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Hard Metal Exposures. Part 2: Prospective Exposure Assessment

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Hard metal exposures may precipitate lung disease in exposed workers. This article reports on a project investigating the relationship between local exhaust hood air flow levels and workplace hard metal exposures. Airborne cobalt, chromium, and cadmium exposure concentrations, and ventilation system function were monitored for three consecutive days prior to installation of three new ventilation systems, and then were followed monthly for one year. Work activities included wet and dry grinding of saw blades, brazing, welding, and setup. Work task exposures were highly variable over the period of the study. Ventilation air flows failed to meet design goals due to low total air volume and poor distribution; however, worker exposures to metals were controlled in most cases. Hood design, worker acceptance, and use of the hoods were as important in controlling exposures as were exhaust hood air flow levels.

Keywords Hard Metal, Cobalt, Cadmium, Metal Exposures, Tungsten Carbide, Stellite, Ventilation, Intervention Research

Hard metal exposure is known to cause interstitial lung disease and asthma.(1–6) The Field Research and Consultation Group (FRCG) at the University of Washington has documented elevated cobalt and cadmium exposures in resharpening shops, tool manufacturing, and saw filing shops statewide. The University of British Columbia Department of Health Care and Epidemiology found that saw filers, particularly those grinding tungsten carbide or welding stellite, showed varying signs of reduced lung function.(2,7) In response, the Washington State Labor and Industries (WSL&I) issued a "Hazard Alert" to the hard metal tool producers and resharpeners in March 1995.(8)

Cobalt and chromium are metal constituents of the tips of machining tools and saw. Cobalt is used as a binder in tungsten carbide tips, and cobalt and chromium together make up the alloy metal called stellite. Wet grinding tungsten carbide results in higher cobalt exposures than dry grinding tungsten carbide or stellite(2,7,9,10) Cadmium has limited use in the industry, but was once used in the silver solder used to affix carbide tips to saw bodies. Cadmium continues to pose a hazard because of its widespread presence on older saws; it has been associated with kidney damage and lung disease.

Previous worker exposure and engineering control studies have focused primarily on cobalt and wet grinding.(11–14) Linnainmaa found workers' exposure to cobalt was reduced substantially after installation of effective enclosing hoods and local exhausts on wet grinding machines.(12) In most reports in which local exhaust ventilation is cited as the primary exposure control, limited information is available describing the ventilation system design, long-term effectiveness in controlling exposures, or maintenance strategies. A Washington State company had been cited by the state Occupational Safety and Health Administration (OSHA) for overexposures to cobalt and was interested in renovating an existing ventilation system to better control hard metal particulate exposures. They agreed to work with the Field Research and Consultation Group from the University of Washington to evaluate effectiveness of the new ventilation system. Worker cobalt exposures in the saw reconditioning company exceeded the Washington State Permissible Exposure Level (PEL) of 50 $\mu g/m^3$ at seven of eight work stations. A local ventilation engineer worked with the company to design three new ventilation systems according to the methods described in the 22nd edition of *Industrial Ventilation, A Manual of Recommended Practice*.(15)

The company directed a local ventilation service contractor to install the three separate systems in the different areas of the shop, one system in the band saw area and two systems in the round saw area. One round way area system was designed to accommodate wet grinding activities and the other was designed to accommodate dry grinding activities. The installed systems deviated from the original design in a number of ways. Due to fiscal constraints and changes in production floor layout, the company: (1) used an existing fan to exhaust the band saw system, (2) declined to install all of the hoods included in the original designs, (3) used flexible ducts for many of the branches, and (4) added branches to the systems that were not included in the original design.

The goal of this project was to better understand the effectiveness of a company-installed ventilation system and its ability to reduce workplace exposures over time. The prospective study design included repeated measures of metal concentrations and ventilation parameters over a period of one year. A more detailed description of the ventilation system design and function is presented elsewhere (Part I). The specific aims of the exposure assessment portion of the project were to: (1) characterize hard metal exposures before and after the installation of the ventilation systems, (2) assess the exposure variability over time, (3) conduct task analysis to characterize locations, materials, and worker activity, and (4) compare personal exposures to hood air flow for each ventilation system.

METHODS

Worker activities and related exposures were followed monthly over the course of a year. In addition, various ventilation parameters were assessed during a similar time frame on a monthly basis. All 12 hard metal production workers in the company were eligible to participate in the project. Eight workers who were engaged in grinding and brazing activities consented to participate throughout the year.

Worker Activities

Worker activities and material worked were unique in each work area of the shop. The shop areas in this project included the band saw and round saw areas, with the round saw area divided into the wet and dry areas. Worker activities were monitored throughout each sampling day (Table I). Basic work area tasks are described below.

Band Saw

Three band saw workers operated seven machines along the north wall of the band saw area. Five of the machines were used for swedging/grinding steel-tipped saws and two were usually used for grinding stellite-tipped saws. Workers usually monitored two of these machines at once. Swedging is an automated process in which the steel tooth is "swedged" or formed out of the initial steel tooth pattern with a diebar and shaper. The machine then sharpens each steel tooth by dry grinding the tooth face. One worker from this area of the band saw room (steel grinder) participated in the study.

Another band saw area worker (stellite grinder/welder #1) was stationed along the east wall of the area, where he performed such tasks as resistive welding, annealing, and dry grinding. Stellite-tips first were manually welded onto saw bodies, and then automatically annealed by an unenclosed torch (Figure 1).

