EVALUATION OF BERYLLIUM, TOTAL CHROMIUM AND NICKEL IN THE SURFACE CONTAMINANT LAYER AVAILABLE FOR DERMAL EXPOSURE AFTER ABRASIVE BLASTING IN A SHIPYARD

by

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Thesis submitted to the Faculty of the
Preventive Medicine and Biometrics Graduate Program
Uniformed Services University of the Health Sciences
In partial fulfillment of the requirements for the degree of
Masters of Science in Public Health 2013

UNIFORMED SERVICES UNIVERSITY, SCHOOL OF MEDICINE GRADUATE PROGRAMS
Graduate Education Office (A 1045), 4301 Jones Bridge Road, Bethesda, MD 20814

DISSERTATION APPROVAL FOR THE MASTER IN SCIENCE IN PUBLIC HEALTH DISSERTATION IN THE PREVENTIVE MEDICINE AND BIOMETRICS GRADUATE PROGRAM

Title of Dissertation: "Evaluation of Levels of Beryllium, Total Chromium and Nickel in the Surface Contaminant Layer Available for Dermal Exposure after Abrasive Blasting in a Shipyard"

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April 24, 2013

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ABSTRACT

EVALUATION OF BERYLLIUM, TOTAL CHROMIUM AND NICKEL IN THE SURFACE CONTAMINANT LAYER AVAILABLE FOR DERMAL EXPOSURE AFTER ABRASIVE BLASTING IN A SHIPYARD

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Abrasive blasting is conducted at naval shipyards to prepare surfaces for painting and protection. This study used analyzed results from air and surface samples to determine if there is a skin exposure avenue for beryllium, total chromium and nickel through the surface contaminant layer after abrasive blasting. Areas exposed and not exposed to abrasive blasting were sampled to determine if there was a difference between these two areas.

Surface samples were collected using wipes in the areas where abrasive blasting was conducted and in adjacent non-exposed areas. Blasting areas were chosen because prior air sampling surveys determined these metals of interest were present. The blasting areas were both aboard submarines and in the building used for abrasive blasting with coal grit. Equipment surfaces that were not exposed to abrasive blasting were sampled to determine the background amounts of beryllium, nickel and total chromium. The samples were sent to the Comprehensive Industrial Hygiene Lab Norfolk for analysis of Be, Ni, and total Cr.

All surface sample results from the exposed and unexposed areas were below level of detection for beryllium. Results determined that a greater concentration of total chromium and nickel was found in exposed area samples than the non-exposed area samples. Data determined there was a greater amount of metals of interest from samples taken aboard submarines than sample taken from Building 286.

A potential dermal exposure route for total chromium and nickel does exist through the surface contaminant layer after abrasive blasting. It has been demonstrated that the location of blasting has an influence on the amount of metals of interest available for exposure.

Copyright Statement

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ACKNOWLEDGMENTS

I would like to acknowledge the personnel of the industrial hygiene section at Portsmouth Naval Shipyard and Alexis Sablock for providing data and assistance in collection of data in support of this thesis.

I would like to thank my thesis committee, Lieutenant Colonel Alex Stubner, Lieutenant Colonel Christopher Gellasch, and Commander Jennifer Rous, for their mentorship, guidance and support.

I would also like to thank my classmates who were all working towards the goal of attaining the MSPH, Monica, Mark, Korami, Ted and Erin. Thank you for the time we all studied, talked, and worked together.

DEDICATION

I dedicate this Master of Science thesis to my wife Mary and my son Carson. Thank you for the understanding and patience you have shown to me as I have pursued this goal in life. Your love and encouragement motivate me to achieve more than I can imagine.

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CHAPTER 1: INTRODUCTION

Workers in industrial settings that conduct machining and abrasive blasting may be exposed to many metals including beryllium, total chromium and nickel. Exposures to beryllium, total chromium and nickel potentially cause dermal health issues including sensitization, skin irritation and dermatitis. Dermal health issues from these exposures could lead to lost work time, permanent disabilities and possible delays in completing assigned tasks. A Report from the Occupational Safety and Health Administration in 1996 stated that there were 18 cases of dermatitis for workers exposed to metal ores reported to the U.S. Department of Labor. These 18 cases had a median of 9 lost work days. It was also reported to the U.S. Department of Labor that there were 19 cases of dermatitis for workers exposed to other metallics, and these had a median of 14 lost work days (4). Not completing worker tasks on time have detrimental effects on the missions of the industrial settings including U.S. Navy shipyards. Permanent disabilities of workers exposed to beryllium could lead to lifelong health care costs for shipyards.

THE SHIPYARD

Portsmouth Naval Shipyard's (NSY) was established in 1802 to service and repair U.S. Navy ships. Its current mission is to service and repair U.S. Navy submarines of the Los Angeles and Virginia class. Servicing includes equipment repair, sandblasting, machining, and painting operations of interior compartments and exterior hulls of the submarines. During servicing operations workers are potentially exposed to metals including cadmium, chromium, beryllium, iron, lead, nickel, tin, zinc and copper (43).

Potential worker exposure while conducting servicing operations requires routine air monitoring to ensure the health and safety of the workers.

The Virginia class, the newer submarine, is built to operate faster and deeper than older classes of submarines. To manufacture stronger and more capable parts for this class of submarine, beryllium is added as a component metal of the parts. Although beryllium alloys provide additional strength benefits, the addition results in the potential hazards of dermal and inhalation exposure from dust containing beryllium when the parts are machined or repaired. When parts become worn, they need to be reshaped through the process of machining. Machining includes drilling, grinding, and other mechanical manipulations of parts.

Portsmouth NSY personnel implemented procedures aligned with the safety and health hierarchy of control in order to protect the workers from exposure to the known beryllium parts. Engineering controls for machining areas include a dedicated, portable high efficiency particulate air (HEPA) filtered exhaust unit. Administrative controls consist of allowing only trained workers to conduct the machining and a requirement for a supervisor to observe the machining procedure at all times ensuring adherence to controls. Finally, workers were required to wear personal protective equipment, which included impervious disposable gloves, safety glasses, steel toed shoes, and hearing protection if needed. Workers wore double gloves so that the top glove could be changed with any perception of surface contamination without exposing skin.

During the machining of the beryllium parts, Portsmouth NSY industrial hygiene personnel conducted routine breathing zone air monitoring to determine if there was any worker exposure to beryllium. The results from air sampling showed there were no detectable airborne exposures. Additionally, Portsmouth NSY personnel sampled the surface contaminant layers of machines used during machining operations to determine possible surface contamination. Results for these surface contaminant layer samples contained detectable amounts of beryllium. The analyzed surface levels were compared to the Department of Energy (DOE) beryllium standard for surfaces. The DOE is the sole U.S. government agency that has a beryllium surface standard and many other agencies that work with beryllium use it as a guide(16). Results from this comparison showed that there were higher amounts of beryllium on the machines' surface contaminant layer than the DOE guidance allows.

Based on the beryllium detection on the equipment and work machine surfaces used in the machining of submarine parts, as well as, the management attention provided to the machining of the beryllium parts, a procedural review survey was conducted at Portsmouth NSY to determine other areas where beryllium is present. The survey identified the abrasive blasting process as an additional work area with beryllium. From 2010 to 2012, routine personal air breathing zone samples for workers performing abrasive blasting were collected and analyzed. The samples were collected to comply with Occupational Safety and Health Administration (OSHA) requirements based on potential inhalation exposures. Samples were analyzed for metals including arsenic, lead, manganese, cadmium, chromium and beryllium. Thirty-six percent (12 of 33) of the breathing zone air samples had detectable concentrations of beryllium.

ABRASIVE BLASTING

Repainting consists of three steps, first abrasive blasting, then cleaning, followed by repainting of the original surface. During blasting, many abrasives such as garnet shot and steel shot are used, but where beryllium was identified in the breathing zone air samples at Portsmouth NSY, coal slag was the abrasive in use. Within Portsmouth NSY, there are two main areas where coal slag is used for blasting: the dry docks for blasting of submarines and in Building 286. Building 286 is a large bay room building where submarine shafts and rudders and other large components are brought for specific blasting. See Figure 1 for locations.

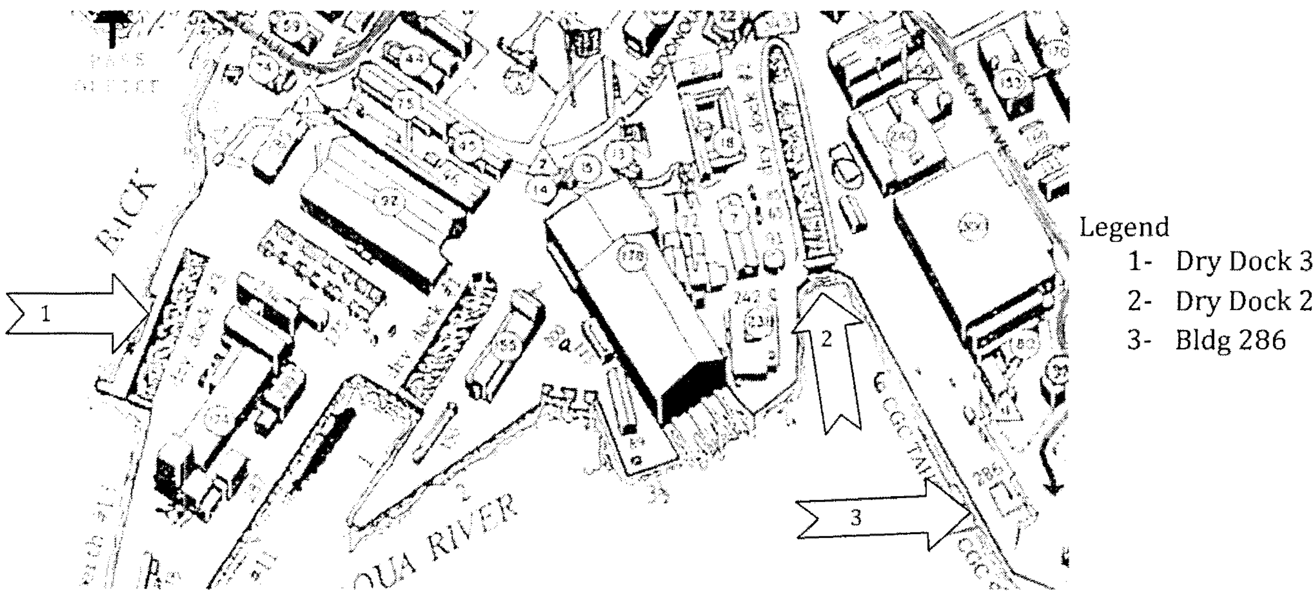

Figure 1: Map of Portsmouth Naval Shipyard with air and wipe sampling locations identified

Coal slag has the potential to contain beryllium as a component but also can contain total chromium and nickel, along with other metals(50). The metals contained in coal slag pose inhalation and dermal health risks for workers conducting abrasive blasting operations. Inhalation and dermal reactions from exposure to metals are recognizable and can create immediate reactions. Historically, control measures tend to focus more on inhalation exposures and reactions rather than dermal exposures (25, 43).

For protection from potential exposures during abrasive blasting, multiple controls are in place. Personnel utilize air supplied respirators and there is a dedicated, portable HEPA filtered local exhaust ventilation system that filters contaminants from the air. Dermal protection includes workers wearing heavy coveralls and hoods. To prevent the contamination of dust from spreading out of the exposed areas, Tyvek® tents are placed around the blasting area. The installed mechanical ventilation creates negative pressure within the structure keeping the dust in to be captured and filtered.

Cleaning of the blasted area, the second step after abrasive blasting, must be accomplished quickly because if the surface prepared is exposed four hours or longer, corrosion may start to occur. If corrosion occurs, repeated blasting is required, increasing the potential for exposure. The workers performing the cleaning are not required to use the same protective measures that are in place during the blasting and may enter the area less protected. This could lead to a greater potential exposure to workers. During cleaning, the possibility of equipment being moved exists, which further increases the potential of exposure. These potential exposures result from the heavier particles of the abrasives and surface coatings removed during blasting, that collect on the equipment surfaces in the area blasted during the blasting operation. Any of the dust that has collected on the surface of the equipment can be re-suspended as items are moved or cleaned posing an inhalation hazard or presenting a direct exposure risk to the skin if personnel are not wearing gloves or other dermal protection. There were no air samples collected during cleaning operations following abrasive blasting by Portsmouth NSY personnel. Wipe samples were taken either before or after cleaning operations throughout the conduct of this study.

THE STUDY

The objective of this research was to determine if there is a potential exposure route through the surface contaminant layer to skin of workers conducting cleaning operations after abrasive blasting, as displayed in the modified conceptual model in Figure 2. This model is modified from a 1999 study by Schneider et al (46). It tracks particles from the source of the blasting grit removing the surface coatings and possibly the base metal. These particles are emitted into the air or deposit on surfaces to form a surface contaminant layer. The particles in the air can also deposit to the surface contaminant layer over time. A potential exposure route is form the transfer to the skin of workers.

To answer the study question regarding potential dermal exposures, three specific aims were identified. Aim 1) compare the surface contaminant concentrations of equipment exposed to dust from abrasive blasting to surface contaminant concentrations of equipment that is not exposed to abrasive blasting. Aim 2) compare the surface contaminant concentrations of equipment exposed in Building 286 to the combined surface contaminant concentrations of the submarines. Aim 3) compare the surface contaminant concentrations of equipment exposed on individual submarines to each other.

