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Special Metals Corporation, Princeton Powder Division
Princeton, Kentucky

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PREFACE

The Hazard Evaluations and Technical Assistance Branch (HETAB) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health (OSHA) Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

HETAB also provides, upon request, technical and consultative assistance to Federal, State, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by NIOSH.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Robert E. McCleery, MSPH, Leo M. Blade, CIH, and Susan E. Burt, ScD, of HETAB, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Field assistance was provided by Elena Page, MD, Calvin K. Cook, CSP, Tamara J. Wise, Jenise Brassell, and Marian E. Coleman. Additional assistance was provided by Douglas Trout, MD. Statistical assistance was provided by Charles Mueller, MS. Analytical support was provided by Tamara J. Wise of the Division of Applied Research and Technology (DART), and Data Chem Laboratories, Salt Lake City, Utah. Desktop publishing was performed by Robin Smith. Review and preparation for printing were performed by Penny Arthur.

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For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

Highlights of the NIOSH Health Hazard Evaluation

Employee Exposures to Chromium (VI) and Other Metals

The health hazard evaluation (HHE) request was based upon employee concern of possible health hazards from exposures to hexavalent chromium (Cr[VI]) and materials associated with the specialty alloy production operations at Special Metals Corporation, Princeton, Kentucky. NIOSH investigators conducted environmental and biological monitoring to characterize exposures to several metals.

What NIOSH Did

- # We took air samples on workers to measure their exposures to metals, including nickel, total chromium, cobalt, niobium, and Cr(VI). We also took area air samples.
- # We took blood samples to check for nickel, and urine samples to check for nickel, total chromium, and cobalt.
- # We spoke to employees about their jobs and their health concerns.

What NIOSH Found

- # We found elevated air levels of nickel and cobalt on samples taken on the laboratory, furnace bay, and inert screening workers.
- # All of the Cr(VI) levels were below the OSHA limits.
- # We found elevated levels of nickel in the urine of tested workers. This suggests possible exposure in the workplace.
- # The urine levels of the other metals were all very low.

What the Special Metals Managers Can Do

- # Put local exhaust hoods in the laboratory to lower metal levels in the air.
- # Lower nickel and cobalt exposures to the furnace bay workers and inert screening workers using local exhaust for tasks more likely to produce metal dust such as re-charging the remelt and container change-out.
- # Make sure that employees that have a greater chance for metal exposure (laboratory, furnace bay, and inert screening personnel) are wearing respirators.
- # Use appropriate housekeeping methods to lower the metal levels. These methods could include dry vacuuming with a high efficiency particulate air (HEPA) filter or periodically wet-washing the plant.

What the Special Metals Employees Can Do

- # Wash your hands and face before eating and drinking.
- # Wear a respirator if you are going to do a work task that may expose you to these metals.



What To Do For More Information:
We encourage you to read the full report. If you would like a copy, either ask your health and safety representative to make you a copy or call 1-513/841-4252 and ask for HETA Report # 97-0141-2819



Health Hazard Evaluation Report 97-0141-2819
Special Metals Corporation, Princeton Powder Division
Princeton, Kentucky
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SUMMARY

The National Institute for Occupational Safety and Health (NIOSH) conducted a health hazard evaluation (HHE) at Special Metals Corporation, Princeton Powder Division, Princeton, Kentucky. NIOSH conducted this HHE at the request of employees at that facility who were concerned about the possible formation of hexavalent chromium (Cr[VI]) in the specialty alloy production operations, and of the potential health hazards from exposures to this and other materials associated with those operations. Health effects mentioned in the request included nose bleeds, sinusitis, gastric disturbance, and fatigue.

In response to this request, NIOSH investigators conducted an initial environmental and medical investigation at the site on July 23 and 24, 1997. NIOSH investigators collected 5 personal breathing-zone (PBZ) and 4 area air samples for Cr(VI), 7 PBZ and 4 area air samples for heavy metals, and 6 residual process bulk-material samples for Cr(VI). Two areas of the facility were also evaluated for noise levels. Based upon the initial findings, the NIOSH investigators determined that a follow-up visit was necessary to better characterize workers' exposures to several of the metals used at the facility, by conducting biological monitoring and additional environmental monitoring. The follow-up visit was conducted on September 17-18, 1998. During this visit, NIOSH investigators collected a total of 40 PBZ and 8 area air samples for Cr(VI), 38 PBZ and 7 area air samples for heavy metals, 4 bulk-material samples for Cr(VI), 2 PBZ air samples for respirable crystalline silica, 1 area "bulk-air" sample for crystalline silica, and 2 bulk-material samples for crystalline silica.

In general, the highest PBZ air sample concentrations of nickel, cobalt, total chromium, and niobium were found in the furnace bay, laboratory, and inert screening areas. During the initial survey, 1 air sample (collected in the breathing zone of the laboratory assistant) exceeded the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) for nickel (1000 micrograms per cubic meter [$\mu\text{g}/\text{m}^3$]) and cobalt ($100 \mu\text{g}/\text{m}^3$). Five PBZ air samples exceeded the NIOSH Recommended Exposure Limit (REL) for nickel ($15 \mu\text{g}/\text{m}^3$) and 1 PBZ air sample exceeded the REL for cobalt ($50 \mu\text{g}/\text{m}^3$). Two PBZ air samples exceeded the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV) for cobalt ($20 \mu\text{g}/\text{m}^3$). One PBZ air sample exceeded the NIOSH REL and the ACGIH TLV for total chromium ($500 \mu\text{g}/\text{m}^3$). Bulk sample analysis revealed that Cr(VI) is present in the facility, however all PBZ air sample concentrations for Cr(VI) were below relevant evaluation criteria.

During the follow-up survey, 2 air samples (collected in the breathing zone of the laboratory assistant and furnace operator's helper) exceeded the OSHA PEL for nickel and cobalt. Twenty-two PBZ air samples exceeded the NIOSH REL for nickel and four PBZ air samples exceeded the REL for cobalt. Seven PBZ

air samples exceeded the ACGIH TLV for cobalt. All results for total chromium were below relevant evaluation criteria. Bulk sample analysis confirmed the initial survey results that Cr(VI) is present in the facility. However, all Cr(VI) PBZ air samples collected were below relevant evaluation criteria. All samples collected for crystalline silica resulted in nondetectable concentrations. Sample results in many cases represent potential exposures, rather than actual inhalation exposures, due to employees wearing respirators.

During the follow-up evaluation, all chromium and cobalt levels in urine were well below their respective biological exposure indices. There is no biological exposure index for nickel in the United States. Urine nickel levels, however, suggested that all 48 participating employees may have been exposed to nickel at work.

We found a potential health hazard from exposure to nickel and cobalt at this facility. Air samples showed potential employee exposures to nickel and cobalt exceeding relevant evaluation criteria. Bulk and air samples indicated the presence of Cr(VI) in various production areas of the facility, however all personal breathing zone air samples collected for Cr(VI) were below relevant evaluation criteria. Urine samples showed evidence of workplace exposure to nickel in all employees, and suggested that low levels of workplace exposure to chromium may be occurring in a small number of workers, but offered no convincing evidence of workplace exposure to cobalt. Use of respirators (by many of the potentially highest-exposed workers) reduced actual inhalation exposures, as well as absorbed doses. Suggestions to improve the health and safety of employees in this facility, through the use of administrative controls, personal protective equipment (PPE) and particularly through the use of engineering control measures to reduce or eliminate reliance on PPE, are presented in the Recommendations section of this report.

Keywords: SIC Code 3399 (Manufacture of primary metal products, not elsewhere classified); hexavalent chromium, chromium (VI), chromium, nickel, cobalt, niobium, columbium, biomonitoring, noise.

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INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) conducted a health hazard evaluation (HHE) at Special Metals Corporation, Princeton Powder Division, Princeton, Kentucky. NIOSH conducted this HHE at the request of employees at that facility who were concerned about the possible formation of hexavalent chromium (Cr[VI]) in the specialty alloy production operations, and of the potential health hazards from exposures to this and other materials associated with those operations. Health effects mentioned in the request included nose bleeds, sinusitis, gastric disturbance, and fatigue. In response to this request, NIOSH investigators conducted an initial environmental and medical investigation at the site on July 23 and 24, 1997. Based upon the initial findings, the NIOSH investigators determined that a follow-up visit was necessary to better characterize workers' exposures to several of the metals used at the facility, by conducting biological monitoring and additional environmental monitoring. An interim letter containing the air and bulk sampling results from the initial survey, preliminary recommendations, and follow-up evaluation details was issued on April 13, 1998. The follow-up visit was conducted on September 17 and 18, 1998. An interim letter containing the current analytical results from the environmental and biological samples was issued on April 28, 1999. Individuals were notified of their own medical test results in May 1999. This final HHE report presents the results of the completed NIOSH evaluation and provides recommendations for improving occupational health and safety at the facility.

BACKGROUND

Special Metals Corporation's Princeton Powder Division produces specialty, nonferrous metal-alloy billets, using a process that includes

alloy powderization, primarily for use in the manufacture of aircraft-engine turbine parts. The Special Metals facility is located along U.S. 62 west of Princeton, Kentucky, and consists of a single building with approximately 40,000 square feet (ft²) of floor area. Most of the building has a single level, although lower-level areas exist below a portion of the main level. The building contains areas for production and production-support operations, maintenance, parts and materials supply and storage, shipping and receiving, testing laboratories, offices, and a lunchroom.

The first step in the production process at the Princeton facility is the powderization of nonferrous metal alloys in ceramic-lined furnaces, using a proprietary process that generally involves melting of already-blended alloys followed by atomization in an inert atmosphere. The raw materials for this process include ingots of blended alloy and "out-sized" metal-alloy powder recycled from previous batches. Alloys used at the Princeton facility may be composed of some or all of the following metals: chromium, cobalt, nickel, titanium, and molybdenum. The ceramic furnace linings, after being used for numerous batches, must be "torn down" from the furnace crucibles, then rebuilt; these operations are performed in an adjacent area of the building, the ceramic room. The ceramic furnace linings are built from ceramic powders as well as pre-fired pieces. The refractory materials can contain various substances, such as silica, alumina, titania, zirconia, magnesia, and oxides and silicates of other elements, including sodium, calcium, potassium, phosphorus, and yttrium. The furnace rebuilding operation requires the machining of some ceramic furnace parts.