TABLE I
Duration of tasks by job title post intervention

	Days			Duration (minutes) of metalworking activities[A]					
Job title	Observed	Setup[C] mean (SD)	DG ST[B] mean (SD)	DG TC[B] mean (SD)	DG/W SL[B] mean (SD)	Brazing mean (SD)	WG ST[B] mean (SD)	WG TC[B] mean (SD)	Other[B] mean (SD)
Band saw									
Steel grinder	8	99 (54)	294 (61)		6 (16)				6 (16)
Stellite grinder/ welder #1	13	103 (40)			301 (39)	1 (4)			
Round saw dry									
Brazer #1	11	80 (36)	55 (65)	26 (47)		95 (50)	4 (13)	45 (59)	100 (39)
Brazer #2	11	83 (48)	5 (12)	18 (32)		130 (93)	38 (69)	15 (34)	116 (80)
Stellite grinder/ welder #2	11	95 (59)			259 (78)	8 (19)	1 (5)	19 (63)	23 (45)
Round saw wet									
Automatic grinder	8	82 (31)					4 (11)	300 (53)	19 (26)
Manual grinder	11	70 (49)		1 (5)			4 (14)	237 (114)	93 (110)
Tool grinder	11	94 (33)	64 (71)	8 (28)	27 (81)	3 (9)	56 (75)	64 (84)	89 (46)

[A]Worker activities were recorded at 15-minute intervals during each observed shift. The number of observations were multiplied by 15 minutes. A total of 405 minutes of observed activities were recorded per shift (excluding lunch and breaks).
[B]The following are abbreviations for activities: DG ST = dry grinding steel, DG TC = dry grinding tungsten carbide, DG/W SL = dry grinding and welding stellite, WG ST = wet grinding steel, WG TC = wet grinding tungsten carbide. Other refers to non-hard metal activities.
[C]Setup includes worker process setup and researcher sampling setup.

After all the saw tips were attached to the saw body, the saw was transferred to a side dresser. A side dresser performs dry grinding at two points: one point grinds the sides of each tooth and another point grinds the tooth face and top. This worker often stood beside the welding machine throughout the work shift.

Round Saw-Dry

The round saw-dry area included two brazer stations and one stellite grinder/welder station. The brazers engaged in some wet and dry grinding of steel and tungsten carbide. The brazing area included a sand blaster, two facer/toppers, a polisher, and a pedestal grinder. The stellite grinder/welder #2 was responsible for reconditioning stellite-tipped saws. He performed both dry grinding and tungsten inert gas (TIG) welding activities; he also used a side dresser, topper, and/or facer machines for grinding.

Round Saw-Wet

Two workers in the round saw-wet area performed wet grinding activities on tungsten carbide and stellite; the manual grinder did manual grinding and the automatic grinder operated automatic grinding machines. Both manual and automatic wet grinding activities were conducted on toppers, facers, and side dressers. A water-soluble metal working fluid (MWF) was used for cooling and removing fines created in the grinding process. The manual wet grinding in this area required the worker to sharpen each tooth individually while standing close to the saw, which was placed at eye level. In contrast, the automatic wet grinder operator set up saws on a number of machines, made necessary adjustments, started the machines, and then went on to other tasks. The automatic wet grinder operator also worked a fully enclosed automatic topper. Tool grinders were also responsible for such activities as wet grinding and machining steel or babbit molds, and knife grinding. Many of the tool grinder tasks were performed simultaneously throughout the work shift.

Task Analysis of Worker Activity

Each participating worker was observed throughout the sampled workday by the project team. An observation-based task analysis of worker activities was conducted to better understand work practices, proximity to equipment, and materials used. Worker location by area, activity, and material worked were recorded at 15-minute intervals. Observations were conducted each shift for 6.75 hours (excluding 75 minutes used for lunch and two breaks). Only work activities observed at each point of observation point were recorded. Activities conducted between the observation points were assumed to be the same as those observed every 15 minutes. Twenty-seven observations were made each shift, accounting for 405 minutes of observed work activity. The activities observed included: wet grinding, dry grinding, brazing, welding, setup, and other less frequent activities (e.g., machining non-hard metal, waxing blades, or pouring babbit). The material worked was recorded as tungsten carbide, stellite, or steel. The stellite grinder/welders #1 and #2 operated two machines simultaneously that did dry grinding and welding, and therefore, an additional category was defined as dry grinding/welding stellite. The recorded observations did not include activities performed by adjacent workers.

The task analysis data were used to estimate the duration of tasks by job title. The total time in minutes of each task was estimated by multiplying the number of observations at a given

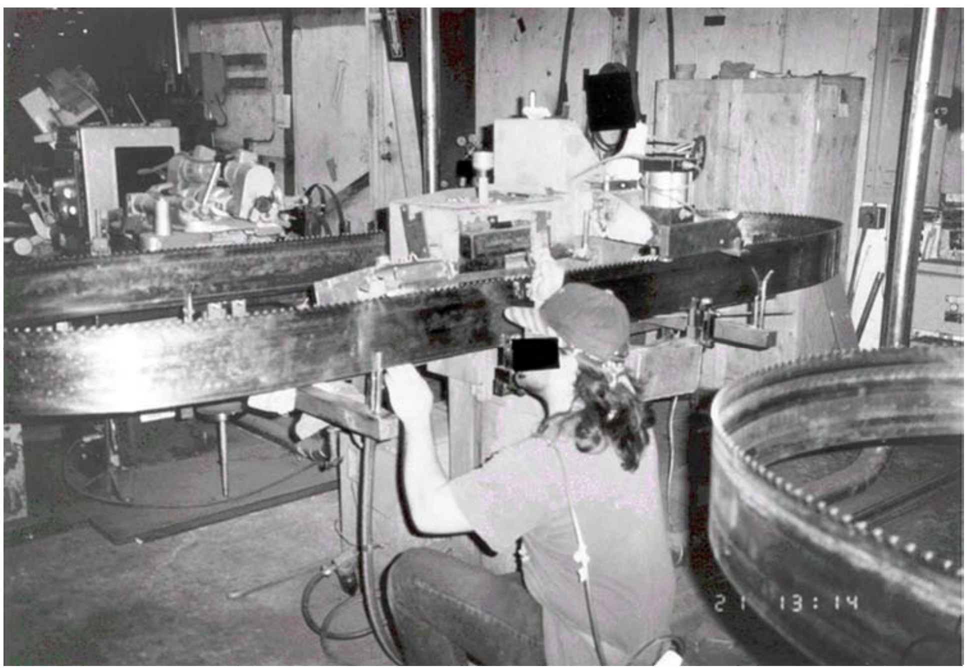

FIGURE 1
Worker checking a stellite-tipped band saw during welding and annealing.

task by 15 (minutes per observation). The mean and standard deviation of the duration of each task was calculated for each job title (Table I).

