1.0 Introduction

In 1990, two events drew the attention of members of this research team to the potential for cobalt exposure in the saw filing trades. In discussions with colleagues at the University of Washington, we learned about elevated exposures to cobalt and cases of hard metal disease in a small shop manufacturing tungsten carbide tipped saw blades in Washington State (1). In addition, we received anecdotal complaints about nasal and upper respiratory irritation in saw filers in a British Columbia lumber mill using stellite saw tips. This information led us to further investigate the potential exposures of saw filers, and eventually resulted in the study reported here.

The study had several purposes. The exposures of saw filing tradesmen to total airborne cobalt and other metals were measured to determine if they were present at levels of concern according to present occupational standards. The study was not designed to monitor non-metal exposures, such as welding gases, dust from grinding wheels, etc. Data about work place characteristics and work activities were collected to determine the causes of metal exposure and allow recommendations for change if necessary. Pre- and post-shift lung function of knife grinders, saw filers, fitters, and benchmen were measured on the same days as the air monitoring, to allow assessment of cross-shift changes in pulmonary function in relation to work exposures. In addition, we wanted to determine if chronic exposure to cobalt was associated with any measurable lung function or respiratory symptom effect.

This report will begin with a description of the composition of saw tip metals, the potential means of exposure of saw filers, and the possible health effects of exposures to cobalt and other metals. It will then describe the methods of the study conducted in British Columbia sawmills and report the results of these investigations. A summary of these results and recommendations are presented at the beginning of this report.

2.0 Background

2.1 Composition of saw tip metals

The bodies of saw blades used by the lumber and wood-working industry are generally made of saw steel ("swedge"). The saw tips may be fashioned from this material, or may be composed of a harder metal composite welded or soldered to the saw body. Tungsten carbide ("carbide" or "hard metal") tips have been widely used, though more recently, a superalloy, stellite, has been introduced. This alloy has a considerably higher cobalt concentration than tungsten carbide and also contains a substantial proportion of chromium compared to the other two metals. A fourth wood-cutting metal is sharpened in some filing rooms: steel used for chipper or planer knives. The relative concentrations of the various metals contained in typical composites and alloys used for saw-blade tips and knife blades in British Columbia sawmills are shown in Table 1 (2-11).

Table 1: Metal composition of saw blade tips and chipper knives in B.C. sawmills based on data from Material Safety Data Sheets (in percent)

	Tungsten carbide	Stellite	Saw Steel	Knife Steel
Carbon	0 - 4.5	1 - 3.5	0.75 - 0.77	0.5 - 0.9
Chromium	-	23 - 33	0 - 0.12	7.3 - 8.8
Copper	-	-	< 1.0	-
Cobalt	2.4 - 30	50 - 63	-	-
Iron	-	1 - 3	91 - 96	85 - 90
Manganese	-	0.5 - 1.5	< 2.0	0.2 - 0.5
Molybdenum	-	0.1 - 1	-	1.3 - 1.8
Nickel	-	1 - 3	< 1 - 2.1	-
Niobium	0.1 - 1	-	-	-
Phosphorous	-	-	<1.25	-
Silicon	-	0.5 - 1.5	0.25 - 0.30	0.8 - 1.1
Tantalum	0 - 5	-	-	-
Titanium	0.1 - 1	-	-	-
Tungsten	60 - 99	7 - 13	-	0 - 1.8
Vanadium	-	0 - 4.2	-	0.2 - 0.6

Tungsten carbide with cobalt as a binder, is the major cemented metal carbide. It has unique properties of extreme strength, hardness, and resistance to high temperatures. It is produced in a powder metallurgy process, in which precisely weighed amounts of tungsten carbide and cobalt are mixed in mills, pressed into the desired shapes, and heated to about 1500 °C (just above the melting point of cobalt) to cement the composite and give it a hardness similar to diamond.

Stellite is a superalloy characterized by high hot hardness due to its cobalt content, and good resistance to oxidation as a result of its chromium content (12). It is produced by only a few firms worldwide, also using powder metallurgy. In this case, the process begins with a pre-alloyed powder which is weighed, mixed with an organic binder and shaped, and then heated to burn off the binder and sinter the alloy.

2.2 Potential means of exposure of saw filers to cobalt and other metals

There are several saw filing activities which may provide the opportunity for exposure to airborne cobalt. When separate tungsten carbide or stellite tips are fixed to saw bodies by soldering or welding, metal fumes may be liberated from the heated metal components. Grinding of saw tips to meet cutting specifications may produce airborne fines of the metal, or of ionized metal if the grinding is done wet with a lubricant capable of dissolving the metal. Bench work for repairing deformities or cracks in the bodies of the saws may include welding, dry grinding, or oxy-acetylene annealing, once again providing the possibility of fume or metal fine production, though cobalt exposures would require that this work involve stellite or tungsten carbide, and not just saw steel.

A review of 27 personal air samples taken in Oregon sawmills, saw repair facilities, and saw production facilities from 1982 to 1986 showed cobalt exposures in the saw filing trades ranging from less than 0.001 mg/m^3 to 0.198 mg/m^3 with an average of 0.048 mg/m^3 (13) (near the Threshold Limit Value (TLV) of 0.05 mg/m^3 (14)). The recent study of a company producing tungsten carbide tipped saw blades for the lumber industry in Washington State reported low concentrations in all areas except the grinding department, where the average air concentrations of cobalt in personal samples were consistently above the TLV (1). There are no reports examining cobalt exposures in facilities using stellite tips.

Working with stellite tips also presents an opportunity for chromium exposures, given the high chromium content of this alloy. Knife steel and some saw steel may also contain chromium, though at lower concentrations. One study (15) found that the dust produced from grinding high alloyed steel (type not specified) contained from 7 to 18% total chromium. Welding of high chromium containing alloys (usually stainless steel) has been shown to result in exposure to chromium oxide (16-19).

Saw filing tradesmen have the opportunity for exposure to toxic metals other than chromium or cobalt. For example, babbitt is used for making round-saw guides and balancing chipper knives. These soft alloys have varying compositions, but the main metal of concern is lead, traditionally the major constituent. Lead-free babbitts composed mainly of tin are also available and are used in some B.C. sawmills. Silver solder used to attach tungsten carbide saw tips may also expose tradesmen to other metals, in particular, cadmium, though cadmium-free solders are also used. The Oregon air samples included data on cadmium exposures, likely from solder; the concentrations ranged from 0.002 mg/m^3 to 0.611 mg/m^3 with an average of 0.063 mg/m^3 (13), greater than the current TLV of 0.05 mg/m^3 (14).

The degree to which saw filing tradesmen are exposed to metals may be influenced by several potentially modifiable work characteristics and procedures. The composition of the metals used in the saw tips, saw bodies, babbitts, and solders will determine which metals are available to be aerosolized. The time spent by an operator in close proximity to heating or grinding operations will be expected to contribute to exposure level, and will vary from mill to mill depending on the degree of automation of the operation, and from day to day depending on the rate at which saws require repairs. Local exhaust ventilation designs are available for both heating and grinding operations (20) and are being used in many saw filing room operations. The effectiveness of these ventilation systems as determined by the capture velocity, and the location of the hood relative to the operator may have an impact on exposure. A recent Dutch study (17) of stainless steel welding processes showed higher exposures to welding fume containing chromium in those operators using poorly designed local exhaust ventilation (hoods drawing fume through the breathing zone) than in operators using no ventilation.

In grinding operations, the use of cooling fluids may alter exposure concentrations, though the direction of the effect may not be simple. Although wet grinding might be expected to reduce the concentration of metal aerosols as they are entrained in the liquid, there is also the possibility that the fluids themselves may dissolve metals and provide exposures to ions in mist which the grinding operations may produce. Because airborne metal concentrations may be related to the concentration of metals in bulk lubricating fluids, the determinants of bulk fluid concentrations may also be important. Many metals, including cobalt and chromium, are more soluble in acid than water or base (21), therefore the pH of bulk lubricating fluid may affect the concentrations of metals in the fluid. Although machining fluids are usually basic (pH = 8.5-9.5 (22)), there is evidence that bacterial decomposition (primarily by *Pseudomonas sp.* and *Enterobacter sp.*) of water-based fluids may cause reductions in pH (23). In 27 samples of bulk machining fluid we took prior to this study, the pH ranged from 6.0 to 11.0 with an average of 7.7. Disinfection, aging, and filtration of the fluid may also be determinants of metal concentrations in bulk samples of coolants.

2.3 Health effects of cobalt exposure

Cobalt exposure has been shown to cause a pneumoconiosis-like lung disease as well as occupational asthma. It is not known if these responses are related.

2.3.1 Hard-metal lung disease (hard metal pneumoconiosis)

Workers engaged in the production of tungsten carbide tools have been investigated in a number of studies (14,24-28) and a small proportion of workers (less than 1%) shown to have an interstitial lung disease termed hard metal lung disease or hard metal pneumoconiosis. The disease is referred to as hard metal disease because a colloquial name for tungsten carbide is "hard metal". The word pneumoconiosis is a misnomer; the pathophysiology is more like interstitial pneumonitis, not silicosis or asbestosis. It is characterized by radiographic evidence of lung infiltrates, reduced diffusing capacity, and reduced lung volumes (24). Pathologically, it is characterized by a fibrosing alveolitis with unusual multinucleated giant cells (25,30). Studies have demonstrated that the exposure of concern is cobalt not tungsten or other metals (29). This same disease has been found in less than 1% of workers in the diamond industry (30-32), who use cobalt grinding wheels not tungsten carbide. Fatal cases have been reported (29). The factors leading to death, as opposed to recovery, are not known.

2.3.2 Cobalt asthma and airflow obstruction related to cobalt

Asthma caused by cobalt exposure has been shown in diamond polishers (30,32), tungsten carbide production workers (24,28,33), dental technicians (29), machinists and grinders using hard metal tools (27), and even in a worker in the animal feed industry whose job involved the addition of cobalt sulphate to the feed (29). The prevalence in industries with widespread exposure is generally reported to be about 5%. In some individuals, both asthma and alveolitis were present (29). Asthma due to cobalt exposure is associated with any of early, late, or dual response to bronchial challenge with cobalt, and does not always subside with removal of the worker from exposure (29,32).

In addition to asthma, one cross-sectional survey of production workers found work-related wheezing in 10% of workers and a dose-response relationship between cobalt exposure level and wheezing (24). Another study of hard metal industry workers has shown an increased frequency of mucous membrane irritation and chronic bronchitis (28) in cobalt exposed workers and a measurable acute reduction in lung function on the first day at work after the weekend in workers most heavily exposed. These reactions were noted at exposure levels below 0.05 mg/m^3.

2.3.3 Lung health effects of cobalt dissolved in machining fluids

Exposure to aerosols of machining fluids has been shown to be associated with occupational asthma (34) and with a measurable decline in lung function on Mondays after a weekend away from work (35). This acute lung function response was found in workers exposed to any one of three different types of cutting fluids with widely varying compositions (straight oils, water soluble oil emulsions, and synthetic fluids) suggesting that some contaminant in the fluids may have been responsible for the observed acute lung reaction. It is possible that cobalt dissolved in the machining fluid may have been the contaminant of interest. Unfortunately, no cobalt measurements were made in that study.

