effect in exposed individuals.

Table 4 presents the metal concentration of airborne PM emitted from dry abrasive blasting using six abrasives. It should be noted that the metal concentrations reported are for the elemental metal concentrations, not their compounds. Also, the chromium reported is total chromium, not hexavalent chromium and their compounds. Figures 15 through 20 illustrate the average metal concentration (expressed in ppm) as well as the standard deviation for each of the six abrasives tested. As it can be seen that the standard deviation is very high which indicates variations in concentrations of metals measured among the samples. This may be attributed to changes in blast pressure, feed rate, and a variety of other field test conditions. However, the average values presented are useful until more refined process specific data is generated through future research.

Table 5 presents the metal concentration of airborne PM, however is organized for each abrasive tested. Figures 21 through 34 illustrate differences in metal concentration from abrasive to abrasive for each tested metal.

Table 3: Inhalation Induced Health Risks Considered by EPA

Airborne Metal	EPA's Carcinogen Currently?	URE, per ug/m^3	EPA's Non carcinogen Currently?	Specific Health Effect?	RfC, mg/m^3
Arsenic (As) Compounds	Yes	4.3 E-03	Yes	Irritation of mucous membrane in humans	3.0 E-05
Barium (Ba)	No		No		
Cadmium (Cd) Compounds	Yes	1.8 E-03	Yes	Kidney damage in humans	2.0 E-05
Lead (Pb) Compounds	Yes	1.2 E-05	Yes	Neurobehavioral effects (CNS) in humans	1.5 E-03
Cobalt (Co) Compounds	No		No		
Chromium (Cr) Compounds	Yes	1.2 E-02	Yes	Lung injury in rats	1.0 E-04
Copper (Cu)	No		No		
Mercury (Hg) Compounds	No		Yes	Neurobehavioral effects (CNS) in humans	3.0 E-04
Manganese (Mn) Compounds	No		Yes	Neurobehavioral effects (CNS) in humans	5.0 E-05
Molybdenum (Mo)	No		No		
Nickel (Ni) Compounds	Yes	4.8 E-04	Yes	Respiratory track inflammation in rats	2.0 E-04
Selenium (Se)	No		No		
Titanium (Ti)	No		No		
Zinc (Zn)	No		No		
Iron (Fe)	No		No		

Source: US EPA; Health Effects Information Used in Cancer and Noncancer Risk Characterization for the NATA 1996 National-Scale Assessment

Note: Metal analysis results reported in this report in subsequent tables correspond to total elemental chromium (not hex-chrome), elemental metals but not their compounds.

Table 4: Average Metal Concentration in Airborne PM Emitted from Dry Abrasive Blasting

Metal in Airborne PM	Barshot/Hematite		Coal Slag		Copper Slag		Garnet		Steel Grit		Specialty Sand	
	AC (ppm)	SD (ppm)	AC (ppm)	AC (ppm)	AC (ppm)	AC (ppm)	AC (ppm)	SD (ppm)	AC (ppm)	SD (ppm)	AC (ppm)	SD (ppm)
As	0.00	0.00	0.00	0.00	11.38	8.21	0.00	0.00	0.00	0.00	0.00	0.00
Ba	3.87	21.18	79.29	131.58	0.00	0.00	25.75	74.15	0.00	0.00	0.00	0.00
Cd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb	40.38	13.22	5.49	7.36	143.98	91.15	7.64	4.05	62.74	83.46	5.74	6.76
Co	12.98	38.81	44.78	51.85	30.80	52.01	53.41	53.07	0.00	0.00	0.00	0.00
Cr	2.26	6.90	1.66	4.81	10.00	14.30	7.79	11.03	163.01	216.64	0.00	0.00
Cu	2.64	2.56	6.53	10.70	497.23	250.03	7.43	7.04	68.59	69.54	2.46	3.37
Hg	0.83	1.20	1.73	2.58	0.00	0.00	0.67	0.89	0.84	2.15	0.04	0.25
Mn	3.87	8.26	27.17	37.34	30.45	20.43	224.54	179.40	595.98	683.65	7.28	12.61
Mo	1.23	1.80	19.23	31.95	87.01	60.10	7.12	5.63	45.07	55.29	40.41	39.94
Ni	0.00	0.00	1.07	5.85	1.84	9.01	1.12	3.59	0.00	0.00	0.05	0.31
Se	0.00	0.00	0.08	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ti	71.94	60.03	203.55	297.36	130.26	92.51	465.29	255.09	290.96	492.32	46.47	52.81
Zn	7.15	7.75	65.89	92.52	585.17	303.96	56.13	137.15	105.04	128.76	13.36	13.35
Fe	38151	9461	7802	11418	26467	13833	12637	6734	72310	79484	1080	948

