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An investigation of wood dust exposure in Alberta sawmills

by

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

Medical Sciences – Public Health Sciences

Edmonton, Alberta

Fall 2000

0-612-59903-5

University of Alberta

Library Release Form

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Title of Thesis: An investigation of wood dust exposure in Alberta sawmills.

Degree: Master of Science

Year this Degree Granted: 2000

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August 22/2000

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ABSTRACT

Wood dust is classified as a human carcinogen based on a marked excess of sino-nasal cancer among workers exposed primarily to hardwood dusts (IARC, 1994). This thesis evaluates the level of softwood dust exposure in Alberta sawmills.

From nine Alberta sawmills, 210 wood dust samples (inhalable) were collected with personal monitors using IOM (Institute of Occupational Medicine) sampler devices. Approximately 9% of samples exceeded the proposed ACGIH TLV (American Conference of Governmental Industrial Hygienists Threshold Limit Value) of 5 mg/m^3 TWA (time weighted average) for inhalable wood dust. "Cleanup" workers (a subset of sawmill workers) had statistically significant higher mean inhalable dust levels compared with the other subsets of sawmill workers. Thirty-two percent of samples for "cleanup" workers exceeded the proposed ACGIH TLV.

With particular attention to the "cleanup" workers, sawmills should review and update their wood dust control methods that include engineering controls, administrative controls, and personal protective equipment.

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "An investigation of wood dust exposure in Alberta sawmills" submitted by Michael Warren Yamanaka in partial fulfillment of the requirements for the degree of MSc in Medical Sciences– Public Health Sciences.

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DEDICATION

I dedicate this thesis to my family and friends who patiently listened to my bitter complaints, and provided the necessary support and encouragement to "get the job done".

ACKNOWLEDGEMENTS

I thank Dr. Tee Guidotti for his patience and persistence for helping me though the initial stages of my thesis. I also wish to acknowledge Mr. Lloyd Harman, Mr. Ken Wong, Mr. Maurice Taylor and Mr. Chris Taylor for their work on the Alberta Sawmill Study. If it weren't for the aforementioned people, I would not have been able to begin my thesis project.

To my supervisor Dr. Duncan Saunders, and my co-supervisor Dr. Jim Cheng, I wish to thank them for their encouragement, and guidance especially during the late stages of my thesis. Although under time constraints with previous commitments, Dr. Saunders and Dr. Cheng were still able to accommodate me and provide direction to my Masters thesis.

For their help with my statistical analysis of the data I thank Mr. Paul Beaulne, Dr. A. Senthilselvan, and Mr. Gian Jhangri.

Many others have helped in one way or another and I thank them collectively. However I would like to specifically acknowledge Dr. Niels Koehncke, Ms. Kathy Lasell, and Ms. Colleen Cartier for their help with the final preparation of the manuscript.

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LIST OF ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
AFPA	Alberta Forest Products Association
FAO	Food and Agriculture Organization
F.R.C.S	Fellowship of the Royal College of Surgeons
IARC	International Agency for Research on Cancer
ICD-9	International Classification of Disease 9th Edition
IOM	Institute of Occupational Medicine
IPM	Inhalable Particulate Mass
mg/m^3	Milligrams per cubic meter
MMAD	Mass Mean Aerodynamic Diameter
NOAL	No Observed Affect Level
NOAEL	No Observed Adverse Effect Level
TWA	Time Weighted Average
UK	United Kingdom

1. INTRODUCTION

The International Agency for Research on Cancer (IARC) is part of the World Health Organization. IARC's mission is to coordinate and conduct research on the causes of human cancer, the mechanisms of carcinogenesis, and to develop scientific strategies for cancer control. In 1994, a committee selected by IARC classified wood dust as a Group 1 or definite human carcinogen, based on very strong evidence of a carcinogenic risk for sino-nasal cancer (IARC Working Group, 1995). No differentiation between dust from softwoods or hardwoods was made. However a footnote to the IARC's committee statement reported that "the evaluation was based on a marked excess of sino-nasal cancer among workers exposed primarily to hardwood dusts".

An account of some historical events, and a review of nasal cancer, wood types, and dust measurements will provide background information for this thesis.

1.1 Historical events

1.1.1 Interplay between chance and scientific observation

With new medical discoveries, there is often an interplay between chance and trained scientific observation. The case of woodworkers' nasal cancer is an example of this. In 1963 Dr. R.G. Macbeth was invited to deliver the Sir William Wilde oration in Dublin (Macbeth, 1991). This was a prestigious event, and Dr. Macbeth was to lecture on a subject of his choice within the medical specialty of otolaryngology (ears, nose, and throat). He decided to speak about nasal cancer since it had not been reviewed recently, and because it was an area of interest to him (Macbeth, 1991). Dr. Macbeth began studying cases of nasal cancer that were observed at the Radcliffe Infirmary (the Oxford teaching hospital) in the previous 25 years. A disproportionately large number of nasal cancer cases were found to come from the small town of High Wycombe that had a population of approximately 25,000 residents (Macbeth, 1991). This was the starting point for the eventual discovery of woodworkers' nasal cancer. Dr. Macbeth stated that chance played a role in this discovery simply because of the fact that he was nominated to give the oration, and that his special interest was in nasal cancer.