Exposure Assessment

Airborne cobalt, chromium, and cadmium particulate concentrations were monitored in July 1995, on three consecutive days prior to installation of the three new ventilation systems. Exposures to the same workers were assessed immediately after the installation of the ventilation systems, and then for one shift each month, thereafter, for one year. The Washington State Permissible Exposure Level (PEL) is 50 $\mu g/m^3$ for cobalt, 5 $\mu g/m^3$ for cadmium, and 500 $\mu g/m^3$ for chromium. The American Conference of Governmental Industrial Hygienists®(ACGIH®) has established an eight hour time-weighted average (TWA) threshold limit value®(TLV®) for cobalt at 20 $\mu g/m^3$.[16] The exposure assessment discussion focuses primarily on worker cobalt exposures.

All personal samples were collected with the IOM (Institute of Occupational Medicine, Edinburgh, United Kingdom) sampler containing a 25-millimeter (mm), 0.8-micrometer (um) pore size mixed cellulose ester filter. The IOM sampling device was chosen for this project to better understand the sampler's performance under field conditions, and to collect the inhalable particulate mass as recommended by the ACGIH and add to the literature on the use of IOM sampler.[17,18] In addition, the IOM models particulate behavior in the human respiratory system. The IOM device collects most sizes of particulates expected to penetrate the lower lung and thoracic portion of the respiratory system, and 50 percent of the particulates reaching the nasal region. Several studies have shown that the IOM sampler collects up to 3.5 times more particulate than does the closed-face cassette.[19–22] Strict comparison of the IOM-generated data to the regulatory limits is problematic. The Washington State PEL (50 $\mu g/m^3$) was used as a benchmark for comparison purposes only.

Sampling flow rate was at 2.0 liters per minute (lpm) as specified for the IOM sampling protocol. Gillian HFS-115 and SKC sampling pumps were pre- and post-calibrated using a Gilibrator (Model D80026A, Gillian Corporation, West Caldwell, NJ). Following field use, assembly components of the IOM were cleaned in a washing machine with soap, dried with air, and reassembled for future use.

Laboratory Quality Assurance

The accredited Department of Environmental Health (DEH) Laboratory analyzed filters for chromium, cobalt, and cadmium using a modified version of National Institute for Occupational Safety and Health (NIOSH) methods #7024, #7027, and #7048, respectively. In general, the method quantitation limits (MQLs) for cobalt, cadmium, and chromium were < 0.8, < 0.5, and < 0.8 ug/filter, respectively. For statistical purposes, concentrations which fell below the MQL were calculated by dividing the MQL by the square root of 2.

Fifty-two quality assurance samples were analyzed for all three metals or for one metal, depending on the sample type. Three different types of samples were used to evaluate laboratory precision and accuracy: laboratory spiked samples, American Industrial Hygiene Association (AIHA) samples, and NIOSH PAT samples. AIHA and NIOSH PAT samples were not available for cobalt. The laboratory recovery efficiencies for all samples of cobalt ($n = 18$), cadmium ($n = 31$), and chromium ($n = 34$) were 102 (± 5), 101 (± 4), and 100 (± 5), respectively.

Field Quality Assurance

All field quality assurance samples were handled, stored, and transported in the same manner as field samples. Twenty field blanks and twelve field spikes were collected and submitted during the study period. Field blanks were collected during most sampling months. Field spikes were prepared by the DEH Laboratory for field use. During sampling months 7 through 13, two field spikes per sampling month were submitted blindly to the laboratory for analysis. Cobalt, cadmium, and chromium concentrations were not detected in 19 of the 20 field blanks. The remaining field blank sample had measurable cobalt levels present. The source of this contamination is unknown. The mean field spike recovery efficiencies for cobalt, cadmium, and chromium samples were 102 percent, 104 percent, and 106 percent, respectively.

Ventilation Design and Assessment

Each of the three work areas, band saw, round saw wet, and round saw dry had three separate ventilation systems each with several workstations. A workstation was defined as the specific area where each worker conducted his or her primary work tasks (figures of each work area and their specific workstations are presented in Part I). The number of machines at each workstation ranged from two to eight. For example, in the band saw work area there were 10 machines with accompanying hoods; however, the steel grinder workstation included only machines attached to hoods 4 and 5 and the stellite grinder/welder #1 workstation included machines attached to hoods 8 to 10. The round saw dry ventilation work area contained 14 different machines. Here the stellite grinder/welder #2 workstation included machines using hoods 1 to 8, and the brazers used machines connected to hoods 9 to 14. The round saw wet work area contained 10 different machines; machines with hoods (1, 2, 4, 5 and [3, 6, 7] and [8, 9, 10]) were workstations for the automatic wet grinder, manual wet grinder, and tool grinder, respectively.

Several months after the ventilation systems were installed, new hoods were designed by company management and the project team to address continued elevated personal exposures to cobalt. The new hoods included enclosing hoods designed for the band saw area stellite grinding machine (hoods 8 and 9). Additional hoods were designed for the round saw dry brazing workstations (hoods 10 and 13) to reduce cadmium exposures (Figure 2).

Velocity pressure measurements of the three systems were made during or shortly after each personal exposure sampling day. Velocity pressures were taken using Dwyer stainless steel Pitot tubes (model 167, 1/8-inch diameter, 6-inch maximum insertion depth, 1.5-inch lead tube, Michigan City, IN). Velocity pressures were logged electronically from the Alnor Compu-Flow ElectroManometer (Model 8530D-I) to a computer-using commercially available ventilation software (HV_Meas).[23] An Olympic borescope with 3/4 inch diameter and 20 inch length also was used to examine the duct work and hood interior. Wet and dry bulb temperatures were recorded during each sampling day from values taken using a battery-powered psychrometer (Cole-Parmer Psychro-Dyne).