Footnote 1: AC - Average Concentration; SD - Standard Deviation

Footnote 2: Note: Metal analysis results reported in the above table correspond to total elemental chromium (not hex-chrome), elemental metals but not their compounds

Table 5: Average Metal Concentration in Airborne PM Emitted from Abrasive Blasting – Abrasive Wise

Abrasive	As	Ba	Cd	Pb	Co	Cr	Cu	Hg	Mn	Mo	Ni	Se	Ti	Zn	Fe
BS	0.00	3.87	0.00	40.38	12.98	2.26	2.64	0.83	3.87	1.23	0.00	0.00	71.94	7.15	38151
CO	0.00	79.29	0.00	5.49	44.78	1.66	6.53	1.73	27.17	19.23	1.07	0.08	203.55	65.89	7802
CU	11.38	0.00	0.00	143.98	30.80	10.00	497.23	0.00	30.45	87.01	1.84	0.00	130.26	585.17	26467
GA	0.00	25.75	0.00	7.64	53.41	7.79	7.43	0.67	224.54	7.12	1.12	0.00	465.29	56.13	12637
SG	0.00	0.00	0.00	62.74	0.00	163.01	68.59	0.84	595.98	45.07	0.00	0.00	290.96	105.04	72310
SS	0.00	0.00	0.00	5.74	0.00	0.00	2.46	0.04	7.28	40.41	0.05	0.00	46.47	13.36	1080

Footnote 1: BS - Barshot/Hematite; CO - Coal Slag; CU - Copper Slag; GA - Garnet; SG - Steel Grit; SS - Specialty Sand

Footnote 2: Metal analysis results reported in the above table correspond to total elemental chromium (not hex-chrome), elemental metals but not their compounds