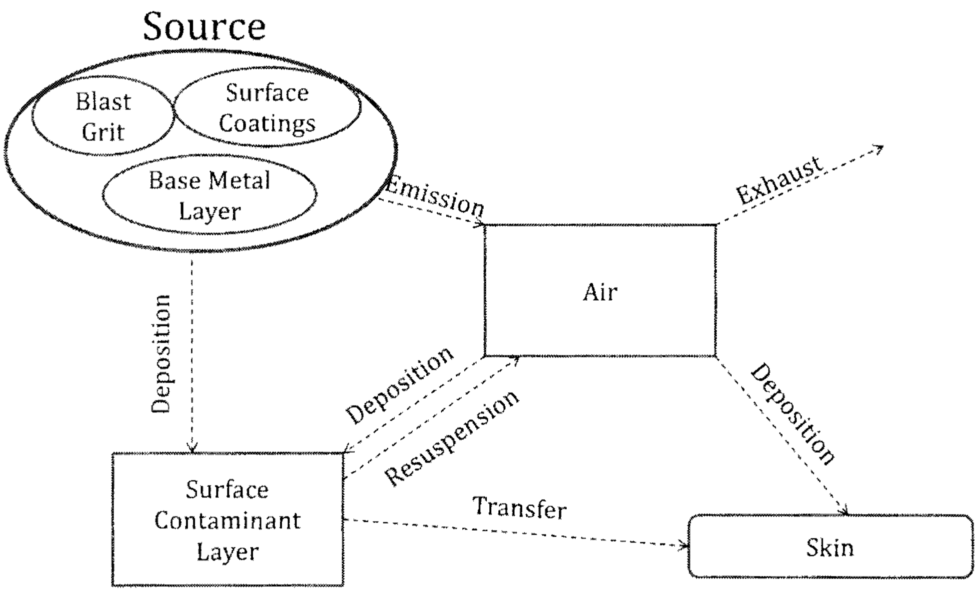

Figure 2: Conceptual model for dermal exposure used for comparison exposed and non-exposed surface contaminant layer study. Source is combination of blast grit, surface coatings and base metal layer.

Ultimately the comparisons in the aims will help answer the objective question of exposure potential to workers conducting cleaning operations after abrasive blasting. The comparisons of the individual exposed work area surface contaminant concentrations were conducted to determine if there is greater potential exposure in one work area over another.

The objective was accomplished by first characterizing the surface contaminant layer concentrations of beryllium, total chromium and nickel in the areas exposed to abrasive blasting and areas near but not exposed to abrasive blasting through collection of surface wipe samples. Characterization will show the amount of these metals that are available for potential dermal exposure. The results show additional controls may be required to protect from dermal exposure to beryllium, total chromium and nickel after abrasive blasting.

CHAPTER 2: LITERATURE REVIEW

SOURCE: ABRASIVE BLASTING COAL GRIT

Abrasive blasting is one step in the process of repainting surfaces. In typical abrasive blasting processes, abrasives are propelled by high pressure air towards a surface to prepare that surface for painting. The type of abrasive used depends on the blasting being conducted(28). The abrasives are used to remove the old surface coatings and surface corrosion. Abrasives travel at high speed as they are pushed by the air. When they hit the surface being treated, the abrasives bounce off into the air. The particles settle out onto the surface contaminant layer and are available for dermal exposure. This potential dermal exposure is highest for workers conducting the cleaning process after abrasive blasting, when they come in contact with the contaminants in the surface contaminant layer of equipment. The workers conducting the cleaning are not required to have the same protective equipment as the abrasive blasters, leaving workers vulnerable for exposure.

Commonly used abrasives include steel, coal, or nickel grit with coal grit being the most widely used (32; 50). Portsmouth NSY uses many abrasives. The abrasive blast area where beryllium was found in the air monitoring sample results used coal grit. Beryllium, chromium and nickel, have been shown to be components of coal used for abrasive blasting material (50) and present risk of dermal exposure. These three elements are a known cause of dermatitis (9; 12; 13) as well as other medical issues.

CONCEPTUAL MODEL

Figure 3 outlines the study model used in this research. It is an example of a dermal exposure assessment conceptual model(46). This model describes pathways from the source of the contamination to the receptor individual. The contaminants can pass through multiple compartments by mass transport processes. For example one possible pathway is from the source, to the air, then to the surface contaminant layer, and finally to the skin. The processes used in this pathway are emission, deposition and transfer. The amount of contaminant on the surface contaminant layer is the amount that is available for exposure. The amount transferred onto the skin from the surface contaminant layer is the amount of contaminant that is available for absorption.

This model has been used many times for research. Many of these studies have focused on the exposure to skin, such as Fogh and Anderson who used the model to determine skin exposure using the processes of deposition and resuspension (21). The conceptual model was used as a framework to discuss the advantages and disadvantages of patch and whole body sampling in dermal exposure assessment by Soutar and Semple (49). The dermal exposure assessment model (DREAM) is based on this model (52) while the skin contaminant layer was the focus of the Hughson study(25).

Day and Dufrense simplified the model to answer three objectives from their study. First, what were the concentrations in the air and on work surfaces? Second how much was transferred from work surfaces to the workers' cottons gloves? Lastly, how much was transferred from the gloves to the necks and faces of the workers(10)?

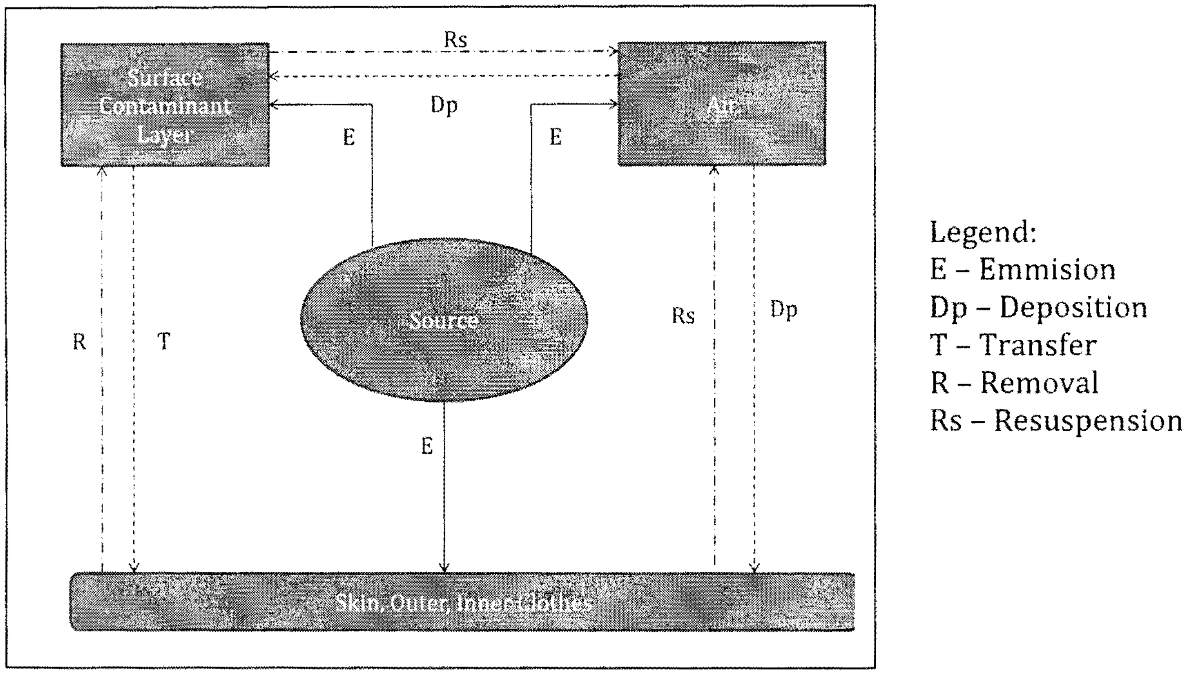

Figure 3: Conceptual model for dermal exposure
(Schneider et al., 1999)

Sanderson conducted a study that did not reference the conceptual model but did sample the surface contaminant layer in a military ammunition plant. The source of beryllium for the ammunition plant was copper beryllium tools. When they were machined, the beryllium was released from the tool into the surface contaminant layer. To sample the surface contaminant layer, OSHA method 125G was used, the same method that will be discussed in the methods chapter for this current research. Sanderson's survey for beryllium surface concentrations was accomplished to identify work areas where employees could have been exposed to beryllium and to recommend these employees be screened for beryllium sensitization. (45).

EXPOSURE HAZARDS

Overexposure to beryllium can lead to sensitization and allergic skin reactions. Sensitization to beryllium from dermal exposure is the first step to developing Chronic Beryllium Disease (CBD). CBD could develop if subsequent exposure to beryllium occurs in the future by the inhalation route (38; 40; 43; 45). Once sensitization has occurred, it is medically prudent to prevent additional exposure to beryllium (41) . CBD consists of inflammation and scaring of the lungs, which makes diffusion of oxygen through the lungs to the bloodstream more difficult.

Beryllium is a lightweight strong metal used in numerous industries including shipbuilding and defense. Beryllium is added to copper, iron, and nickel to form alloys (27). Machining and grinding of parts generates dust. Workers involved in these tasks have been shown to have the highest rates of beryllium-related diseases. In previous studies characterizing work processes and exposures, workers had been protected from beryllium with respiratory and engineering controls and until recently did not focus on skin exposure(14; 30; 51). In a prospective cohort study of workers who were sensitized to beryllium, machinists progressed to CBD at a higher rate than workers in other areas (39). Beryllium sensitization rates by task were shown in a study at a nuclear plant, where sawing and bandsawing had the highest sensitization rate. The task of cleaning tools and machines had a 2.8% rate (31). This shows that exposure during cleaning of equipment does have the potential to sensitize workers if they do not protect themselves properly. It appears that skin is an important route of exposure as studies have shown dermal exposure to poorly soluble particles of beryllium is highly possible (51). Beryllium materials, including salts have been shown to lead to dermatitis and sensitization(9). With this information ACGIH assigned a skin notation to the Threshold Limit Value (TLV) of beryllium(7). Being exposed to a high amount of beryllium is not required to become sensitized or develop CBD. However, living near a facility or living with someone who works in a facility using beryllium can cause enough exposure for a person to develop beryllium sensitization and CBD (35).

There are currently multiple standards for airborne concentrations of beryllium, for example the 8 hour OSHA permissible exposure limit is 2 $\mu g/m^3$, and a 5 $\mu g/m^3$ ceiling (42), but there is only one standard, from the Department of Energy (DOE), for beryllium on the surface contaminant layer. This standard is based on health outcomes and to lower potential exposures to a minimum concentration. The DOE standard for surface level beryllium is separated into two categories is set forth in 10 CFR 850. The first category, in 10CFR 850.30, is for equipment that is being cleaned and kept in use. This is known as the housekeeping standard and the concentration of beryllium allowed is 3 $\mu g/m^2$(16). This is also the concentration at which personal protective equipment is required. The second category, in section 850.31, is the release standard for equipment leaving a facility. The concentration of beryllium allowed in this situation is 0.2 $\mu g/m^2$. This is based on the research conducted by DOE that states resuspension of contamination from surfaces to the air would be less than the EPA's emission standards(41).

Chromium is used in production of corrosion resistant products, stainless steel alloys, tanning agents for leather, and electroplating. Since chromium is a frequent cause of skin sensitization, the American Conference of Governmental Industrial Hygienists

(ACGIH) recommends a TLV-TWA of 0.5 mg/m3 as Cr. This was established to minimize the potential of dermal irritation and dermatitis (6).

Chromium exposure can lead to allergic contact dermatitis, irritant dermatitis and chrome holes which are typically crusted, painless lesions with a pitted ulcer (13). Exposure to both chromium (VI) and chromium (III) elicit allergic reactions (22; 36). Chromium (III) exposure leads to allergic reaction but at a higher concentration than chromium (VI). Studies involving chromium (III) have involved chrome tanned leather since Chromium (III) is used to stabilize the leather in many products (23; 34). There are numerous studies demonstrating the effects Chromium (VI) has on skin. The earliest studies were conducted in 1827, when it was reported dye workers handling potassium dichromate developing skin ulcers and dermatitis (8). Tanners and dyers in 1916 developed chrome ulcers and dermatitis (11). In 1930 electroplaters showed signs of skin ulcers(18).

Nickel is used in many products from stainless steel, jewelry, coins, and batteries Several conditions can be caused by overexposure to nickel compounds, including increased risk of lung and nasal cancers, occupational asthma and allergic dermatitis with skin contact. (5; 15; 25; 33; 47). Nickel is potentially the most common contact allergen among the general population. Some studies estimate the rate of allergy in the population at 10% or higher (44), while others suggest a rate of 2.5% to 5% (24). Nickel itch or nickel allergy is a reaction that develops after repeated and prolonged exposure to nickel or nickel-containing items (12). For this reason, the European Union has set nickel release from items with prolonged skin contact at 0.2 μg per cm^2 (20).

A review of nickel patch exposure studies discussed that the average exposure that caused a 5% reaction rate was 0.44 μg per cm^2 and a reaction rate of 10% was caused by 1.04 μg per cm^2 (20). Another study was conducted to determine the threshold level of exposure to nickel that would cause a reaction in nickel sensitive human subjects. The subjects were exposed to nickel in two ways; first with a nickel contaminated patch being placed on the skin, and second placing 20 ml of nickel solution on the forearm. The results showed that in the patch test 10% of the patch test subjects had reactions at 0.78 μg per cm^2, and a 10% reaction rate at .35 μg per cm^2 for nickel solution(19). This supports that there is a difference of exposure between nickel being emitted from the patch and direct nickel exposure to the skin. This is equivalent to nickel being retained in workers clothing, then passing through workers clothing, and finally exposing skin.

Movement of equipment presents risk to personnel resulting in dermal exposure from any dust that is left on the equipment. Using beryllium as an example, the following studies explain why dermal exposure is important. Protective measures have decreased inhalation beryllium exposures over time but beryllium sensitization has not declined (10; 29). Beryllium is not the only metal in the dust on equipment, total chromium and nickel could be there as well. In Portsmouth NSY workers move equipment from one work area to another.

CHAPTER 3: METHODS

AIR SAMPLING METHODS

Portsmouth NSY industrial hygiene personnel conducted individual worker breathing zone air samples as routine monitoring. The personal breathing zone air samples used in this study were taken while abrasive blasting was conducted. The abrasive blasting task occurred on individual days over a three year period from 2009 to 2012. Portsmouth NSY personnel provided the analysis results for inclusion in this study. The results from the routine monitoring were used in this study to determine presence of beryllium and total chromium.