Velocity pressure measurements were used to calculate work area-specific total air flow and workstation-specific hood air flow. Total air flow is a measure of overall system performance, and is most likely to be used by plant personnel to evaluate ventilation system performance. In this project, total air flow was found to decrease over time in all three ventilation systems (calculations and results are presented in Part I). Total air flow in each system was also compared to the average cobalt exposures each month for which both measures were available to determine whether or not exposures changed in relation to total air flow (two to three individual full-shift exposures were used to estimate the average cobalt exposure).

To better understand the influence of ventilation system function on individual worker exposure, total hood air flow at each workstation was compared to individual worker cobalt exposure. The total hood air flow was the sum of the air flow from individual hoods at each workstation. For example, the automatic wet grinder used machines attached to hoods 1, 2, 4, and 5; the air flow of these hoods was summed to determine total hood air flow for this workstation. The total hood air flow of this workstation was then compared to the individual worker's cobalt concentration each month. Two workers, the automatic grinder and the stellite grinder/welder #2, are selected here to show the relationship found between individual cobalt exposure and average hood air flow at a designated workstation (Figures 6 and 7).

The weighted sum of workstation hood air flow based on the time the worker spent at each machine would have been a better indicator of the effectiveness of the workstation-specific ventilation in controlling individual worker exposures. However, workers operated a number of different machines during a shift, often more than one machine at a time, and occasionally operated machines outside their designated workstations. In addition, worker use of all machines as well as hood functioning was not consistently recorded during the task analysis.

RESULTS

Cobalt exposures to eight saw-reconditioning workers were evaluated monthly for 12 months. The Washington State PEL was used as a benchmark value for comparison; however, the use of the IOM sampler precludes strict comparison of our findings to regulatory limits. Respiratory protection was used during the study period to reduce personal exposures to metal particulate.

FIGURE 2
A worker brazing with the new flanged slot hood.

Worker Exposure Pre-Ventilation System Intervention

Twenty-six samples were collected (average of three separate samples per worker) prior to the installation of the ventilation systems. Seventy-three percent of the pre-intervention cobalt samples exceeded 50 $\mu g/m^3$ (range 10 to 707 $\mu g/m^3$) (Table II), and 82 percent exceeded 20 $\mu g/m^3$. Worker exposures to cadmium ranged from < MQL to 113 $\mu g/m^3$. Brazers and the tool grinder had the highest cadmium exposures (brazer #1 mean cadmium 32 $\mu g/m^3$, range 11 to 52 $\mu g/m^3$; brazer #2 mean cadmium 57 $\mu g/m^3$, range 22 to 113 $\mu g/m^3$; tool grinder mean cadmium 4.2 $\mu g/m^3$, range 2 to 12 $\mu g/m^3$). Other worker exposures to cadmium did not exceed 5 $\mu g/m^3$ at any time. Worker mean exposures to chromium were below 500 $\mu g/m^3$ (range 6 to 368 $\mu g/m^3$).

Exposures Within One Month of Ventilation Installation

All worker exposure was reassessed within one month of the installation of three ventilation systems. A reduction in cobalt exposure was noted at that time. Twenty-five percent of the exposures exceeded 50 $\mu g/m^3$ (range 9 to 560 $\mu g/m^3$) with workers at two workstations continuing to have overexposures. Cobalt exposures to the stellite grinder/welder #1 remained elevated, most likely due to the fact that the capturing hoods in the band saw area were located at least 12 inches away from the point of dust generation.

One month after installation of ventilation, worker exposure to cadmium ranged from < 0.4 to 18 $\mu g/m^3$. Only brazer #2 continued to have elevated cadmium exposures. Exposures to chromium were not elevated one month after ventilation installation.

The Effect of New Hoods on Exposures

Repeat sampling over the ensuing year confirmed that exposures remained low for most workers. However, stellite grinder/welders #1 and #2 and the brazers continued to have elevated exposures. These exposures were most likely due to reliance on capturing hoods that were placed at least 12 inches from particulate generation sources. Redesigned hoods were installed at these sites during months 2 and 5, and cobalt and cadmium exposures initially fell substantially. The stellite grinder/welder #1 exposure to cobalt was reduced from a full-shift exposure of 560 $\mu g/m^3$ during month 1 to 62 $\mu g/m^3$ by month 2 after an enclosing hood replaced a capturing hood. However, sampling throughout the year demonstrated that this reduction in exposure was not consistently maintained. In fact, the overall mean cobalt concentration for the stellite grinder/welder #1 was reduced from an average of 444 $\mu g/m^3$ before ventilation to an average of 351 $\mu g/m^3$ after installation of the ventilation system and a new enclosing hood (Table II). Among the brazers, cadmium exposures were initially reduced after the installation of flanged slot hoods in month 5 (Table III). During months 5 to 8, cadmium exposures to both brazers remained low; however, exposures were again elevated during months 9, 11, and 12, particularly for brazer #1.

Worker Exposure Post-Ventilation System Intervention

Eighty-four samples were collected throughout one year after the installation of three new ventilation systems, for an average of 11 samples per worker. Cobalt and cadmium concentrations were log-normally distributed based on probability plots. When averaged over the entire year, 60 percent of all cobalt exposures

TABLE II

Cobalt concentrations ($\mu g/m^3$) of all operators before and after ventilation control

	Before ventilation cobalt ($\mu g/m^3$)					After ventilation cobalt ($\mu g/m^3$)				
	N[A]	Range	AM[B]	GM[B]	GSD[B]	N	Range	AM[B]	GM[B]	GSD[B]
Band saw										
Steel grinder	3	10–23	14	13	1.6	8	4–26	10	8	2.2
Stellite grinder/ welder #1	3	212–707	444	396	1.8	13	26–1104	351	239	2.8
Round saw dry										
Brazer #1	3	10–346	146	66	5.9	11	3–21	8	6	1.9
Brazer #2	3	16–95	51	40	2.4	11	4–32	9	7	2.1
Stellite grinder/ welder #2	4	116–476	307	273	1.8	11	11–106	45	37	1.9
Round saw wet										
Automatic grinder	3	58–158	108	99	1.7	8	8–39	18	16	1.6
Manual grinder	3	77–108	88	87	1.2	11	6–63	26	22	1.9
Tool grinder	4	41–116	89	83	1.6	11	4–15	9	8	1.6

[A]Number of samples.
[B]AM = arithmetic mean; GM = geometric mean; GSD = geometric standard deviation.