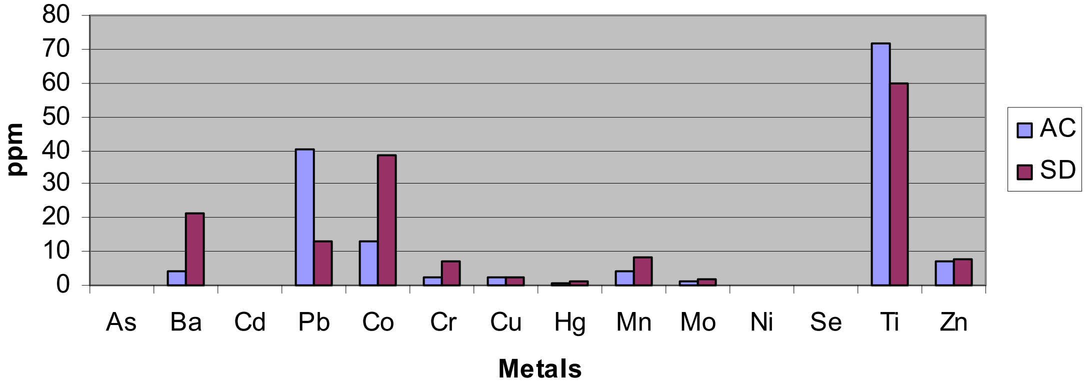


Fig 15. Metals in Airborne PM - Barshot Blasting

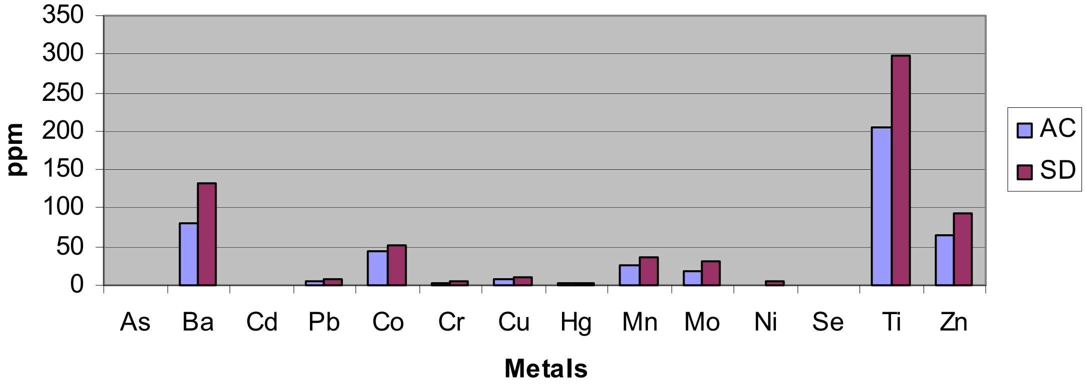


Fig 16. Metals in Airborne PM - Coal Slag Blasting

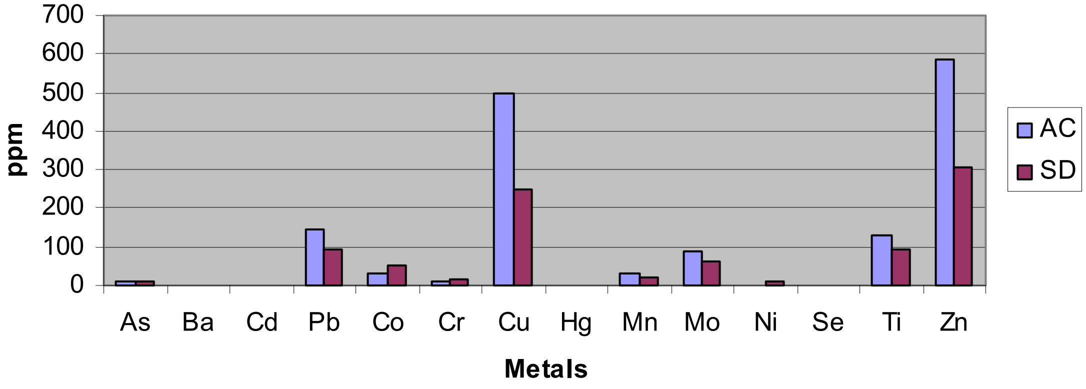


Fig 17. Metals in Airborne PM - Copper Slag