In a study of over 100 tungsten carbide production workers (24), Sprince and colleagues found that hard grinders (the wet grinding process) were at special risk for a lowered diffusing capacity compared to other workers in the plant despite lower measured cobalt exposures in this area than in other areas in the plant. The authors suggested that the dissolution of cobalt in the coolant fluids may have resulted in enhanced cobalt toxicity. In an earlier case series reported by Sjogren and colleagues (36), four workers, all from the wet grinding area in a similar plant, were the only workers with diagnosed cobalt disease. These authors noted that dissolved cobalt, in the ionic form, can combine readily with body proteins and therefore act as a hapten, triggering an allergic response.

2.4 Health effects of other metals which may be present in saw filing

Metallic chromium is believed to be non-toxic. However, trivalent and hexavalent chromium compounds (chromic acids, chromates) have been shown to be associated with contact dermatitis, ulceration of the skin and nasal mucosa, respiratory irritation, occupational asthma, and respiratory tract cancer (16,37). Studies of the effects of exposure to these compounds have generally been confined to workers exposed as a result of chromium plating, chromate manufacturing or processing, and stainless steel welding. Skin and nasal ulceration has been found in over 50% of workers in some studies (16). Chromium VI compounds are associated with an increased cancer risk (16). As no information is available about whether or not saw filers using stellite-tipped saw blades are exposed to chromium compounds, this must be determined before planning any investigation of chromium-related health effects in these workers. It is highly likely, however, that the welding process would result in exposure to oxidized chromium compounds as this has been repeatedly shown in other studies (16).

Saw filing tradesmen may be exposed to many other metals, including antimony, cadmium, copper, lead, molybdenum, nickel, silver, tin, tungsten, and vanadium. Many of these are associated with a variety of adverse health outcomes. For example, cadmium exposures have been shown to be related to proteinuria, anemia, bone pain, and emphysema (21). Lead may cause anemia, encephalopathy, peripheral neuropathy, and reproductive effects (21). Because of the wide range of potential outcomes of exposures to these and other metals, this study will not include health assessments for such exposures. However, in order to determine whether further follow-up on other metals is warranted, exposure evaluations will be carried out for all metals to which saw filers may be exposed, because of the cost efficiency of multi-element analyses.

3.0 Methods

3.1 Participating sawmills

Eight coastal sawmills participated in the study; all used saw steel tips for at least some of their saws, seven used tungsten carbide, and six used stellite. Every mill was visited for sampling on four days or pairs of days at least one month apart in the period from June to December 1991.

3.2 Industrial hygiene measurements and analyses

3.2.1 Personal air samples

Each saw filing tradesman working on the day shift on the selected sampling days was asked to participate in the personal air sampling. Full-shift air samples were collected on 0.8-µm-pore-size 37-mm-diameter cellulose ester membrane filters (Nucleopore) mounted in 3-piece plastic cassettes positioned at the lapels of the employees. The flow rates of constant-flow personal sampling pumps (SKC, Gilian, or Dupont) were calibrated before and after sampling using an automatic soap-bubble calibrator (Gilibrator). Two field blanks were sent for analysis with every 15 air samples.

All samples were extracted using nitric acid, and metal concentrations were quantified by inductively coupled argon plasma atomic emission spectrophotometry (ICP) according to Workers' Compensation Board of B.C. method 1051 (38). The samples were analyzed for total cobalt, aluminum, antimony, barium, beryllium, bismuth, boron, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, molybdenum, nickel, selenium, silver, tellurium, vanadium, and zinc.

3.2.2 Potential determinants of exposure

The operations performed by each sampled tradesman were recorded by a hygiene technician on a time sheet every 10 minutes throughout the sampling day (Form D, in Appendix A). At each reading, the technician also recorded whether the employee was smoking, the name of the nearest operating machine or area likely to produce airborne contaminants, and the distance in feet between the tradesman's breathing zone and the contaminant generation point of the operation.

Information about each machine and work location was gathered on the first visit to each mill, and on any subsequent visit if changes had occurred (Form A, Appendix A). Data collected included the following: the types of wood used at the mills; a description of each operating area; the types of saw tips, if any, used in the area; whether there was local exhaust ventilation; whether coolant was used; and the names of materials other than saw tips used in the area. Material Safety Data Sheets were gathered to identify the compositions of saw tips and other materials used in the filing rooms.

For each operation which had local exhaust ventilation, the following information was recorded (Form B, Appendix A): the distance from the hood to the point of contaminant generation; the dimensions of the hood; the average face velocity (measured using an Alnor Compuflow Thermoanemometer at a minimum of 10 points with 6-inch maximum distances between measurement points); a description of smoke behaviour at the contaminant generation points; and the range and average capture velocity at the points of contaminant generation. All smoke tube tests and capture velocity measurements were taken with the saw filing room equipment in its normal operating mode. Wherever possible, normal operating mode was also used for the face velocity measurements, however, in a few cases where this required the thermoanemometer probe to rest dangerously close to a quickly rotating grinding wheel, the grinding wheel was turned off for the measurement period.

3.2.3 Bulk Samples of Coolants

Bulk samples of grinding machine coolants were collected in wide mouth glass vials with teflon-lined caps on every day when wet grinding machines were used. The samples were taken at the point where the fluid empties onto the grinding surface. Approximately 20 mL of coolant was collected in a sampling bottle at the beginning of operation and every two hours thereafter for a maximum sample volume of 100 mL. For each coolant sample, the following information was also collected (Form C, Appendix A): the brand of coolant; the date when the coolant was last completely changed; the type of filtration; details about disinfectant use; the speed of the grinding wheel; whether a spray shield was used; and the type of grinding done at the machine.

An undiluted unused sample of coolant from the original container as received by the mill was also taken for each brand of coolant.

The pH of all coolant samples was measured at the end of the sampling day using Accutint indicator paper (Anachemia) with pH range of 1 to 12.

Metals in the coolant samples were dissolved with nitric and hydrochloric acids and quantified using ICP according to WCB method 5080 (39). The samples were analyzed for total cobalt, aluminum, antimony, barium, beryllium, bismuth, boron, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, molybdenum, nickel, selenium, silver, tellurium, tin, vanadium, and zinc.

3.2.4 Exposure data summarization and statistical analyses

Descriptive and inferential analyses were performed using Statview II, SAS, and Gauss statistical analysis packages. All metal concentrations were blank corrected. For descriptive summaries of the sampling data, levels below the detection limit are not included in the means and standard deviations. For the inferential analyses involving metal concentrations in air or coolant, however, measurements below the detection limits needed to be estimated. In this case, the method of Hornung and Reed (40) was used and, in all cases, levels below the detection limit were recorded as one-half the detection limit. Although the concentration data appeared positively skewed for most of the metals, many of the concentration distributions were truncated at the limit of detection and none met the test of normality with or without log-transformation. All data analyses were therefore performed with the data untransformed. This minimized the effect of the choice of values entered for measurements with concentrations below the detection limit. In addition, using the data untransformed meant that arithmetic averages rather than geometric averages were compared, an advantage since, for most chronic effects, the arithmetic average rather than the geometric average is the best predictor of risk (41).

For each metal analyzed, average air concentrations were calculated including only those measurements above the detection limit. Where the average of detectable concentrations of a metal was above 5% (1/20th) of the TLV, further investigations were carried out. Averages of air concentrations above the detection limit were summarized by mill. To test whether exposures to any of these metals exceeded air exposure standards, individual shift measurements, and the upper 95% confidence limit of the arithmetic average exposure for each individual were checked against the Permissible Concentrations (PC) set by the Workers' Compensation Board of B.C. (42) and the Threshold Limit Values (TLV) of the American Conference of Governmental Industrial Hygienists (ACGIH) (14). For the calculation of confidence limits around individual average exposure levels, measurements below the detection limit were included as described above.

In order to identify the determinants of exposure to cobalt and chromium, information about the activities, locations, jobs, mills, and sampling times for each saw filer were summarized into several groups of independent variables. The activities of saw filers throughout the sampling day were summarized into 7 continuous variables indicating the number of times the sampled employee was observed performing operations consistent with the following activities:

- doing paper work, attending meetings, being interviewed, having a coffee or lunch break, or supervising;
- vacuuming, sweeping, or cleaning with compressed air;
- melting babbitt;
- otherwise handling babbitt;
- benching;
- changing saws in the mill; or
- doing other operations, such as dressing a grinding wheel, working on resin guides, painting, doing maintenance on machines, etc.

Information about the locations of the saw filers was summarized into 10 continuous variables indicating the number of times the sampled employee was observed 5 feet or less from:

- a dry tungsten carbide grinder;
- a tungsten carbide grinder using coolant;
- a tungsten carbide heating operation;
- a dry stellite grinder;
- a stellite grinder using coolant;
- a stellite heating operation;
- a saw steel heating operation;
- a saw steel grinder using coolant;
- a knife grinding operation; or
- a lead babbitt operation.

Primary analyses were done on dichotomous versions of each of the above variables (i.e., did the employee do this activity or not?), so that regression coefficients would indicate the average level of exposure for each activity or location related to metal concentration. Continuous versions of the variables were also tested to look for linear relationships between exposures and activities or locations.

Several other variables from the recorded data were also used in the analysis of the determinants of exposure:

- job title of the sampled employee;
- mill where the employee worked;
- number of times the sampled employee was observed smoking;
- month of sampling;
- day of week of sampling; and
- number of years the employee had worked at the mill.

The determinants of aerosol exposure to cobalt and chromium were tested using stepwise multiple linear regression, using robust variance estimates (43-45). Robust estimates were used for two reasons: 1) because the variance of the metal concentrations could not be assumed to be constant over all values of the independent variables, as required in classical regression analysis using pooled estimates; and 2) because repeat measurements involving the same worker might have correlation beyond what would be accounted for by similarity of the covariates. For all steps, a Fisher score test p-value of less than 0.10 was required for an independent variable to enter the model. Variables representing activities and locations which might be expected to contribute to cobalt or chromium exposure were tested first. Only activities and locations with positive coefficients (i.e., which were associated with increased exposure) were included in the final model. Job titles were tested to see if they explained any variance beyond that of the activity and location model. Differences in metal concentrations between mills not explained by activities, locations, or job titles were tested by entering dichotomous variables for 7 of the 8 mills as a group. Score tests for all remaining variables not included to this point (the day of the week that sampling was done, the month of sampling, observed time smoking, and activities and locations not expected *a priori* to contribute to chromium or cobalt exposure (e.g., time spent in a lead babbitt area)) were examined. Variables significant at less than 0.10 were plotted against the model residuals to determine whether the relationship indicated patterns which should be considered further.

Associations between various factors (such as saw tip material and type of operation) and metal concentrations in bulk coolant samples or local exhaust ventilation effectiveness were tested using analysis of variance and linear regression techniques.

3.3 Respiratory health assessment

3.3.1 Subjects

3.3.1.1 Determination of eligible study participants

Potential study participants were originally identified from lists provided by the management and filing room personnel at each mill. Eligible participants were defined as those workers assigned on a regular basis to the filing room(s), whose work rotation provided for them to be on day shift at least some of the time. All eligible participants were male.

3.3.1.2 Participant recruitment

Each eligible participant was contacted by letter at his home address and invited to participate. Participation was entirely voluntary. A copy of the letter of introduction is included as Appendix B. Each participant signed a "consent to participate" form prior to testing, after having the aims and objectives of the study explained to him.