TABLE III
Cadmium concentrations ($\mu g/m^3$) among brazers during the study period

Months into study	Cadmium concentration ($\mu g/m^3$) Brazer #1	Brazer #2
No ventilation		
0–1	32	57
Capturing hoods		
2	0.4	18
3	19	7
4	0.5	24
New slot hoods		
5	1	0.6
6	2	3
7	0.8	2
8	1.5	<0.6
9	81	5
10	*	*
11	75	4
12	10	0.8
13	3	<0.6

*No samples collected.

were less than 20 $\mu g/m^3$ and 79 percent of the exposures were less than 50 $\mu g/m^3$. Cobalt concentrations were reduced to below 50 $\mu g/m^3$ in five workstations: the steel grinder in the band saw area, two brazers, the automatic grinder, and the tool grinder in the round saw area. Cadmium exposures were consistently controlled to less than 3 $\mu g/m^3$ for all workers, except the brazers. Chromium exposures were low for all workers with the exception of one day when the band saw stellite grinder/welder #1 had a chromium exposure of 579 $\mu g/m^3$.

Cadmium concentrations were significantly reduced in the brazing area; however, brazer exposures periodically increased (Table III). In addition, the average exposure of brazer #1 (18 $\mu g/m^3$) was three times that of brazer #2 (6 $\mu g/m^3$) after the installation of the ventilation systems. Work practices and duties differed among the brazers. This exposure variability may also be due to the inconsistent use of hoods (brazers were observed not using hoods close to their work at all times), decrease in hood air flow due to duct plugging, and conducting brazing operations on large saws in locations without access to local exhaust.

Airborne cobalt exposures remained a problem for stellite grinder/welder #1 and #2 (Table II). Ninety-two percent of the stellite grinder/welder #1 exposures and 36 percent of stellite grinder/welder #2 exposures exceeded 50 $\mu g/m^3$. The cobalt exposure to the brazers was substantially reduced from a mean of 146 and 51 $\mu g/m^3$ to a mean concentration of 8 and 9 $\mu g/m^3$ for brazer #1 and brazer #2, respectively (Table II). The manual grinder had an overexposure to cobalt during month 11. On that day, the manual grinder was side-dressing (wet grinding the sides of saw teeth) a tungsten carbide saw on a side grinder attached to hood 6. During other months, this worker used other machines throughout the workday.

Cobalt Exposures and Worker Activity Post-Ventilation

During the project period, most workers performed the same set of tasks each month. Though workers were responsible for certain tasks at their workstations, there was considerable variability of task duration over the year (Table I). The automatic and manual grinders consistently conducted wet grinding on tungsten carbide. The band saw workers and stellite grinder/welders #1 and #2 usually performed dry grinding/welding on stellite and steel saws. The brazers and tool grinders engaged in the most varied activities. Several workers in both of the round saw areas (brazers and wet grinders) spent approximately 90 minutes doing other activities. The "other" category included activities such as waxing saws for shipping, other metal machining, and pouring babbit.

Dry grinding stellite/welding activities contributed to the highest cobalt concentrations (Table II). Most notably, stellite grinder/welder #1 had an average cobalt exposure of 351 ug/m^3, a value eight times higher than stellite grinder/welder #2. The fact that band saw and round saw grinding and welding activities, machines, and ventilation systems differed greatly from one another is the most likely reason for this difference.

Cobalt exposures to stellite grinder/welder #1 were not reduced with the addition of an enclosing hood. Observations of work activities indicated that the operator removed the hood throughout the day to side dress the grinding wheels. The hood was often removed for three to five minutes or more per saw. The operator usually completed six to ten saws per day. Furthermore, the operator also did resistive welding on a nearby machine, an activity that lasted approximately 20 minutes per saw. This adjacent welding/annealing machine had only a partial hood. Findings from short-term personal sampling (20 to 30 minutes) indicated that this worker's cobalt exposures during welding ranged from 1078 to 1444 $\mu g/m^3$, which was six to eight times higher than exposures related to side dressing. In addition, short-term exposure assessment of two different workers conducting these tasks confirmed that the exposures were not worker-specific. Hood designs for the welding/annealing machine were provided to the company, but were not implemented.

Cobalt Exposures and Total Hood Air Flows

Two assessments of ventilation effectiveness were conducted: (1) the total hood air flow was calculated for each ventilation system (see Part I) and was compared to the average cobalt exposure for all the participating workers using that system; and (2) the cobalt exposures for each worker was compared to the sum of the hood air flow at his or her workstation. Total hood air flow tended to decrease over time in all three ventilation systems and there was no apparent relationship between cobalt concentrations and total air flow (Figures 3 to 5). Average cobalt exposure in the dry and wet round saw varied little