Fig 18. Metals in Airborne PM - Garnet Blasting

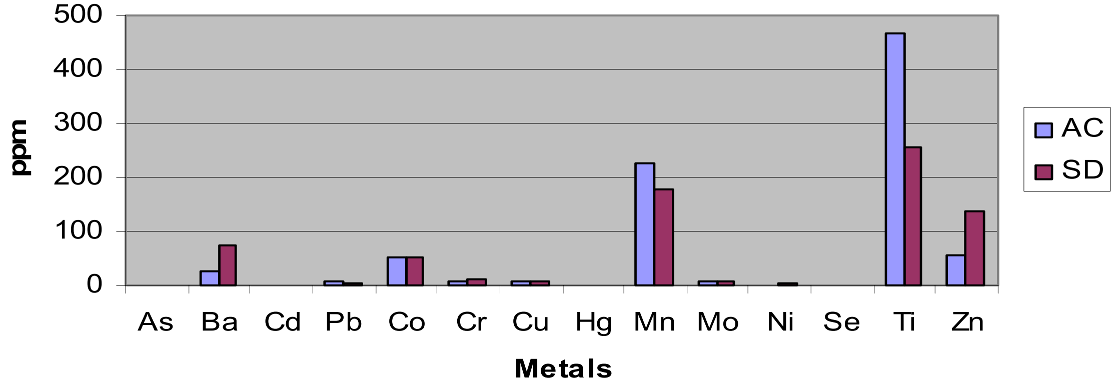


Fig 19. Metals in Airborne PM - Steel Grit Blasting

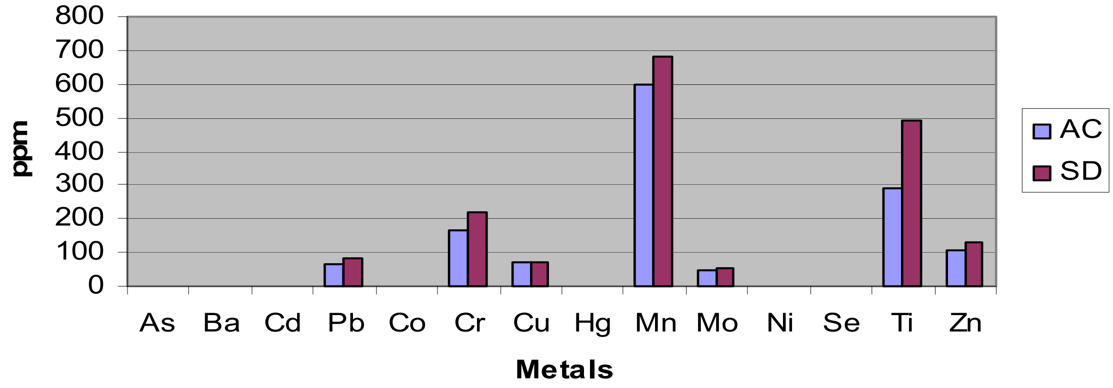


Fig 20. Metals in Airborne PM - Specialty Sand Blasting

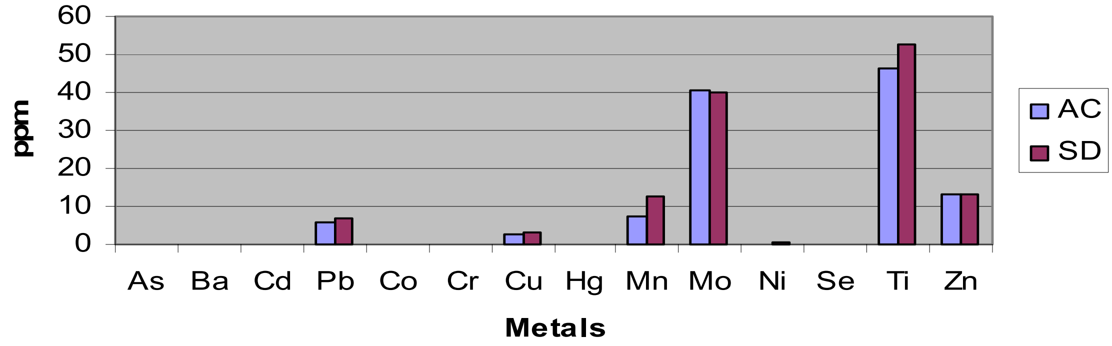