3.3.2 Questionnaire administration

An expanded version of the American Thoracic Society standard respiratory symptoms questionnaire was administered to each participant by a trained interviewer. A copy is included as Appendix C. Additional questions were asked to determine whether symptoms suggestive of occupational asthma or metal fume fever were present. The questionnaire also recorded a detailed past and present occupational history. In addition to recording all previous jobs and employers, the history of work in the saw filing trade included a record of the duration and frequency of each of 9 job tasks which may have been performed by the participant in this trade. These tasks were:

- manual welding/brazing/soldering of saw tips;
- automatic welding/brazing/soldering of saw tips;
- manual grinding of saw tips;
- automatic grinding of saw tips;
- benchwork;
- knife grinding;
- preparing asbestos saw guides;
- preparing babbitt saw guides; and
- preparing rubber/plastic saw guides.

For the first four tasks listed above, an inquiry was also made about the duration and frequency of tungsten carbide and stellite use, and, for the grinding tasks, details about the frequency of coolant use were also obtained.

3.3.3 Lung function testing

Spirometry was carried out at the work sites by a trained technician using standard procedures. The equipment used was a 10-litre dry rolling seal spirometer (S&M Instruments Ltd, Doylestown PA) connected to a lap-top computer. Subjects were seated, with nose-clips in place, and were required to perform at least three acceptable forced expiratory manoeuvres. The end of test criterion was a minimum two-second plateau in expired volume (determined by the technician's visual inspection of the volume time tracing). The best value for FEV1 (forced expired volume in one second, a measure of air flow rate) and FVC (forced vital capacity, a measure of lung capacity), and the MMF (mid-maximal flow rate, also a measure of small airway flow rate) from the blow with the largest sum of FEV1 and FVC were used for analysis. This is the standard lung function test procedure recommended by the American Thoracic Society. Results were digitized and the output sent to the personal computer for storage and printing.

Spirometry was performed just prior to starting work and at the end of the shift on the same days that the worker wore personal air monitors. Subjects were asked to refrain from smoking for at least one hour prior to each test.

3.3.4 Allergy skin tests

Allergy skin tests were performed using the prick method on the volar aspect of the forearm using three common environmental allergens (house dust mite, mixed Pacific grasses, and cat epidermal antigen) plus cobalt and chromium in solution, with normal saline and histamine (2.5 mg/mL) as negative and positive controls. The diameter of the wheal reaction was measured at 15 minutes and a wheal measuring 3 mm or more greater than the saline control was considered evidence of a positive test.

3.3.5 Data handling and analysis

Results were coded and key punched and extensively checked for completeness and accuracy. Analyses were performed using SAS-PC statistical software and user-written edit routines. Each individual participant received a letter indicating the results of his own tests. Where abnormalities of any kind were noted, the family physician was notified (providing the participant had consented to this).

Personal test results continue to be stored securely and confidentially in the research team's office and will be released only with the written consent of the individual. This report presents only aggregated, group results.

The analyses and tables included in this report use the following definitions:

Smoking status

Non-smokers:	Life-time non-smokers
Ex-smokers:	Those who had stopped smoking completely for more than one month
Current smokers:	All others

Symptoms

Cough:	Positive response to: Do you **usually** have a cough?
Phlegm:	Positive response to: Do you **usually** bring up phlegm from your chest?
Wheezing:	Chest sounding wheezy or whistling, on occasions other than having a "cold"
Breathlessness:	Shortness of breath when hurrying on the level or walking up a slight hill
Nasal symptoms:	Positive response to: Do you **usually** have a stuffy nose?

(Any uncertainty or hesitation in response to questions regarding these symptoms or symptom complexes was treated as a negative response. This is the accepted approach when using this standard questionnaire and ensures that symptom reporting reflects well recognized and established symptoms.)

Work related: A symptom was defined as being work related if all of the following applied:
- symptom not present prior to starting employment in the current trade;
- symptom aggravated by exposure to substances at work; and
- symptom improves on weekends or long holidays.

Pulmonary function abnormality

Low FEV1:	Forced expired volume in one second (FEV1) of less than 80% of predicted value.
Low FVC:	Forced vital capacity (FVC) of less than 80% of predicted value.
Low MMF:	Mid maximal flow rate (MMF, or flow rate when half of the vital capacity has been exhaled) of less than 60% of the predicted value.

These definitions of "abnormality" in lung function are consistent with generally accepted clinical practice.

Analysis of Job Tasks (current and past)

For each of the specific jobs performed by each saw filer (starting with the earliest in the saw filing trade and working forward to the current job), each of the following tasks were identified as being performed or not performed according to the criteria noted beside each task. It is important to point out that a job typically involved more than one task (i.e., these are not mutually exclusive task categories). This was not true, however, for the distinction between wet and dry grinding. A saw filer could only be classified as performing <u>either</u> wet <u>or</u> dry grinding, depending on which was done more frequently. Total duration for each of these tasks was calculated as the sum of the years in each specific job during which the task was present (as defined below).

Tungsten carbide wet grinding: The job involved manual or automatic grinding of saw tips (of which tungsten carbide was used at least 10% of the time) and for which at least 50% of the grinding was performed using coolant.

Tungsten carbide dry grinding: The job involved manual or automatic grinding of saw tips (of which tungsten carbide was used at least 10% of the time) and for which at least 50% of the grinding was performed without using coolant.

Stellite wet grinding: The job involved manual or automatic grinding of saw tips (of which stellite was used at least 10% of the time) and for which at least 50% of the grinding was performed using coolant.

Stellite dry grinding: The job involved manual or automatic grinding of saw tips (of which stellite was used at least 10% of the time) and for which at least 50% of the grinding was performed without using coolant.

Tungsten carbide soldering: The job involved manual or automatic welding/brazing/soldering of saw tips (of which tungsten carbide was used at least 10% of the time).

Stellite welding: The job involved manual or automatic welding/brazing/soldering of saw tips (of which stellite was used at least 10% of the time).

Benchwork: These five tasks were simply identified as present or absent
Knife grinding: (without additional criteria) for each specific job held by the saw filer.
Preparing asbestos saw guides:
Preparing babbitt saw guides:
Preparing composite saw guides:

3.3.6 External comparison population

The study protocol did not include an explicit comparison population; however, comparisons can be made with other groups studied by our research team using the identical testing procedures. Where appropriate, comparisons were made between the saw filer group results and an external comparison group of bus maintenance workers employed by B.C. Transit. This group was studied due to concern about possible lung abnormalities associated with the use of asbestos in brake linings; however, the results of that study indicated that there was little or no health impairment associated with that possible exposure. Therefore, direct comparison of results between the saw filers and the bus mechanics provides a comparison of two groups of skilled industrial workers who may be exposed to many similar general industrial exposures but who differ in their exposure potential to cobalt- and chromium-containing metals.

4.0 Industrial Hygiene Results

4.1 Characteristics of participating sawmills

Various characteristics of the participating sawmills are presented in Table 2. Most of the mills volunteered to participate, and may therefore have different characteristics than a random selection of mills from around the province.

Table 2: Characteristics of the mills participating in the study

	Mill Number							
Characteristic	1	2	3	4	5	6	7	8
# of filing rooms	1	2	1	1	3	1	2	1
Main type(s) of wood cut	cedar	cedar	hemlock	hemlock & fir	cedar	hemlock	hemlock	hemlock
Stellite tips	yes	yes	yes	no	yes	yes	yes	no
Carbide tips	yes	rarely	yes	yes	yes	yes	no	yes
Saw steel tips	yes	yes	yes	yes	yes	yes	yes	yes
Knife grinding	no	yes	no	no	no	no	yes	yes
Lead babbitt	yes	yes	*	no	yes	yes	yes	yes
Cadmium solder	no	no	rarely	?	yes	*	?	rarely

* Used for part of study period; exact date of change not known.
? Unknown, mill unable to provide data.

4.2 Personal exposure levels

Table 3 indicates the number of saw filing room employees who participated in the study as a whole, the number who agreed to participate in the air sampling, as well as the number of air and coolant samples taken in each mill. Of 118 study participants, 112 had personal air samples taken on at least one (and up to four) work shifts. A total of 278 air samples and 73 coolant samples were taken.

Table 4 summarizes the air sampling results for each metal. It indicates the number of samples with levels above the detection limit (the "detection limit" used in this report is actually the "quantitation limit", a more restrictive definition), the average and maximum of the detectable exposures, and the detection limit. Finally, it lists the range of time-weighted-average Threshold Limit Values (TLV-TWA) (14) set by the ACGIH for the elemental metals and their soluble salts and oxides, since any of these forms of the metals might be found in saw filing room air and could be detected by the analytical techniques used.

Table 3: Number of employees participating in the study, and number of air and coolant samples taken at each mill

	Mill Number							
Characteristic	1	2	3	4	5	6	7	8
# of employees who participated in study	13	12	15	15	19	19	15	10
# of employees who participated in air sampling	13	12	14	14	18	18	13	10
# of air samples	28	34	23	44	45	58	22	24
# of grinding fluid samples	2	11	13	11	6	10	8	12

Only three metals had any measured air concentrations greater than occupational exposure limits: cobalt; chromium; and silver. Three cobalt concentrations were greater than the TLV of 0.05 mg/m^3; one of these measurements was also greater than the Workers' Compensation Board PC of 0.1 mg/m^3. In 1992, the American Conference of Governmental Industrial Hygienists proposed an amendment to lower the TLV for elemental cobalt and inorganic cobalt compounds to 0.02 mg/m^3; five air samples had concentrations above this proposed limit. Two chromium concentrations were greater than 0.05 mg/m^3, the TLV and PC for chromium VI compounds. The method of chemical analysis in this study measured total metal regardless of valence. None of the chromium concentrations was above the occupational exposure limits for chromium metal or valence III compounds of 0.5 mg/m^3. One silver concentration was above the PC for silver and the TLV for soluble silver compounds of 0.01 mg/m^3. None of the measurements had concentrations of silver greater than the TLV for elemental silver of 0.1 mg/m^3.

The averages of the detectable air concentrations of six metals were greater than 5% of the lowest TLV or PC: cadmium; chromium; cobalt; iron; lead; and silver. The average and maximum of the detectable air concentrations in each mill for these six metals are presented in Table 5. The highest cobalt exposure levels were measured in Mills 3 and 4; the remaining mills had similar lower exposures. The highest chromium levels were measured in mills 2 and 3. Patterns of exposure to these metals and the others listed in Table 5 are discussed in greater detail in the sections that follow.

Table 4: Detected airborne metal concentrations and Threshold Limit Values

Metal	N > DL†	Metal Concentrations in Air* (mg/m^3) Minimum Detectable§	Average Detected	± Standard Deviation	Maximum Detected	TLV-TWA (mg/m^3)
aluminum	41	0.002	0.0030	± 0.0012	0.007	2 - 10
antimony	7	0.002	0.0071	± 0.0072	0.022	0.5
barium	31	0.0002	0.0003	± 0.0001	0.001	0.5
beryllium	0	0.00006	-	-	-	0.002
bismuth	0	0.003	-	-	-	5 - 10
boron	7	0.002	0.0029	± 0.0006	0.004	1 - 10
cadmium	10	0.0003	0.0069	± 0.0081	0.028	0.05
calcium	179	0.002	0.0051	± 0.0039	0.045	2
chromium	92	0.0007	0.0042	± 0.0093	0.055	0.05 - 0.5
cobalt	59	0.0007	0.0098	± 0.021	0.11	0.05
copper	44	0.002	0.0042	± 0.0022	0.012	0.2 - 1
iron	277	0.002	0.051	± 0.073	0.68	1 - 5
lead	39	0.003	0.0138	± 0.019	0.097	0.15
magnesium	20	0.0009	0.0012	± 0.0004	0.003	10
manganese	278	0.0001	0.0004	± 0.0004	0.003	1 - 5
molybdenum	22	0.0005	0.0023	± 0.0028	0.011	5 - 10
nickel	90	0.0009	0.0024	± 0.0023	0.014	0.1 - 1
selenium	0	0.002	-	-	-	0.2
silver	9	0.0003	0.0042	± 0.0087	0.027	0.01 - 0.1
telurium	0	0.004	-	-	-	0.1
vanadium	7	0.0004	0.0013	± 0.0009	0.003	0.05
zinc	13	0.0009	0.0058	± 0.0033	0.011	5 - 10

* All values are based on full-shift time-weighted-average concentrations.
† Number of air samples, of the total of 278, with measured levels above the quantitation limit.
§ Based on mass quantitation limit divided by average volume of air sampled.