The air sampling was performed on abrasive blasting workers in Building 286, on the USS SAN JUAN (SSN 751), the USS MIAMI (SSN 755) and the USS VIRGINIA (SSN 774). The USS SAN JUAN and USS MIAMI are Los Angeles class Submarines and the USS VIRGINIA is a Virginia class submarine. The equipment used for air sampling were individual sampling pumps capable of sampling at 2 liters per minute, mixed cellulose ester filters, cellulose backup pads, three piece cassettes to hold the filters, gel bands to hold the cassettes together, flexible tubing and a calibration meter to ensure that the sampling pumps operates at 2 liters per minute. The Portsmouth NSY industrial hygiene section purchased pre-assembled cassettes with filter.

The procedure for collecting air samples was as follows. Personnel attached the cassette with the filters to the sampling pump with the flexible tubing running from the outlet of the cassette to the air inlet of the pump. The pump with the filter attached was calibrated to within 5 % plus or minus of the sampling method recommended operating flow of 2 liters per minute using the calibration meter. Once calibrated, the pumps, tubing and filters were placed on workers before the blasting was performed. The equipment was collected from the workers when they finished blasting and pumps flow rate checked to determine the total volume of air that flowed passed the filter. The equipment was separated into its individual parts and the cassettes with filters were sent to the Navy - Marine Corps Public Health Center Comprehensive Industrial Hygiene Lab Norfolk for analysis. Descriptive statistics were conducted on the air sample results to determine medians, maximum and minimum concentrations. The total chromium air samples were divided into groups based on placement of the filters. One group being the filters placed on the right collar and the other group the filters placed on the right shoulder. To evaluate the differences in sampling media placement the Statistical Product and Service Solutions (SPSS) statistics program version 20 (26) was used to run test for normality and comparison of these groups. As some of the air sampling results were above the limit of detection (LOD), it is assumed that there is a small amount of these metals on all samples. Based on this assumption, all air samples with non-detected results were substituted with specific analysis method LOD divided by 2.

WIPE SAMPLING MATERIALS

The method used for surface contaminant layer wipe sampling was OSHA ID-125G. The materials used by this method were ghost wipes; 100 cm^2 templates to outline the sample area; and sample vials/ bags to submit the samples for inductively coupled plasma mass spectrometry analysis. Figure 4 shows examples of the ghost wipes and the glass vials. The ghost wipes were manufactured by Environmental Express and are pre-moistened with deionized water packaged in individually sealed packets. When analyzed at the lab, the ghost wipes completely dissolve in solution allowing for total analysis of dust from the wipe (17).The templates were ordered from SKC Corp. For shipping the collected samples to the laboratory, glass vials were used until supply was exhausted, then plastic Ziploc® bags were used.

a.  b. 

Figure 4: Examples of supplies used for wipe sampling
a) Ghost Wipes for collecting dust from surface contaminant layer
and b) Glass Shipping Vials to send samples to laboratory

WIPE SAMPLING METHOD

Surface wipe samples were collected from both exposed and non-exposed areas. Exposed areas were defined as areas where abrasive blasting had been conducted. The areas were sampled either between shifts or as the cleaning crew was preparing to enter. The non-exposed areas were defined as areas near the abrasive blasting areas, but exposure was prevented by the Tyvek® tents in place around the blasting area and the in-place ventilation system. Each element can be detected separately from the same sample, for this reason multiple samples at each sampling event did not need to be taken for each element.

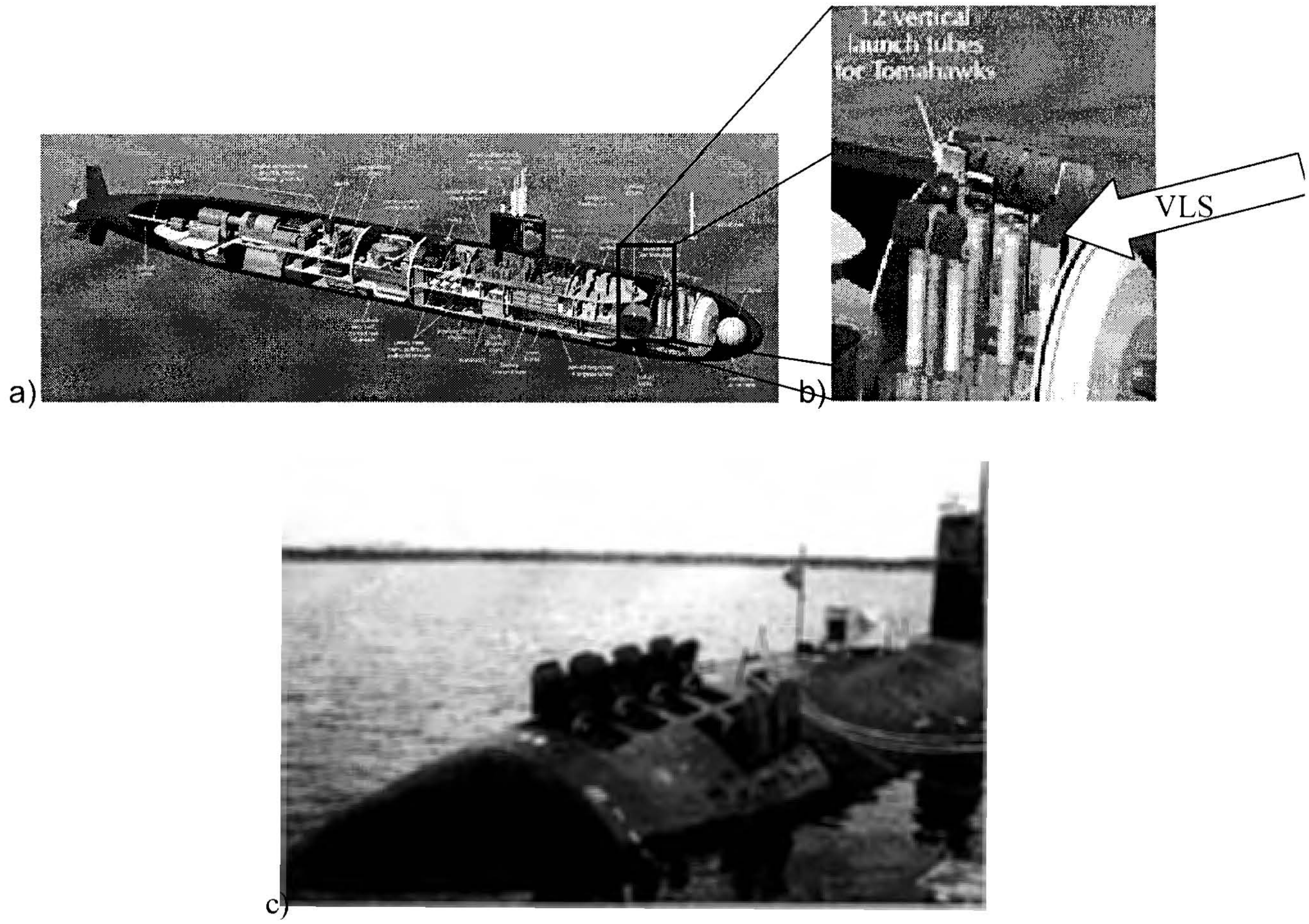

Figure 5: Los Angeles Class Submarine
a) Cut away of Los Angeles Class Submarine and b) close up of Vertical Launch System, with c) photo of VLS open, which is the exposed area on the submarines where wipe

Table 1: Wipe sampling locations

Exposed Sample Work Areas
USS MIAMI
USS PASADENA
Building 286 Blast Room
Non-Exposed Sample Work Areas
USS MIAMI SHT
USS PASADENA SHT
Building 286 Supply Trailer

The submarines sampled were the USS MIAMI (SSN 755) and the USS PASADENA (SSN 752). At the time of the study, these were the two submarines that were present for repair and maintenance services. The exposed areas were limited to the vertical launch system (VLS) areas at the bow of the USS MIAMI and the cap stand area on the USS PASADENA, both Los Angeles class submarines, and the large abrasive blast building (Bldg 286). The cap stand is between the VLS and the sail of the submarine. Figure 5 shows the location of the exposed areas on the submarines. The three exposed sampling areas were distinct and did not have influence on each other; Figure 1 shows the locations of the sampling areas. The USS PASADENA was in dry dock 1 and the USS MIAMI was in dry dock 2.

The non-exposed areas sampled included the support structures around the USS MIAMI and the USS PASADENA and the supply trailer next to Building 286. These areas were open to the ambient air and had limited to no exposure to blasting operations. Equipment surfaces targeted for sampling were surfaces that would be contacted when cleaning. Examples of these are railings, blast hoses, exhaust ventilation tubes, structure walls, Tyvek® tent walls, and light fixtures, which were found in both the exposed and non-exposed areas.

The procedure used for sampling was the single wipe sample technique outlined in Navy Industrial Hygiene Field Operations Manual NEHC–TM6290.91–2 Rev. B, Chapter 3 Section 17, 3, i. This specified that OSHA method ID-125G be used to conduct the wipe sampling(37). To prevent sample contamination, each individual wipe sample was taken when clean gloves were donned.

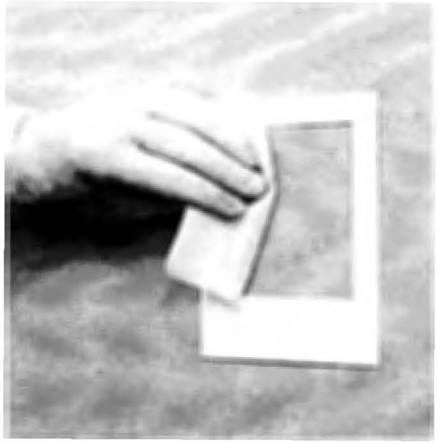

Figure 6: Example of Wipe Sampling Procedure

The wipe samples were sent to the Navy-Marine Corps Public Health Center Comprehensive Industrial Hygiene Lab Norfolk for analysis. The analysis method was in accordance with OSHA method 206 modified. This method uses Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES) to analyze samples. This method is used for the identification of metals in dust collected by air or wipes. It has been validated for 8 elements, including beryllium. Using this method, another 13 elements, including total chromium and nickel, can be determined for screening purposes only. The level of detection for beryllium by this laboratory is 0.5 μg/sample. For total chromium and nickel the level of detection is 10 μg/sample. All results were described as μg per sample, and since the sample area was 100 cm^2, the results reported in this study are μg per 100 cm^2.

STATISTICAL METHODS FOR WIPE SAMPLE

In order to answer specific aim #1 of detecting a difference in exposed vs. non-exposed areas, the minimum sample size to have 80% power to detect a 25% difference between groups was 72 samples per group. The two groups for each element in this study were the exposed samples and the non-exposed samples.

SPSS was used to conduct the statistical tests for this study. Samples were analyzed in two ways; 1) using all samples regardless of results and 2) using only those samples with results greater than LOD. To determine if the groups were normally distributed, the Shapario-Welk test for normality was conducted. The results from the groups of wipe samples, both with and without samples the below LOD results, did not follow a normal distribution in either the exposed or non-exposed groups. To compare the groups of wipe sampling results that are non-normally distributed, the Mann Whitney U test was the statistical test used. This test is best used for non-parametric groups. The Mann Whitney U test is used to determine if two sets of data are significantly different from each other. When the Mann Whitney U test is performed, any p-value result that is below 0.05 is considered significant.

From the air sampling results establishing that beryllium and total chromium were present in the air, the assumption was that the metals were expected in the wipe samples. Based on this assumption, all wipe samples with non-detect results were substituted with specific analysis method LOD divided by 2. The LOD for both total chromium and nickel was 10 $\mu g/m^3$. The wipe sampling results below LOD were reported as 5 $\mu g/m^3$ rather than 10 $\mu g/m^3$ or 0 $\mu g/m^3$. If either 10 or the 0 $\mu g/m^3$ were used, this would bias the mean either too conservatively by returning a median that was higher or more positive than what was really there or move the median negatively by returning a mean that was lower than expected. This method of substitution was described by the Environmental

Protection Agency's Region 3 (2) and was chosen as a representative method based on similar sampling results.

The initial groups compared all the exposed samples to all the non-exposed sampled. The samples from the blasting areas on the USS MIAMI, the USS PASADENA, and in Building 286 were all combined for the exposed group. The samples from the support structures for the USS MIAMI, the USS PASADENA and the trailer next to Building 286 were all combined for the non-exposed group. The next comparison was between the combined abrasive blasting areas on the submarines and Building 286. This is to determine whether there was a difference between the work areas aboard the submarines compared to Building 286. The submarines were able to be combined because they are the same class and were construction completed within 2 years of each other by the same contractor in the same shipyard. Any difference found would support a greater possibility of exposure to workers in that area with greater concentrations of metals. The final stratification and comparison was between the exposed samples of the two submarines. The samples from the USS PASADENA comprised one group and the samples from the USS MIAMI comprised the other group. This was done to determine if there was a difference between the work area concentrations aboard the submarines.

CHAPTER 4: RESULTS AND DISCUSSION

AIR SAMPLE RESULTS

There were 33 air samples analyzed for beryllium from the four work areas, 18 from Building 286, 8 from the USS SAN JUAN, 4 from the USS MIAMI, and 3 from the USS VIRGINIA. The median concentrations for beryllium in the air are displayed in figure 7 and listed in table 2 with a range from 3.0 x 10^{-5} $\mu g/m^3$ to 2.04 x 10^{-3} $\mu g/m^3$. Median values are used to minimize the impacts of the outliers. Detectable amounts of beryllium were observed in 12 of the 33 samples, 10 detectable samples were taken aboard submarines and 2 were taken in Building 286. Factoring out samples with results falling below LOD, the range of detectable samples was from 6.5 x 10^{-4} $\mu g/m^3$ to of 2.04 x 10^{-3} $\mu g/m^3$. Detailed results are provided in Appendix 3.

Beryllium results above LOD were dependent on location. From the USS MIAMI, all 4 samples analyzed for beryllium were below the LOD. All 8 beryllium samples taken aboard the USS SAN JUAN were above the LOD. Two of 3 beryllium samples taken aboard the USS VIRGINIA were above the LOD and 2 of 18 beryllium samples from Building 286 were above LOD. The beryllium results above the LOD demonstrate that there is a potential for beryllium to be present in the work area in the surface contaminant layer.