Fig 21. Aresenic in Airborne PM

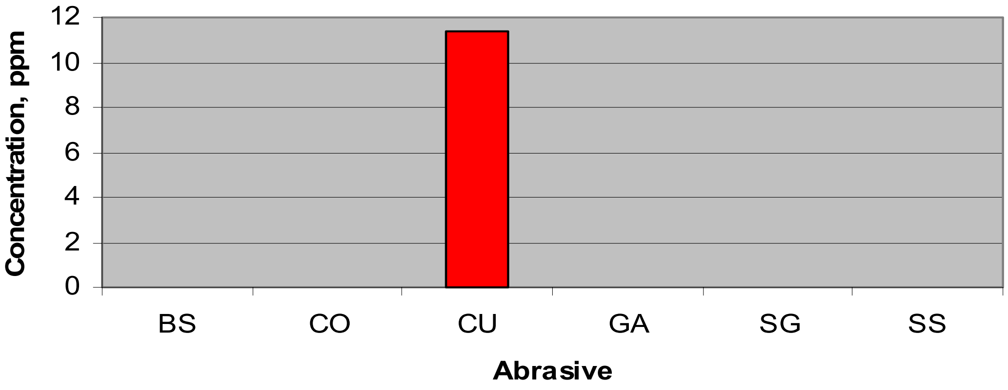


Fig 22. Barium in Airborne PM

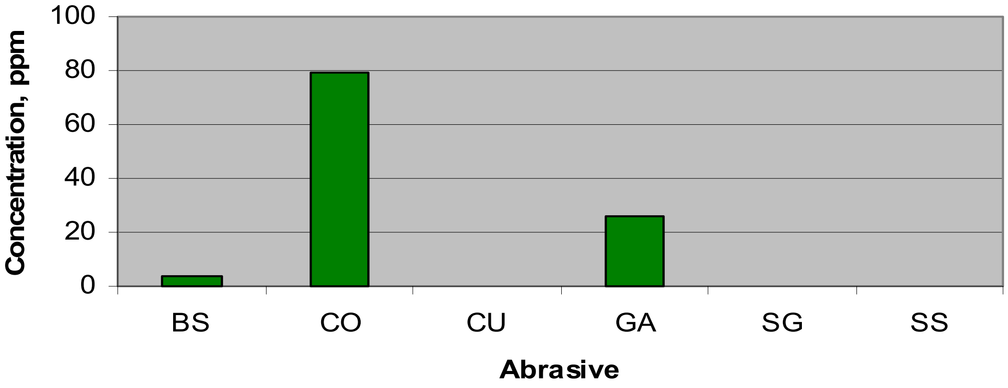


Fig 23. Lead in Airborne PM

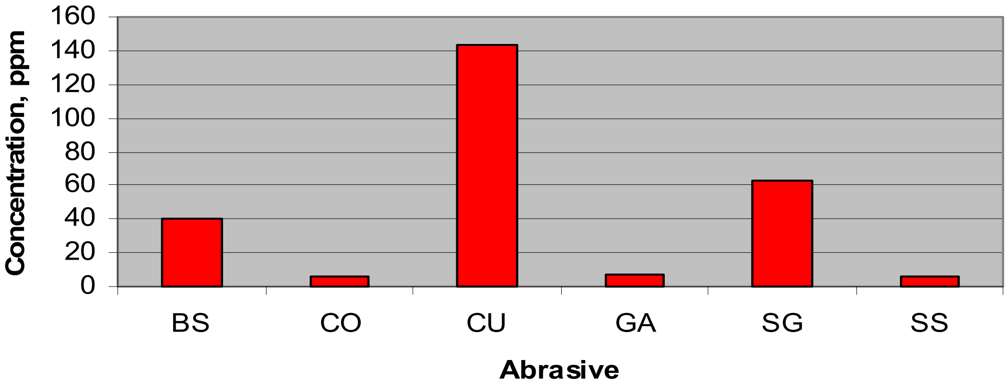


Fig 24. Cobalt in Airborne PM

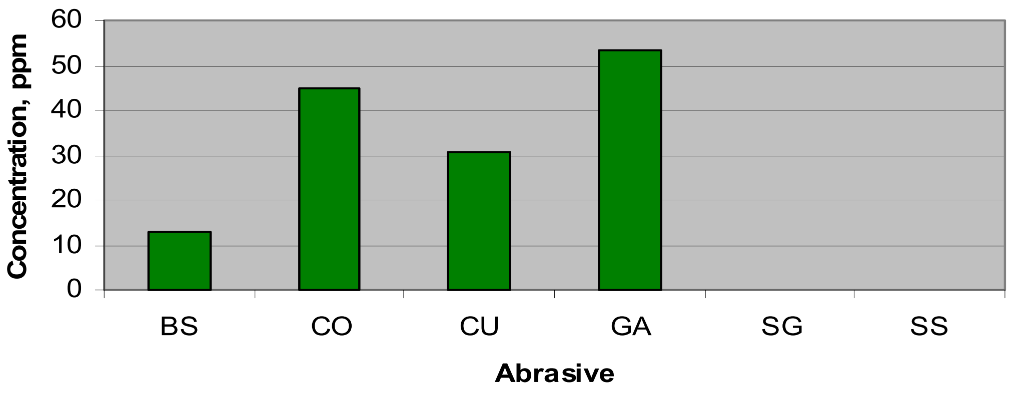