Table 5: Detected airborne concentrations of cobalt, chromium, iron, lead, cadmium, and silver, by mill

		Cobalt		Chromium	
Mill #	N total	N > DL†	Air Concentration* (mg/m^3)	N > DL†	Air Concentration* (mg/m^3)
Mill 1	29	6	0.0031 (0.008)	8	0.0018 (0.003)
Mill 2	34	4	0.0023 (0.005)	27	0.0064 (0.054)
Mill 3	23	20	0.0202 (0.106)	15	0.0073 (0.052)
Mill 4	45	11	0.0093 (0.041)	7	0.0010 (0.001)
Mill 5	46	5	0.0013 (0.002)	5	0.0016 (0.002)
Mill 6	58	8	0.0026 (0.005)	11	0.0012 (0.003)
Mill 7	22	0	-	10	0.0034 (0.006)
Mill 8	25	5	0.0034 (0.006)	9	0.0029 (0.012)

		Iron		Lead	
Mill #	N total	N > DL†	Air Concentration* (mg/m^3)	N > DL†	Air Concentration* (mg/m^3)
Mill 1	29	28	0.0421 (0.162)	12	0.0182 (0.097)
Mill 2	34	34	0.0951 (0.680)	6	0.0115 (0.045)
Mill 3	23	23	0.0552 (0.357)	5	0.0092 (0.020)
Mill 4	45	45	0.0288 (0.147)	2	0.0059 (0.008)
Mill 5	46	46	0.0460 (0.407)	5	0.0167 (0.032)
Mill 6	58	58	0.0353 (0.115)	1	0.0065
Mill 7	22	22	0.0631 (0.352)	5	0.0036 (0.005)
Mill 8	25	25	0.0667 (0.244)	3	0.0049 (0.007)

		Cadmium		Silver	
Mill #	N total	N > DL†	Air Concentration* (mg/m^3)	N > DL†	Air Concentration* (mg/m^3)
Mill 1	29	0	-	0	-
Mill 2	34	0	-	0	-
Mill 3	23	1	0.0008	4	0.0021 (0.006)
Mill 4	45	6	0.0099 (0.028)	2	0.0006 (0.001)
Mill 5	46	0	-	1	0.0005
Mill 6	58	1	0.0057	2	0.0139 (0.027)
Mill 7	22	0	-	0	-
Mill 8	25	2	0.0015 (0.002)	0	-

* Average (and maximum) of full-shift time-weighted-average concentrations.
† Number of samples with measured concentrations greater than the quantitation limit.

4.3 Patterns and determinants of metal exposures

Table 6 summarizes the data recorded about the activities and locations of the study participants while they were having full-shift air samples taken. Observations were made every ten minutes whenever a study subject was present in the filing room. It is interesting to note that because of the variety of tasks performed by the saw filing tradesmen, little time overall was spent at any of the locations expected to contribute to cobalt or chromium exposure.

Those activities and locations considered able to influence exposure were used as independent variables in regression analyses to distinguish factors which contributed to exposure to cobalt and chromium. The remaining four metals (iron, lead, cadmium, and silver) were examined descriptively only.

Table 6: Average, minimum, and maximum number of times a study subject was observed performing the following activities or within 5 feet of the following locations while a full shift air sample was being taken

	Average # of times observed per sampling day	Minimum # of times observed per sampling day	Maximum # of times observed per sampling day	# of air samples that subject was observed at this activity or location at least once
Activities:				
Meeting, paperwork, etc.	18.2	4	42	278
Vacuuming, sweeping, etc.	0.4	0	16	44
Melting babbitt	0.4	0	9	31
Otherwise handling babbitt	0.6	0	15	37
Benching	8.5	0	34	236
Changing saws in mill	3.0	0	18	194
Performing other operations	1.5	0	20	156
Locations:				
Dry carbide grinder	0.3	0	16	21
Wet carbide grinder	0.4	0	16	21
Carbide heating operation	0.3	0	16	20
Dry stellite grinder	1.6	0	26	69
Wet stellite grinder	0.3	0	12	22
Stellite heating operation	0.5	0	10	33
Wet saw steel grinder	< 0.1	0	4	4
Saw steel heating operation	0.3	0	6	46
Wet knife grinder	0.5	0	15	23
Lead babbitt operation	0.3	0	13	18

4.3.1 Cobalt air concentrations

About 21% of the air samples had detectable cobalt concentrations, and 43 of the 112 employees who took part in the personal air sampling had breathing zone exposures above the detection limit on at least one of up to four sampling days. The highest cobalt exposure levels were measured in Mill 3; all three observations exceeding the current ACGIH TLV were measured in this mill. No employee had an average cobalt concentration greater than the

TLV, although the upper 95% confidence limit of the average exposure (based on two or three measurements per person) was greater than the TLV for six individuals: five from Mill 3 and one from Mill 4.

In the regression analysis conducted to find the determinants of cobalt exposure, the following activity and location variables were considered in the initial analysis as potential contributors: vacuuming, sweeping, or cleaning with compressed air; benching; dry carbide grinders; wet carbide grinders; carbide heating operations; dry stellite grinders; wet stellite grinders; and stellite heating operations. All job titles, mills, and other variables were tested after the initial activity and location models were developed. The analysis was done first including all measurements. When the residuals for this first model were examined, the three highest cobalt exposure levels remained outliers which had not been explained by the model. Therefore it was decided to examine the activities performed on the days of these three samples descriptively, and to conduct another regression analysis excluding these three measurements.

Table 7 outlines the variables found to influence cobalt exposure in the two analyses. Because all the variables reported are dichotomous, the regression coefficients indicate the average increase (or decrease, if negative) in cobalt air concentration for samples with the characteristic indicated. For example, air samples taken on individuals who had spent time within 5 feet of a wet carbide grinder had cobalt concentrations on average 0.00765 mg/m^3 higher than those taken on individuals who had not done wet carbide grinding, after controlling for other determinants. The initial model (Table 7a) includes all the cobalt measurements. It indicates that the average background cobalt air concentration was slightly above the detection limit. Wet carbide grinding contributed the greatest increases in cobalt levels. Dry grinding and stellite heating also increased cobalt concentrations but to a slightly lesser extent. Knife grinders and head filers had decreased cobalt exposures compared to individuals in other jobs. When the three highest measurements were excluded (Table 7b), stellite heating was no longer important. In addition, the average cobalt concentration for those who spent time near carbide grinders was slightly lower than in the previous model.

Table 7a: Factors which contributed to cobalt exposure (all measurements included)

Variable	Average Cobalt Concentration (mg/m^3)*	p
Background cobalt concentration (intercept)	0.00077	< 0.001
Additional cobalt if time spent near:		
Wet carbide grinder	0.00765	0.003
Dry carbide grinder	0.00518	0.021
Stellite heating operation	0.00566	< 0.001
Less cobalt with the following jobs:		

Knife grinder	-0.00044	0.030
Head filer	-0.00074	0.069

Percentage of variance in cobalt air concentrations explained by the above factors = 12%

Table 7b: Factors which contributed to cobalt exposure (three highest measurements excluded)

Variable	Average Cobalt Concentration (mg/m^3)*	p
Background cobalt concentration (intercept)	0.00077	< 0.001
Additional cobalt if time spent near:		
Wet carbide grinder	0.00469	0.037
Dry carbide grinder	0.00447	0.030
Less cobalt with the following jobs:		
Knife grinder	-0.00044	0.030
Head filer	-0.00044	0.018

Percentage of variance in cobalt air concentrations explained by the above factors = 24%

* Regression coefficient; can be interpreted as average cobalt concentration for these variables since they are all dichotomous.

The models reported in Table 7 tested dichotomous versions of the activity and location variables. We also examined whether continuous versions of these variables were associated with cobalt exposure. This was the case for only one variable. Cobalt concentrations increased on average by about 0.001 mg/m^3 for every ten minutes spent within 5 feet of a wet carbide grinding machine, after controlling for other determinants.

An additional 7% (model without 3 highest measurements) to 13% (model with all observations) of the variability in cobalt air concentrations was explained by differences between mills not explained by the activities, locations, or jobs performed. Mill 3 had the highest residual cobalt air concentrations, both with and without the three highest cobalt air concentrations. Differences between the remaining mills were small. The three highest concentrations of cobalt were measured in the breathing zones of individuals from Mill 3 whose jobs and sampling day activities were as follows: individual #1) circular saw filer who soldered carbide tips (~ 29% of the day), adjusted a wet carbide grinder (14%), changed saws in the mill (8%), and changed babbitt (6%); individual #2) saw fitter who tended dry stellite grinders (~ 71% of the day); and individual #3) benchman who did miscellaneous benching activities (55% of the day), and tended dry stellite grinders (~ 10%).

4.3.2 Chromium air concentrations

About one-third of the air samples had measurable chromium concentrations, and 27 of the 112 employees who took part in the air sampling had at least one breathing zone sample with a concentration greater than the detection limit. Mills 2 and 3 had the highest exposure levels for this metal; these were the mills where the chromium VI standard was exceeded. No employee had an average chromium level greater than the TLV, though the upper 95% confidence limit of the average exposure (based on two to four measurements per person) was greater than the chromium VI standard (the lowest air concentration standard) for three individuals, one from Mill 2, and two from Mill 3.

In order to find the factors influencing chromium exposure, the following variables were considered in the initial regression analysis: knife grinding; vacuuming, sweeping, or cleaning with compressed air; benching; dry carbide grinders; wet carbide grinders; carbide heating operations; dry stellite grinders; wet stellite grinders; stellite heating operations; saw steel heating operations; wet saw steel grinders; and wet knife grinders. All job titles, mills, and other variables were tested after the initial activity and location models were developed.

The variables found to be determinants of chromium exposure are reported in Table 8. Background chromium exposure was below the detection limit. The most important determinant of increased chromium exposure was a job as a knife grinder. Heating stellite also contributed some chromium exposure, as did heating saw steel though to a lesser extent. In our examination of the continuous variables, wet knife grinding showed a linear relationship with chromium levels. Chromium concentrations increased by about 0.00053 mg/m^3 for every ten minutes spent within 5 feet of a wet knife grinding machine, after controlling for the other factors.

Differences between mills explained an additional 10% of the variability in chromium concentrations beyond that explained by the job and locations described above. Mills 2 and 3 had the highest residual chromium concentrations.

The three individuals who had average chromium concentrations with an upper 95% confidence limit above the chromium VI standard also had the highest individual measurements of chromium. These three high measurements were the most poorly explained by the model described above. Two of these measurements were taken on two of the individuals at Mill 3 with the highest cobalt exposures (the saw fitter and the benchman). The other individual with a high chromium air measurement was a knife grinder at Mill 2 who spent his day operating chipper knife grinders (~24% of the day), handling babbitt (~30%), and going down into the mill (~12%).