Powderized metal alloy from the furnaces descends, for initial particle-size separation, to large cyclone separators located on the facility's lower levels. Multiple cyclone batches are blended, and blended batches are further separated by particle size inside screening vessels (located

on the main level) that contain a series of metal screens. The rejected, “out-sized” powders are recycled as raw material for subsequent furnace batches. Batches of the selected powders are “containerized,” i.e., placed into stainless-steel cylinders that are then welded shut. These cylinders, several feet long and a few feet in diameter, are made from stainless-steel plates in the welding area of the building. The stainless-steel alloys used at the facility contain iron, chromium, nickel, manganese, carbon, and silicon, plus various combinations of other elements, including molybdenum, aluminum, copper, titanium, phosphorus, sulfur, selenium, cobalt, niobium (columbium), and tantalum.

The sealed containers are shipped off site, where they are pressed and extruded into long, narrow poles. The conditions of this process cause the metal-alloy powders inside to become a solid with the desired physical properties. The resulting poles, consisting of an alloy core with a relatively thin stainless-steel skin, are returned to the Special Metals Princeton facility for additional processing. This includes sawing, machining with lathes to remove the stainless-steel skin, polishing, and grinding. The resulting specialty alloy billets have sizes and properties desired by the manufacturers of aircraft-engine turbines.

The laboratory and laboratory annex at the facility are used for a variety of small-scale operations related to materials testing. This includes sample remelting, cutting, grinding, and acid dissolution. Also at the facility is a separate operation (unrelated to alloy-billet production) called “H.I.P. lathe” machining, which involves the machining of different shaped products, made of nonferrous metal alloys of similar compositions as those previously described.

METHODS

Initial site visit (July 24, 1997)

NIOSH investigators conducted an initial environmental and medical investigation at the site on July 23 and 24, 1997. The visit began with an opening conference and facility tour. The environmental evaluation included the collection of air samples and residual process bulk-material samples for subsequent chemical analyses, to evaluate potential environmental contaminants. In addition, “spot” measurements of ambient noise levels were made at two locations (adjacent to the large lathe near the polisher and in the aisle near the large screener) perceived by NIOSH investigators to be high in noise.

Initial and follow-up survey air samples were collected using portable, battery-powered air-sampling pumps (Gilian[®], high flow, Model HFS 513A) to draw air at measured rates through collection media appropriate for the specific air contaminants of interest. Some of the air samples were personal breathing-zone (PBZ) samples, with the sampling apparatus worn by a worker and the air inlet in his breathing zone, while others were stationary “general area” samples.

Nine air samples for Cr(VI) were collected and later analyzed, in accordance with NIOSH Method 7600, detailed in the NIOSH Manual of Analytical Methods (NMAM), Fourth Edition.¹ Sample collection was performed with polyvinyl chloride (PVC) membrane filters in plastic cassettes, using a nominal airflow rate of 2.5 liters per minute (L/min). The analytical procedure involves chromate extraction from the filters using sulfuric acid, followed by reaction with diphenylcarbazide to form a complex that is then measured with visible-light spectrophotometry. The analytical limit of detection (LOD) for Cr(VI) was 0.2 micrograms per filter ($\mu\text{g}/\text{filter}$), which equates to a minimum detectable concentration (MDC) of 0.2 micrograms per cubic meter

($\mu\text{g}/\text{m}^3$) of air, based on a 1000 liter (L) air sample volume. The analytical limit of quantitation (LOQ) for Cr(VI) was 0.67 $\mu\text{g}/\text{filter}$, which equates to a minimum quantifiable concentration (MQC) of 0.67 $\mu\text{g}/\text{m}^3$, based on a 1000 L air sample volume.

Eleven air samples for other metals were collected and later analyzed in accordance with NIOSH Method 7300,¹ modified for a “microwave digestion” sample-preparation procedure. Sample collection was performed with mixed cellulose-ester (MCE) membrane filters in plastic cassettes, using a nominal airflow rate of 2.5 L/min. After the samples are prepared for analysis, analyte masses are determined using inductively-coupled argon-plasma atomic-emission spectroscopy. The LODs, LOQs, MDCs, and MQCs for all the metals are listed in Table 1 for convenience.

Six bulk-material samples for Cr(VI) were collected by scraping or scooping small amounts of settled dusts from surfaces, or from other selected bulk materials, into glass scintillation vials for subsequent laboratory determination with the analytical procedures of NIOSH Method 7600. The LOD for Cr(VI) was 1.0 microgram per gram ($\mu\text{g}/\text{g}$) of collected material. The LOQ for Cr(VI) was 3.6 $\mu\text{g}/\text{g}$.

Noise levels were evaluated at two selected locations in the facility using a hand-held sound-level meter set to use the “A-weighted” network with slow meter response.

The medical evaluation during the initial site visit included discussions with management and union representatives, a review of the company’s medical surveillance program, a review of the Occupational Safety and Health Administration log of occupational injuries and illness (OSHA 200) and workers’ compensation records, and confidential, voluntary medical interviews with 19 of 58 employees (which included representation from each of the three shifts).

NIOSH investigators relied upon the assistance of the HHE requestor and a union representative to inform employees of the site visit and of the opportunity to be interviewed. A management representative assisted in scheduling interviews, relieving employees from work responsibilities, and provided an appropriate room for confidential interviews. The purpose of the medical interviews was to identify any potentially work-related health problems. Relevant medical records were obtained from health care providers, with signed consent by participants, and subsequently reviewed for additional information.

Determination of need for follow-up evaluation

Based upon the initial findings (Cr[VI] and other metals present in the work environment), the NIOSH investigators determined that a follow-up visit was essential to better characterize worker exposures to several of the metals used at the facility. The NIOSH investigators decided to focus attention on exposures to chromium, cobalt, and nickel, due to their potential toxicity. To best assess exposures to these metals, biological monitoring and additional air sampling was conducted. For these metals, biological monitoring may provide a better estimate of workers’ exposures than air monitoring because it provides a measure of an actual, absorbed dose integrated over time, and chronic exposures are the greater concern for these substances.

Follow-up site visit (September 17 and 18, 1998)

NIOSH investigators conducted a follow-up environmental and medical evaluation at the Princeton facility on September 17 and 18, 1998. The environmental evaluation included further PBZ and area air sampling during the day and evening shifts on both September 17 and 18, 1998, and further bulk-material and settled-dust

sampling. The follow-up medical evaluation at the Princeton facility included biological monitoring for total chromium, cobalt, and nickel.

Environmental

Forty-eight air samples (40 PBZ and 8 area) for Cr(VI) and 45 air samples (38 PBZ and 7 area) for other metals were collected in all areas of the plant to more carefully characterize employee exposures. Air samples were collected in accordance with the methods described above, except that for some of the samples, nominal airflow rates of 2.0 L/min were used. The samples for metals (other than Cr(VI)) were analyzed for cobalt, nickel, total chromium, and niobium in accordance with NIOSH Method 7300. The LODs for cobalt, nickel, niobium, and total chromium were 0.3, 0.5, 0.8, and 0.5 $\mu\text{g}/\text{filter}$, respectively, which equates to MDCs of 0.3, 0.5, 0.8, and 0.5 $\mu\text{g}/\text{m}^3$, respectively, based on a 1000 L air sample volume. The LOQs for cobalt, nickel, niobium, and total chromium were 0.9, 1.0, 3.0, and 2.0 $\mu\text{g}/\text{filter}$, respectively, which equates to MQCs of 0.9, 1.0, 3.0, and 2.0 $\mu\text{g}/\text{m}^3$, respectively, based on a 1000 L air sample volume.

The air samples for Cr(VI) were analyzed using one of two techniques. Some were analyzed on-site using a new NIOSH-developed field-portable method, draft NIOSH Method 7703,² which is similar in principle to NIOSH Method 7600. The remaining Cr(VI) air samples were later analyzed in accordance with a modified NIOSH Method 7600. The modification included determination of Cr(VI) by high-performance liquid chromatography (HPLC). In some cases, side-by-side air samples were collected with one filter being analyzed by NIOSH Method 7703 and the other by NIOSH Method 7600. All other air samples for Cr(VI) were spread as equal as possible (for both methods) in the specific areas of the plant over the two sampling days. For NIOSH Method 7600, the LOD for Cr(VI) was 0.03 micrograms per

sample ($\mu\text{g}/\text{sample}$) which equates to a MDC of 0.03 $\mu\text{g}/\text{m}^3$ based on a 1000 L air sample volume. The LOQ for Cr(VI) was 0.09 $\mu\text{g}/\text{sample}$ which equates to a MQC of 0.09 $\mu\text{g}/\text{m}^3$ based on a 1000 L air sample volume. For Method 7703, the LOD for Cr(VI) was 0.12 $\mu\text{g}/\text{sample}$ which equates to a MDC of 0.12 $\mu\text{g}/\text{m}^3$ based on a 1000 L air sample volume. The LOQ for Cr(VI) was 0.41 $\mu\text{g}/\text{sample}$ which equates to a MQC of 0.41 $\mu\text{g}/\text{m}^3$ based on a 1000 L air sample volume.

Two air samples for respirable crystalline silica were collected in the breathing zone of employees working in the ceramic room and analyzed in accordance with NIOSH Method 7500.¹ These air samples were collected based on the potential for silica-containing particulates to be present in the ceramic-room air since silica is present in the refractory materials used there. PBZ samples were collected with tared PVC filters, preceded by a 10-millimeter (mm) Dorr-Oliver cyclone to select only respirable-sized particles, using a nominal airflow rate of 1.7 L/min. The PBZ samples were analyzed gravimetrically (in accordance with NIOSH Method 0600¹) for respirable mass, and those that contained sufficient mass were subsequently analyzed for crystalline silica (in the quartz and cristobalite forms) content using x-ray powder diffraction (in accordance with NIOSH Method 7500). In addition, one "bulk-air" area sample was collected without the size selector, using a nominal airflow rate of 3.0 L/min. The "bulk-air" sample was also analyzed gravimetrically (NIOSH Method 0500) for total mass, and subsequently analyzed for crystalline silica (in the quartz and cristobalite forms) content using x-ray powder diffraction (NIOSH Method 7500). The LOD for respirable mass was 0.02 milligrams per sample (mg/sample) which equates to a MDC of 0.02 milligrams per cubic meter (mg/m^3) based on a 1000 L air sample volume. The LOD for quartz was 0.01 mg/sample which equates to a MDC of 0.01 mg/m^3 based on a 1000 L air sample volume. The LOD for cristobalite was 0.02 mg/sample which equates to a MDC of 0.02 mg/m^3 based on

a 1000 L air sample volume. The LOQ for quartz and cristobalite was 0.03 mg/sample which equates to a MQC of 0.03 mg/m³ based on a 1000 L air sample volume.