Fig 25. Chromium in Airborne PM

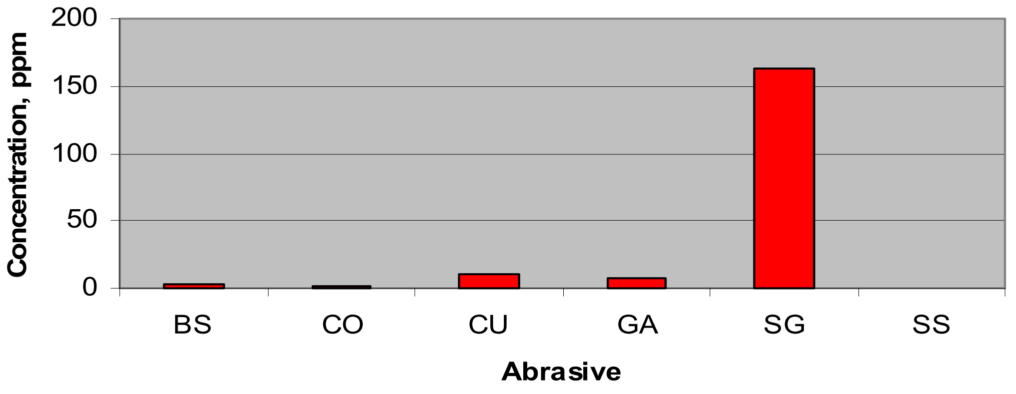


Fig 26. Copper in Airborne PM

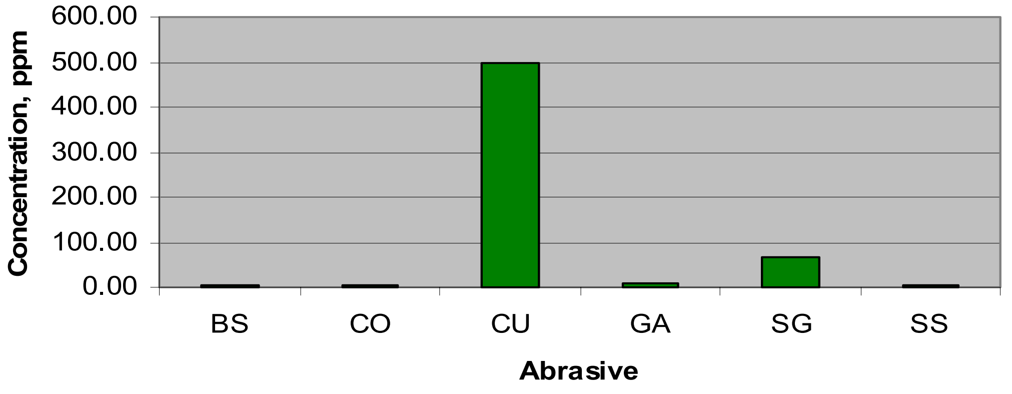


Fig 27. Mercury in Airborne PM

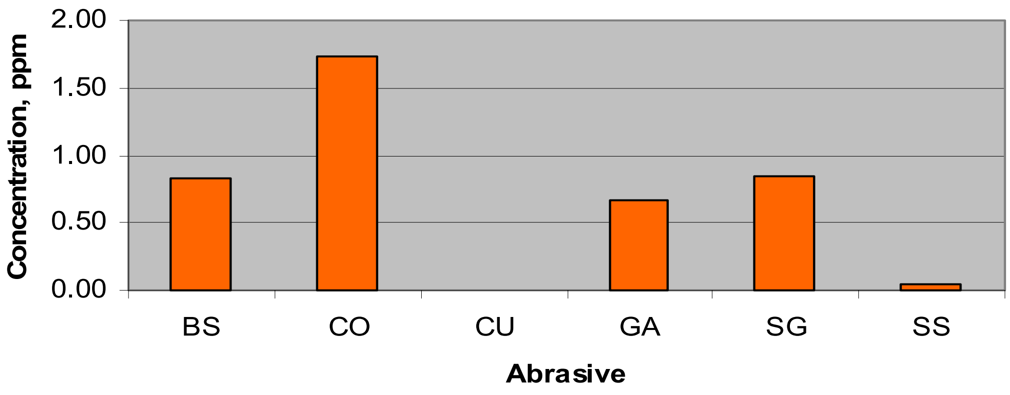


Fig 28. Manganese in Airborne PM

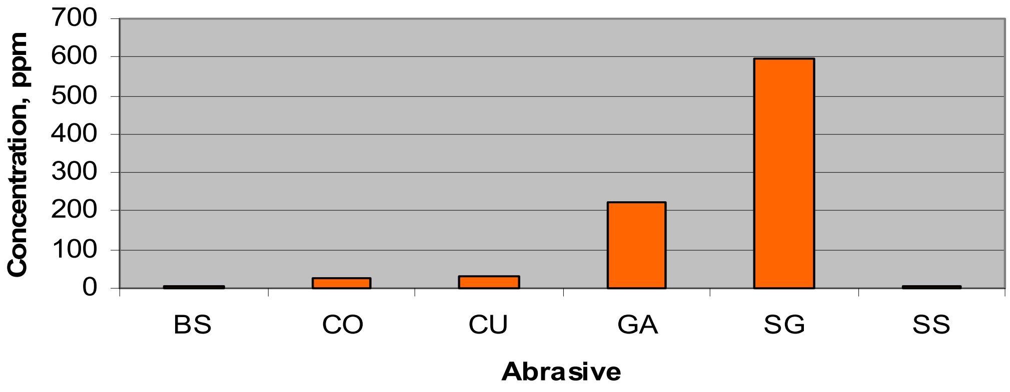