Table 8: Factors which contributed to chromium exposure (all measurements included)

Variable	Average Chromium Concentration (mg/m^3)*	p

Background chromium concentration (intercept)	0.00051	< 0.001
Additional chromium with the following job:		
Knife grinder	0.01221	< 0.001
Additional chromium if time spent near:		
Stellite heating operation	0.00244	< 0.001
Saw steel heating operation	0.00142	< 0.001

Percentage of variance in chromium air concentrations explained by the above factors = 24%

* Regression coefficient; can be interpreted as average cobalt concentration for these variables since they are all dichotomous.

4.3.3 Iron air concentrations

All samples but one had iron concentrations above the detection limit, not surprising since the bodies of all saws and knives used in the mills contain large proportions of this metal. Although every individual had at least one breathing zone sample with detectable iron concentrations, no employee had average iron concentration with an upper 95% confidence limit above the TLV or WCB PC of 1 mg/m^3 for soluble iron salts. The overall average exposure level was 5.1% of the TLV or PC, and the maximum exposure was 68% of the standard. There was no more than a four-fold difference in average exposures between mills, with the highest average exposures in Mills 2, 7, and 8, and the lowest averages in Mills 4 and 6. It is unlikely that there are significant health implications of iron exposures in the range measured in this study.

4.3.4 Lead air concentrations

Only 12% of samples had measurable lead levels, at least one sample from each mill. Only one mill (Mill 4) did not use lead babbitt during the measurement period; but two of the 45 air samples taken in this mill had measurable lead levels. The source of lead in air at this mill is unknown. The average of samples with concentrations above the detection limits was 9.2% of the TLV and PC for lead of 0.15 mg/m^3, and the maximum concentration was 65% of this value. No employee had an average lead concentration with an upper 95% confidence limit above the TLV or WCB PC.

Since babbitt used for balancing chipper knives or circular saw guides may contain 75 - 99% lead (46), we examined whether activities or locations of subjects with detectable lead concentrations included melting babbitt, otherwise handling babbitt, or working within 5 feet of a lead babbitt operation. Of the 39 samples with detectable lead, 17 (43%) had observations which included working with lead babbitt, whereas only 12% of the 239 samples without detectable lead had such observations. Ten (26%) of the remaining samples with detectable lead concentrations were measured on filers whose main activities were carried out within 15 feet of a lead babbitt area. Other common activities of filing room employees who had detectable exposures to lead in air included benching and circular saw filing. The source of lead exposure for these employees is not known.

4.3.5 Cadmium air concentrations

Only 10 air samples (3.6%) had detectable cadmium concentrations; no cadmium was detected in air samples from Mills 1, 2, 5, or 7. The average concentration of samples with detectable cadmium was 13.8% of the TLV and WCB PC of 0.05 mg/m^3, and the maximum concentration was 56% of the this standard. No employee had an average cadmium concentration with an upper 95% confidence limit above the TLV or WCB PC.

Since some silver solders contain about 16% cadmium (47), we examined the activities of the filers with detectable cadmium levels to determine whether they had soldered tungsten carbide saw tips. For 7 of the 10 (70%) detectable measurements, carbide tipping was performed during the air sampling period. Carbide tipping was observed during only 21 of the 268 (7.8%) air samples without detectable cadmium. One of the remaining three samples with detectable cadmium was taken on an employee whose main activity was operating a circular-saw dry-grinding machine near a carbide tipping area. The activities during the remaining two samples with detectable cadmium included benching and grinding saw steel saws. It is possible that these operations may have involved heating or grinding solder material, though there may be other unknown explanations for the exposures measured in these samples.

4.3.6 Silver air concentrations

Silver was detected in 9 (3.2%) air samples; no silver was detected in any of the air samples from Mills 1, 2, 7, or 8. One air sample had a silver concentration greater than the PC for silver and the TLV for soluble silver compounds of 0.01 mg/m^3 (the lowest air concentration standard for this metal). No employee had an average silver concentration above the TLV or WCB PC, though the employee with the one high measurement had an upper 95% confidence interval for his average exposure above this standard (based on three full-shift samples).

Silver solder used for tungsten carbide tipping contains 30 - 60% silver (47,48). During four of nine (44%) sampling periods with silver measurements above the detection limit, subjects were observed performing tungsten carbide tipping. Four other samples involved circular saw grinding during the measurement period, including the sample greater than the TLV. The main activity during the remaining sample with a detectable silver concentration was band saw grinding. The explanation for this latter exposure is unknown.

4.4 Bulk samples of coolants

Because wet carbide grinding and wet knife grinding were contributors to elevated cobalt and chromium air concentrations respectively, we decided to examine the concentrations of these two metals in bulk samples of coolants from every wet grinding machine operating on an air sampling day.

Twenty-five grinding machines used coolants or lubricating fluids. All of the wet grinding machines used sedimentation to filter out particulate matter, and all but five used no disinfectant in the fluid. About two-thirds of the machines had some kind of shielding between the fluid stream and the normal breathing zone of the filer. The rotation speeds of the grinding wheels ranged from 880 to 3600 rpm, with an average of 2945 rpm. Samples of unused concentrate were taken of each of the seven types of coolants used in the mills. Concentrations of chromium and cobalt in these samples, prior to use in the machines, were all at or near detection limits. Seventy-three samples of used coolant were taken during the operation of wet grinding machines: 23 from stellite grinders; 29 from tungsten carbide grinders; 16 from knife grinders; and 3 from saw steel grinders.

Table 9 summarizes the cobalt and chromium concentrations measured in the coolant samples, separated according to the type of metal ground in the machine sampled. Data on the pH of the fluid samples is also included in the table. The average pH of the coolants was neutral to slightly basic, with only small differences between the various metals ground.

Table 9: Concentrations of cobalt and chromium in coolants, and pH of fluids, by type of metal ground at each machine

	Type of metal ground				
	Tungsten Carbide N=29	Stellite N=23	Saw Steel N=3	Chipper Knives N=18	p
Cobalt concentrations					
Average (mg/L)	664	75.9	42.1	0.25	< 0.0001
Standard error (mg/L)	108	20.2	39.8	0.03	
Maximum (mg/L)	2,495	361	122	0.71	
Minimum (mg/L)	52.2	2.84	1.37	< 0.50	
# < DL of 0.35 mg/L	0	0	0	17	
Chromium concentrations					
Average (mg/L)	0.25	14.8	17.4	1.86	0.033
Standard error (mg/L)	0.01	6.86	17.2	0.71	
Maximum (mg/L)	0.43	154	51.8	13.1	
Minimum (mg/L)	< 0.60	0.61	< 0.60	0.58	
# < DL of 0.40 mg/L	28	2	2	8	
pH					
Average	8.41	7.33	7.00	7.81	NS
Standard error	0.09	0.32	0.58	0.38	
Maximum	9.5	10.5	8.0	10.5	

Minimum	8.0	5.5	6.0	5.5

# < DL = Number of samples below the detection limit
NS = not statistically significant at $p < 0.05$

Average cobalt concentrations were almost an order of magnitude higher in fluids from tungsten carbide grinding machines than in fluids from the next highest group of grinding machines, those which ground stellite. This finding is consistent with the earlier analyses which showed that time spent near wet carbide grinding machines, but not other wet grinders, contributed to increased cobalt air concentrations. Cobalt was found at detectable levels in only one sample from a chipper knife grinder, not surprising since chipper knives do not contain cobalt. Although saw steel also does not contain cobalt, all three samples from machines which grind this metal had measurable cobalt concentrations. This might indicate that stellite or tungsten carbide saw tips were also sometimes ground at these stations. As with the air samples, the highest cobalt concentrations in coolants were measured in samples from Mill 3. There were no patterns of cobalt concentration with pH or coolant type. There was also no pattern of cobalt concentration with the duration since the coolant was last replaced in the grinding machine, however, details of the dates when coolants were replaced were not generally recorded by mill personnel, and memories of the replacement dates sketchy, therefore it would be difficult to find a relationship for this variable.

Average chromium concentrations in coolant were highest in saw steel grinding machines, but this average is skewed by one of three samples with a relatively high level. The remaining two samples were below detection limits, more consistent with the fact that saw steel contains very little chromium. Stellite grinding machines had the most consistently elevated chromium concentrations, and averaged almost an order of magnitude higher than samples from knife grinders. Knife grinding, not stellite grinding, was associated with elevated air concentrations of chromium, suggesting that factors other than simply the chromium concentration in coolants must have influenced personal exposures to airborne chromium. Knife grinders appear to spend most of their time in the vicinity of their grinding machines, whereas employees tending stellite machines perform a variety of other tasks that make them relatively mobile. Only one of 29 samples from a tungsten carbide grinding machine had detectable chromium; tungsten carbide does not contain chromium. There were no patterns of chromium concentration in fluid samples with mill, coolant type, or the duration since the coolant was last changed. The pH of the fluid did have an influence; chromium concentrations in coolant increased by about 3.2 mg/L per unit decrease in pH ($p=0.044$).

4.5 Ventilation at machines in the saw filing rooms

The saw filing rooms at the eight study mills had local exhaust ventilation at 196 stations where such operations as grinding, heating, drilling, cleaning, and surfacing of metals took place. The effectiveness of the ventilation at each station was evaluated primarily by visual inspection of the draw at the point(s) of contaminant generation using smoke tubes, supplemented by measurements of the average capture velocity of the hood. These measures were used to classify the effectiveness of each system into one of three categories: good, fair, or poor. In systems rated "good", all the smoke was quickly drawn into the hood. In those rated "fair", most of the smoke was drawn in quickly, but there was some opportunity for drafts away from the hood. In systems rated "poor", the smoke moved slowly towards the hood, and some smoke drifted away from the hood. Table 10 indicates the average capture and face velocities for each category, as well as the average distance from the exhaust hood face to the point of contaminant generation. These measurements represent measurements taken on the first visit to each mill. Two mills had alterations made to their ventilation systems part way through the study; measurement data taken after the alterations were made are not included. In addition, one local exhaust hood had no velocity measurements taken and is also not included in Table 10.

Table 10: Ventilation parameters for three classes of local exhaust system effectiveness

	Poor (N=28)	Fair (N=43)	Good (N=124)	p
Average capture velocity (ft/min)	44	241	425	0.0001
(Standard error (ft/min))	(11)	(55)	(45)	
Average face velocity (ft/min)	850	1759	2040	< 0.0001
(Standard error (ft/min))	(190)	(158)	(90)	
Average distance from contaminant to hood (in)	9.6	8.6	6.2	0.0085
(Standard error (in))	(1.7)	(1.0)	(0.4)	

Table 11 lists the numbers of local exhaust systems in each of these three categories separated according to several characteristics: type of operation; type of material used at the station; and mill. Some operations with functions and materials similar to those which were commonly ventilated did not have local exhaust ventilation. These were also tallied, and figures for these are also included in Table 11. Tests for differences by type of operation, type of material, and mill were performed 1) comparing the number of ventilated and unventilated operations, and 2) within the ventilated operations, comparing the numbers rated good, fair, and poor.

Most of the local exhaust ventilation systems in the saw filing rooms (64%) operated very effectively, and another 22% worked fairly well. The remaining 14% were classified as having poor ventilation. The main problems with systems rated poor were: 1) a hood position too distant from the contaminant source; 2) insufficient enclosure, e.g., open sides on canopy hoods; and 3) not ensuring that the entire area of contaminant generation was served by the hood, e.g., canopy over the babbitt pot but not over the adjacent babbitt pouring area. A total of 61 grinding, cutting, or heating stations were not served by local exhaust ventilation. Certain of these stations are not frequently used, and therefore may not warrant dedicated local exhaust.