Four settled-dust and bulk-material samples were collected and analyzed for Cr(VI). These samples were collected in areas where there was an accumulation of process dust (lower level, inert screening, and ceramic room areas). The settled-dust samples were collected using air samplers and PVC filters in plastic cassettes to “vacuum” surfaces. Cr(VI) was measured using the same modified NIOSH Method 7600 as described above. Each of the four samples collected had the LOD and LOQ calculated separately. The LOD and LOQ for bulk-1 were 0.4 µg/g and 1.0 µg/g, respectively. The LOD and LOQ for bulk-2 were 0.03 µg/g and 0.09 µg/g, respectively. The LOD and LOQ for bulk-5 were 0.5 µg/g and 2.0 µg/g, respectively. The LOD and LOQ for bulk-6 were 0.03 µg/g and 0.1 µg/g, respectively.

Two bulk-material samples also were collected in the ceramic room and analyzed for crystalline silica in accordance with NIOSH Method 7500. Samples were analyzed by x-ray powder diffraction. The LOD and LOQ for these bulk samples were 0.8 percent and 2.0 percent, respectively.

Medical

All workers in the plant were invited to voluntarily participate in the medical portion of the evaluation. This included biological sampling for metals and a questionnaire to identify possible nonoccupational metal exposures. Urine specimens were collected and analyzed for chromium, cobalt, and nickel; and blood specimens were collected and analyzed for nickel only. Workers from all three shifts, including the presumably lesser-exposed office personnel, were asked to participate. To account for the distribution and excretion times of cobalt, nickel,

and chromium in the human body, urine specimens were collected at the beginning and end of the last shift of the work week (Friday day and Friday “swing” shifts), and blood was drawn, by certified phlebotomists, at the end of those shifts.

The urine specimens were analyzed for chromium, cobalt, and nickel by the National Center for Environmental Health; blood specimens were analyzed for nickel by a NIOSH-contracted laboratory. (For nickel, there is some evidence that urine specimens are more likely to reflect recent exposure, while blood specimens may reflect longer-term exposure.) In addition to these analyses, complete blood counts were also performed to determine whether any participants had elevated red blood cell (RBC) counts, which may be an indicator of a biological response to exposure to cobalt. Urine creatinine levels were measured to provide more accurate results for chromium levels, by adjusting them according to each individual’s creatinine level, an indicator of urine concentration. Personal results of laboratory analyses and a letter explaining their results were mailed to individual workers at their home addresses.

The determination of urine chromium and nickel was made by Zeeman-effect graphite-furnace automatic absorption spectrometry (AAS). Urine cobalt was determined with inductively-coupled argon-plasma mass spectrometry, using a Perkin-Elmer Model 6000 quadrupole. Quality control was established with replicate measurements of bench and blind urine quality control materials whose target values were established by the methods used for these determinations. Standard Reference Material (SRM) 2670 (Toxic Metals in freeze-dried urine) from the National Institute of Standards and Technology (NIST) was also used as part of the quality control for these measurements. Creatinine was measured with a Kodak automated system.

Blood specimens were analyzed by a NIOSH–contracted laboratory using inductively coupled plasma/mass spectrometry.

Biological monitoring data were statistically analyzed to determine whether concentrations of metals in urine or blood varied by type of job or area of the plant. In cases where elevated levels were detected, data from questionnaires were reviewed to determine whether any non–occupational exposures might have contributed to the levels detected. Data were entered using EpiInfo software, then analyzed using Statistical Analysis System (SAS) data analysis software. Analyses compared job titles and areas of the plant with background metal levels and higher metal levels.

EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre–existing medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the criterion. These combined effects are often not considered in the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and

thus potentially increases the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs),³ (2) the American Conference of Governmental Industrial Hygienists' (ACGIH[®]) Threshold Limit Values (TLVs[®]),⁴ and (3) the U.S. Department of Labor, OSHA Permissible Exposure Limits (PELs).⁵ Employers are encouraged to follow the OSHA limits, the NIOSH RELs, the ACGIH TLVs, or whichever are the more protective criterion.

OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 95–596, sec. 5.(a)(1)]. Thus, employers should understand that not all hazardous chemicals have specific OSHA exposure limits such as PELs and short–term exposure limits (STELs). An employer is still required by OSHA to protect their employees from hazards, even in the absence of a specific OSHA PEL.

A time–weighted average (TWA) exposure refers to the average airborne concentration of a substance during a normal 8– to 10–hour workday. Some substances have recommended STEL or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short–term.

Chromium (VI)

The toxicity and solubility of chromium compounds that contain chromium in the Cr(II), Cr(III), or Cr(VI) valence states vary greatly, but those that contain Cr(VI) are of the greatest

health concern. Cr(VI) compounds include lead chromate and zinc chromate pigments, chromic acid, and soluble compounds such as those used in chromium plating. Some Cr(VI) compounds are severe irritants of the respiratory tract and skin, and some (including chromates) have been found to cause lung cancer in exposed workers.⁶ Allergic dermatitis is one of the most common effects of chromium toxicity among exposed workers.

The NIOSH REL for a 10-hour TWA exposure to airborne Cr(VI) is 1.0 $\mu\text{g}/\text{m}^3$. NIOSH considers Cr(VI) to be a potential occupational carcinogen based upon research suggesting a relationship between Cr(VI) exposures and the development of lung cancers.³ The applicable OSHA PEL, for Cr(VI) trioxide (chromic acid, or CrO_3), is a “ceiling” of 100 $\mu\text{g}(\text{CrO}_3)/\text{m}^3$; this is equivalent to 52 $\mu\text{g}(\text{Cr}[\text{VI}])/m^3$. The ACGIH TLVs are 50 $\mu\text{g}(\text{Cr}[\text{VI}])/m^3$ for water-soluble Cr(VI) compounds and chromates, and 10 $\mu\text{g}(\text{Cr}[\text{VI}])/m^3$ for insoluble Cr(VI) compounds; these exposure criteria apply to full-shift TWA exposures of 8 hours. Cr(VI) is classified as a human carcinogen by ACGIH.⁴

The ACGIH Biological Exposure Indices (BEIs[®]) for soluble Cr(VI) fume are a 10 $\mu\text{g}/\text{g}$ of creatinine increase during the work shift, and 30 $\mu\text{g}/\text{g}$ of creatinine at the end of the work week.⁷ The BEIs for chromium were developed to prevent potential health effects among workers with long-term exposure to operations where water soluble Cr(VI) fume is present. The BEIs represent levels that are likely to be found in biological samples collected from healthy workers who have inhalation exposures to water soluble Cr(VI) at the current TLV-TWA of 50 $\mu\text{g}/\text{m}^3$. Non-occupational sources of exposure to chromium may include food, water, air, and cigarette smoke. Persons not occupationally exposed generally have urine levels less than 1.0 microgram per liter ($\mu\text{g}/\text{L}$).

Most of the *air-contaminant* exposure limits cited above and below are *published* in units of milligrams (mg) per m^3 of air (mg/m^3), but for convenience $\mu\text{g}/\text{m}^3$ is used throughout this document. Any value listed in $\mu\text{g}/\text{m}^3$ may be divided by 1000 to convert it to mg/m^3 .

Nickel

Nickel is one of the most common causes of allergic contact dermatitis (“nickel-itch”).⁸ The condition has been seen in various occupations, including hairdressers, nickel platers, and jewelers. Once a worker is sensitized to nickel, the sensitivity persists even after the exposure is removed.⁹ The major route of occupational exposure to nickel and nickel compounds is through inhalation.¹⁰ Inhalation exposures have been associated with cancer of the lung and of the nasal sinuses in workers employed in nickel refineries and smelters.¹¹ Although not common, other health effects of nickel inhalation exposures include nasal irritation, damage to the nasal mucosa, perforation of the nasal septum, and loss of sense of smell.

The NIOSH REL for a 10-hour TWA exposure to total airborne nickel is 15 $\mu\text{g}/\text{m}^3$. NIOSH considers nickel to be a potential occupational carcinogen, based upon research suggesting a relationship between nickel exposures and the development of lung and nasal cancers.³ The ACGIH TLVs (for 8-hour TWA exposures) are 100 $\mu\text{g}/\text{m}^3$ for nickel in the form of soluble compounds, 1500 $\mu\text{g}/\text{m}^3$ for metallic nickel, and 200 $\mu\text{g}/\text{m}^3$ nickel in the form of insoluble compounds. The OSHA PEL is 1000 $\mu\text{g}/\text{m}^3$ for an 8-hour TWA exposure to all forms of this element.

There are no established guidelines for levels of nickel in blood or urine in this country. The Finnish Institute of Occupational Health has set a Biological Action Limit (similar to a BEI, mentioned above) for nickel of 76 $\mu\text{g}/\text{L}$ for a urine

specimen taken at the end of the work week.¹² Researchers in the U.S. have suggested a limit of about 70 µg/L in urine in the electroplating and refining industries, because it corresponds to a TWA exposure of 100 µg/m³ of soluble nickel in air.¹³ In welders, a urine nickel between 30 µg/L and 50 µg/L, corresponded to a TWA exposure of 500 µg/m³ in air.¹⁴ Persons without occupational exposure to nickel generally have urine nickel levels in the range of <1–4 µg/L.¹⁵ Researchers have suggested that serum nickel levels be kept below the range of 5 µg/L to 10 µg/L.¹⁵

Cobalt

The majority of cobalt is used in the form of alloys, specifically so-called superalloys.¹⁶ The high temperature stability of these alloys lends them directly to the fabrication of aircraft engine parts. Cobalt is also used in hard-metal production (e.g., for drilling and machining) and in the diamond polishing industries. Cobalt salts are also widely used in a number of different applications, including: drying agents in paints, varnishes and inks; as pigments; and as bonding agents.¹⁶ The major routes of exposure are inhalation and dermal. Chronic inhalation of cobalt in hard-metal production has resulted in forms of obstructive lung disease such as occupational asthma. Contact dermatitis has been reported in many cobalt-related industries, including hard metal, paint, pottery, and cement use during construction.¹⁶

The OSHA PEL for full-shift TWA exposures to airborne cobalt is 100 µg/m³, while the NIOSH REL is 50 µg/m³ and the ACGIH TLV is 20 µg/m³; these exposure limits apply to full-shift exposures of 8, up to 10, and 8 hours, respectively.

The ACGIH BEI for cobalt is 15 µg/L urine at the end of the last work shift of the week.¹³ There is no reference value for urine cobalt in people not occupationally exposed. ACGIH estimates that

persons without occupational exposure to cobalt will have cobalt levels in urine of less than 2 µg/L.¹³ WHO notes that values in the range of 0.1–1 µg/L should be expected.¹⁵

Chromium (other than Cr[VI])

Cr(II) and Cr(III) are minimally absorbed following exposure via inhalation.¹⁷ However, occupational asthma can occur with inhalation exposures to Cr(III) salts.¹⁸ Cr(III) is also very poorly absorbed via dermal exposure, although absorption can be increased if the skin is broken.¹⁷ However, biological levels of chromium are generally associated with exposure to Cr(VI) and not Cr(II) or Cr(III).