Total chromium metal was also analyzed and results are displayed on figure 8 and listed in table 2. Analysis of 28 samples resulted in a range from 2.1 $\mu g/m^3$ to a maximum of 1030 $\mu g/m^3$. There were 3 samples with results below LOD and all were from Building 286. Ten of the detectable results came from Building 286 and 15 from aboard submarines. From Building 286, 13 samples were analyzed of which 3 were below LOD. The submarines had a total of 15 samples analyzed all of which were above LOD. The total chromium results found above the LOD demonstrate that there is a potential for this metal to be present in these work areas. Detailed results are provided in Appendix 2.

Table 2: Air sample results, n = number samples collected, > LOD = number of sample results above LOD, minimum and maximum values above LOD results reported as μg/m^3

Be Air Samples	N	> LOD	Minimum μg/m^3	Maximum μg/m^3
Buliding 286	18	2	6.50E-04	1.67E-03
USS SAN JUAN	8	8	6.90E-04	1.40E-03
USS MIAMI	4	0	-	-
USS VIRGINIA	3	2	8.90E-04	2.04E-03
Cr Air Samples	n	> LOD	Minimum	Maximum
Building 286	13	10	5	257
USS SAN JUAN	8	8	91	664
USS MIAMI	4	4	248	1030
USS VIRGINIA	3	3	15	293

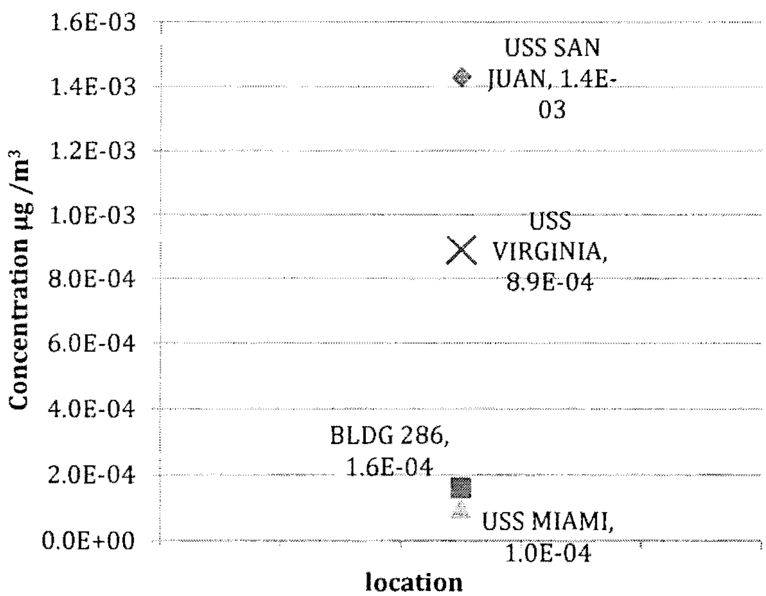

Figure 7: Median beryllium air sample by work place location with below LOD results reported as equal to LOD divided by 2

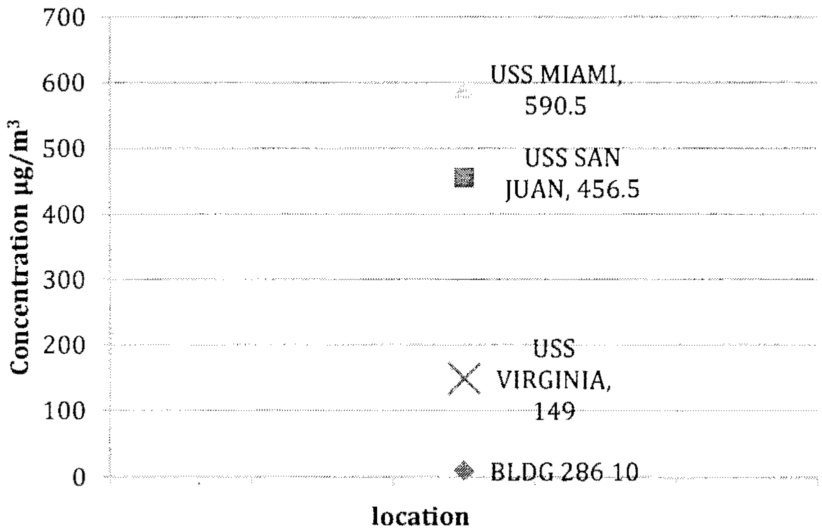

Figure 8: Median total chromium air sample by work place location with below LOD results reported as equal to LOD divided by 2

AIR SAMPLE RESULTS DISCUSSION

Beryllium

Air is one of the links in the conceptual model for dermal exposure from Figures 2 and 3. Air sampling results show that beryllium was detected in the air and it is expected that it would fall out through deposition to the surface contaminant layer and the skin. When the air samples were analyzed for beryllium, a majority were below LOD. Placement of the sample media on the worker's right shoulder resulted in levels below LOD. Of the 33 samples taken, 11 were placed on the right shoulder and all 11 of these were below LOD. More than 50 percent of the results for sample filters placed on the collar were above LOD. The sample filters from the USS SAN JUAN were all placed on the collar of the worker, and all results were above LOD for beryllium, while the sample filters from the USS MIAMI were all placed on the right shoulder and all results were below LOD.

Table 3: Number of sample filters by placement on worker and number of results from sample filters above LOD for beryllium by work area

Right Shoulder	n	> LOD
Buliding 286	7	0
USS SAN JUAN	0	0
USS MIAMI	4	0
USS VIRGINIA	0	0
Collar	n	> LOD
Building 286	11	2
USS SAN JUAN	8	8
USS MIAMI	0	0
USS VIRGINIA	3	2

The right shoulder placement does seem to have some effect on eliciting non-detects for beryllium. The results from the groups of collar placement filters and right shoulder placed filters, when results below LOD were added, showed a non parametric distribution. The Shapiro-Wilk test for normality had results for both groups below the significance level of 0.05. Comparing these two groups using the Mann-Witney U test resulted in a significance level of 0.036. This significance level demonstrates an existing statistical difference of air sampling results between the groups based on placement location of sampling filter on the worker when sampling for beryllium.

One possible explanation of this difference could be from the procedures employed by the workers conducting the abrasive blasting. If the workers are holding the blast hose over their right shoulder and the sample filter is placed there, the pressure of the blast grit may have enough power to move to the sides away from the filter. If the filter is on the other shoulder from the hose, the same side arm holding the hose might block and take more of the exposure from the rebound of the grit than the filter. The same reasons apply if the hose is held under the arm, the force of the grit may cause it to rebound away from the source and away from the filter if placed on the same side. It is unknown what side the collar filters were placed, but the same effect could occur if the filters on the collar are on the same side as the hose.

In evaluating the lower concentrations from the four samples from the USS MIAMI, samples were all collected on the same day presenting potential confounding variables affecting the right shoulder sample findings. For same day samples, possible confounders include the grit could have been different, the location could have been blasted before, or the protective equipment that workers were using could have protected the filter. Alternatively, these workers could be experienced and know blasting methods that minimize exposure to themselves. The area of blasting could be different as well as, the VLS tubes or the hatches.

Total Chromium

There are many reasons that total chromium values were observed at an increased concentration on the submarines as compared to the Building. When abrasive blasting is conducted on submarines, additional total chromium from the composition of the submarines surface, the VLS tubes and the hatch covers, as well as surface coatings being blasted could add to the total amount. In addition to the substrate metal composition addition, the residue from launching missiles through these tubes has the potential to be added to the sample results. It is unknown whether the blasting was conducted inside the VLS tube or in the hatch cover area of the VLS tubes. If the blasting was done in the tubes the confined area of the tube may lead to collection of greater amounts of total chromium.

The mean total chromium from the air samples showed that there was a lower level of chromium in samples from the USS VIRGINIA compared to the USS MIAMI and USS SAN JUAN. The USS VIRGINIA is a newer submarine and a different class that has not had the operational history that the other two submarines have had. The USS VIRGINIA was launched in 2005, while the USS SAN JUAN and USS MIAMI were launched in 1986 and 1988, respectively. More missiles may have been fired through the VLS tubes on the two older submarines than from the USS VIRGINIA. This launching of missiles adds to the concentration of heavy metals as missiles go through the tubes. Pressure from the launch of missiles may increase release of chromium and other metals from the metal tubes. The released metals settle out into the residue left after the launch of missiles. When this residue is blasted off it has the chance to enter the air and collect on the surface contaminant layer.

The materials used to build the submarines may have an effect on the amount of total chromium available for exposure. The Los Angeles class and Virginia class submarines are from different decades with updated construction designs. The materials used in the newer submarines may have different formulations of materials and these may have lower amounts of total chromium. Additionally, the older submarines are more likely to have surface coverings containing total chromium(48).

WIPE-SAMPLE RESULTS

There were a total of 168 beryllium, total chromium and nickel wipe samples taken at Portsmouth NSY. There were 75 samples taken from areas exposed to abrasive blasting and 93 samples taken from areas not exposed to abrasive blasting. The distribution of the samples results was shown as non-parametric for both groups, with and without the below LOD results, when tested for normality with the Shapiro-Welk test. Summary results are listed in table 4 and the groups with only above LOD sampling results are displayed in figures 9 - 12. Beryllium was not detected in any of the 168 samples, in either the exposed or non-exposed areas.

Table 4: Descriptive statistics for wipe samples, n = number samples collected, > LOD = number of sample results above LOD, minimum and maximum above LOD results reported as μg/m^3, and Shapiro-Welk test for normality (< 0.05 = non parametric distribution)

Sample	n	>LOD	Minimum	Maximum	Shapiro-Welk Test for Normality
Ni Non Exposed	93	23	10.1	283	0.03
Ni Exposed	75	62	14.7	356	0.00
Cr Non Exposed	93	8	10.8	35.8	0.00
Cr Exposed	75	52	11.3	126	0.00

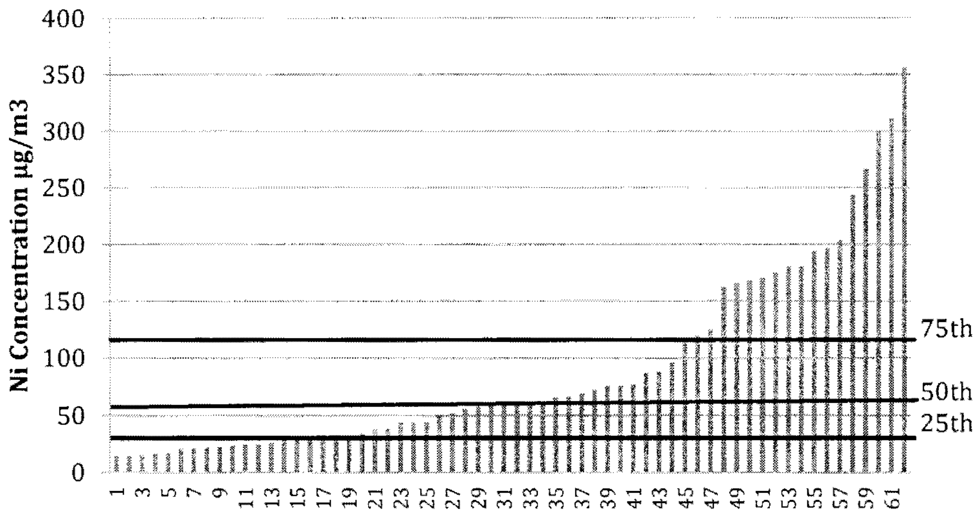

Figure 9: Exposed work area nickel wipe sample above LOD result distribution with 25th, 50th and 75 quartiles.

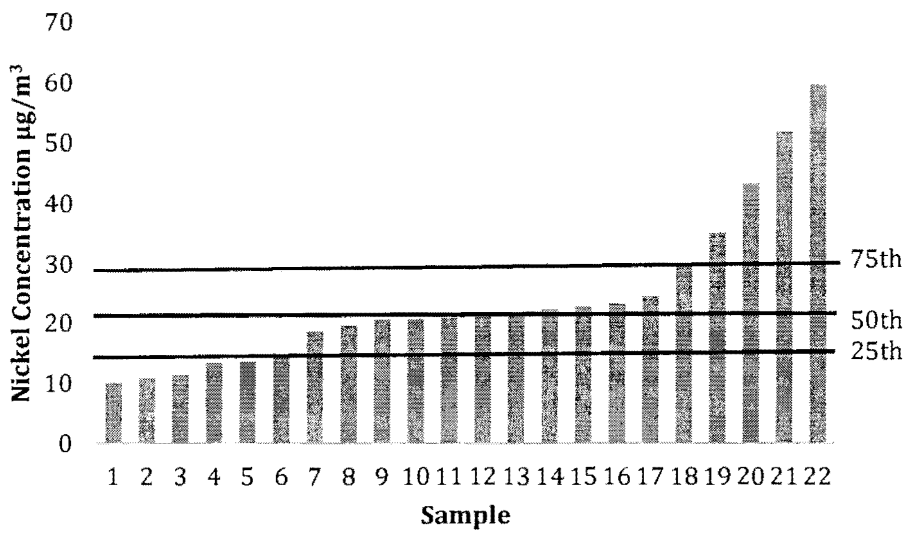

Figure 10: Non-exposed work area nickel wipe sample above LOD result distribution with 25th, 50th and 75th quartiles.

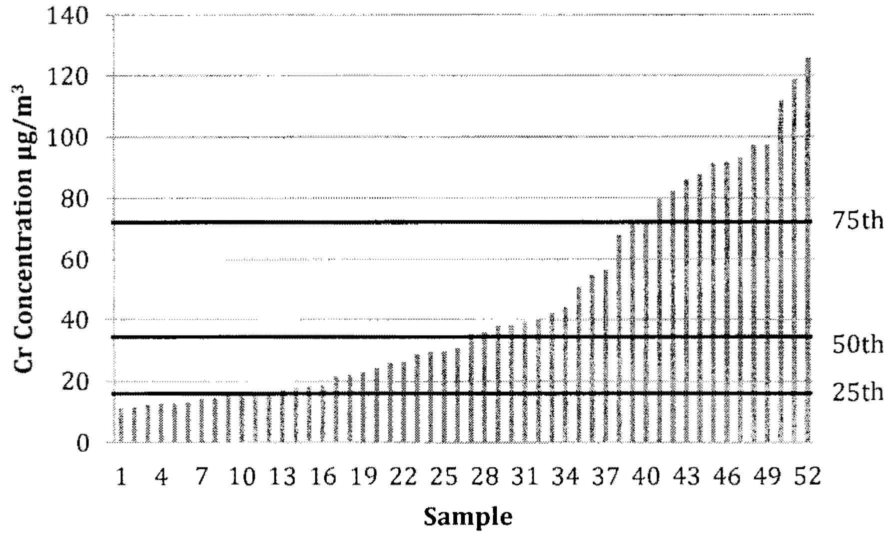

Figure 11: Exposed work area total chromium wipe sample above LOD result distribution with 25th, 50th and 75th quartiles.