Table 11: Local exhaust system effectiveness, by type of operation, type of material used in the operation, and mill

	Number of similar operations with no ventilation (N=60)	Number of ventilation systems with the following effectiveness: Poor (N=28)	Fair (N=43)	Good (N=125)
Type of operation:				
Wet grinding	14	5	3	3
Dry grinding	28	9	28	76
Heating metal	6	9	8	18
Other operations	12	5	4	28
Type of material used in the operation:				
Tungsten carbide	10	1	6	19
Stellite	10	6	11	38
Saw steel	21	8	17	38
Knife steel	4	1	0	0
Babbitt	3	7	5	2
Other materials	12	5	4	28
Mill:				
Mill 1	8	3	4	8
Mill 2	5	2	10	15
Mill 3	0	2	4	14
Mill 4	8	3	7	11
Mill 5	14	7	5	30
Mill 6	3	5	7	22
Mill 7	13	5	4	11
Mill 8	9	1	2	14

There were differences in ventilation by type of operation (p=0.03 for ventilated or not; p=0.004 for ventilation effectiveness). Fewer than half of the wet grinding operations (44%) were ventilated, and of those which were, the effectiveness was rated poor more frequently than in other types of operations. This pattern may help to explain the contribution of wet grinding operations to both cobalt and chromium air concentrations. In contrast, most dry grinding operations were ventilated (80%), and more than half of them had good ventilation (54%).

Ventilation also differed between operations using different materials (p=0.0007 for ventilated or not; p=0.002 for ventilation effectiveness). Only one of five knife steel operations (all wet knife grinders) was ventilated; the one vented system was rated poor. Only 15% of stellite operations did not have local exhaust ventilation, whereas 31% of tungsten carbide operations were not vented. Although most babbitt operations had exhaust hoods, many of these systems were not rated as effective.

The proportions of operations ventilated differed between mills ($p=0.003$), but there were no differences in ventilation effectiveness between mills. Mills 3 and 6 had the highest proportions of operations with local exhaust ventilation.

5.0 Respiratory Health Assessment Results

5.1 Study participation

Overall participation rates for each mill are shown in Table 12. A total of 131 filing room personnel were eligible to participate; 118 took part (participation rate: 90%). The reasons for lack of participation were:

sickness/off on WCB or LTD	3
refused	3
not available	7

This level of participation is extremely good, with a refusal rate of only 2%. This suggests that the results obtained from this study can be assumed to be a fair reflection of the true respiratory health status of filing room personnel, and are not likely to be a biased sample of the healthiest or sickest persons.

Table 12: Participation rates by mill

Mill	Number Eligible	Number Participated (%)
1	13	13 (100%)
2	12	12 (100%)
3	15	15 (100%)
4	15	15 (100%)
5	21	19 (90%)
6	25	19 (73%)
7	18	15 (83%)
8	12	10 (83%)
Total	131	118 (90%)

5.2 Characteristics of study participants

5.2.1 Saw filers compared to bus mechanics - demographics

Demographic characteristics of the saw filer group are shown in Table 13, with comparison information also shown for the bus mechanic group. These results show that the saw filers were slightly older than the bus mechanics, had a higher proportion of former smokers (but the same proportion of current smokers), and had been employed by their current employer for a considerably longer period of time than the bus mechanic group. As both lung function values and rates for respiratory symptoms vary with age and with smoking behaviour, these differences require that age and smoking differences be taken into consideration when comparing results from the two groups. The groups did not differ in the rates for history of childhood asthma, heart disease (treated by a physician), or positive skin tests to common allergens.

Table 13: Demographic Characteristics

	Saw Filers N=118	Bus Mechanics N=287	p
participation rate	90%	88%	
age, average (range)	46.7 (31,62)	44.1 (25,64)	< 0.02
height (m) average (sd)	176.8 (6.6)	175.7 (6.8)	NS
yrs with current employer	21.3 (9.2)	13.0 (7.3)	< 0.001
yrs in saw filing trade	15.5 (8.6)		
sex, male	100 %	100 %	
race, non-white	5 %	10 %	NS
atopic (positive skin test)	32 %	31 %	NS
history of heart disease	2 %	0 %	NS
history of childhood asthma	3 %	5 %	NS
cigarette smoking			
never smoked	21 %	37 %	
former smoker	59 %	42 %	< 0.002
current smoker	19 %	21 %	

5.2.2 Demographic characteristics among saw filers, according to different job titles

Among the sawmill study population, there were also differences in demographic characteristics, for workers with different job titles. These are shown in Table 14. Round saw filers and fitters were younger than knife grinders, benchmen, and head filers (p=0.09), although the years of employment with the current employer was no different across job title groups. Years in the saw filing trade, however, were significantly different for the various jobs. There were no statistically significant differences in smoking behaviour by job title, although the proportion of non-smokers varied from 6% of round saw fitter to 30% of head filers.

Table 14: Demographic characteristics according to job title

	Knife Grinders N=7	Round Saw Filers N=17	Fitters N=45	Bench Men N=39	Head Filers N=10	p
age in years (average)	50.8	44.0	45.2	48.0	49.1	0.09
years with current employer	25.3	21.4	18.6	23.5	21.8	NS
years in saw filing trade (average)	6.9	13.5	11.5	19.8	26.3	< 0.001
cigarette smoking						
non smoker	29 %	6 %	27 %	18 %	30 %	
ex smoker	57 %	71 %	56 %	60 %	60 %	NS
current smoker	14 %	24 %	18 %	23 %	10 %	

5.3 Reported current and historical job tasks among sawmill study population

The results from the questionnaire assessment of the specific tasks associated with current and past jobs in the saw filing trade are shown in Table 15. In interpreting the results shown in this table, it is important to remember that the criteria for classifying a job as having tungsten carbide or stellite grinding or heating are more stringent than for the other tasks listed. For these specific tasks, the tungsten carbide or stellite had to be handled at least 10% of the time (e.g., of the total amount of grinding, at least 10% of must include grinding of tungsten carbide tips) in order for the job to be classified as positive for that task. Therefore the frequency and duration for these tasks is somewhat smaller than for the other tasks listed below.

As can be seen in the table, although more participants currently report more frequent grinding or heating of stellite tips compared to tungsten carbide tips, the average duration of time over which tungsten carbide has been handled is greater. The maximum number of years over which stellite was reported as handled was 10 years, whereas the maximum number of years for tungsten carbide handling was 35 years.

Table 15: Frequency and duration of job tasks in the saw filing trade (current and past)

	Number ever performing this task	Number performing this task in current job	Duration* of jobs in which this task was performed years	(range)
Tungsten carbide wet grinding (≥10%):	43 +	18	6.9	(0.5-22)
Tungsten carbide dry grinding (≥10%):		9		
Stellite wet grinding (≥10%):	58 +	11	3.8	(0.5-10)
Stellite dry grinding (≥10%):		18		
Tungsten carbide soldering (≥10%):	56	19	9.6	(0.5-35)
Stellite welding (≥10%):	51	36	3.4	(0.5-8)
Benchwork (any)	85	72	14.4	(1.5-39)
Knife grinding (any)	40	15	8.3	(0.5-35)
Preparing asbestos saw guides (any)	33	3	10.7	(0.5-28)
Preparing babbitt saw guides (any)	60	37	8.9	(0.5-32)
Preparing composite saw guides (any)	76	46	10.2	(0.5-35)
Mill handling cedar	49	43	14.3	(2.5-35)

* average duration is shown only for those who have ever performed this task
\+ distinction between wet and dry grinding was not always possible for past jobs (therefore, except for the current job, these are taken together)

In all of the results which follow, when possible work related predictors of respiratory health were investigated, the tasks listed above were tested to determine whether or not one or more of these specific tasks (either the fact of current performance of the task, or the duration over which the task was performed) were associated with respiratory health outcomes.

5.4 Respiratory symptoms

5.4.1 Simple comparison of symptom rates between saw filers and bus mechanics

Table 16 shows the prevalence rates for respiratory symptoms, comparing saw filers to bus mechanics. The numbers shown in the table are the actual numbers of subjects reporting the symptom listed; the p values listed reflect the statistical probability that the differences shown are due to chance alone (after taking into consideration differences in smoking behaviour between the two groups). As seen in the table, the saw filers were significantly more likely to report phlegm production and wheezing (without reference to work), as well as more work-related cough, phlegm, and wheezing.

Table 16: Respiratory Symptom Prevalence Rates

	Saw Filers N=118	Bus Mechanics N=287	p*
Symptoms, without reference to work:			
Cough	11 (9%)	24 (8%)	NS
Phlegm	26 (22%)	31 (11%)	< 0.01
Wheezing	19 (23%)	29 (10%)	< 0.01
Breathlessness	14 (14%)	25 (9%)	NS
Nasal symptoms	28 (24%)	61 (21%)	NS
Work-related symptoms:			
Cough	16 (14%)	10 (3%)	< 0.001
Phlegm	17 (14%)	11 (4%)	< 0.001
Wheezing	11 (9%)	11 (4%)	< 0.03

p probability value, comparing saw filers to bus mechanics, after taking differences in smoking status into account
NS - not statistically significant at p < .05 level

5.4.2 Comparison of work and demographic predictors of respiratory symptoms

In addition to simply comparing rates for symptoms between saw filers as a group and bus mechanics as a group, we looked at the various kinds of work tasks performed by saw filers to see if filers who did specific tasks were more or less likely to have respiratory symptoms (Table 17).

Table 17: Odd ratios* for respiratory symptoms

Symptoms, without reference to work:

	cough		phlegm		wheezing		breathlessness		nasal symptoms	
saw filer vs bus mechanic	1.0	(0.4,2.5)	***2.4***	***(1.2,4.7)***	***2.0***	***(1.0,4.1)***	1.2	(0.5,2.5)	0.7	(0.3,1.3)
current smoker vs non smoker	***9.5***	***(3.0,30.2)***	***5.8***	***(2.4,14.0)***	***5.9***	***(2.6,13.5)***	***4.5***	***(1.6,12.5)***	1.4	(0.7,2.6)
ex smoker vs non smoker	1.2	(0.4,3.8)	2.0	(0.8,4.0)	1.2	(0.5,2.7)	2.1	(0.8,5.5)	1.0	(0.6,1.8)
tungsten carbide wet grinding (current job)	0.5	(0.1,4.8)	0.6	(0.1,3.3)	1.7	(0.4,6.7)	1.3	(0.2,6.8)	1.7	(0.5,6.1)
stellite welding (current job)	1.1	(0.2,5.7)	1.2	(0.4,3.4)	1.4	(0.5,4.4)	0.8	(0.2,3.4)	***5.0***	***(1.9,13.1)***

Work-related symptoms:

	cough		phlegm		wheezing	
saw filer vs bus mechanic	***3.1***	***(1.2,8.1)***	***3.4***	***(1.4,8.3)***	***2.7***	***(1.0,7.2)***
current smoker vs non smoker	2.8	(0.9,9.1)	2.0	(0.7,6.2)	2.8	(0.9,9.0)
ex smoker vs non smoker	1.1	(0.4,3.5)	1.1	(0.4,3.1)	1.0	(0.3,3.1)
tungsten carbide wet grinding (current job)	0.2	(0.0,2.2)	0.8	(0.2,4.2)	1.5	(0.3,8.2)
stellite welding (current job)	***3.7***	***(1.1,12.0)***	2.2	(0.7,7.0)	1.0	(0.2,4.6)

* Odds ratios (and 95% confidence limits) from logistic regression analysis, with age (3 categories: < 40, 40-55, >55) also taken into account. Significantly elevated odds ratios ($p < 0.05$) are shown in bold italics.