The NIOSH REL and ACGIH TLV for full-shift TWA exposures to airborne, non-hexavalent chromium (chromium in the metallic, Cr[II], or Cr[III] forms) are both 500 µg/m³. The OSHA PEL for 8-hour TWA exposures is 500 µg/m³ for chromium in the form of soluble Cr(II) and Cr(III) salts, and 1000 µg/m³ for insoluble salts and metallic chromium.

Complete Blood Count (CBC)

The complete blood count (CBC) is a routine blood test which measures the concentration and characteristics of RBCs, white blood cells (WBCs), and platelets. The RBCs provide oxygen to cells of the body, the WBCs are involved in fighting infections, and the platelets are involved in the blood clotting process. CBC results can be used to detect certain conditions such as anemias, infections, or vitamin deficiencies. The CBC can be affected by many factors such as genetic make-up, eating habits, pregnancy, tobacco and alcohol use, and exposures to certain substances or medications. Exposure to cobalt has been reported to cause an increase in the number of RBCs in the blood (polycythemia).

RESULTS

Initial Site Visit

Environmental

The results for the Cr(VI) air samples, the air samples for other metals, and the bulk-material samples for Cr(VI) are shown in Tables 2, 3, and 4, respectively.

Chromium (VI)

As the data in Table 2 shows, Cr(VI) was detected in the air. The “trace” airborne concentrations detected are not reliably quantifiable but are between 0.2 and 0.67 $\mu\text{g}/\text{m}^3$. These concentrations are below all of the relevant evaluation criteria previously cited.

Other Metals

The results for the air samples for other metals are shown in Table 3. The measured full-shift PBZ exposure of the laboratory assistant to total airborne nickel, 2500 $\mu\text{g}/\text{m}^3$, exceeds the OSHA PEL of 1000 $\mu\text{g}/\text{m}^3$ for an 8-hour TWA exposure, the NIOSH REL (for a 10-hour TWA exposure) of 15 $\mu\text{g}/\text{m}^3$, and the ACGIH TLVs (for 8-hour TWAs) of 100 $\mu\text{g}/\text{m}^3$ for nickel in the form of soluble compounds, 1500 $\mu\text{g}/\text{m}^3$ for metallic nickel and 200 $\mu\text{g}/\text{m}^3$ for nickel in the form of insoluble compounds. Since the analytical results do not distinguish between these forms, it is unclear which TLV applies or if any other measured airborne levels exceed the applicable TLV. The measured full-shift PBZ nickel exposures of four other employees (furnace operator, inert screener, machine operator, and welder) exceed the NIOSH REL, and two measured general-area (furnace and laboratory areas) airborne concentrations of this metal also exceed that level.

The measured PBZ, full-shift TWA exposure of the laboratory assistant to cobalt, 320 $\mu\text{g}/\text{m}^3$, exceeds all the relevant evaluation criteria previously cited. The measured full-shift PBZ cobalt exposure of one other employee (machine operator) also exceeds the ACGIH TLV of 20 $\mu\text{g}/\text{m}^3$ for an 8-hour TWA exposure, and one measured general-area (laboratory area) airborne concentration of this metal also exceeds that level.

The measured full-shift PBZ exposure of the laboratory assistant to total airborne chromium, 530 $\mu\text{g}/\text{m}^3$, exceeds the NIOSH REL and the ACGIH TLV for 8-hour TWA exposures to non-hexavalent forms of chromium, which both are 500 $\mu\text{g}/\text{m}^3$. The OSHA PEL for 8-hour TWA exposures to non-hexavalent chromium is 500 $\mu\text{g}/\text{m}^3$ for chromium in the form of soluble Cr(II) and Cr(III) salts, and 1000 $\mu\text{g}/\text{m}^3$ for insoluble salts and metallic chromium. Since the analytical results do not distinguish between these forms, it is unclear which PEL applies or if this measured exposure level exceeds the applicable PEL.

The PBZ exposures to the other metals (except niobium) detected in the air were all well below the relevant exposure criteria. No evaluation criteria for exposures to niobium (often called columbium) are currently available.

Bulk Samples

As the data in Table 4 show, Cr(VI) was detected in four of the six samples of bulk materials (collected in the furnace, multiple inspection, polishing grinder, and ceramic areas). Although the specific concentrations of Cr(VI) within the bulk materials sampled are not meaningful in terms of evaluation criteria, the detection of this substance in these materials confirms its formation and presence in the facility; its detection in these materials also helps to confirm the validity of the air-sampling results showing its presence in the air in “trace” concentrations for four of nine sampling results.

Noise

Two areas were evaluated for noise levels since they were perceived by the NIOSH investigators to have the highest levels in the facility. First, noise levels were measured adjacent to the large lathe that is located near the polisher. Continuous noise levels of 95 to 96 decibels on the A-weighted scale (dBA) were measured near the location where the worker (who was wearing hearing protection) was standing. *Unprotected* exposure to a TWA level of 96 dBA would be permitted under the relevant OSHA PEL for only 3.5 hours per day; the NIOSH REL and ACGIH TLV for noise both recommend limiting *unprotected* exposure to noise at this level to only 30 minutes per day. Also, noise levels were measured at ear level in the aisle nearest to the large screener located furthest toward the east end of the building. Continuous noise levels of 85 to 86 dBA were measured in this aisle, where no workers normally dwell. The OSHA PEL would allow 13.9 hours per day of exposure to a TWA level of 86 dBA, while the NIOSH REL and ACGIH TLV would recommend only 4 hours. Both the NIOSH and ACGIH recommended limits for 8-hour TWA exposures are 85 dBA, compared to the OSHA PEL of 90 dBA.

Medical

Symptoms reported by interviewees during the initial site visit that might be related to work included upper respiratory irritation, sinus-related symptoms, difficulty breathing, nosebleeds, nasal sores and ulcerations, and musculoskeletal symptoms. Review of the medical records that were obtained with employees' written consent did not provide further information, other than to confirm that individuals had sought medical care for symptoms such as recurrent nosebleeds.

Follow-up Evaluation

Work Practices and Personal Protective Equipment (PPE)

The company had recently written and implemented a respiratory protection program. In the furnace bay areas, workers during the day shift wore Scott® air-purifying respirators (stock# 642-H) with cartridges to be used for dusts, mists, fume, and radionuclides. This respirator is now NIOSH certified under the stock# of 642-P100.¹⁹ Evening-shift furnace bay area workers used the 3M® 8500 comfort mask and the 3M 7200 half-mask, air-purifying respirator with P100 cartridges for cleaning the interior of the bay and depositing the collected oversize material from the 55 gallon drum containers into the remelting container. The laboratory assistant used the 3M 7200 half-mask, air-purifying respirator with P100 cartridges for dry polishing micros (small parts made of alloy) and screening dry powder. The screening workers used a 3M 7000 series half-mask, air-purifying respirator with P100 cartridges when unloading dust from the screening process.

Environmental

The results for the Cr(VI) air samples, the air samples for other metals, and the bulk-material samples for Cr(VI) are shown in Tables 5 and 6, 7 and 8, and 9, respectively. The "other metals" air samples were only analyzed for the four metals of greatest interest, generally those with the greatest toxicological significance and/or measured at relatively high concentrations during the initial site visit.

Chromium (VI)

The area and PBZ air samples for Cr(VI) collected during day and evening shifts on September 17, and 18, 1998, are presented in Tables 5 and 6, respectively. Cr(VI) air sample concentrations

ranged from nondetectable concentrations to $0.38 \mu\text{g}/\text{m}^3$. The highest air sample concentration, $0.38 \mu\text{g}/\text{m}^3$, was collected in the PBZ of the furnace helper during the evening shift on September 17, 1998, while working at Furnace Bay B. Since the worker wore the appropriate respirator, this air sample result represents potential exposure, not actual inhalation exposure. All concentrations found during the two days of sampling were below the relevant evaluation criteria.

Other Metals (Nickel, Cobalt, Total Chromium, and Niobium)

The area and PBZ air samples for nickel, cobalt, total chromium, and niobium collected during day and evening shifts on September 17 and 18, 1998, are presented in Tables 7 and 8, respectively. Nickel concentrations in air samples ranged from nondetectable concentrations to $1373 \mu\text{g}/\text{m}^3$. The highest air sample concentration, $1373 \mu\text{g}/\text{m}^3$, was collected in the PBZ of the furnace helper during the day shift on September 17, 1998, while working at Furnace Bay B. Two PBZ air sample results (furnace helper and laboratory assistant) exceeded the OSHA PEL of $1000 \mu\text{g}/\text{m}^3$ for an 8-hour TWA exposure. Twenty-two air sample results exceeded the NIOSH REL (for a 10-hour TWA exposure) of $15 \mu\text{g}/\text{m}^3$. Eight air sample results exceeded the ACGIH TLVs (for 8-hour TWAs) of $100 \mu\text{g}/\text{m}^3$ for nickel in the form of soluble compounds, $1500 \mu\text{g}/\text{m}^3$ for metallic nickel, $200 \mu\text{g}/\text{m}^3$ for nickel in the form of insoluble compounds. Since the analytical results do not distinguish between these forms, it is unclear which TLV applies or if any other measured airborne levels exceed the applicable TLV. PBZ exposures exceeding the NIOSH REL and ACGIH TLV were found for the following workers: furnace operators/helpers, inert screeners, laboratory personnel, maintenance personnel, machinists, and lathe operators. Due to respirator use, many of these results represent potential exposures, not actual inhalation exposure. Area air sample concentrations

exceeding the NIOSH REL and ACGIH TLV were measured in the furnace and inert screening areas of the facility.

Cobalt concentrations ranged from nondetectable levels to $276 \mu\text{g}/\text{m}^3$. The highest air sample concentration, $276 \mu\text{g}/\text{m}^3$, was measured in the PBZ of the laboratory assistant during the day shift on September 18 while working in the laboratory. Two PBZ air sample results (furnace helper and laboratory assistant) exceeded the OSHA PEL (for 8-hour TWAs) of $100 \mu\text{g}/\text{m}^3$. Seven air sample results (various workers around the facility) exceeded the ACGIH TLV (for 8-hour TWAs) of $20 \mu\text{g}/\text{m}^3$. Four air sample results exceeded the NIOSH REL (for a 10-hour TWA exposure) of $50 \mu\text{g}/\text{m}^3$. PBZ exposures exceeding the NIOSH REL and ACGIH TLV were found for the following workers: furnace helpers, inert screeners, and laboratory personnel. Due to respirator use, many of these results represent potential exposures, not actual inhalation exposure.