1.1.2 High Wycombe

High Wycombe is a small market town in the United Kingdom about halfway between Oxford and London. It is situated within the Chiltern Hills, an area famous for its beech and elm trees. For about 300 years the major industry has been furniture making from this local timber (Macbeth, 1991). The overall incidence for nasal cancer in the United Kingdom was 0.5 cases per million people per year. Professor D. Acheson, Chair of Epidemiological Medicine at Southampton, estimated that "male woodworkers at High Wycombe have a 140 times greater likelihood of contracting sino-nasal cancer than the general population at large" (Macbeth, 1991).

1.1.3 Furniture makers

Esmé Hadfield, F.R. C.S., an otolaryngology resident in High Wycombe analyzed the occupational histories obtained from the furniture workers in High Wycombe. She noted that "workers who had been exposed to fine dust from high-speed machinery were most at risk", and that "wood dust is in itself irritating to the nose" (Macbeth, 1991). In addition Esmé Hadfield examined the furniture workers and noted deposition of wood dust in the nose at the anatomical site where the majority of nasal cancers had been discovered. She proposed a mechanism of injury that specialized protective hairs within the lining of the nose were destroyed by the wood dust. Therefore carcinogenic or "cancer causing" material gained entry into specialized mucous glands of the nose, and produced a specific type of nose cancer called adenocarcinoma or "cancer of the glandular cells" (Hadfield, 1970). Esmé Hadfield was recognized for her contribution to the uncovering of the etiology of woodworkers' nasal cancer. However the mechanism of injury and the pathogenesis of woodworkers' nasal cancer is still currently an issue of debate.

1.2 Nasal Cancer

1.2.1 Epidemiology

The nasal cavity consists of a bony framework that is lined with respiratory epithelium (tissue lining). Associated with the nasal cavity are paranasal sinuses. These are air-filled bony cavities, which are also lined with respiratory epithelium. The epithelium performs protective, secretive or other functions depending on the type of cells. Adenocarcinoma is one of several histological types of nasal cancer (others are anaplastic, transitional cell, sarcoma, and squamous cell). Adenocarcinoma is a cancer of the glandular or secretory tissue of the nasal cavity. Although adenocarcinoma was the major cell type (histological type) of nasal cancer discovered in High Wycombe, it is an uncommon form of nose cancer, and is very rare in the general population (Acheson et al., 1984). The most common type of nasal cancer is squamous cell carcinoma or "tumors of the protective epithelial lining of the nose" (Harrison's, 1996). The data for Table 1-1 was obtained from the Alberta Cancer Board.

Table 1-1. Paranasal cancer diagnosed amongst Alberta residence 1990-1998

Type of cancer (ICD-9 code 160)	*Number of cases (and %)
Squamous cell	57 (64%)
Adenocarcinoma	29 (32.5%)
Other	3 (3.5%)
Total	89

*The numbers provided in the tables are provisional as some cases (or deaths) may be registered in subsequent years. Methods for coding of cancers on the Alberta Cancer Registry have varied though the years. Therefore, caution should be exercised when comparing this data to that of previous years. (Alberta Cancer Board, 2000).

In Alberta squamous cell accounts for approximately two thirds (64%) of all paranasal cancers diagnosed during the period 1990 - 1998, (Alberta Cancer Board, 2000). For the same time period adenocarcinoma accounts for approximately one third (33%) of all paranasal cancers.

In Canada, the incidence of nose/sinus (ICD-9 code160) cancer cases is 0.77/100,000 per year (Health Canada, 1995). In the province of Alberta the incidence of nose/sinus cancer cases is slightly lower at 0.53/100,000 per year (Health Canada, 1995). This figure quoted by Health Canada is an age-standardized rate for both sexes combined and all ages.

When one applies the proportion of squamous cell cancers (approximately two thirds according to the Alberta Cancer Board) to 0.53/100,000 per year (Health Canada's incidence statistics), the incidence of paranasal squamous cell cancer is approximately 0.35/100,000 cases per year in Alberta.

1.2.2 Clinical features

Nasal or sinus cancer may present as facial pain, nasal obstruction, epistaxis (nose bleeds), foul odor, or it may present as a secondary infection. Unlike the acute effects of exposure to a strong acid or noxious chemical, nasal cancer may take several years to develop. Often a tumor can grow for many years without symptoms (asymptomatic). Specialized radiographic studies such as CT (computerized tomography) and MRI (magnetic resonance imaging) scans can assist in the diagnosis of nasal cancer, and image the extent of cancer involvement in order to plan management. The definitive diagnosis is confirmed with a biopsy from the cancer site. From the pathological specimen the histological cell type of nasal cancer can be ascertained (e.g. squamous, adenocarcinoma, other).