We found that the increased symptoms of cough, phlegm, and wheezing were reported by saw filers, regardless of their specific work tasks, but saw filers doing stellite welding were also about 5 times more likely to report nasal symptoms in addition to these chest symptoms.

The relationship between work tasks and various symptoms are shown in the table on the previous page. The table shows the odds ratios for work tasks and smoking history associated with the symptoms identified. (Odds ratios are a way of comparing the symptom rates for different groups. An odds ratio of 1 means that the rates are the same. The value of the odds ratio gives an indication of the increase or decrease in risk for having the symptom given the presence of the specific exposure factor.) In the analysis shown in the table, tungsten carbide wet grinding was also included as a potential predictor of respiratory symptoms as it was the task shown to be most strongly associated with cobalt exposure in the analysis of exposure factors (described in section 4.3.1 of this report). Inclusion or exclusion of this task in the analysis of symptoms did not make any difference to any of the other results shown.

As can be seen in the table, stellite welding was associated with a 5-fold increase in nasal symptoms and a 3.7-fold increase in work-related cough. However, the relationship between stellite welding and these symptoms did not fully explain the overall increase in symptoms among the saw filers compared to the bus mechanics. Saw filers were still shown to have approximately twice the risk of symptoms of phlegm production and wheezing, and 3 times the risk of work-related cough, phlegm, and wheezing. Smoking-associated increases in risk for these symptoms are also shown in the table for comparison purposes. No significant increase in the symptom of breathlessness was seen among saw filers as a group, or associated with any particular work task.

5.5 Lung function test results

5.5.1 Explanation of test results

To compare lung function test results between groups, the average of the morning and afternoon values from the first complete day of test results was used. This was done to prevent comparison of only early morning or late afternoon results (for the saw filers) to results collected at various times throughout the day (for bus mechanics). Lung function is examined with results from four tests. FEV1 is a measure of air flow and becomes reduced in the presence of obstruction in the larger air passages. MMF and FEV1/FVC are also measures of airflow, but tend to become reduced in the presence of obstruction of the smaller air passages. This typically occurs sooner than large air passage obstruction. FVC is a measure of lung capacity and can be reduced in the presence of scarring or congestion of lung tissue. It can also be reduced as a reflex response to some acute irritants. If lung capacity is reduced, FEV1 will also be reduced. All four of these measures of lung function will become reduced with aging. FEV1, MMF, and FEV1/FVC are also reduced as a result of airflow obstruction from cigarette smoking.

5.5.2 Lung function among saw filers compared to bus mechanics

A comparison of average levels of each of the lung function tests between saw filers and bus mechanics is shown in Table 18a. These results have been adjusted to take into account the effects of age, height, race, history of childhood asthma, and cigarette smoking. This comparison shows that saw filers had average levels of MMF and FEV1/FVC that were significantly lower than levels seen in the bus mechanics and suggests that, as a group, saw filers had a greater degree of obstruction of small airways than expected.

Table 18a: Adjusted lung function values*, comparing saw filers to bus mechanics

	Saw Filers average (se)	Bus Mechanics average (se)	p+
FEV1 (litres)	3.77 (0.05)	3.83 (0.05)	NS
FVC (litres)	4.98 (0.06)	4.98 (0.04)	NS
MMF (litres/sec)	3.25 (0.10)	3.47 (0.06)	0.06
FEV1/FVC (%)	75.6 (0.60)	77.0 (0.40)	<0.05

* average lung function values, after adjustment for differences in age, height, race, history of childhood asthma, cigarette smoking status and amount smoked

\+ p-value, comparing saw filers and bus mechanics

When we looked at the prevalence of lung function levels in the clinically abnormal range (Table 18b), we found no significant differences, on average, between the rate of clinical abnormality in these test results between saw filers and bus mechanics. This suggests that, although there is evidence of airflow obstruction in saw filers (greater than would be expected due to cigarette smoking alone), it is not apparent as clinically obvious respiratory abnormality when saw filers as a whole group are compared to an external comparison population.

Table 18b: Prevalence rates for abnormal lung function*, comparing saw filers to bus mechanics

	Saw Filers number (%)	Bus Mechanics number (%)	p+
Abnormal FEV1	15 (13%)	29 (10%)	NS
Abnormal FVC	4 (3%)	11 (4%)	NS
Abnormal MMF	29 (25%)	54 (19%)	NS

* abnormal (as defined in text): < 80% predicted value for FEV1 and FVC, and < 60% of predicted value for MMF
\+ p-value, comparing saw filers and bus mechanics, taking into account differences in cigarette smoking status only
NS not statistically significant at $p > 0.05$

5.5.3 Comparison of work and demographic predictors of lung function results

In the same way as for the analysis of respiratory symptoms, we looked at the lung function test results to see saw filers who did any particular job task or tasks were more or less likely to have changes in lung function. These results are shown in Table 19a and Figure 1. We found that the saw filers doing wet grinding of tungsten carbide had significant reductions in lung volumes (FEV1 and FVC) and those doing welding of stellite had a slight reduction in FEV1/FVC % (indicative of airflow rates).

When these job tasks were taken into account, the difference in lung function between saw filers and bus mechanics was no longer seen, suggesting that performance of these tasks are sufficient to explain the difference between the groups. The number of years spent in tungsten carbide grinding jobs (either wet or dry) was significantly associated with reduced lung capacity when current job tasks were not considered, but when current tungsten carbide wet grinding was taken into account, years spent at this task became only marginally significant. The latter results only are shown in Table 19a.

Figure 1 shows this same information in graphic form, comparing the effects of tungsten carbide grinding and cigarette smoking on lung volume (FVC in litres, on the left hand side of the figure) and airflow rates (MMF, in litres/sec, on the right hand side of the figure).

Table 19a: Effect on lung function* of various work task and demographic variables

	FEV1 litres	p	FVC litres	p	MMF L/sec	p	FEV1/FVC %	p
saw filer vs bus mechanic	+0.010	NS	+0.073	NS	-0.118	NS	-0.88	NS
tungsten carbide wet grinding (current job)	-0.384	<.05	-0.376	<.05	-0.607	.06	-2.21	NS
stellite welding (current job)	-0.016	NS	+0.158	NS	-0.334	NS	-3.27	<.05
age (each year)	-0.032	<.001	-0.024	<.001	-0.061	<.001	-0.26	<.001
cigarette smoking (each pack/day per year)								
current smokers	-0.006	<.05	+0.004	NS	-0.025	<.001	-0.18	<.001
former smokers	-0.005	<.05	-0.002	NS	-0.008	<.05	-0.06	<.01
tungsten carbide grinding (wet or dry) (each year at a job with this task)	-0.007	NS	-0.023	.08	+0.023	NS	+0.22	NS

* Values shown are the estimated effect on each of the lung function values of the predictors shown vertically in the table, as determined from multiple linear regression models in which age, height, race, history of childhood asthma were included in the analyses, in addition to all of the predictor variables shown in the table.

NS not statistically significant at p > 0.05

Table 19b and Figure 2 show odds ratios (also adjusted for age, childhood asthma, and race) for possible predictors of lung function test results in the clinically abnormal range (for FEV1 and MMF). FEV1 would be expected to be abnormal due to factors which cause reductions in lung volume (similar to FVC) as well as factors which cause airflow obstruction.

This adjusted logistic regression analysis was not possible for FVC because the number of subjects with FVC in the clinically abnormal range was too small to allow for stable statistical modeling. Descriptive information and simple analysis of this outcome is, nevertheless, informative. There were four saw filers with FVC in the clinically abnormal range. None were current smokers and all but one had quit smoking at least 10 years prior to testing. None had any history of previous or concurrent respiratory diseases. Three of the four were currently working in a job involving wet grinding of tungsten carbide tips; the other was a head filer who had worked at this task for six years in his most recent previous job. The unadjusted odds ratio for abnormal FVC associated with wet tungsten carbide grinding in the current job was 5.3 (95% confidence interval: 0.7, 40.0), and for each decade of wet tungsten carbide grinding (past or present) was 5.0 (95% confidence interval: 1.1, 23.9).

Table 19b: Odds ratios* for clinically abnormal levels of lung function, for various job tasks and demographic predictors of lung function

	Abnormal FEV1		Abnormal MMF	
current smoker	***2.6***	***(1.0, 7.0)***	***3.1***	***(1.5, 6.5)***
former smoker	1.7	(0.7, 3.9)	1.1	(0.6, 2.0)
saw filer vs bus mechanic	0.5	(0.2, 1.3)	0.9	(0.5, 1.8)
tungsten carbide wet grinding (current job)	***6.6***	***(1.7,24.8)***	1.5	(0.4, 5.4)
stellite welding (current job)	2.9	(0.8, 9.8)	2.3	(0.8, 6.2)

* Odds ratios (and 95% confidence limits) taking into account age, history of childhood asthma, race, and all of the variables listed above (from logistic regression analysis). Statistically elevated odds ratios ($p < 0.05$) are shown in bold italics.

The results indicate that saw filers currently engaging in wet grinding of tungsten carbide had an approximately 6-fold increase in risk for a level of FEV1 in the clinically abnormal range, compared to the remainder of the study population. Stellite welding was also associated with a nearly significant 2-fold increase in the prevalence of clinically abnormal FEV1 and MMF. No other job task (either current or past) was associated with a significant increase in risk for these outcomes.

5.6 Other possible predictors of respiratory health outcomes

When the specific job tasks were taken into consideration as shown in the analyses described above, there were no additional differences found from one mill to another for any of the lung function or respiratory symptom variables studied. Similarly, several other possible work and demographic factors were considered but were not found to be associated with any of the health outcomes. These included working in a cedar mill (or duration of time in a cedar mill), having a positive cobalt or chromium skin prick test, average frequency of saw changes (representing potential for wood dust exposure), and duration of employment in the saw filing trade, with the current employer, and in sawmilling.

5.7 Changes in lung function over one work shift in relation to measured exposure to metals

The change in FEV1 from before shift to after shift (measured on the day shift) was calculated as the change from morning to afternoon as a percentage of the pre-shift level. A 5% reduction in FEV1 was considered as evidence of a significant drop (i.e., a decrease greater than the expected hour-to-hour variation in this test). A total of 35 saw filers experienced a 5% or greater drop in FEV1 over the shift on at least one testing day. Each individual's average change in FEV1 for each of the four test days was also calculated and an average change of 5% or greater was seen in 12 of the study participants.

Analyses were performed in which potential work and demographic predictors of average change in FEV1 over the shift were evaluated. There were no significant relationships between the change in FEV1 over one work shift and any of the following: measured cobalt or chromium exposure (both log-transformed and untransformed); number of saw changes; cigarette smoking; age; cobalt and chromium skin test status; or cedar mill (compared to non-cedar). Participants with asthma were significantly more likely to experience an increase in FEV1 over the work shift. This is not unexpected, as asthmatics often have slightly lower levels of lung function first thing in the morning compared to later in the day. (As pre- and post-shift testing was not performed on the bus mechanics, they could not be used for comparisons of this effect.)

A careful examination of the respiratory symptoms reported and the changes in lung function (and corresponding cobalt and chromium exposures) revealed no suggestive cases of specific cobalt or chromium occupational asthma.