Total chromium concentrations in air samples ranged from nondetectable concentrations to $274 \mu\text{g}/\text{m}^3$. The highest air sample concentration, $274 \mu\text{g}/\text{m}^3$, was collected in the PBZ of the furnace helper during the day shift on September 17, 1998, while working at Furnace Bay B. All concentrations found during the two days of sampling were below the relevant evaluation criteria.

Niobium concentrations in air samples ranged from nondetectable concentrations to $20.3 \mu\text{g}/\text{m}^3$. The highest air sample concentration, $20.3 \mu\text{g}/\text{m}^3$, was collected in the PBZ of the laboratory assistant during the day shift on September 18, 1998, while working in the laboratory. Niobium does not have any relevant occupational exposure evaluation criteria at the present time. Niobium was detected in the initial site visit air samples and was analyzed in the follow-up air samples due to the lack of occupational exposure and health data on this metal.

Respirable Crystalline Silica

The NIOSH investigators collected one area “bulk-air” sample for total particulate and two PBZ air samples for respirable particulate. These were subsequently analyzed for crystalline silica (quartz and cristobalite forms). The polishing machine operator PBZ sample on September 17, 1998, resulted in nondetectable respirable particulate and respirable crystalline silica levels. The air sample of the ceramic room employee’s PBZ on September 18, 1998, resulted in an 8-hour TWA respirable particulate exposure of 0.06 mg/m³. This concentration is below all relevant evaluation criteria. The respirable crystalline silica analysis of this sample resulted in a nondetectable level. The area “bulk-air” sample was collected in the ceramic room atop the machining device on September 18, 1998. This total particulate sample resulted in an 8-hour TWA of 0.15 mg/m³. This concentration is below all relevant evaluation criteria. The crystalline silica analysis of this sample resulted in a nondetectable level.

Bulk Samples

As the data in Table 9 shows, Cr(VI) was detected in all four of the bulk materials (collected in the ceramic room, inert screening, and lower-level areas). Although the specific concentrations of Cr(VI) within the bulk-materials sampled are not meaningful in terms of evaluation criteria, the detection of this substance in these materials confirms its formation and presence in the facility. Its detection in these materials also helps to confirm the validity of the air-sampling results showing its presence in the air in “trace” concentrations or above for 31 of 48 sampling results.

Two bulk samples were collected for crystalline silica (quartz and cristobalite forms) analysis. Both bulk samples were collected in the ceramic room. The first sample was ceramic material located on the surface of the ceramic machine.

The analysis did not reveal either form of crystalline silica. The second sample was “used” furnace ceramic material. The analysis did not reveal either form of crystalline silica.

Medical

The following are results of blood and urine tests from samples collected from participating employees. Individuals have been notified of their own results. Forty-eight (of 58 hourly and 18 salaried) employees participated in the medical survey. Forty-four employees provided a blood sample and pre- and post-shift urine samples, and four employees provided a blood sample and either a pre- or a post-shift urine sample.

Complete blood count

None of the participants had an increased concentration of red blood cells.

Chromium

The majority of urine chromium samples had nondetectable levels of chromium (i.e., below 0.4 µg/L). Among those with trace chromium concentrations, the maximum value was 1.9 µg/g of creatinine. Thus, all participants had urine chromium concentrations well below the BEI (a 10 µg/g creatinine increase over the course of a work shift or 30 µg/g creatinine at the end of the last work shift).

Cobalt

Urine cobalt concentrations ranged from 0.1–1.1 µg/L with a mean of 0.48 µg/L in the pre-shift samples and from 0.1–1.6 µg/L with a mean of 0.65 µg/L in the end-of-shift, end-of-week samples. All participants had urine cobalt concentrations well below the BEI (15 µg/L). Seven individuals had results above 1.0 µg/L, suggesting occupational exposure, according to the World Health Organization (WHO), but none were above the background

level of 2 µg/L, given by the ACGIH.^{13,15} The two individuals with personal air samples for cobalt above the OSHA PEL had urine cobalt levels in the estimated range for non-occupationally exposed people; both were wearing a respirator during the NIOSH evaluation.

Nickel in urine and blood (serum)

Urine nickel concentrations ranged from 4–66.2 µg/L with a mean of 21.0 µg/L in the pre-shift samples and from 0–91.4 µg/L with a mean of 33.4 µg/L in the end-of-shift, end-of-week samples. All participants had a urine nickel level in one or both samples above the range noted for persons not occupationally exposed to nickel (<1–4 µg/L), suggesting that they may have been exposed to nickel in the workplace. The mean individual change in urine nickel over the course of the work week was 12.5 µg/L; this increase was statistically significant ($p < 0.01$). Twenty-seven (56%) of the participants had one or more urinary nickel levels greater than 30 µg/L, a suggested limit based on a study of welders.¹⁴ Based on questionnaire responses, nonoccupational exposures did not appear to contribute to elevated urine nickel levels. The levels of nickel in blood for all participants were below the lowest occupation exposure level of 0.5 µg/L that has been suggested by available research.¹⁵

Comparison of group results for urine nickel

Urine nickel levels were generally higher in hourly employees than salaried employees, but the differences were not statistically significant. In pre-shift samples, the mean was 21.8 µg/L in hourly employees and 16.3 µg/L in salaried employees ($p = 0.30$). In end-of-shift, end-of-week samples, the mean was 35.1 µg/L in hourly employees and 24.0 µg/L in salaried employees ($p = 0.28$). The mean individual change over the course of the work week was 13.4 µg/L

in hourly employees and 7.7 µg/L in salaried employees ($p = 0.55$).

Comparison of air and urine nickel levels

There was no statistically significant correlation between urine nickel (the maximum of the pre- and post-measures) and air nickel measures (p -value > 0.10).

DISCUSSION

The control of occupational exposures to chemical, biological, and physical agents is accomplished by the application of engineering measures, work practices, and personal protective equipment (PPE). These measures, practices, and/or equipment are applied at the source of the contaminant generation, to the general workplace environment, or at the significant exposure point of an individual. The application of engineering measures at the source provides the most effective control of both occupational and environmental contaminants. Substitution with a less hazardous material is the preferred approach to providing a safe work environment. Where material substitution is not feasible, process/equipment modification, isolation, or automation and the use of local exhaust ventilation (LEV) can be effective source control methods. Additionally, work practices can be modified to minimize the potential for contaminant generation and subsequent exposure. Under those circumstances where source control is not a feasible solution, modifications to the general work environment can provide the next level of control. The techniques employed include dilution ventilation, aerosol (e.g., dust) suppression, and improved housekeeping activities. The last level of control attempts to separate the exposed worker from the chemical, biological, or physical agent. Separation can be attained by the application of isolation environments (e.g., remote control rooms, isolation booths, and supplied-air cabs). Separation can also be achieved by employing

PPE including chemically impervious clothing and respirators approved by NIOSH. However, PPE should be applied as a last resort for control of exposures.

Initial Site Visit

The following preliminary findings were discussed at the closing meeting of the initial visit on July 24, 1997:

The ventilation system in the ceramic room which filters collected air and recirculates it to the work environment is a source of concern. The responsibility for, frequency of, and criteria for periodic replacement of the prefilter and high-efficiency particulate air (HEPA) filter are unclear. The possibility of contaminant leakage at some seams in the hardware was observed.

Regarding the hazard communication program, the organization of the material safety data sheets (MSDSs) did not facilitate ease of use.

Finally, a safety concern was noted regarding hand grinding of samples by laboratory personnel.

Additionally, air sampling and medical results from the initial visit revealed:

The presence of Cr(VI) in the facility.

The potential for excessive exposures to some workers to nickel, cobalt, and possibly total chromium.

Symptoms reported by employees that may be related to work.

Follow-up Evaluation

Environmental

In general, detectable levels of Cr (VI) in PBZ air samples were found in a variety of job

classifications around the plant. PBZ air sample concentrations were consistent over the two-day period for workers in the inert screening areas, the Furnace Bay A and B areas, and laboratory workers. However, these employees typically wore respirators. PBZ air samples collected from other job classifications only detected Cr(VI) during a specific shift or specific day. The area air samples collected in the basement above the Bay B collector, in the inert screening area on the No. 5 screener platform, and at the Furnace Bay B step rail leading to the top level all revealed detectable concentrations of Cr(VI).

The highest PBZ air sample concentrations of cobalt, total chromium, niobium, and nickel were found among those working in the Furnace Bay B area, the laboratory, and the inert screening area. At least one of these four metals was detected in every PBZ air sample collected during the two days of sampling. The two air samples that resulted in cobalt concentrations above the OSHA PEL of $100 \mu\text{g}/\text{m}^3$ were found in the PBZ (but outside the respirator) of the furnace operator's helper and the laboratory assistant on September 17 and 18, 1998, respectively. The two air samples that had total chromium concentrations above $200 \mu\text{g}/\text{m}^3$, but below the OSHA PEL, were found in the PBZ (but outside the respirator) of the furnace operator's helper and the laboratory assistant on September 17 and 18, 1998, respectively. All PBZ and area air samples that resulted in "trace" concentrations or above for niobium were found in the laboratory, inert screening, furnace, or basement areas (except for one maintenance PBZ "trace" air sample result). The two air samples that resulted in nickel concentrations above the OSHA PEL of $1000 \mu\text{g}/\text{m}^3$ were found in the PBZ (but outside the respirator) of the furnace operator's helper and the laboratory assistant on September 17 and 18, 1998, respectively.

The potential for increased exposure by the furnace operator's helper to the metals mentioned above could be attributed to a number of different

factors. First, change-out of the filters occurs in the Bay areas. Bulk-2 (initial survey, Table 4) analytical results revealed Cr(VI) on a discarded Bay B filter, which may indicate that other metals would be found since the process is known to contain other metals. Second, oversized material is reintroduced into the furnace for remelting from the 55-gallon drum holding containers. The material is taken from the 55-gallon drum and placed into a remelt container at the top of the Bay by taking a can, scooping the material out, and pouring the material into the remelt container. This has the potential for creating an airborne metallic dust. Last, there are employee duties in the lower level (e.g., change-out of collectors underneath cyclone separators). Cr(VI) was found in bulk samples collected in the lower level area.

There is also an increased metal exposure potential to the laboratory assistant resulting from the amount of contact with the powdered material. The assistant is involved with screening a portion of the material to determine the size fractionation and also performing all of the other laboratory duties related to quality assurance and quality control. Handling of different forms of the metal material by the laboratory personnel are routine based on the various tests required in day-to-day activities.

Inert screeners have an increased potential for exposure to metals as well. Screeners are involved in change-out of containers filled with process generated metal material. Containers have to be unattached from the filling process and new empty containers installed. Residual metal dust can be released into the vicinity of the screeners.