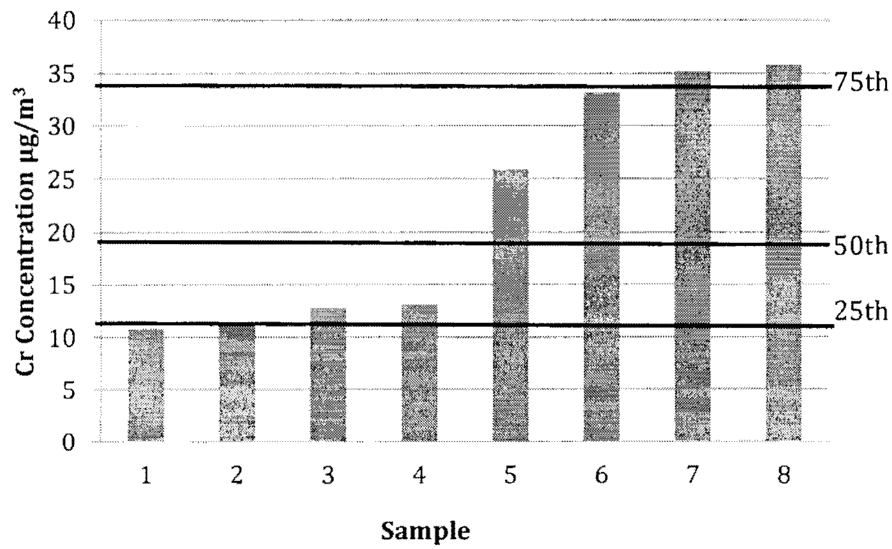

Figure 12: Non-exposed work area total chromium wipe sample above LOD result distribution with 25th, 50th and 75th quartiles.

The nickel and total chromium exposed samples were compared to the non-exposed samples using the Mann Whitney U test. This comparison determined that there were statistical differences between the exposed and non-exposed samples for both nickel and total chromium, with significance levels below 0.001 for both metals, as seen in table 5. Figure 13 shows the median sample results for each group. One non-exposed sample had high levels of nickel, this sample remained in the group analysis that is displayed in Figure 13. This sample was from a table top in the lower level of a support structure for the USS PASADENA that was coated with dust. The Mann Whitney U comparison test was repeated with this outlier removed and the test still determined that there was a statistical difference with the significance level below 0.05.

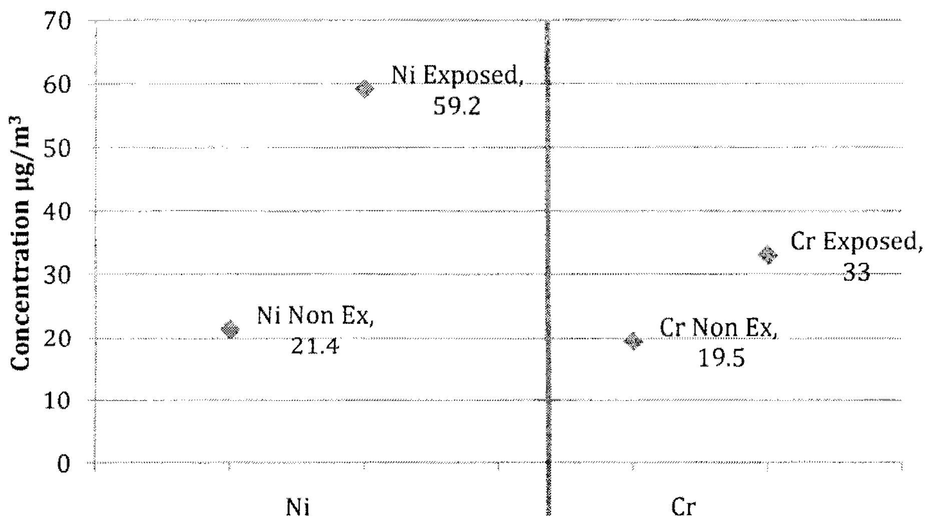

Figure 13: Total chromium and nickel median wipe sample results for exposed and non-exposed work areas

To complete aim #2 the exposed samples from the combined submarines were compared to the exposed samples from Building 286. Using the Man Whitney U test, a statistical difference was found between samples with a significance level below 0.001. This demonstrates that there was a greater amount of nickel and chromium aboard the submarine exposed samples than the Building 286 exposed samples as shown in Figure 14, which displays the median sample results for each group.

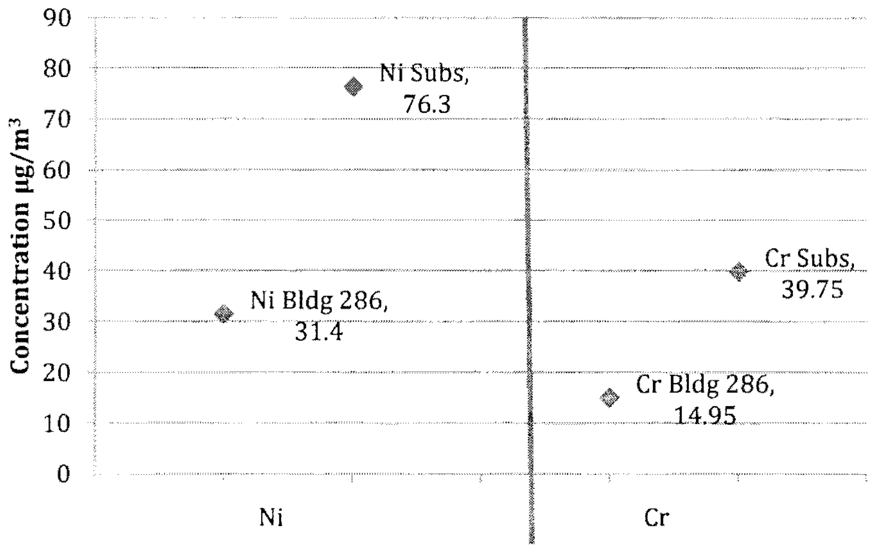

Figure 14: Total chromium and nickel median wipe sample results for exposed work area in Building 286 and on combined submarines

The exposed samples from the individual submarines were compared to each other to complete aim #3. The comparisons using the Mann Whitney U test determined that there were statistical differences between the individual submarines for both the nickel and total chromium. The significance levels for both metals were below 0.05 as shown in table 5. Figure 15 exhibits the median results from samples of nickel and chromium of exposed and non-exposed work areas aboard the USS MIAMI and the USS SAN JUAN.

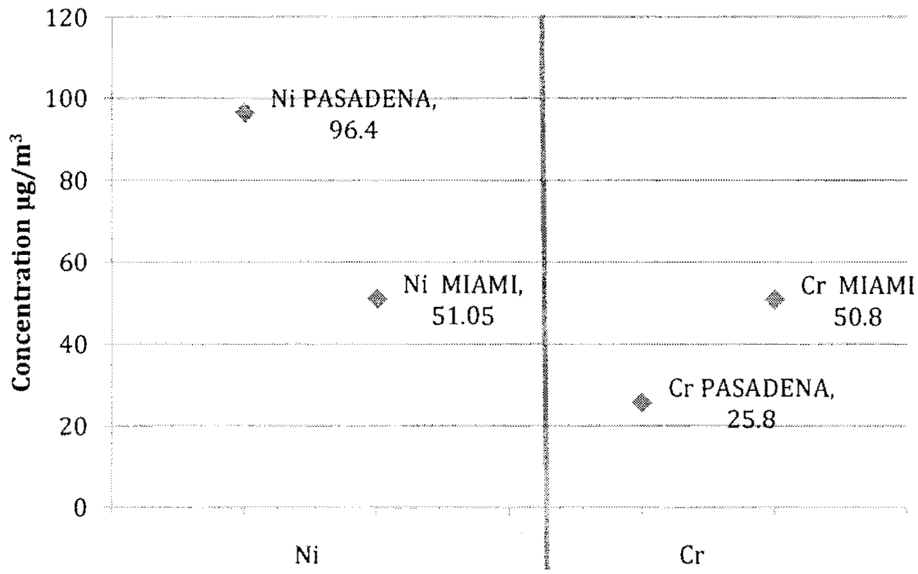

Figure 15: Total Chromium and nickel medians wipe sample results of individual submarines

Table 5: Significance levels for comparisons of total chromium and nickel wipe sample results to complete aims 1 and 2. Levels that are <.05 demonstrate significant differences for the comparisons

	Nickel	Total Chromium
Exposed/ Non-exposed	> 0.001	> 0.001
Submarines/ Building 286	> 0.001	> 0.001
USS MIAMI/ USS PASADENA	0.007	0.028

WIPE SAMPLE RESULT DISCUSSION

Comparison of the wipe sample results revealed four things. 1) Exposed samples had higher levels of total chromium and nickel than non-exposed samples, 2) The samples from the USS MIAMI had more total chromium and nickel than the samples from the USS PASADENA, 3) the submarines were statistically different than Building 286 and 4) nickel was found in the non-exposed areas.

Exposed areas were potentially influenced by the coal slag abrasive used, the coating being removed, the substrate metal surface being treated, and outside events such as a fire that may have added to the residue in the area. These influences all could add to the concentration of total chromium and nickel exposure during and after abrasive blasting. The non-exposed areas had only the influences of outside events. With fewer influences adding to the total concentration, the non-exposed areas had lower amounts of these metals present for exposure.

The events that occurred on the USS MIAMI prior to the study might be a cause of the differences between the USS MIAMI and the USS PASADENA. This event took place aboard the USS MIAMI while it was in the dry dock and it resulted in significant damage. The event did not occur in the direct location of the VLS system but could have resulted in release of total chromium and nickel from the submarine structure and coatings to the surface contaminant layer in the VLS area. The area of the event needed to be vented and the most likely location of the exhaust ventilation would be through the VLS area. Any released metals and other contamination from the damaged area could have been moved through the ventilation system and into the VLS area.

The operational history of the USS MIAMI may also have had an influence on the levels found compared to the USS PASADENA. At the time of the wipe sampling, the deployment histories of these two submarines were unknown for this study. With the age of the submarines at over 20 years, it is assumed that they have been through many deployments. These two submarines were constructed around the same time by the same manufacturer with the USS PASADENA being launched a year earlier that the USS MIAMI.

The limited number of samples from the USS PASADENA and the specific location of the samples could also have an effect. Only 10 exposed samples were taken aboard the USS PASADENA, while 35 were taken aboard the USS MIAMI. Samples were taken from work locations as the locations were made available. On the USS PASADENA abrasive blasting operations were not being conducted on the same schedule as the USS MIAMI. The differences in schedules lead to the limited number of samples from the USS PASADENA. The limited number of samples might not be representative of the potential exposure on the USS PASADENA. The range of detected concentrations may have been limited and skewed the data to one direction. This skew in direction may have contributed to finding that one group is different from the other.

Differences between the Building and the submarines can be explained by a number of variables. First the large size of the blasting room in Building 286 compared to small areas of the Tyvek® tent used aboard submarines; a more enclosed area has the potential of more concentrated metals present in the surface contaminant layer. The amount of blasting conducted in these areas was not similar. Building 286 blasting operations are limited to smaller parts brought to the building. The VLS areas on the submarines were blasted continuously while sampling was occurring. Additionally, difference in results between the buildings and the submarines can be related to the ventilation system set up on the submarines. This ventilation system was powered to remove the particles from the air in the work area within 30 minutes of stoppage of blasting operations. This may prevent settling out of lighter metal particles while the heavier particles fall out quickly, and altered the deposition phase as seen in the conceptual model.

Results from the non-exposed samples are expected to have detectable amounts of nickel. Nickel is commonly used in metal structures as most metal items are alloys containing nickel to add strength. The support structures set up around the submarines were mostly metal. It was observed that 25 percent of the non-exposed samples had levels of nickel above LOD. The support structures, railings, table tops, and other items that were sampled in the non-exposed areas were made of metal When the support structures are moved there is a chance that items will be scraped and scratched releasing some of the nickel that was in the items to the air and the surface contaminant layer. The scraping that occurs during movement is limited and only affects a small area of the surface. Abrasive blasting however removes the whole surface layer which could release much more nickel into the air and surface contaminant layer. Nickel released from the surfaces that are blasted would be added to the nickel that is a component of the coal grit used as the abrasive. The coal grit itself was not sampled for levels of nickel and total chromium as this study was focusing levels of these metals on the surface contaminant layer after abrasive blasting.

The Mann Whitney U test demonstrated that there was a statistical difference in the levels of total chromium and nickel between the abrasive blasting exposed areas and the non-exposed areas. The medians for the exposed total chromium and nickel are 72% and 88% higher than the medians for the unexposed samples. The means of the exposed samples are 80% and 83% higher for the exposed samples. The difference in results demonstrates that measures taken to keep metals in the abrasive blasting areas and cleaning of these areas are effective in preventing the spread of these metals. It also shows greater availability of these metals in the surface contaminant layer in areas where abrasive blasting occurs. From the conceptual model in Figure 2, this greater availability of metals in the surface contaminant layer increases potential dermal exposure to workers who are not properly protected.

CHAPTER 5: CONCLUSION

The objective of this research was to determine if there is a potential exposure route through the surface contaminant layer to the dermal layer of skin after abrasive blasting operations. In conducting the comparison of the different work area surface contaminant layers it was demonstrated that there is a greater potential for exposure in work areas to total chromium and nickel after abrasive blasting operations. The amount of total chromium and nickel transferred to skin and then absorbed into the body is unknown. Beryllium was not detected in any wipe samples, however, a determination cannot be made about potential exposures which may exist at lower concentrations.