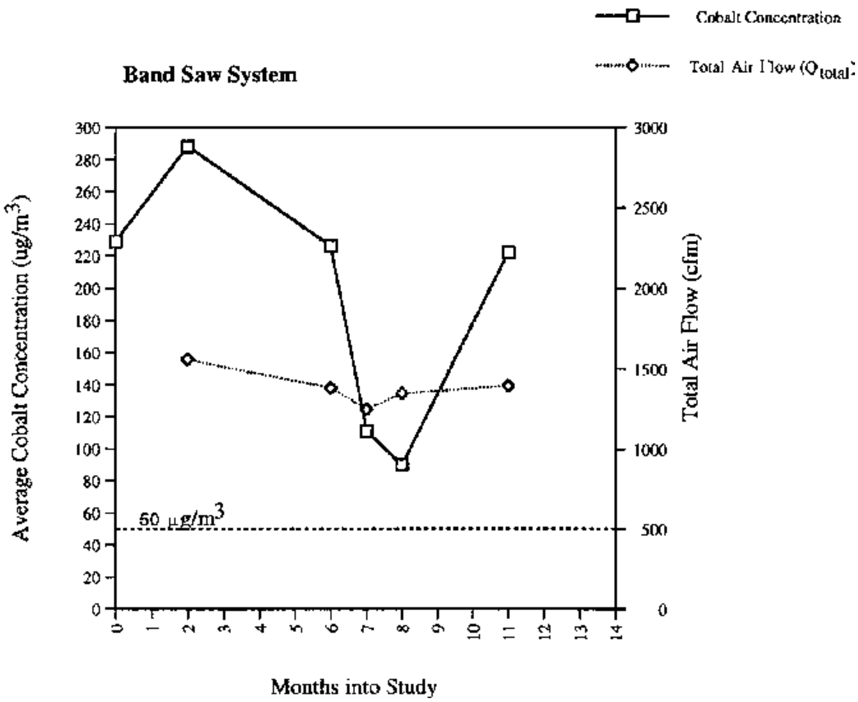

FIGURE 3
Comparison between average cobalt concentrations and total air flow (Q_{total}) among workers using the band saw ventilation system. The cobalt Washington PEL is used as a benchmark value only; the use of the IOM sampler precludes strict comparison of our findings to the regulatory limit.

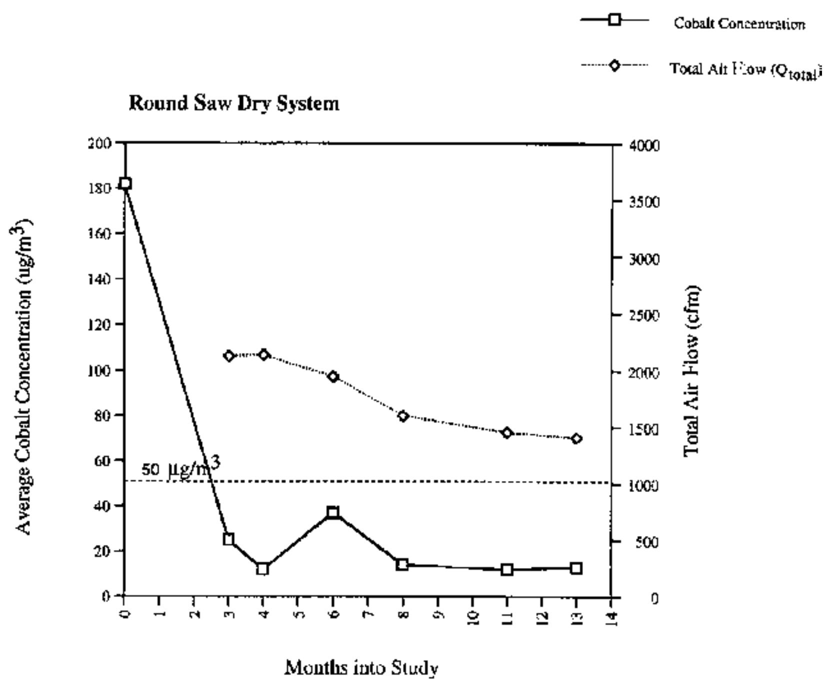

FIGURE 4
Comparison between average cobalt concentrations and total air flow (Q_{total}) among workers using the round saw-dry ventilation system. The cobalt Washington PEL is used as a benchmark value only; the use of the IOM sampler precludes strict comparison of our findings to the regulatory limit.

after the initial reduction following the installation of the ventilation system. The activities of the stellite grinder/welder #1 were the primary contributor to the cobalt exposures in the band saw area.

The relationship between individual worker cobalt exposures and the sum of the hood air flow at his or her workstation is shown for two job titles, automatic grinder and stellite grinder/welder #2 (Figures 6 and 7). There does not appear to be a relationship between individual exposure and hood air flow; specifically, the variability in exposures did not correspond with the variability in hood air flow.

DISCUSSION

This project is the first, to our knowledge, to simultaneously characterize metal exposures and ventilation system performance over an extended period of time. Intervention studies usually are limited to evaluations immediately before and after an intervention, often to single days of sampling. The high day-to-day variability of exposures documented here suggests that reliance on such point estimates is a dubious practice. Many factors affect exposure, including system maintenance, hood design, air flow level, work practices, hood use, contaminant generation rate, and duration of contaminant generation. The variability documented may be due to a combination of these factors.

Summary of Hard Metal Exposure Results

The majority of worker exposures to cobalt and cadmium at this site exceeded Washington State PEL for cobalt and cadmium prior to installation of three new ventilation systems. Given the high airborne concentrations of cobalt and cadmium, all workers were advised to use appropriate respiratory protection until permanent exposure controls were implemented.

After the installation of the ventilation systems, cobalt concentrations were reduced to 50 $\mu g/m^3$ or lower at all workstations, with the exception of the stellite welder/grinder stations. Forty percent of all personal cobalt concentrations were above 20 $\mu g/m^3$. In addition, all workers, with the exception of the tool grinder, had at least one sample above 20 $\mu g/m^3$ at some time during the year. Cobalt exposures to the stellite grinder/welders remained problematic. Wet grinding of tungsten carbide produces the highest personal cobalt exposures[2,7,9,10]. However, we found high cobalt exposures among dry stellite grinder/welders. This difference may be due to the type of machinery (manual versus semi-automatic) used by the participating company, coolant management practices, work practices, and ventilation. The results from this study are in agreement with the work of Linnainmaa, which showed that local exhaust ventilation reduces cobalt exposures in wet grinding areas when measured within a few months of the installation of a ventilation system.