The bulk sample Cr(VI) results indicate that there is Cr(VI) in the lower level, ceramic room, and the inert screening areas. There were PBZ and/or area air samples collected in each of these areas that also indicated the presence of Cr(VI).

Crystalline silica (quartz) is associated with silicosis, a fibrotic disease of the lung caused by the deposition of fine particles of crystalline silica in the lungs. However, air and bulk sample results did not indicate the presence of crystalline silica.

Combined Environmental and Medical

The air sampling and biological monitoring results both suggest that there is an occupational exposure potential to nickel at Special Metals Corp.; air samples had concentrations that exceeded current exposure limits. However, workers with the highest potential exposures wore respirators during their regular daily work activities. Although urine nickel levels did not differ significantly between hourly and salaried employees (which might have been expected based on initial assumptions that salaried employees would be less exposed), the evidence still suggests that exposure was occurring in the workplace. The lack of a significant difference between the two groups of employees could occur if exposures were occurring throughout the plant, rather than in any particular location. Also, it is possible that the results were biased; the participation rate was lower for salaried employees compared to hourly employees, and it is possible that salaried employees whose jobs required them to spend time in the plant, and thus have potential exposure to metals, were more likely to participate in the survey. Finally, although the differences were not significant, the urine nickel results consistently showed higher levels in hourly workers; the lack of statistical significance may be the result of small sample size and/or a reduced absorbed dose among hourly workers wearing respirators.

The air sampling results and biomonitoring results for cobalt are ambiguous. The biological monitoring results for cobalt offer no convincing evidence of workplace exposure, however, the environmental results indicated that cobalt was

found in virtually all areas of the plant, and some air samples had cobalt concentrations in excess of current exposure limits. The low urine cobalt levels may be due to the use of respirators and generally low levels of airborne cobalt.

Neither the air sampling results nor the biological monitoring suggest overexposure to chromium. The air sample results indicate the presence of chromium in the facility, albeit below relevant exposure limits. Biological monitoring results suggest that low levels of workplace exposure to chromium may be occurring in a small number of workers.

CONCLUSIONS

Environmental

The results from the collected air and bulk samples indicate that there is potential for overexposure to nickel and cobalt in the laboratory, furnace, and inert screening areas. There is also an increased exposure potential to Cr(VI) and other metals to laboratory, furnace, and inert screening personnel. Virtually all areas and employees sampled indicated exposures to one or more of the metals discussed in this report. Actual exposures to furnace operators, laboratory assistants, and inert screeners are being reduced by respirator use. However, PPE is the least desirable control measure. With the use of the recommendations given at the end of this report, it may be possible to decrease the potential metal exposures to the employees of Special Metals Corp. while reducing reliance on the use of PPE.

Medical

All chromium and cobalt levels in urine were well below their respective biological exposure indices. There is no biological exposure index for nickel in the United States. Urine nickel levels, however, suggested that all 48 participating

employees may have been exposed to nickel at work.

RECOMMENDATIONS

The following recommendations are based on the findings of both initial and follow-up investigations and are offered to improve the safety and health of employees working with materials used in the operations discussed in this report. Items 1 through 7 are based on the findings of the initial visit and were presented in the interim letter. The remaining items followed from the follow-up visit.

1. PBZ exposures of the laboratory assistant, and other laboratory personnel with similar duties, to airborne nickel, cobalt, and total chromium should be reduced. The provision of local exhaust ventilation systems and/or improved area ventilation for the work stations used by these employees should be considered. One work station of particular concern, based upon the general-area air concentration of nickel measured directly adjacent to it, is the sample remelt furnace in the "lab annex" area. In the interim, PPE (respiratory protection) may be used, in which case a written respiratory protection program should be established that includes elements such as fit testing, cleaning and maintenance, and proper selection logic, in accordance with the OSHA Respiratory Protection Standard.²⁰

2. Exposures of workers in several other job descriptions, including the furnace operator, seam welder, inert screener, and H.I.P. lathe operator, to airborne nickel (and also airborne cobalt exposures from the latter job) should be reduced.

3. Housekeeping and hygiene practices should be reviewed to assure they are appropriate, considering the presence of Cr(VI) and nickel in the work environment. Exposures to these substances should be minimized whenever

possible, due to the possibility of carcinogenic effects, since exposure thresholds, below which no risks of adverse effects are posed, have not been demonstrated for any carcinogens. Intermittent re-entrainment of contaminant-laden dusts may result in additional inhalation exposures that are missed by one-time or periodic air sampling. Hygiene practices affect the possibility of exposures by routes other than inhalation, such as ingestion by hand-to-mouth contact.

4. The responsibility for, frequency of, and criteria for periodic replacement of the prefilter and HEPA filter in the ceramic-room ventilation system should be clearly prescribed in a written policy. The policy also should require periodic inspection of the hardware for leakage or other problems, and timely repair of any observed problems. The filter and/or equipment manufacturer should be consulted for recommendations for the installation and use of differential-pressure gauges, which then could be used to determine when particulate loadings require filter changes.

5. To facilitate ease of use, the MSDSs should be grouped within their binders based upon the area of the facility in which each material is used.

6. A technique should be developed for the hand grinding of samples by laboratory personnel that would reduce the risk of injury from the grinder.

7. Potential PBZ exposures of the laboratory assistant, other laboratory personnel with similar duties, and furnace operator helpers to airborne cobalt, total chromium, and nickel should be reduced. Engineering controls are preferred. Use of PPE can then be reduced or eliminated. As stated in the interim letter, recommendations for laboratory personnel, local exhaust ventilation systems and/or improved area ventilation for the work stations used by these employees should be considered. The job requirements naturally lend

themselves to potential exposures to these metals. A similar ventilation system recommended by ACGIH for a movable exhaust hood, (Figure VS-90-02 in ventilation manual)²¹ is one engineering control strategy option to assist in the reduction of PBZ exposures of laboratory personnel to airborne metals. Air sampling should be conducted after exhaust ventilation is installed to ensure that the ventilation is sufficient in controlling the potential metal exposures. In addition, general housekeeping and preventive measures should be taken to avoid the movement of metal particles in dust from areas of the plant where they are generated to other areas of the plant and the offices.

8. Potential PBZ exposures of the inert screeners to airborne cobalt and nickel should be reduced. Although there were no PBZ overexposures of the OSHA PEL to airborne cobalt and nickel, NIOSH REL and ACGIH TLV exposure limits were exceeded. NIOSH encourages employers to follow the more protective evaluation criterion among the OSHA PELs, the NIOSH RELs, or the ACGIH TLVs.

9. During the NIOSH visits, the cleaning of a furnace bay's interior was not conducted. Subsequently, no air or bulk samples were collected and analyzed. However, there may be a considerable potential for exposure to metals during bay cleaning. Employees communicated to NIOSH investigators that bay cleaning is a very dirty process. Based on these conversations, employees involved with this cleaning should wear coveralls (such as Tyvek[®] suits) and the appropriate respirator. Air sampling should be conducted to characterize the potential exposures to metals during this task. This information will assist in the appropriate choice of respirator and other PPE if needed.

10. The initial site visit indicated noise levels in the plant above 90 dBA. Special Metals Corp. should conduct a facility noise survey and personal noise monitoring to identify areas of

potential noise exposure. The OSHA Occupational Noise Exposure Standard²² should be referenced when deciding whether a written noise program should be implemented in the facility according to the results of the noise survey.

11. Although no air sampling was conducted by NIOSH for metal working fluids (MWFs), Special Metals Corp. should develop and implement a MWFs program. Exposure to MWFs can increase the risk for respiratory and skin diseases. Various types of MWFs are used in the facility (i.e., lathe and blade retainer areas). Publications developed by NIOSH can also be consulted when developing an effective MWF program, including the *NIOSH Criteria for a Recommended Standard: Occupational Exposure to Metalworking Fluids* and *What You Need to Know About Occupational Exposure to Metalworking Fluids*.^{23,24}

12. Special Metals Corp. should also conduct air sampling for MWFs in applicable areas to characterize the potential exposures. Fluids should be routinely tested to determine the microbiological burden. Indicators that have been used include: pH of the fluid, endotoxin concentration, and viable microorganisms. The documents listed above discuss fluid use and maintenance.

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Table 1. Initial site visit – limits of detection (LODs), limits of quantitation (LOQs), minimum detectable concentrations (MDCs), and minimum quantifiable concentrations (MQCs) for metals based on 1000 liter air sample volume.

Metal	LODs (µg/filter)	MDCs (µg/m³)	LOQs (µg/filter)	MQCs (µg/m³)
Aluminum (Al)	1.0	1.0	3.5	3.5
Cobalt (Co)	0.2	0.2	0.43	0.43
Chromium (Cr)	0.5	0.5	1.7	1.7
Cr (VI)	0.2	0.2	0.67	0.67
Copper (Cu)	0.08	0.08	0.25	0.25
Iron (Fe)	0.8	0.8	2.5	2.5
Magnesium (Mg)	0.5	0.5	1.7	1.7
Manganese (Mn)	0.01	0.01	0.035	0.035
Molybdenum (Mo)	0.3	0.3	0.85	0.85
Niobium (Nb)	0.8	0.8	Not available	Not available
Nickel (Ni)	0.5	0.5	1.0	1.0
Silicon (Si)	5.0	5.0	17.0	17.0
Titanium (Ti)	0.2	0.2	0.43	0.43
Zirconium (Zr)	0.08	0.08	0.25	0.25

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Table 2. Results from July 24, 1997, air sampling for chromium (VI)

Area	Job title (PBZ samples) or sampling location (AREA samples)	Field sample number	Start time, a.m.	Stop time, p.m.	Airborne concentration of chromium (VI)
Furnace area	Furnace operator	PVC-1	6:57	2:58	Trace
Furnace area	AREA: Furnace-operator control panel	PVC-2	7:09	3:05	ND
Furnace area, lower level	AREA: Middle cyclone-separator platform	PVC-4	7:20	3:09	ND
Inert screening	Inert screener	PVC-8	8:30	2:43	ND
Multiple inspection	AREA: Adjacent to hand grinder	PVC-6	8:39	3:14	ND
H.I.P. lathes	Machine operator	PVC-12	9:29	2:47	ND
Welding	Welder (seam welding)	PVC-3	7:26	2:52	Trace
Ceramic room	Furnace crucible builder/tear-down	PVC-7	8:56	2:42	Trace
Laboratory annex	AREA: atop sample-melt furnace	PVC-5	9:12	3:20	Trace

Trace: The substance was detected in the air (and therefore was present above the minimum detectable concentration [MDC]), but at a concentration below that at which it is reliably quantifiable (the minimum quantifiable concentration [MQC]).

ND: Not detected. The substance was not detected in the air at a concentration at or above the minimum detectable concentration (MDC).