6.0 Relationships Between Exposures and Respiratory Health Effects

6.1 Qualitative exposure-response relationships

The results of this study suggest that wet grinding of tungsten carbide may be associated with significant reductions in measured lung capacity (specifically FEV1 and FVC), but without accompanying symptoms to date in saw filers at the study mills. Stellite welding may be associated with symptoms of irritation (nasal symptoms and cough) and small reductions in airflow rates (specifically FEV1/FVC and MMF). These two exposures and combination of outcomes must be evaluated separately.

First, with respect to stellite use, it is noteworthy that, despite the increased cobalt concentration in the stellite alloy, this was not associated with increased airborne cobalt concentrations, nor in increased cobalt in the coolant fluid from machines on which stellite tips were ground. Furthermore, stellite grinding was not associated with decreases in lung volumes nor with increases in respiratory symptom rates.

However, stellite welding was associated with increased nasal symptoms, and slight decreases in measures of air flow. This suggests that irritation of both upper and lower airways was occurring in association with stellite welding. It is possible that these effects are the result of chromium exposure as both have been shown to be associated with airborne chromium exposure in other studies. Because these effects were not observed in the group most highly exposed to total chromium, knife grinders, it might be argued that the effects are due to differences in the form of chromium between these operations or to other components of welding fume or welding gasses. The form of chromium present (i.e., hexavalent or otherwise) was not determined in this study. Until this is known, it would be prudent to assume that the chromium from stellite welding is in the hexavalent form (as is found with stainless steel welding), and to make every attempt to lower exposures as much as possible, given the known association between hexavalent chromium exposure and lung cancer.

Tungsten carbide grinding was associated with increased airborne cobalt concentrations and very high levels of cobalt in the coolant from tungsten carbide grinding machines. Workers who performed this task, particularly those who used coolant the majority of the time, had significant reductions in lung volumes compared to other saw filing tradesmen. Airborne cobalt exposure levels were similar for dry grinding and wet grinding, but statistically significant lung volume reductions were found only in association with predominantly wet grinding, therefore one might assume that the coolant itself is the etiologic agent. This is not likely to be the case since wet grinding of the other saw filing room metals, stellite and knife steel, did not result in these reductions in lung volume. The grinding fluids may, however, have contributed to a change in form of the cobalt, for example cobalt from dry grinding may remain in elemental form, whereas cobalt from wet grinding may be ionized. Other possibilities are that the cobalt has enhanced toxic potential when present in the coolant, or that additional exposure from other sources (e.g., ingestion or skin absorption) may occur more frequently or intensely in association with wet grinding. As with all the metals in this study, speciation was not done for cobalt; this issue warrants follow-up.

Wet grinding of tungsten carbide by workers in the manufacturing of tungsten carbide tools has been shown in two previous studies to be associated with an increased rate of hard metal lung disease (24,36). This disease is characterized by reductions in lung volumes (as found in this study), however, it is also typically associated with symptoms of breathlessness (not found in this study). As the lung function values found in this study were still mostly above the "abnormal" level, it is not surprising that there was no obvious increase in the reporting of breathlessness. This would not be expected until the lung function levels had declined further. We cannot determine from this study, whether or not the reduced lung volumes seen will progress further to the stage of symptomatic hard metal disease.

Further characterization of the nature of the lung health abnormalities reported here will require additional testing of the current study population (e.g., measurement of subdivisions of lung volume, diffusing capacity, chest xrays, CT scanning, skin patch testing, and blood measurement of lymphocyte transformation), and/or additional studies of a larger number of saw filers from other mills with similar exposures. Both types of investigation are warranted given the results of this study.

6.2 Quantitative exposure-response relationship for cobalt

This study was designed mainly to study exposure levels in the saw filing trade and to evaluate possible predictors of elevated airborne cobalt and chromium levels. The respiratory health assessment was included as a pilot study with the understanding that the numbers of workers being studied may not be sufficient to evaluate a quantitative relationship between exposure levels and health outcomes. However, a limited exposure-response evaluation can be performed for the exposure to cobalt among saw filers.

Saw filing tradesmen in the mills studied can be assumed to have a background exposure to cobalt in air approximately equal to the background level estimated by the exposure modeling analysis described earlier in the industrial hygiene section of this report (Table 7b). That level was 0.00077 mg/m^3. Saw filers performing tungsten carbide grinding in their current job (as defined above, section 3.3.5) can be estimated to be exposed to cobalt concentrations of approximately 0.0055 mg/m^3 (0.00077 plus 0.0047 for wet grinding or 0.0045 for dry grinding) as determined from the exposure model (Table 7b). The average lung volumes (FVC) for three groups of workers, after adjusting for age, height, and smoking differences, are shown by exposure level in Figure 3. Those with only background exposures had average FVC levels slightly above 100% of predicted. This is similar to the average value for FVC expected in any population of currently employed workers. Exposure-response is shown by the lower value for FVC in saw filers who mainly do tungsten carbide wet grinding (i.e., who use coolant 50% of the time or more), and for those who mainly do tungsten carbide dry grinding (i.e., who use coolant less than 50% of the time). Knife grinders and head filers were excluded from these results. The cobalt exposure axis is shown up to 0.020 mg/m^3 as this is the proposed ACGIH TLV and the proposed B.C. WCB Permissible Concentration for cobalt. In the figure, a horizontal line is drawn across the graph at FVC = 80% predicted. This is the value below which one considers lung volume to be entering the abnormal range.

6.3 Evaluation of the proposed Permissible Concentration for cobalt

The exposure-response evaluation indicates that statistically significant reductions in lung volume among tungsten carbide wet grinders were found in association with average cobalt exposure levels well below the proposed Permissible Concentration. If one were to extrapolate linearly from the values shown in Figure 3, it would appear that the average value for FVC associated with exposure to 0.020 mg/m^3 of cobalt in air would be less than 80% predicted for wet tungsten carbide grinders. (This same conclusion would also be reached if the exposure model from Table 7a were used. That model includes values for three outliers, and would give an estimate of average exposure for tungsten carbide wet grinders of 0.0084 mg/m^3.) This implies that exposure at the proposed Permissible Concentration would result in abnormal lung capacity in over half of the tungsten carbide wet grinding population and suggests that the Permissible Concentration should be set at a value lower than 0.020 mg/m^3.

However, this tentative conclusion is dependent on the assumption that the average cobalt concentration measured in the 8 study mills is a reasonable reflection of the exposures that would have been found in these mills over the past several years. This may not be the case, as we are aware that improvements in ventilation were made in two of the mills between the time that the study was announced and the time that our testing occurred.

The induction period for hard metal lung disease has been reported to vary from as little as 2 up to 30 years from first exposure (24-28), therefore both relatively recent as well as past exposures may contribute to the disease process. In the absence of information to evaluate recent and distant past exposures, it would be prudent to assume that the exposures measured in this study are not significantly different (e.g., by an order of magnitude) from past exposures in these mills. This would argue in favour of establishing a Permissible Concentration for cobalt exposure closer to the average values measured in tungsten carbide grinders in this study (e.g., a time-weighted-average of 0.005 mg/m^3). The exposure measurements made in this study demonstrate that air concentrations of cobalt can be controlled to this level.

7.0 Epilogue

During the period from January to March 1993, a preliminary version of these results was presented to managers and employees of each of the participating sawmills, as well as to occupational health professionals in the forest industry, the Workers' Compensation Board, and the academic community. During this round of discussions, many interesting pieces of information were brought to our attention. Although this information does not constitute part of this study, it is relevant to the issue of saw filers' exposure to metals, therefore we are taking this opportunity to share it with you.

7.1 Information from the study mills

During the period since data collection was completed at the mills, one mill conducted a small experiment to determine how often to change the coolant in their tungsten carbide wet grinding machines. They tested cobalt levels in the coolant at 0, 2, and 7 weeks after use, and found cobalt levels less than 10 mg/L at 0 and 2 weeks. By the 7th week, the levels had increased to 165 mg/L, therefore they now completely change their coolant every 4 to 5 weeks. The sludge from the machine is sent to a landfill, and the liquid apparently meets standards which allow it to be disposed down the drain. This data represents a small trial of one of the follow-up studies we have recommended. Although this mill's results may be specific to the coolant they use and the frequency with which they use their grinding machine, it presents at least some data to suggest coolant change frequency before more is known.

One mill added a new local exhaust system for their chipper knife grinder. The knife grinder in this case is the common design in which the grinding wheel moves back and forth along the length of the chipper blades. The ventilation system consists of a canopy hood covering the length of the knife grinder, with plastic strip curtains (similar to a welding enclosure) surrounding both short sides and one long side of the hood to reduce the surface area of the open face. One other mill had two knife grinding machines with a different design: the grinding wheel itself was stationary and the blades circulated under it. Although these machines were not ventilated, we expect that this design would require a smaller fan size since the area required for enclosure would be much smaller than the moving wheel design.

Another mill has switched to lead-free babbitt, so that now 3 of the 8 mills do not use any lead babbitt for either round-saw guides or knife balancing.

Employees at one mill were concerned about the dust created by grinding band saw wheels. Because this job is done relatively infrequently, this operation was not captured in our study measurements. The head filer at another mill told us that they had also had concerns, and have now implemented a policy of using an airline respirator with a sandblasting hood during this operation.

7.2 Information from University of British Columbia medical colleagues

At one meeting in which the results were presented to a group of medical colleagues, we were made aware of a saw filer working in a small northern B.C. sawmill who had died of hard metal lung disease in 1988. This man was originally diagnosed as having interstitial lung fibrosis of unknown origin; however, the pathologist who examined his lung tissue after his death now reports a confirmed diagnosis of hard metal lung disease.

Very little exposure information is known with respect to this fatality. The facts of the case are as follows. The man worked at a mill in northern B.C., mostly handling lumber outdoors for approximately 25 years. He was an ex-smoker, having smoked only about 1/2 pack per day for a few years during his twenties. In 1977, at the age of 39, he began his saw filing apprenticeship. The mill used tungsten carbide saw tips and he reported to his doctor that his work area was "very dusty, with lots of fumes". He first noticed trouble with breathlessness in 1979, and this became worse over the next several years. In 1980, his FVC was 83% of the predicted value. In 1983, his lung function was markedly reduced (FVC = 40% of predicted value). A lung biopsy was done and diagnosed as interstitial fibrosis (unknown cause). By 1984, he was unable to continue work as a saw filer due to increasing breathlessness, so was transferred to a sedentary job elsewhere in the mill. By 1987, he was totally disabled and left work with a disability pension (not a WCB pension). He died in 1988 at the age of 50. The pathological diagnosis made after reviewing the lung tissue was hard metal interstitial lung disease, associated with tungsten carbide exposure.

This information confirms that hard metal lung disease is a possible outcome from exposures found in saw filing rooms in British Columbia. Whether or not this is the only case is completely unknown to us. It is notable that the diagnosis was not made during the life of this man. This is likely because most physicians are not aware of the potential association between work as a saw filer and interstitial lung fibrosis. In addition, it is possible that in some cases a lung biopsy may not detect cobalt or tungsten metal, however, their absence does not rule out hard metal lung disease (25,27).

This unfortunate case does suggest the possibility that additional cases of hard metal lung disease may occur in B.C. sawmills. This is a compensable disease (listed in Schedule B of the Workers Compensation Act) and factors which lead to death, as opposed to recovery, are not known. As use of tungsten carbide tipped saw blades has only become widespread in the past two decades, the absence of historical evidence of cases of this disease cannot be taken as cause for inaction now.

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