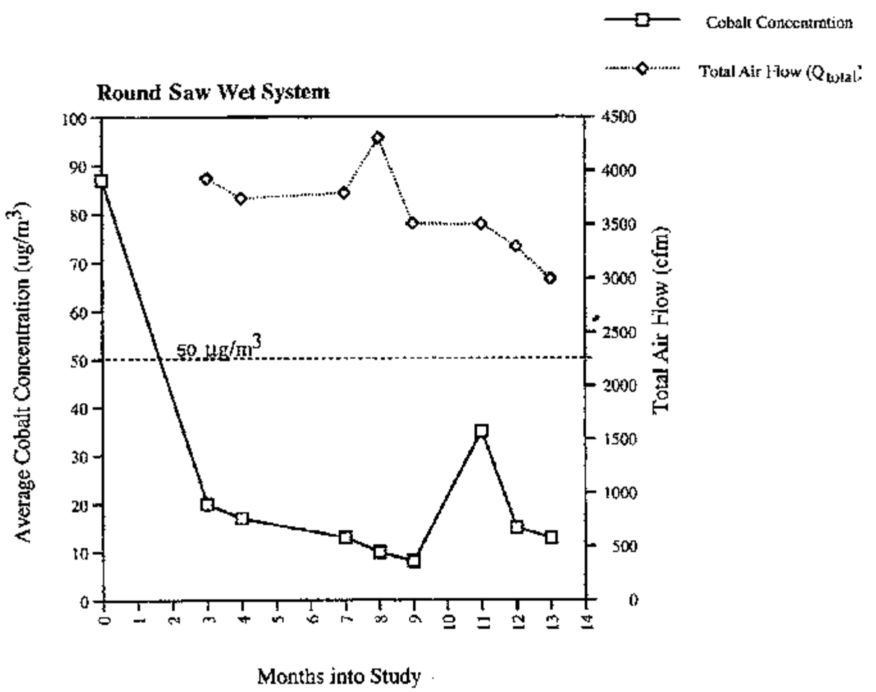

FIGURE 5

Comparison between average cobalt concentrations and total air flow (Q_{total}) among workers using the round saw-wet ventilation system. The cobalt Washington PEL is used as a benchmark value only; the use of the IOM sampler precludes strict comparison of our findings to the regulatory limit.

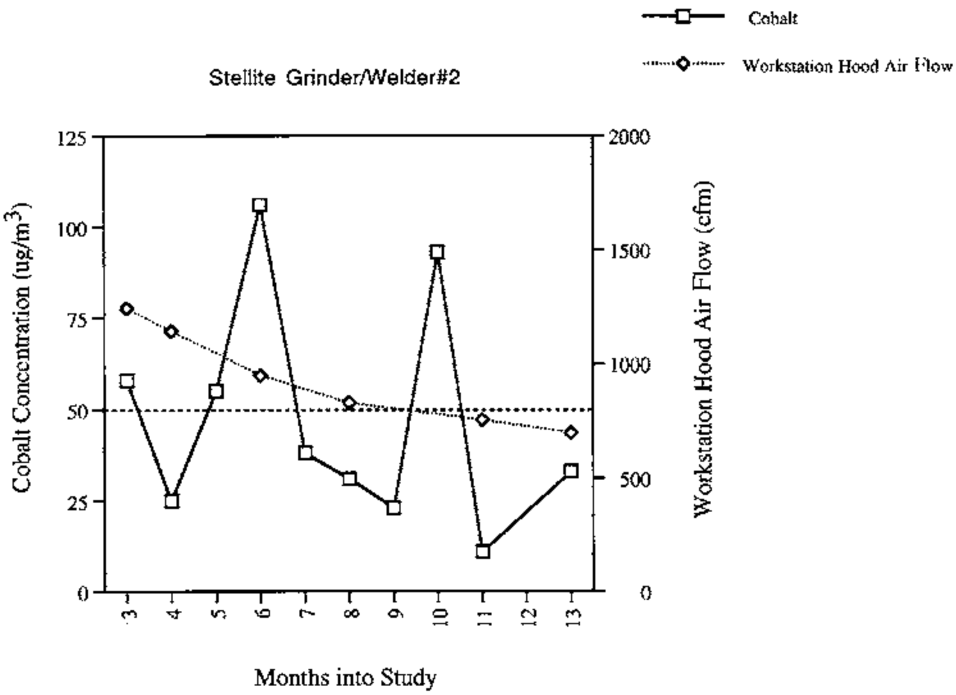

FIGURE 6

Comparison between cobalt concentrations and workstation hood air flow for the stellite welder/grinder in the round saw-dry ventilation system. The cobalt Washington PEL is used as a benchmark value only; the use of the IOM sampler precludes strict comparison of our findings to the regulatory limit.

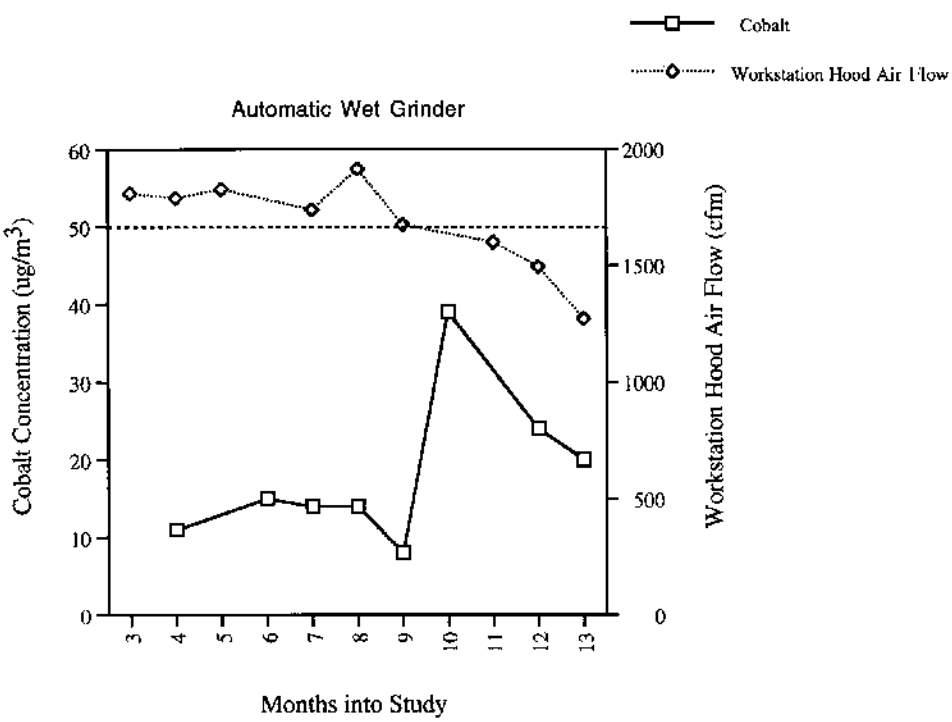

FIGURE 7

Comparison between cobalt concentrations and workstation hood air flow for the automatic grinder in the round saw-wet ventilation system. The cobalt Washington PEL is used as a benchmark value only; the use of the IOM sampler precludes strict comparison of our findings to the regulatory limit.