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Table 3. Results from July 24, 1997, air sampling for metals (except chromium [VI])

Area	Job title (PBZ samples) or sampling location (AREA samples)	Field sample no.	Start time, a.m.	Stop time, p.m.	Airborne concentrations of selected* metals, µg/m ³												
					Al	Co	Cr	Cu	Fe	Mg	Mn	Mo	Nb	Ni	Si	Ti	Zr
Furnace area	Furnace operator	AA-1	6:57	2:58	Trace	3.2	7.2	Trace	Trace	Trace	0.08	1.5	ND	24.	ND	1.2	Trace
Furnace area	AREA: Furnace operator control panel	AA-2	7:09	3:05	2.2	5.2	8.2	Trace	Trace	Trace	0.05	1.2	2.2	38.	ND	1.6	ND
Furnace area, lower level	AREA: Middle cyclone-separator platform	AA-4	7:19	3:09	2.8	4.2	6.8	Trace	Trace	1.2	0.01	1.8	1.9	3.3	Trace	1.3	ND
Inert screening	Inert screener	AA-8	8:30	2:47	7.8	17.	27.	Trace	3.0	Trace	0.08	6.6	ND	120	Trace	5.2	Trace
Multiple inspection	AREA: Adjacent to hand grinder	AA-6	8:39	3:14	Trace	0.70	Trace	Trace	0.7	ND	0.06	ND	ND	3.4	Trace	Trace	Trace
H.I.P. lathes	Machine operator	AA-10	9:29	2:46	Trace	43.	4.1	Trace	Trace	Trace	0.13	Trace	ND	19.	Trace	0.86	ND
Welding	Welder (seam welding)	AA-3	7:26	2:51	6.7	1.7	12.	1.2	47.	1.0	5.1	1.7	ND	15.	Trace	1.1	Trace
Ceramic room	Furnace crucible builder/tear-down	AA-11	8:54	2:41	8.6	2.1	7.2	Trace	Trace	Trace	0.11	ND	ND	8.5	Trace	Trace	ND

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Table 3 (Continued). Results from July 24, 1997, air sampling for metals (except chromium [VI]).

Area	Job title (PBZ samples) or sampling location (AREA samples)	Field sample no.	Start time, a.m.	Stop time, p.m.	Airborne concentrations of selected* metals, µg/m ³												
					Al	Co	Cr	Cu	Fe	Mg	Mn	Mo	Nb	Ni	Si	Ti	Zr
Ceramic room	Ceramic-material machining	AA-7	9:00	1:58	5.7	1.5	2.6	Trace	1.5	Trace	0.06	ND	ND	7.2	Trace	Trace	Trace
Laboratory	Laboratory assistant	AA-14	9:50	2:53	140	320	530	1.6	16.	Trace	0.29	140	36.	2500	32.	110	2.4
Laboratory annex	AREA: atop sample-melt furnace	AA-5	9:12	3:20	10	22.	30.	9.2	13.	Trace	0.22	4.9	4.6	170	Trace	4.3	Trace

* Each sample also was analyzed for lead (for which most results were ND, but “trace” concentrations were detected for samples AA-1, AA-4, AA-8, AA-7, and AA-14), selenium and tantalum (neither were detected), and yttrium (for which all but one result was “ND,” and a “trace” concentration was detected for sample AA-7).

Trace: The substance was detected in the air (and therefore was present above the minimum detectable concentration [MDC]), but at a concentration below that at which it is reliably quantifiable (the minimum quantifiable concentration [MQC]).

ND: Not detected. The substance was not detected in the air at a concentration at or above the minimum detectable concentration (MDC).

Substance symbols: Al, aluminum; Co, cobalt; Cr, chromium; Cu, copper; Fe, iron; Mg, magnesium; Mn, manganese; Mo, molybdenum; Nb, niobium (columbium); Ni, nickel; Si, silicon; Ti, titanium; and, Zr, zirconium.

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Table 4. Results from July 24, 1997, bulk-material sampling for chromium (VI).

Area	Description of bulk material collected	Field sample number	Chromium (VI) composition of collected material, $\mu\text{g Cr(VI)/g material}$
Furnace area	Material from floor near furnace and discarded "Bay B" filter	Bulk-2	95
Furnace area, lower level	Material from floor, near cyclone separators	Bulk-3	ND
Multiple inspection	Material from floor adjacent to hand grinder	Bulk-4	Trace
Polishing belt-type grinder	Material from the dust collector on this device	Bulk-5	Trace
Ceramic room	Material from furnace crucible tear-down	Bulk-1	3200
Laboratory annex	Material from sample-melt furnace	Bulk-6	ND

Trace: The substance was detected in the bulk material (and therefore was present above the analytical limit of detection [LOD]), but at a concentration below that at which it is reliably quantifiable (the analytical limit of quantification [LOQ]).

ND: Not detected. The substance was not detected in the bulk material at a concentration at or above the analytical limit of detection (LOD).

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Table 5. Results from September 17, 1998, air sampling for chromium (VI)

Area	Job title (PBZ samples) or sampling location (AREA samples)	Field sample number	Start time	Stop time	Analytical Method	Airborne Cr(VI) ($\mu\text{g}/\text{m}^3$)
Ceramic Room	Machinist	CR6 - 15	7:30 a.m.	2:52 p.m.	NMAM 7703	Trace
Furnace Bay A	Furnace operator	CR6 - 6	7:35 a.m.	2:45 p.m.	NMAM 7600	0.23
Furnace Bay A	Furnace operator	CR6 - 5	7:38 a.m.	2:41 p.m.	NMAM 7703	ND
Maintenance	Maintenance	CR6 - 2	7:42 a.m.	3:03 p.m.	NMAM 7600	Trace
Plant - wide	Preventive maintenance	CR6 - 4	7:47 a.m.	2:49 p.m.	NMAM 7703	ND
Blade Retainer	Machinist	CR6 - 11	7:53 a.m.	2:34 p.m.	NMAM 7703	ND
Inert Screening	Inert screener	CR6 - 13	8:00 a.m.	2:47 p.m.	NMAM 7600	Trace
Welding	Welder	CR6 - 14	8:05 a.m.	2:42 p.m.	NMAM 7703	Trace
Lathes	Lathe operator	CR6 - 16	8:09 a.m.	2:40 p.m.	NMAM 7703	ND
Lathes	Lathe operator	CR6 - 10	8:15 a.m.	2:46 p.m.	NMAM 7600	0.13
Laboratory	Lab technician	CR6 - 12	8:21 a.m.	3:01 p.m.	NMAM 7703	Trace
Collector Maintenance	Collector cleaner	CR6 - 1	8:26 a.m.	2:40 p.m.	NMAM 7600	ND
Plant - wide	Janitor	CR6 - 9	8:38 a.m.	2:47 p.m.	NMAM 7703	ND

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Table 5 (Continued). Results from September 17, 1998, air sampling for chromium (VI)

Area	Job title (PBZ samples) or sampling location (AREA samples)	Field sample number	Start time	Stop time	Analytical Method	Airborne Cr(VI) ($\mu\text{g}/\text{m}^3$)
Inert Screening	AREA – on No. 5 screener platform	CR6 – 8	8:46 a.m.	3:29 p.m.	NMAM 7600	0.10
Furnace area, Lower Level	AREA – above collector @ Bay B	CR6 – 7	8:49 a.m.	3:05 p.m.	NMAM 7600	0.27
Laboratory	Lab assistant	CR6 – 3	10:51 a.m.	10:47 p.m.	NMAM 7600	Trace
Inert Screening	Inert screener	CR6 – 17	3:20 p.m.	10:40 p.m.	NMAM 7600	Trace
Inert Screening	Inert screener	CR6 – 18	3:17 p.m.	10:29 p.m.	NMAM 7600	Trace
Maintenance	Maintenance	CR6 – 19	3:29 p.m.	10:34 p.m.	NMAM 7600	Trace
Furnace Bay B	Furnace helper	CR6 – 20	3:18 p.m.	10:34 p.m.	NMAM 7600	0.38
Laboratory	Lab technician	CR6 – 21	3:37 p.m.	10:47 p.m.	NMAM 7600	0.12
Lathes	Lathe operator	CR6 – 22	3:35 p.m.	10:40 p.m.	NMAM 7600	ND
Furnace area, Lower Level	AREA – above collector @ Bay B	CR6 – 23	3:50 p.m.	10:57 p.m.	NMAM 7600	0.24

Trace: The substance was detected in the air (and therefore was present above the minimum detectable concentration [MDC]), but at a concentration below that at which it is reliably quantifiable (the minimum quantifiable concentration [MQC]).

ND: Not detected. The substance was not detected in the air at a concentration at or above the minimum detectable concentration (MDC).

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Table 6. Results from September 18, 1998, air sampling for chromium (VI)

Area	Job title (PBZ samples) or sampling location (AREA samples)	Field sample number	Start time	Stop time	Analytical Method	Airborne Cr(VI) ($\mu\text{g}/\text{m}^3$)
Furnace Bay A	Furnace helper	CR6 - 26	7:23 a.m.	3:01 p.m.	NMAM 7703	ND
Maintenance	Maintenance	CR6 - 27	7:30 a.m.	2:46 p.m.	NMAM 7703	ND
Inert Screening	Inert screener	CR6 - 39	7:35 a.m.	2:39 p.m.	NMAM 7703	Trace
Containerize	Can filler	CR6 - 30	7:37 a.m.	2:44 p.m.	NMAM 7600	Trace
Blade Retainer	Machinist	CR6 - 36	7:41 a.m.	2:40 p.m.	NMAM 7600	ND
Collector Maintenance	Collector cleaner	CR6 - 25	7:47 a.m.	2:37 p.m.	NMAM 7703	ND
Saw	Saw operator	CR6 - 31	7:51 a.m.	2:38 p.m.	NMAM 7703	Trace
Saw	Saw operator	CR6 - 34	7:51 a.m.	2:38 p.m.	NMAM 7600	Trace
Lathes	Lathe operator	CR6 - 41	7:56 a.m.	2:42 p.m.	NMAM 7703	Trace
Lathes	Lathe operator	CR6 - 33	7:59 a.m.	2:51 p.m.	NMAM 7600	ND
Belt Polishing	Polishing machine operator	CR6 - 37	8:04 a.m.	2:43 p.m.	NMAM 7703	Trace
Plant - wide	Janitor	CR6 - 35	8:07 a.m.	2:41 p.m.	NMAM 7600	ND
Laboratory	Lab technician	CR6 - 28	8:14 a.m.	2:58 p.m.	NMAM 7600	0.14
Office	AREA - general open space	CR6 - 29	8:31 a.m.	3:04 p.m.	NMAM 7600	ND
Furnace Bay B	AREA - top level, on step rail	CR6 - 38	8:38 a.m.	3:00 p.m.	NMAM 7703	Trace
Furnace Bay B	AREA - top level, on step rail	CR6 - 40	8:38 a.m.	2:58 p.m.	NMAM 7600	Trace
Laboratory	Lab assistant	CR6 - 32	11:13 a.m.	3:04 p.m.	NMAM 7703	ND
Inert Screening	Inert screener	CR6 - 48	3:15 p.m.	10:26 p.m.	NMAM 7600	ND