Aim 1 involved comparing the surface contaminant concentrations of equipment exposed to dust from abrasive blasting to surface contaminant concentrations of equipment that is not exposed to abrasive blasting. Surface wipe sampling in the abrasive blasting areas found detectable levels of total chromium and nickel. If workers are not properly protected there is a potential for exposure. Exposures could lead to dermatitis, sensitization and allergic reactions. These health issues could lead to lost work time, delays in project completion and health care costs to disabled workers. There are many possible sources of these metals including the coal grit used as an abrasive, the substrate metal that is being blasted, the surface coatings being removed, or residue from operations in the area. When blasting occurs these metals are released and are available for exposure.

Beryllium was found in the air samples taken while abrasive blasting was occurring. It was noted in chapter 4 that all the samples which were placed on the right shoulder came back below LOD. Worker practices may have an effect on the ability of the filters to collect beryllium. Beryllium was not observed on the surfaces of equipment in the abrasive blast areas, but it is still assumed to be there since it was found in air samples. The LOD of the analytical method used by the laboratory was not as low as the DOE beryllium standard discussed in chapters 1 and 2 and a lower limit of detection may have identified beryllium. Dermal exposure to beryllium increases the chance of sensitization of personnel.

Aim 2 involved comparing the surface contaminant concentrations of equipment exposed in Building 286 to the exposed surface contaminant concentrations of the combined submarines. The submarines had higher levels of total chromium and nickel in the samples than Building 286. These metals are available for exposure if workers are not properly protected. The confined space of the sample areas, the residue left from operations, and the substrate metal that was being blasted could all have an effect on the concentration of these metals that was observed. This shows that there is a greater potential of exposure aboard the submarines, and potential exposure still exists for Building 286. If abrasive blasting with coal grit was done in another building the characteristics of that building could change the potential for exposure to these metals.

The surfaces contaminant layer on the submarines is in a more confined space allowing for faster sedimentation of the particles from the air. This is a concern because the equipment on the submarines is moved from one work area to another, and handled more often than the equipment in Building 286. Handling of equipment increases the potential for exposure to the contaminants in the surface contaminant layer as displayed in the conceptual model in Figure 2. This increase in potential exposure requires that cleaning of the equipment be conducted and personal protective equipment be worn to prevent exposure to skin, in both Building 286 an on the submarines.

Aim 3 involved comparing the exposed surface contaminant concentrations of equipment on individual submarines to each other. It was shown that the USS MIAMI and USS SAN JUAN had higher amounts of total chromium in the collected air samples than the USS VIRGINIA. The USS MIAMI and USS SAN JUAN were Los Angeles class submarines that were constructed in the 1980's and the USS VIRGINIA is a Virginia class submarine built in the 2000's. Newer submarines may have different composite metals used for constructing the hull and component parts. These components may have higher or lower amounts of total chromium that can be released when abrasively blasted. As stated in Chapter 4 operational history can also have an effect on the concentration levels. The wipe samples demonstrated that the USS MIAMI and the USS PASADENA had varying amounts of metals present even though they are the same class and were constructed a year apart. Deployment history likely has an influence as well as the fire that occurred before sampling was conducted.

Other Findings: Twenty-five percent of the non-exposed samples had levels of nickel above LOD. The support structures, railings, table tops, and other items that were sampled in the non-exposed areas were made of metal. Most metal items are alloys containing nickel to add strength. When the support structures are moved there is a chance that items will be scraped and scratched releasing some of the nickel that was in the items to the air and the surface contaminant layer. The scraping that occurs during movement is limited and only affects a small area of the surface. As described in Chapter 2 nickel allergy may be the most common allergy in the general population (44). With the potential presence of nickel in the non-exposed areas personnel with allergies to nickel should be properly protected.

PUBLIC HEALTH SIGNIFICANCE

Blasting occurs in many different industrial and non industrial work places outside of shipyards. The work accomplished for this thesis can be applied to other work areas where abrasive blasting is conducted. Bridges, buildings and vehicles may all undergo blasting. With wide spread blasting, the workers, conducting the blasting and the personnel that enter after, may have dermal exposure to dust and grit waste products of the blasting. Exposures could lead to dermatitis, sensitization and allergic reactions. The conceptual model for dermal exposure in Figure 2 shows that a source, pathways through the air and surface contaminant layer, and the workers skin are all required for exposure. These requirements are fulfilled in areas outside the shipyard.

This study focused solely on beryllium, total chromium and nickel on the surface contaminant layer, which workers could be exposed to during and after abrasive blasting. Exposure potential depends on several factors. The abrasive used, the coating removed, the surface treated, and outside influences that may have added to the residue in the area are all influences on exposure during and after abrasive blasting.

The metal components that comprise coal grit, which is used as a blasting abrasive, presents potential exposure for workers (50). Other abrasives have hazards that are not discussed in this study. The abrasives used will depend on the surface treated and the surface coating removed.

The surface coatings removed will have different components based on age of the coating and the task of equipment the coating was on. Vehicles with chemical agent resistant coating (CARC) paint applied working in combat areas are an example of a piece of equipment with a task. In other areas older equipment may be found with chromium or lead containing paint in addition to the abrasive and surface coatings the substrate surface blasted can add to the concentration of materials that workers are exposed to.

Research Limitations

The conclusions reached in this study are limited by three significant issues. The first limitation was that air sampling and skin transfer sampling could not be conducted at same time as wipe sampling. Concerns expressed by the workforce and management limited the study to only sampling the surface contaminant layer and not the skin layer.

A second limitation was that work schedules at the shipyard were tightly organized. Each task is set for a specific time and deadlines tightly upheld. Sampling must be conducted at a specific time or the job task requiring sampling might be completed, and the opportunity to sample might be missed. This occurred on one occasion where there was miscommunication, and the storage tank that was blasted was completed early, cleaned and painted before sampling could occur. This missed opportunity limited wipe sampling to the VLS area. The VLS area is not representative of the whole submarine. Only having results from this area biases the characterization of the submarine to what the levels are in only this location. Having other areas to sample would allow for better characterization of the submarine and may modify the median and mean.

The third limitation relates to the LOD for beryllium used by the laboratory performing the sample analysis. This LOD, 0.5 μg/sample, $100cm^2$ for this study, was higher than the DOE standard, 0.2 μg/100 cm^2. Using this higher LOD, more samples potentially exposed to beryllium may have been excluded from this study. Prior discussion with the laboratory conducting sample analysis regarding the LODs standards used and comparing these LODs with study objectives may have resolved this limitation. However, as this is the laboratory used by the Navy for this type of analysis, the results of this study show the potential limitations for this methodology to detect surface contamination.

FUTURE RESEARCH

Future research could include mapping the blasting grit from the time it arrives at a facility to the time it leaves; performing a mass balance approach through the facility. When grit arrives, the activity should conduct a complete characterization of it to determine components. The components, such as total chromium and nickel, of the grit when it arrives do not get destroyed during use. The mass of the components of the grit when it arrives should equal the mass of the components of the waste grit as it is disposed of from the facility. If the masses are different the study can focus on locations where the grit is used and may have been removed from the grit that was collected after use. In addition to this characterization a determination can be made as to what should be sampled for, and what could be studied. Knowing the characterization and concentration of the grit would allow for studies on the effects blasting has on the grit, and the effects the grit has on dermal exposure to workers. The first time grit is used personal air and surface wipe sampling could be done for the workers conducting the blasting and cleaning. This would determine what is in the air and on surfaces that could expose personnel. The results from the sampling could be compared to the original levels to determine if there are any differences. Differences may be based on the surfaces blasted and the location of the sampling media. A follow-on study would involve characterizing all the potential exposures from materials in coal grit. This study only looked for beryllium, total chromium and nickel.

Another research avenue involves dermal skin exposure sampling from the workers conducting the cleaning and abrasive blasting. This would show the amount of metals transferred to the skin of workers conducting these two tasks. It would provide characterization of the amount of metal exposure that is available for absorption. This sampling would also reveal potential skin exposure areas needing protection.

Another area that could be explored is the health outcome of workers that were conducting abrasive blasting and cleaning operations. Workers who are conducting these operations can be followed to determine the amount of time that they are assigned these tasks. The workers can be surveyed and asked questions about dermal health issues including skin irritation and dermatitis, while they are working in these areas. The answers to these questions may show a trend that has not been found through normal medical appointments. A few questions might include: In the past year have you had any skin rashes? If yes, when did they occur? How long did the rashes last?

To determine if there is beryllium in the surface contaminant layer after abrasive blasting it is recommended that characterization of the blast grit be done with analysis using a method that obtains a lower LOD. If it is shown that beryllium is in the blast grit from this characterization a study on the sensitization of workers to beryllium is recommended. The reason for this is beryllium exposures have outcomes that are different from total chromium and nickel exposures. It is recommended that a person who is sensitized to beryllium not work in areas beryllium is used.

In addition to the wipe sampling of skin, sampling of the surface of the protective clothing that the workers use is another study opportunity. If clothing is Tyvek® the sampling would help answer the mass balance question asked earlier, considering where some of the components of the grit go. If clothing is cloth the material components of the grit may become imbedded and expose the worker further as it is released from the clothing. This would also include any shoes and the bottom of shoes to ensure that tracking is not occurring. Clothing is part of the original conceptual model in figure 3.

Determining what part of the body received the most potential exposure for specific contaminants during blasting and cleaning is another study. During the air sampling used in this study all samples analyzed from the right shoulder placement of the filters were below LOD for beryllium. The highest chromium reading was from one of these same filters, leasing to questions regarding why total chromium was collected and not beryllium, whether the same effect be found on the left shoulder and whether alternate filter placement might change this effect. The recommended study for clothing exposure could be used to answer this question.

Abrasive blasting is one area for occupational exposures to workers. Future research will help determine the potential exposures for workers in abrasive blasting environments. In other areas where abrasive blasting is occurring and the research procedures in this study could be modified for these specific areas.

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APPENDIX A: Air Sample Results

1) Place a 100 cm^2 template over the area to be sampled
2) Remove individual ghost wipe from package and open
3) Fold ghost wipe in half and draw across the sample area in a horizontal motion as shown in Figure 6
4) Fold the wipe with the dirty face on the inside and draw the wipe across the sample area for a second time in a vertical motion
5) Fold the wipe a third time with the dirty face on the inside and draw across the sample area a third time in a horizontal motion
6) After the last wiping motion, place the wipe in a pre-labeled bag or vial
7) Send to laboratory conducting analysis

APPENDIX B: Air Sample Results

Beryllium

Work Area Location	Filter Location	Sample #	Be
USS MIAMI	Right shoulder	P001	0.064
USS MIAMI	Right shoulder	P002	0.064
USS VIRGINIA	Collar	PN11-0031	0.092
BLDG 286	Right shoulder	PN12-0119	0.099
BLDG 286	Right shoulder	P001	0.106
BLDG 286	Right shoulder	P002	0.113
BLDG 286	Collar	PN10-0117	0.120
BLDG 286	Collar	PN10-0119	0.120
BLDG 286	Collar	PN10-0259	0.120
BLDG 286	Collar	PN10-0059	0.141
USS MIAMI	Right shoulder	P003	0.141
USS MIAMI	Right shoulder	P004	0.141
BLDG 286	Right shoulder	P001	0.148
BLDG 286	Collar	PN11-0039	0.156
BLDG 286	Collar	PN10-0060	0.163
BLDG 286	Right shoulder		0.170
BLDG 286	Collar	PN10-0258	0.184
BLDG 286	Right shoulder	P002	0.191
BLDG 286	Collar	PN10-0120	0.304
BLDG 286	Collar	PN10-0118	0.530
BLDG 286	Right shoulder	P003	0.587
BLDG 286	Collar	PN11-0038	0.650
USS SAN JUAN	Collar	PN10-0255	0.690
USS SAN JUAN	Collar	PN10-0208	0.810
USS VIRGINIA	Collar	PN11-0027	0.890
USS SAN JUAN	Collar	PN10-0209	1.280
USS VIRGINIA	Collar	PN11-0028	1.400
USS SAN JUAN	Collar	PN10-0211	1.430
USS SAN JUAN	Collar	PN10-0212	1.430
USS SAN JUAN	Collar	PN10-0210	1.630
BLDG 286	Collar	PN10-0154	1.670
USS SAN JUAN	Collar	PN10-0254	1.760
USS SAN JUAN	Collar	PN10-0207	2.040

TOTAL CHROMIUM

Work Area Location	Filter Location	Sample #	Cr
BLDG 286	Collar	PN10-0259	2.1
BLDG 286	Collar	PN10-0258	3.5
BLDG 286	Collar	PN10-0059	5.0
BLDG 286	Right shoulder		7.0
BLDG 286	Right shoulder	PN12-0119	8.0
BLDG 286	Right shoulder	P002	9.0
BLDG 286	Collar	PN10-0060	10.0
BLDG 286	Collar	PN10-0118	10.6
BLDG 286	Collar	PN10-0119	11.6
BLDG 286	Collar	PN10-0120	17.0
BLDG 286	Collar	PN10-0117	18.0
USS VIRGINIA	Collar	PN11-0031	18.9
USS MIAMI	Right shoulder	P004	91.3
BLDG 286	Right shoulder	P001	95.1
USS VIRGINIA	Collar	PN11-0027	149.0
USS SAN JUAN	Collar	PN10-0255	248.0
BLDG 286	Collar	PN10-0154	257.0
USS VIRGINIA	Collar	PN11-0028	293.0
USS SAN JUAN	Collar	PN10-0208	335.0
USS SAN JUAN	Collar	PN10-0209	400.0
USS SAN JUAN	Collar	PN10-0254	437.0
USS SAN JUAN	Collar	PN10-0211	476.0
USS SAN JUAN	Collar	PN10-0212	476.0
USS SAN JUAN	Collar	PN10-0207	568.0
USS MIAMI	Right shoulder	P002	570.0
USS MIAMI	Right shoulder	P001	611.0
USS SAN JUAN	Collar	PN10-0210	664.0
USS MIAMI	Right shoulder	P003	1030.0