Cobalt Exposures and Air Flow

The variability of our results suggests that air flow was only one of several possible factors affecting exposure levels associated with these work conditions and tasks. The lack of association between exposures and moderate changes in air flow may be explained by several conditions. First, hood air flow may have been inappropriately weighted (e.g., workers may have used some hoods more frequently than others, or conducted more dust-generating activities on one machine). The variability in the amount of time a worker spent at a given task may have affected exposure from one day to the next (Table I).

Second, the high stellite grinder/welder exposures may have been due to factors not associated with hood performance, such as work practices (e.g., working outside the hood). Third, the generation rates of dust may have varied with production rate and source. Without quantitative measures of total generation rate or duration of machine use, neither factor could be controlled in the analyses. These uncontrolled sources of variability could be masking an association between exposure levels and air flow levels. Unfortunately, the available time and resources did not allow the investigators to record detailed hood usage and production information.

Exceeding design air flow levels, based on the industrial ventilation manual, did not guarantee low exposures. In addition, failing to provide design air flow levels did not always produce high exposures. This does not imply that the design guidelines are without merit. It does, however, suggest that the amount of air flow required depends not only on the operation, but also on the specific hood type that is employed. In this case, many of the hoods were poor choices for the specific grinding/welding operations in the company or were not placed close enough to the point of dust generation. Alternative hood designs were recommended by the researchers but not implemented by the company during the project time frame due to financial constraints.

Importance of Hood Design and Work Practices

This project suggests that hood design, worker acceptance of hoods, and proper use of hoods are important factors to consider when interpreting exposure variability. Because the design air flow was never met in the band saw system, it is not possible to determine if the intended ventilation system would have been adequate to control cobalt exposures. Though hood modifications were made to the band saw stellite welder/grinder #1 station, personal cobalt concentrations remained above 50 $\mu g/m^3$. A number of factors may have contributed to a high cobalt exposure to the band saw stellite welder/grinder #1: (1) insufficient air flow, (2) manual spot welding, (3) frequent removal of the hood, (4) side dressing the grinding wheels without ventilation, and (5) distance from the grinding wheel to the enclosed hood.

Cadmium exposures were reduced in all job activities except for brazing. Worker hood use and work practices may have contributed to the variability in cadmium exposure to the brazers. Workers did not always place the articulating hoods in the most advantageous location to control brazing fume, possibly due to the bulky hood design and stiff duct work. Also larger saws were brazed in the middle of the room without the use of local exhaust ventilation.

Importance of Assessing a Ventilation System

Despite the inability of the ventilation systems to reduce cobalt exposures adequately and consistently, these results raise some crucial issues. Single observations before and after a ventilation intervention may be naive. Monthly measurements over time allowed for a more complete picture of the exposure and air flow patterns. Ventilation air flow was highly erratic in the band saw and dry round saw systems because the ducts gradually became plugged with grinding residue (Part I). Air flow remained high in ducts that were relatively unplugged, while low air flow levels occurred in branches where plugs had not yet been removed. Duct cleaning by plant personnel was infrequent, despite repeated demonstrations that such maintenance was important to the success of the ventilation systems in controlling exposures.

Velocity pressure measurements were useful in troubleshooting the ventilation system problems. For example, one round saw-dry brazing hood had extremely low velocity pressure measurement during the first two months of measurements. At that time, the hood was simply an open duct inlet. The worker at this brazing workstation reported that foreign objects (rags, glasses) had been sucked into the system. Velocity pressure measurements improved once these objects were removed.

Worker and management training about the principles of good ventilation design, maintenance, air flow testing, hood design and placement, and work practices are lacking in this industry. Employers often are not aware that options are available for testing a ventilation system or for incorporating user-friendly maintenance strategies into ventilation designs. For example, employees did not regularly clean plugged ducts or remove foreign objects because such tasks required removal of several sheet metal screws from the duct work. Careful selection of duct components (e.g., u-clamps rather than sheet metal screws) could make a difference in frequency of maintenance.

CONCLUSIONS

The findings of this project indicate that worker exposures to hard metal particulate were sufficiently controlled at most workstations through the use of local exhaust ventilation. Data insufficiencies with regard to individual machine and hood use limited further analysis of the relationship between worker cobalt concentrations and hood air flow levels. Some work activities were more labor-intensive than others and required the worker to stand close to the point of dust generation (brazers, stellite grinders/welders, manual grinder). More consistent recording of observed activities would have permitted a more thorough examination of the interaction between such variables as cobalt concentration, type and duration of worker activity, and ventilation system performance.

Reducing contaminant exposures through engineering controls is the first method in the hierarchy of controls recommended by industrial hygienists. Unfortunately, once ventilation systems are installed, evaluation of their ongoing performance is rarely conducted. Repeat measurements over time showed that the variability in worker exposures was not entirely explained by ventilation system air flow; hood design, worker acceptance, and proper use of the hoods were also important factors. Though this case study cannot be used to evaluate the ACGIH *Ventilation Manual*[15] design parameters, it does, provide a good example of how these recommendations are often applied by companies as well as some of the issues that arise when companies deviate from the guidelines. The variability of air flow reported in this study provides strong evidence that ventilation systems need to be installed as designed, and that one should test, monitor, and maintain a ventilation system regularly to adequately and consistently control hard metal exposures.

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