Fig 29. Molybdenum in Airborne PM

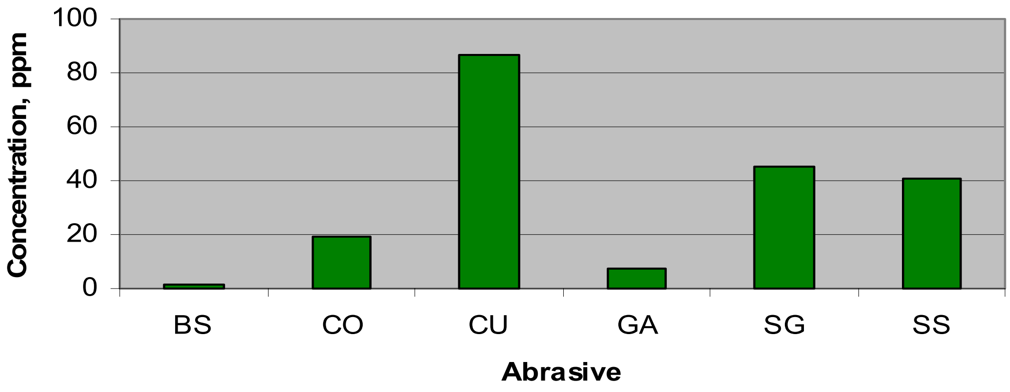


Fig 30. Nickel in Airborne PM

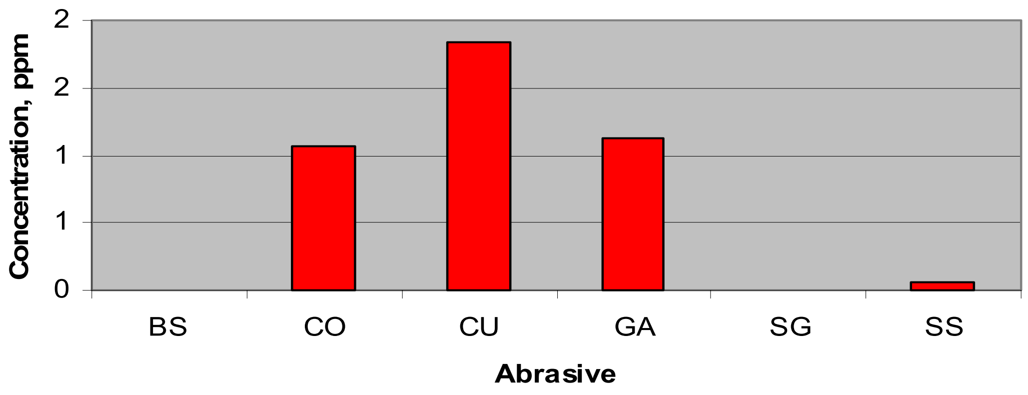


Fig 31. Selenium in Airborne PM

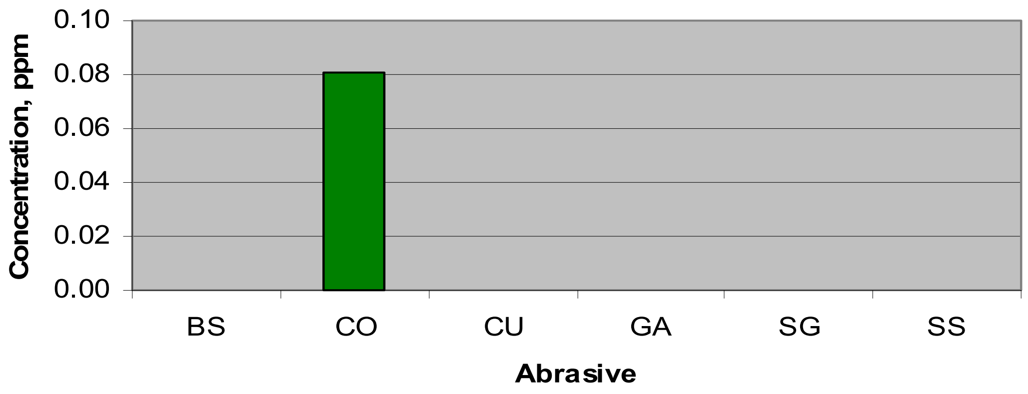
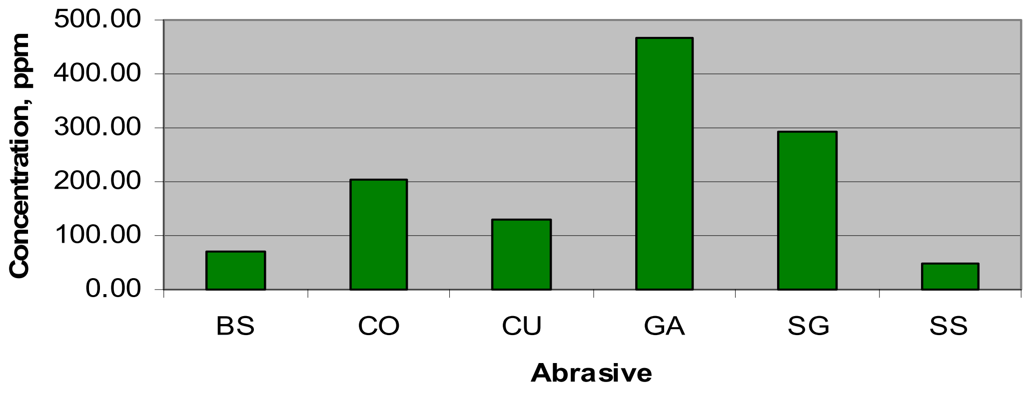