APPENDIX C: Wipe Sample Results

Exposed Nickel Samples and Concentrations

Work Area Location	Specific Location	Sample #	Ni
USS PASADENA	Top of Cap Stand	1	57.9
USS PASADENA	Lower railing	2	66.2
USS PASADENA	Warm hose	3	32.7
USS PASADENA	Side wall	4	76
USS PASADENA	Air suction hose	5	17.6
USS PASADENA	upper railing	6	28
USS PASADENA	Back wall	7	44.2
USS PASADENA	Front wall	8	58.9
USS PASADENA	Deck	9	163
USS PASADENA	Vacuum	10	21.7
USS MIAMI	1st Lower railing right side	21	16.7
USS MIAMI	Mid area entry wall	22	166
USS MIAMI	Left side wall	23	120
USS MIAMI	Blast hose	24	197
USS MIAMI	Outer surface of exhaust hose	25	300
USS MIAMI	Right side wall	26	311
USS MIAMI	Blast hose	27	181
USS MIAMI	Middle low railing	28	69.5
USS MIAMI	Right side wall by exhaust vent	29	96.4
USS MIAMI	Outer surface of exhaust hose far side	30	125
USS MIAMI	Blast hose	31	267
USS MIAMI	Interior of Exhaust hose	32	356
USS MIAMI	Support Structure post	33	44.6
USS MIAMI	Entry wall by entrance	36	204
USS MIAMI	Sign in entry room	37	38.9
USS MIAMI	Left wall by door	70	181
USS MIAMI	Left wall by railing	71	58.5
USS MIAMI	Lower railing left section	72	77.5
USS MIAMI	lower railing mid section	73	55.7
USS MIAMI	Blast hose	74	87.2
USS MIAMI	Blast hose	75	168
USS MIAMI	Right wall by hatch	76	194
USS MIAMI	Right wall by air supply	77	115
USS MIAMI	Entry wall by air supply	78	244
USS MIAMI	Entry wall by door	79	175
USS MIAMI	Mid ship high railing left section	80	59.9

APPENDIX C: Wipe Sample Results

Work Area Location	Specific Location	Sample #	Ni
USS MIAMI	Mid ship high railing mid section	81	59.5
USS MIAMI	Outer surface exhaust hose	82	24.8
USS MIAMI	Inner Surface exhaust hose	83	170
USS MIAMI	Wall by vent	84	87.9
USS MIAMI	Far lower railing left side	85	29
USS MIAMI	Far higher railing mid section	86	72.2
USS MIAMI	Blast hose	87	76.3
USS MIAMI	red tape on exhaust hose	88	28.9
USS MIAMI	Mid ship mid railing mid section	89	24.1
BLDG 286	Plastic on shelf	126	38.2
BLDG 286	Door surface facing inside of room	128	22.4
BLDG 286	Electrical conduit by door	129	44.2
BLDG 286	Tyvek tent by door	130	61.8
BLDG 286	Blast hose	131	65.8
BLDG 286	Building support post surface	132	31.4
BLDG 286	Hose holder	135	15.6
BLDG 286	tape on exhaust hose	136	15.1
BLDG 286	Interior of Exhaust hose	137	52
BLDG 286	Blast hose	140	34.1
BLDG 286	Blast hose	142	25
BLDG 286	Interior Surface of left door	164	31.5
BLDG 286	tape on exhaust hose	165	50.6
BLDG 286	Scaffolding post	166	21.7
BLDG 286	Fire extinguisher	169	26
BLDG 286	Exhaust hose by stairs	170	22.6
BLDG 286	Light by left door	173	14.7
BLDG 286	Ladder post	125	5
BLDG 286	Back Wall	127	5
BLDG 286	Scaffolding board	133	5
BLDG 286	Scaffolding post	134	5
BLDG 286	Eye wash sign	138	5
BLDG 286	Light	139	5
BLDG 286	Plexiglas in wall	141	5
BLDG 286	Building post	143	5
BLDG 286	Light	144	5
BLDG 286	Light	167	5
BLDG 286	Structure post	168	5
BLDG 286	Fire extinguisher holder	171	5
BLDG 286	Interior Surface of far door	172	5

APPENDIX C: Wipe Sample Results

NON-EXPOSED NICKEL SAMPLES AND CONCENTRATIONS

Work Area Location	Specific Location	Sample #	Ni
USS PASADENA	Upper railing	11	13.3
USS PASADENA	Deck	13	23.3
USS PASADENA	Back wall	15	21.7
USS PASADENA	Side wall	16	13.6
USS PASADENA	Front wall	17	18.6
USS PASADENA	Ceiling	19	14.9
BLDG 286 Trailer	Middle shelf	43	11.4
BLDG 286 Trailer	Folder front on table	47	20.7
BLDG 286 Trailer	Wood pallet on middle shelf	53	22.3
USS PASADENA SHT	Stack 11 Level 5 Table top	92	283
USS PASADENA SHT	Stack 11 Level 5 Floor between lights	100	35.2
USS PASADENA SHT	Stack 11 Level 5 Right light	101	29.6
USS PASADENA SHT	Stack 13 Level 4 Table top	103	20.7
USS PASADENA SHT	Stack 13 Level 4 Light	108	10.9
USS PASADENA SHT	Stack 13 Level 4 Floor	109	19.6
USS PASADENA SHT	Stack 15 Level 4 Railing	110	10.1
USS PASADENA SHT	Stack 17 Level 3 Table top	114	20.9
USS PASADENA SHT	Stack 17 Level 3 Left light	118	24.5
USS PASADENA SHT	Stack 17 Level 3 Light	120	21.4
USS MIAMI SHT	Stack 4 Level 1 Table top	147	51.9
USS MIAMI SHT	Stack 4 Level 2 Table top	153	59.6
USS MIAMI SHT	Stack 4 Level 3 Table top	158	43.2
BLDG 286 Trailer	Sign under shelving on floor	180	22.9
USS PASADENA	Lower railing	12	5
USS PASADENA	Top of cap stand	14	5
USS PASADENA	warm hose	18	5
BLDG 286 Trailer	Locker Face	38	5
BLDG 286 Trailer	Wall of left door	39	5
BLDG 286 Trailer	Entrance door inside surface	40	5
BLDG 286 Trailer	Lower railing inside door	41	5
BLDG 286 Trailer	Upper railing left of s/m	42	5
BLDG 286 Trailer	inside cardboard box on floor	44	5
BLDG 286 Trailer	Front of cabinet above microwave	45	5
BLDG 286 Trailer	Top of microwave	46	5
BLDG 286 Trailer	Table top	48	5
BLDG 286 Trailer	Top of water cooler dispenser	49	5
BLDG 286 Trailer	Top of refrigerator	50	5
BLDG 286 Trailer	Front of refrigerator	51	5

APPENDIX C: Wipe Sample Results

Work Area Location	Specific Location	Sample #	Ni
BLDG 286 Trailer	Upper railing of shelf by side door	52	5
BLDG 286 Trailer	Plastic bag holding gloves middle shelf	54	5
BLDG 286 Trailer	Floor under shelves	55	5
BLDG 286 Trailer	right front post of shelving	56	5
BLDG 286 Trailer	Chair seat	57	5
BLDG 286 Trailer	Wall behind chair near shelving	58	5
BLDG 286 Trailer	table next to chair	59	5
BLDG 286 Trailer	wall left of exit door	60	5
BLDG 286 Trailer	exit door surface	61	5
BLDG 286 Trailer	Chair in middle of room	62	5
BLDG 286 Trailer	chair by entrance door	63	5
BLDG 286 Trailer	wall next to black dot	64	5
BLDG 286 Trailer	Wall right of mirror	65	5
BLDG 286 Trailer	floor in front of lockers	66	5
USS PASADENA SHT	Stack 11 Level 5 Wall next to table	93	5
USS PASADENA SHT	Stack 11 Level 5 Emergency phone box	94	5
USS PASADENA SHT	Stack 11 Level 5 Ladder	95	5
USS PASADENA SHT	Stack 11 Level 5 Lower part of door	96	5
USS PASADENA SHT	Stack 11 Level 5 small hatch right of door	97	5
USS PASADENA SHT	Stack 11 Level 5 Power box	98	5
USS PASADENA SHT	Stack 11 Level 5 Left light	99	5
USS PASADENA SHT	Stack 11 Level 5 Post scaffolding	102	5
USS PASADENA SHT	Stack 13 Level 4 Wall next to table	104	5
USS PASADENA SHT	Stack 13 Level 4 Wall between table and door	105	5
USS PASADENA SHT	Stack 13 Level 4 Lower part of door	106	5
USS PASADENA SHT	Stack 13 Level 4 Post right of door	107	5
USS PASADENA SHT	Stack 15 Level 4Light	111	5
USS PASADENA SHT	Stack 15 Level 4Lower part of door	112	5
USS PASADENA SHT	Stack 15 Level 4Stair down to level 3 railing	113	5
USS PASADENA SHT	Stack 17 Level 3 Wall next to table	115	5
USS PASADENA SHT	Stack 17 Level 3 Wall between table and door	116	5
USS PASADENA SHT	Stack 17 Level 3 Lower part of door	117	5
USS PASADENA SHT	Stack 17 Level 3 Railing between lights	119	5
USS PASADENA SHT	Stack 17 Level 3 Post opposite light	121	5
USS MIAMI SHT	Stack 4 Level 1 Top railing	148	5
USS MIAMI SHT	Stack 4 Level 1 light	149	5
USS MIAMI SHT	Stack 4 Level 1 scaffolding post	150	5
USS MIAMI SHT	Stack 4 Level 1 Wall left of table	151	5
USS MIAMI SHT	Stack 4 Level 2 Top railing	154	5
USS MIAMI SHT	Stack 4 Level 2 light	155	5

APPENDIX C: Wipe Sample Results

USS MIAMI SHT	Stack 4 Level 2 scaffolding post	156	5
Work Area Location	Specific Location	Sample #	Ni
USS MIAMI SHT	Stack 4 Level 2 Wall left of table	157	5
USS MIAMI SHT	Stack 4 Level 3 Top railing	159	5
USS MIAMI SHT	Stack 4 level 3 light	160	5
USS MIAMI SHT	Stack 4 Level 3 scaffolding post	161	5
USS MIAMI SHT	Stack 4 Level 3 Wall left of table	162	5
BLDG 286 Trailer	Light above refrigerator	175	5
BLDG 286 Trailer	Ceiling between fridge and shelves	176	5
BLDG 286 Trailer	Circuit breaker box	177	5
BLDG 286 Trailer	Rescue buoy	178	5
BLDG 286 Trailer	Top side railing	179	5
BLDG 286 Trailer	Wipe containers on shelve	181	5
BLDG 286 Trailer	side of refrigerator	182	5
BLDG 286 Trailer	Side of cabinet	183	5
BLDG 286 Trailer	Locker Face	184	5

APPENDIX C: Wipe Sample Results

EXPOSED TOTAL CHROMIUM SAMPLES AND CONCENTRATIONS

Work Area Location	Specific Location	Sample #	Cr
USS PASADENA	Top of Cap Stand	1	30.8
USS PASADENA	Lower railing	2	35.2
USS PASADENA	Warm hose	3	14.5
USS PASADENA	Side wall	4	39.5
USS PASADENA	upper railing	6	15.4
USS PASADENA	Back wall	7	22.1
USS PASADENA	Front wall	8	25.8
USS PASADENA	Deck	9	97.2
USS PASADENA	Vacuum	10	11.7
USS MIAMI	Mid area entry wall	22	72.3
USS MIAMI	Left side wall	23	56.6
USS MIAMI	Blast hose	24	82.5
USS MIAMI	Outer surface of exhaust hose	25	112
USS MIAMI	Right side wall	26	126
USS MIAMI	Blast hose	27	68.1
USS MIAMI	Middle low railing	28	21.6
USS MIAMI	Right side wall by exhaust vent	29	38
USS MIAMI	Outer surface of exhaust hose far side	30	54.9
USS MIAMI	Blast hose	31	97.3
USS MIAMI	Interior of Exhaust hose	32	72.4
USS MIAMI	Support Structure post	33	16.4
USS MIAMI	Entry wall by entrance	36	91.4
USS MIAMI	Sign in entry room	37	18
USS MIAMI	Left wall by door	70	86.1
USS MIAMI	Left wall by railing	71	29.7
USS MIAMI	Lower railing left section	72	36.1
USS MIAMI	lower railing mid section	73	26.3
USS MIAMI	Blast hose	74	40
USS MIAMI	Blast hose	75	91.8
USS MIAMI	Right wall by hatch	76	93
USS MIAMI	Right wall by air supply	77	50.8
USS MIAMI	Entry wall by air supply	78	119
USS MIAMI	Entry wall by door	79	79.8
USS MIAMI	Mid ship high railing left section	80	29.8
USS MIAMI	Mid ship high railing mid section	81	29
USS MIAMI	Outer surface exhaust hose	82	12.5
USS MIAMI	Inner Surface exhaust hose	83	87.7
USS MIAMI	Wall by vent	84	42.1
USS MIAMI	Far lower railing left side	85	18.3

APPENDIX C: Wipe Sample Results

Work Area Location	Specific Location	Sample #	Cr
USS MIAMI	Far higher railing mid section	86	38.3
USS MIAMI	Blast hose	87	44.1
USS MIAMI	red tape on exhaust hose	88	16
BLDG 286	Plastic on shelf	126	23.2
BLDG 286	Electrical conduit by door	129	12.9
BLDG 286	Tyvek tent by door	130	24.4
BLDG 286	Blast hose	131	18.8
BLDG 286	Building support post surface	132	14.4
BLDG 286	Interior of Exhaust hose	137	17.2
BLDG 286	Blast hose	140	15.5
BLDG 286	Blast hose	142	12.9
BLDG 286	Interior Surface of left door	164	11.3
BLDG 286	tape on exhaust hose	165	13.3
USS PASADENA	Air suction hose	5	5
USS MIAMI	1st lower railing left side	21	5
USS MIAMI	Mid Ship Railing post mid	89	5
BLDG 286	Ladder post	125	5
BLDG 286	Back Wall	127	5
BLDG 286	Door surface facing inside of room	128	5
BLDG 286	Scaffolding board	133	5
BLDG 286	Scaffolding post	134	5
BLDG 286	Hose holder	135	5
BLDG 286	tape on exhaust hose	136	5
BLDG 286	Eye wash sign	138	5
BLDG 286	Light	139	5
BLDG 286	Plexiglas in wall	141	5
BLDG 286	Building post	143	5
BLDG 286	Light	144	5
BLDG 286	Scaffolding post	166	5
BLDG 286	Light	167	5
BLDG 286	Structure post	168	5
BLDG 286	Fire extinguisher	169	5
BLDG 286	Exhaust hose by stairs	170	5
BLDG 286	Fire extinguisher holder	171	5
BLDG 286	Interior Surface of far door	172	5
BLDG 286	Light by left door	173	5