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Table 6 (Continued). Results from September 18, 1998, air sampling for chromium (VI)

Area	Job title (PBZ samples) or sampling location (AREA samples)	Field sample number	Start time	Stop time	Analytical Method	Airborne Cr(VI) ($\mu\text{g}/\text{m}^3$)
Blade Retainer	Machinist	CR6 - 49	3:13 p.m.	10:26 p.m.	NMAM 7600	0.16
Maintenance	Maintenance	CR6 - 50	3:25 p.m.	10:31 p.m.	NMAM 7600	Trace
Laboratory	Lab technician	CR6 - 51	3:30 p.m.	10:42 p.m.	NMAM 7600	ND
Lathes	Lathe operator	CR6 - 52	3:27 p.m.	10:38 p.m.	NMAM 7600	Trace
Furnace Bay B	AREA - top level, on step rail	CR6 - 53	3:45 p.m.	10:45 p.m.	NMAM 7600	0.16
Furnace Bay B	AREA - top level, on step rail	CR6 - 54	3:45 p.m.	10:45 p.m.	NMAM 7600	Trace
Furnace Bay B	Furnace operator	CR6 - 55	3:20 p.m.	10:35 p.m.	NMAM 7600	0.12

Trace: The substance was detected in the air (and therefore was present above the minimum detectable concentration [MDC]), but at a concentration below that at which it is reliably quantifiable (the minimum quantifiable concentration [MQC]).

ND: Not detected. The substance was not detected in the air at a concentration at or above the minimum detectable concentration (MDC).

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Table 7. Results from September 17, 1998, air sampling for cobalt (Co), total chromium (Cr), niobium (Nb), and nickel (Ni)

Area	Job title (PBZ samples) or sampling location (AREA samples)	Field sample number	Start time	Stop time	Airborne Concentration ($\mu\text{g}/\text{m}^3$)			
					Co	Cr	Nb	Ni
Ceramic Room	Machinist	MCE - 3	7:30 a.m.	2:54 p.m.	0.91	Trace	ND	3.6
Furnace Bay B	Furnace helper	MCE - 1	7:33 a.m.	2:50 p.m.	172	274	10	1373
Furnace Bay B	Furnace operator	MCE - 2	7:40 a.m.	3:38 p.m.	4.6	7.9	Trace	37
Maintenance Department	Maintenance	MCE - 15	7:42 a.m.	3:02 p.m.	3.2	4.7	ND	17
Plant - wide	Preventive Maintenance	MCE - 8	7:46 a.m.	2:49 p.m.	2.0	3.1	ND	14
Containerizing	Can filler	MCE - 5	7:50 a.m.	2:44 p.m.	ND	ND	ND	4.4
Blade Retainer	Machinist	MCE - 9	7:54 a.m.	2:34 p.m.	4.1	Trace	ND	5.4
Inert Screening	Inert screener	MCE - 14	8:00 a.m.	2:48 p.m.	23	34	5.8	158
Saw	Saw operator	MCE - 16	8:07 a.m.	2:39 p.m.	ND	ND	ND	6.3
Lathes	Lathe operator	MCE - 10	8:12 a.m.	2:56 p.m.	0.99	Trace	ND	9.0
Laboratory	Lab technician	MCE - 4	8:21 a.m.	3:02 p.m.	71	78	7.7	349
Collector Maintenance	Collector cleaner	MCE - 6	8:26 a.m.	2:40 p.m.	1.3	2.4	ND	9.5
Lathes	Lathe operator	MCE - 7	8:32 a.m.	1:46 p.m.	ND	5.7	ND	10
Plant - wide	Janitor	MCE - 13	8:38 a.m.	2:46 p.m.	14	11	ND	52
Inert Screening	AREA - on No. 5 screener platform	MCE - 12	8:46 a.m.	3:28 p.m.	1.4	2.6	ND	14
Furnace area, Lower Level	AREA - above collector @ Bay B	MCE - 11	8:49 a.m.	3:07 p.m.	Trace	Trace	ND	7.8
Laboratory	Lab assistant	MCE - 17	10:51 a.m.	10:47 p.m.	51	44	6.4	217

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Table 7 (Continued). Results from September 17, 1998, air sampling for cobalt (Co), total chromium (Cr), niobium (Nb), and nickel (Ni)

Area	Job title (PBZ samples) or sampling location (AREA samples)	Field sample number	Start time	Stop time	Airborne Concentration ($\mu\text{g}/\text{m}^3$)			
					Co	Cr	Nb	Ni
Inert Screening	Inert screener	MCE - 18	3:15 p.m.	10:29 p.m.	14	23	6.2	115
Blade Retainer	Machinist	MCE - 19	3:25 p.m.	10:52 p.m.	1.7	3.5	ND	18
Maintenance	Maintenance	MCE - 20	3:27 p.m.	10:33 p.m.	2.3	4.8	ND	24
Laboratory	Lab technician	MCE - 22	3:37 p.m.	10:47 p.m.	1.7	2.1	ND	11
Lathes	Lathe operator	MCE - 21	3:35 p.m.	10:40 p.m.	1.8	3.8	ND	20
Inert Screening	AREA - on No. 5 screener platform	MCE - 23	3:55 p.m.	10:55 p.m.	4.2	7.6	Trace	41
Furnace area, Lower Level	AREA - above collector @ Bay B	MCE - 24	3:50 p.m.	10:57 p.m.	ND	ND	ND	ND

Trace: The substance was detected in the air (and therefore was present above the minimum detectable concentration [MDC]), but at a concentration below that at which it is reliably quantifiable (the minimum quantifiable concentration [MQC]).

ND: Not detected. The substance was not detected in the air at a concentration at or above the minimum detectable concentration (MDC).

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Table 8. Results from September 18, 1998, air sampling for cobalt (Co), total chromium (Cr), niobium (Nb), and nickel (Ni)

Area	Job title (PBZ samples) or sampling location (AREA samples)	Field sample number	Start time	Stop time	Airborne Concentration ($\mu\text{g}/\text{m}^3$)			
					Co	Cr	Nb	Ni
Furnace Bay A	Furnace operator	MCE - 29	7:20 a.m.	2:45 p.m.	19	24	Trace	85
Maintenance Department	Maintenance	MCE - 31	7:30 a.m.	2:57 p.m.	9.8	12	Trace	50
Inert Screening	Inert screener	MCE - 26	7:36 a.m.	2:36 p.m.	30	38	9.3	198
Blade Retainer	Machinist	MCE - 41	7:41 a.m.	2:40 p.m.	5.3	5.0	ND	24
Welding	Welder	MCE - 38	7:45 a.m.	2:50 p.m.	1.7	5.3	ND	14
Collector Maintenance	Collector cleaner	MCE - 27	7:47 a.m.	2:37 p.m.	Trace	Trace	ND	6.2
Lathes	Lathe operator	MCE - 37	7:54 a.m.	2:46 p.m.	5.0	6.2	ND	25
Lathes	Lathe operator	MCE - 33	8:12 a.m.	2:42 p.m.	3.0	3.4	ND	16
Belt Polishing	Polishing machine operator	MCE - 36	8:05 a.m.	2:43 p.m.	Trace	Trace	ND	4.8
Plant - wide	Janitor	MCE - 35	8:07 a.m.	2:41 p.m.	1.7	2.4	ND	12
Laboratory	Lab technician	MCE - 34	8:14 a.m.	2:58 p.m.	2.1	Trace	ND	11

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Table 8 (Continued). Results from September 18, 1998, air sampling for cobalt (Co), total chromium (Cr), niobium (Nb), and nickel (Ni)

Area	Job title (PBZ samples) or sampling location (AREA samples)	Field sample number	Start time	Stop time	Airborne Concentration ($\mu\text{g}/\text{m}^3$)			
					Co	Cr	Nb	Ni
Office	AREA – general open space	MCE – 40	8:31 a.m.	3:04 p.m.	ND	ND	ND	Trace
Furnace Bay B	AREA – top level, on step rail	MCE – 28	8:38 a.m.	2:58 p.m.	5.0	7.2	Trace	36
Laboratory	Lab assistant	MCE – 32	11:13 a.m.	3:04 p.m.	276	220	20	1087
Inert Screening	Inert screener	MCE – 44	3:17 p.m.	10:28 p.m.	Trace	Trace	ND	9.1
Inert Screening	Inert screener	MCE – 45	3:16 p.m.	10:29 p.m.	5.4	8.6	Trace	47
Maintenance	Maintenance	MCE – 46	3:25 a.m.	10:32 p.m.	Trace	Trace	ND	7.2
Furnace Bay B	Furnace helper	MCE – 47	3:20 p.m.	10:35 p.m.	33	59	14	267
Laboratory	Lab technician	MCE – 48	3:30 p.m.	10:42 p.m.	ND	ND	ND	2.4
Lathes	Lathe operator	MCE – 49	3:27 p.m.	10:38 p.m.	ND	ND	ND	1.3
Furnace Bay B	AREA – top level, on step rail	MCE – 50	3:45 p.m.	10:15 p.m.	ND	Trace	ND	7.4

Trace: The substance was detected in the air (and therefore was present above the minimum detectable concentration [MDC]), but at a concentration below that at which it is reliably quantifiable (the minimum quantifiable concentration [MQC]).

ND: Not detected. The substance was not detected in the air at a concentration at or above the minimum detectable concentration (MDC).

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Table 9. Results from September 18, 1998, bulk-material sampling for chromium (VI)

Area	Description of bulk material collected	Field sample number	Chromium (VI) composition of collected material, $\mu\text{g Cr(VI)/g material}$
Ceramic room	Residue from "used" furnace	Bulk-1	71
Furnace area, Lower level	Waste material from old collector	Bulk-2	0.62
Inert screening	Surface vacuum of support structure	Bulk-5	35
Furnace area, Lower level	Surface vacuum, side of electric panel	Bulk-6	Trace

Trace: The substance was detected in the bulk material (and therefore was present above the analytical limit of detection [LOD]), but at a concentration below that at which it is reliably quantifiable (the analytical limit of quantification [LOQ]).

ND: Not detected. The substance was not detected in the bulk material at a concentration at or above the analytical limit of detection (LOD).

For Information on Other
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