Fig 32. Titanium in Airborne PM



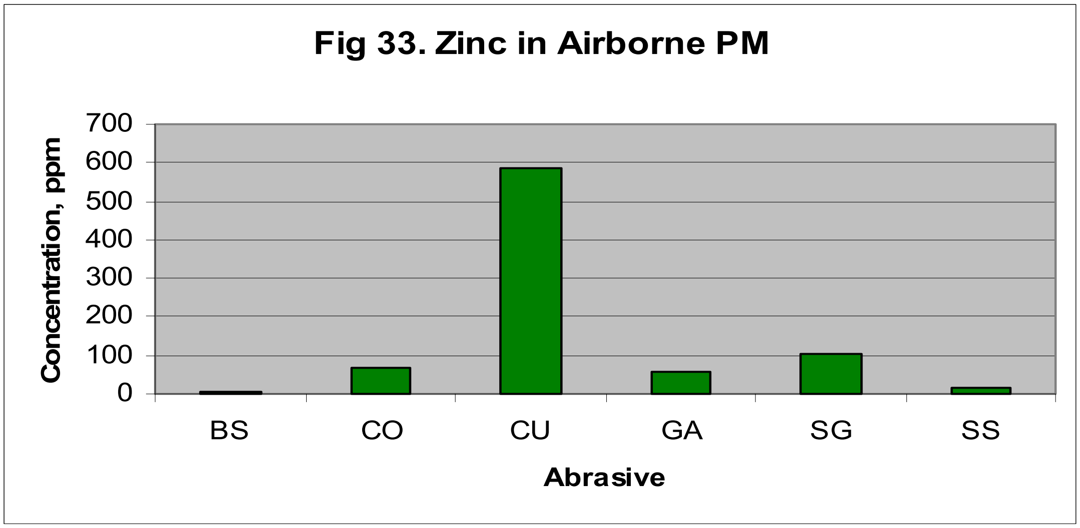


Fig 33. Zinc in Airborne PM

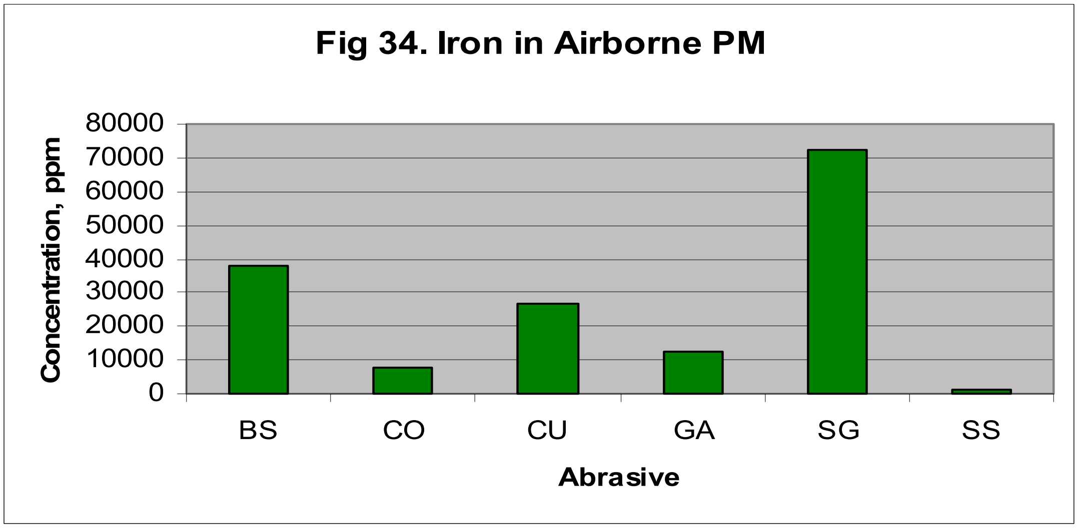


Fig 34. Iron in Airborne PM

CONCLUSIONS

Particle size distribution data (PM_{10} fraction) and the metal fraction of airborne total PM (TPM) presented in this report will be of great use in correctly determining the inhalation induced health risks or residual risks anticipated from dry abrasive blasting processes.

For particle size, variation was observed between the results obtained from the Interferometer method and the SPOS method. Wide range of particle size in the samples, "submicron (less than one micron)" to "400 and above microns," caused measurement problems in both, Interferometer as well as SPOS methods. Using micro sieving, measurement errors were minimized to some extent in case of the Interferometer method. However, larger particles caused blockage of the instrument mechanism in case of SPOS method. SPOS method has ignored some particles that are larger than 400 microns; hence the PM_{10} data obtained from SPOS method may be an overestimated value.

It is believed that Interferometer results are more accurate because it integrates the particle volume by measuring the particle image at various altitudes along the vertical axis, thus volume is integrated using the x-y-z measurements. Whereas, the SPOS method uses the decrease in the light transmission to estimate the particle size with the help of a calibration curve. Because of these differences in the measurement principles, it is suggested that PM_{10} fraction obtained by the Interferometer method should be used for residual risk calculations.

In case of steel grit, PM_{10} fraction could not be determined using micro sieve and interferometer method as it was below the determination level. PM_{10} fraction however is expected to be far smaller than PM_{30} fraction which is listed in the results.

High standard deviation was observed in case of metal fraction data which indicates large fluctuations in metal concentration from sample to sample. This may be due to variations in process conditions such as blast pressure, feed rate, any variations in paint thickness, and other field conditions. The average metal concentration data presented in this report should be very useful until more refined data is available as the currently available data is not relevant to shipyard conditions.

All the results presented are based on airborne PM samples that were generated for painted panels (Rust Oleum © Safety Yellow Paint) of approximately 0.73 mil thickness. It should be noted that variation in paint, paint thickness, and other variations can affect the results. Also, it should be noted that blasting on rusted steel surfaces are expected to produce different results as one can expect different mix of airborne particles.

Future studies should consider other particle sizing and metal analysis procedures to further verify and refine the findings of this report.

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40 CFR 60, Appendix A: Test Methods, Method 1 – Sample and Velocity Traverses for Stationary Sources.

40 CFR 60, Appendix A: Test Methods, Method 2 – Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)

40 CFR 60, Appendix A: Test Methods, Method 3 – Gas Analysis for the Determination of Dry Molecular Weight.

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