APPENDIX C: Wipe Sample Results

NON-EXPOSED TOTAL CHROMIUM SAMPLES AND CONCENTRATIONS

Work Area Location	Specific Location	Sample #	Cr
BLDG 286 Trailer	Middle shelf	43	11.4
BLDG 286 Trailer	Folder front on table	47	10.8
USS PASADENA SHT	Stack 11 Level 5 Table top	92	12.8
USS PASADENA SHT	Stack 11 Level 5 Floor between lights	100	13.1
USS PASADENA SHT	Stack 11 Level 5 Right light	101	35.2
USS MIAMI SHT	Stack 4 Level 1 Table top	147	35.8
USS MIAMI SHT	Stack 4 Level 2 Table top	153	33.2
USS MIAMI SHT	Stack 4 Level 3 Table top	158	25.9
USS PASADENA	Upper railing	11	5
USS PASADENA	Lower railing	12	5
USS PASADENA	Deck	13	5
USS PASADENA	Top of cap stand	14	5
USS PASADENA	Back wall	15	5
USS PASADENA	Side wall	16	5
USS PASADENA	Front wall	17	5
USS PASADENA	warm hose	18	5
USS PASADENA	Ceiling	19	5
BLDG 286 Trailer	Locker Face	38	5
BLDG 286 Trailer	Wall of left door	39	5
BLDG 286 Trailer	Entrance door inside surface	40	5
BLDG 286 Trailer	Lower railing inside door	41	5
BLDG 286 Trailer	Upper railing left of s/m	42	5
BLDG 286 Trailer	inside cardboard box on floor	44	5
BLDG 286 Trailer	Front of cabinet above microwave	45	5
BLDG 286 Trailer	Top of microwave	46	5
BLDG 286 Trailer	Table top	48	5
BLDG 286 Trailer	Top of water cooler dispenser	49	5
BLDG 286 Trailer	Top of refrigerator	50	5
BLDG 286 Trailer	Front of refrigerator	51	5
BLDG 286 Trailer	Upper railing of shelf by side door	52	5
BLDG 286 Trailer	Wood pallet on middle shelf	53	5
BLDG 286 Trailer	Plastic bag holding gloves middle shelf	54	5
BLDG 286 Trailer	Floor under shelves	55	5
BLDG 286 Trailer	right front post of shelving	56	5
BLDG 286 Trailer	Chair seat	57	5
BLDG 286 Trailer	Wall behind chair near shelving	58	5
BLDG 286 Trailer	table next to chair	59	5

APPENDIX C: Wipe Sample Results

Work Area Location	Specific Location	Sample #	Cr
BLDG 286 Trailer	wall left of exit door	60	5
BLDG 286 Trailer	exit door surface	61	5
BLDG 286 Trailer	Chair in middle of room	62	5
BLDG 286 Trailer	chair by entrance door	63	5
BLDG 286 Trailer	wall next to black dot	64	5
BLDG 286 Trailer	Wall right of mirror	65	5
BLDG 286 Trailer	floor in front of lockers	66	5
USS PASADENA SHT	Stack 11 Level 5 Wall next to table	93	5
USS PASADENA SHT	Stack 11 Level 5 Emergency phone box	94	5
USS PASADENA SHT	Stack 11 Level 5 Ladder	95	5
USS PASADENA SHT	Stack 11 Level 5 Lower part of door	96	5
USS PASADENA SHT	Stack 11 Level 5 small hatch right of door	97	5
USS PASADENA SHT	Stack 11 Level 5 Power box	98	5
USS PASADENA SHT	Stack 11 Level 5 Left light	99	5
USS PASADENA SHT	Stack 11 Level 5 Post scaffolding	102	5
USS PASADENA SHT	Stack 13 Level 4 Table top	103	5
USS PASADENA SHT	Stack 13 Level 4 Wall next to table	104	5
USS PASADENA SHT	Stack 13 Level 4 Wall between table and door	105	5
USS PASADENA SHT	Stack 13 Level 4 Lower part of door	106	5
USS PASADENA SHT	Stack 13 Level 4 Post right of door	107	5
USS PASADENA SHT	Stack 13 Level 4 Light	108	5
USS PASADENA SHT	Stack 13 Level 4 Floor	109	5
USS PASADENA SHT	Stack 15 Level 4 Railing	110	5
USS PASADENA SHT	Stack 15 Level 4Light	111	5
USS PASADENA SHT	Stack 15 Level 4Lower part of door	112	5
USS PASADENA SHT	Stack 15 Level 4Stair down to level 3 railing	113	5
USS PASADENA SHT	Stack 17 Level 3 Table top	114	5
USS PASADENA SHT	Stack 17 Level 3 Wall next to table	115	5
USS PASADENA SHT	Stack 17 Level 3 Wall between table and door	116	5
USS PASADENA SHT	Stack 17 Level 3 Lower part of door	117	5
USS PASADENA SHT	Stack 17 Level 3 Left light	118	5
USS PASADENA SHT	Stack 17 Level 3 Railing between lights	119	5
USS PASADENA SHT	Stack 17 Level 3 Light	120	5
USS PASADENA SHT	Stack 17 Level 3 Post opposite light	121	5
USS MIAMI SHT	Stack 4 Level 1 Top railing	148	5
USS MIAMI SHT	Stack 4 Level 1 light	149	5
USS MIAMI SHT	Stack 4 Level 1 scaffolding post	150	5
USS MIAMI SHT	Stack 4 Level 1 Wall left of table	151	5
USS MIAMI SHT	Stack 4 Level 2 Top railing	154	5
USS MIAMI SHT	Stack 4 Level 2 light	155	5
USS MIAMI SHT	Stack 4 Level 2 scaffolding post	156	5

APPENDIX C: Wipe Sample Results

Work Area Location	Specific Location	Sample #	Cr
USS MIAMI SHT	Stack 4 Level 2 Wall left of table	157	5
USS MIAMI SHT	Stack 4 Level 3 Top railing	159	5
USS MIAMI SHT	Stack 4 level 3 light	160	5
USS MIAMI SHT	Stack 4 Level 3 scaffolding post	161	5
USS MIAMI SHT	Stack 4 Level 3 Wall left of table	162	5
BLDG 286 Trailer	Light above refrigerator	175	5
BLDG 286 Trailer	Ceiling between fridge and shelves	176	5
BLDG 286 Trailer	Circuit breaker box	177	5
BLDG 286 Trailer	Rescue buoy	178	5
BLDG 286 Trailer	Top side railing	179	5
BLDG 286 Trailer	Sign under shelves on floor	180	5
BLDG 286 Trailer	Wipe containers on shelve	181	5
BLDG 286 Trailer	side of refrigerator	182	5
BLDG 286 Trailer	Side of cabinet	183	5
BLDG 286 Trailer	Locker Face	184	5

APPENDIX D: Distribution Graphs

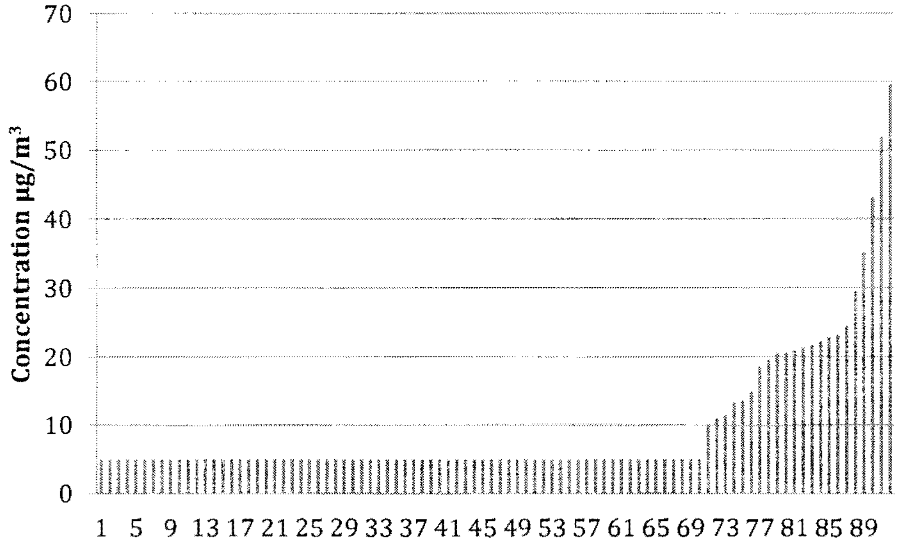

Figure 16: Non-exposed work area nickel wipe sample result distribution with below LOD results and without outlier

Figure 17: Non-exposed work area nickel wipe sample result distribution with below LOD results and with outlier

APPENDIX D: Distribution Graphs

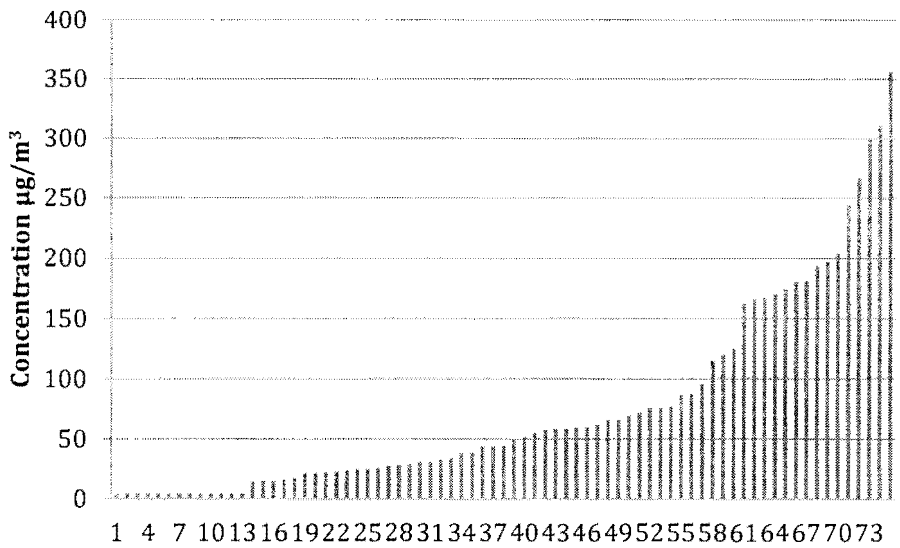

Figure 18: Exposed work area nickel wipe sample result distribution with below LOD results

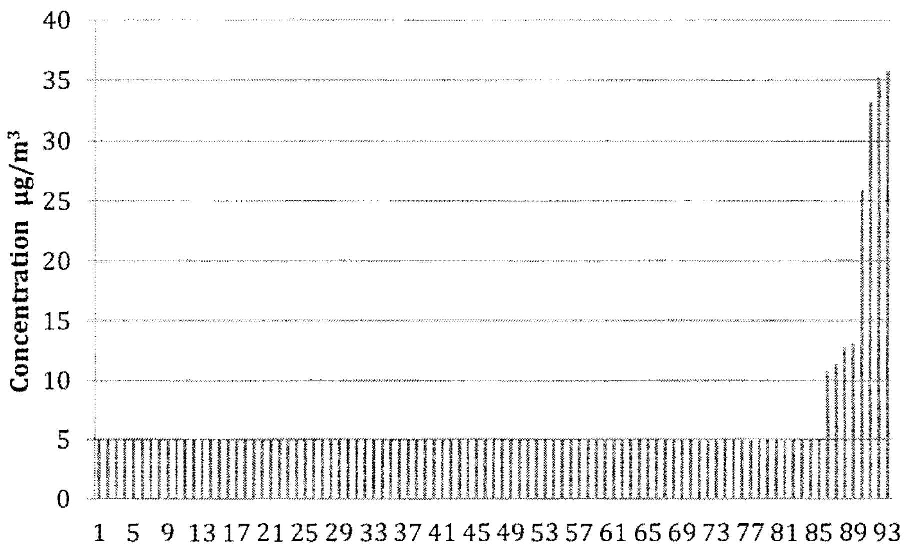

Figure 19: Non-exposed work area total chromium wipe sample result distribution with below LOD results

APPENDIX D: Distribution Graphs

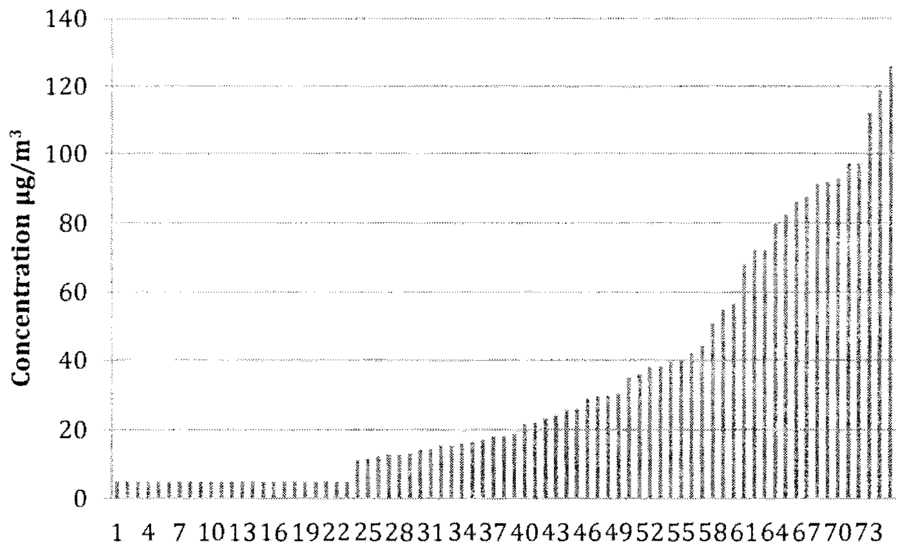

Figure 20: Exposed work area total chromium wipe sample result distribution with below LOD results