1.2.3 Treatment and prognosis

Treatment is dependent on the location and type of cancer, as well as the extent of lymph node gland involvement. Surgical excision and radiation therapy are the most common treatment options (Lange, 1994). The prognosis or probable course of the disease is variable depending on the extent of cancer involvement at the time of diagnosis. Frequently the cancer is at an advanced stage by the time the initial diagnosis is made since this cancer can grow slowly and may therefore be asymptomatic. On average, the 5 year survival rate after diagnosis and treatment is approximately 30% (Lange, 1994).

1.2.4 Etiology of woodworkers' nasal cancer

One hypothesis for the development of nasal cancer in workers exposed to wood dust implicates inhalation of substances extrinsic to the wood, and added during the processing of the wood product such as glues, varnishes, aldehydes, and wood preservatives (Nylander and Dement, 1993). Since that time investigators have found that other woodworking occupations such as cabinet makers, carpenters, loggers, and sawyers were also associated with sino-nasal cancer (Brinton et al, 1984; Hayes et al, 1986; Luce et al, 1992; Blot et al, 1997). Despite having no exposure to extrinsic substances added to the wood, loggers, and sawyers were reported to have excess risks of developing nasal cancer (Elwood, 1981; Voss et al., 1985; Vaughan & Davis, 1991). The fact that raw or natural wood was used in these other occupations may provide additional support that wood itself was contributing to the nasal cancers rather than some extrinsic product such as glue, or finishes that were commonly used by furniture makers (Viren and Imbus, 1989).

It is known that natural wood may contain toxins such as terpenes, tannins, tropolones, resin acids and lignin's, that inhibit fungal growth (Teschke, 2000). It is possible that substances intrinsic to the natural wood itself may be the etiological agent for sino-nasal cancer, however there is insufficient evidence at this time to comment on this hypothesis.

1.2.5 Mucociliary clearance

Impairment of mucociliary (hair like appendages within the respiratory tract that along with mucus act like an elevator for removal of dust) clearance is hypothesized as a mechanism of injury leading to the development of nasal cancer. Following inhalation, normal dust clearance from the nose is inhibited by adherence of wood particles to the mucous membrane of the nose. With interference of the normal mucociliary action, susceptibility to carcinogens is increased (Elwood, 1981; Nebill, 1983). Some authors state that the development of nasal cavity tumors may arise from chronic tissue damage from prolonged exposure to wood dust that initiates mucostasis (inhibition of mucus clearance) and metaplasia "new growth" (Barnes, 1986; Acheson, 1986, Hadfield 1971). Several studies of wood dust exposure have investigated mucociliary clearance and mucostasis. Radioactive labeling used in earlier studies showed slower clearance among wood exposed workers (Black et al., 1974). More recent studies use a saccharine staining test procedure for the exposed, and this method showed similar results (Blot et al., 1997). Mucostasis is defined as a nasal clearance greater than 30 minutes (Anderson et al., 1976). There is an apparent dose response with higher wood dust exposures resulting in greater mucostasis (Anderson et al., 1976). In one study, mean wood dust levels greater than 7 mg/m^3 were required before any significant difference from the unexposed control group could be detected (Blot et al., 1997). However in another, Wilhelmsson and Lundh found mucostasis with a mean wood dust concentration of 2 mg/m^3 (Wilhelmsson, and Lundh, 1984), but no dose response relationships were found. Although there have been interesting findings, there has been no consistent evidence of mucostasis leading to nasal metaplasia or dysplasia (Blot et al., 1997).

1.3 Other health effects

Health effects other than cancer are reported from exposure to wood dust. Increased prevalence of skin irritation, nasal symptoms (obstruction, hypersecretion, or irritation), and chest symptoms (cough, wheeze, shortness of breath, sputum production) are cited (Goldsmith and Shy, 1988). However, unlike sino-nasal cancer, these health effects are often non-debilitating and reversible. For the purposes of this Masters thesis, nasal cancer will be the primary health effect studied.

1.4 Trees and Wood type

Wood is typically classified into hardwood (Angiosperms), which are broad-leaved trees, and softwood (Gymnosperms), which are conifers or cone bearing trees. In High Wycombe hardwood trees such as beech and oak (which had intrinsic properties best suited for furniture making) were used for furniture making. Therefore initially the link between hardwood dusts and nasal adenocarcinoma was observed. Recall that in 1994, the International Agency for Research on Cancer (IARC) classified wood dust as a human carcinogen based on a marked excess of sino-nasal (sinus and nose) cancer among workers exposed primarily to hardwood dusts (IARC, 1995).

Although the majority of wood harvested worldwide (58% by volume) is from hardwood trees, much of this is consumed as fuel (Demers, 1997). For industrial purposes the majority of wood used (69% by volume) is from softwoods (Demers, 1997; FAO, 1993).

1.5 Estimating exposure to wood dust

To estimate the exposure to wood dust (concentration), an air sample from the workplace is drawn though a filter assembly. Dust is collected on the filter and then weighed on a balance. Since a known volume of air is drawn though the filter and the weight of the wood dust is measured, the concentration of wood dust in air can be calculated and is expressed as mass per volume (milligrams per m^3 or mg/m^3). Workplace air samples are generally collected over an 8-hour work period in order to simulate the average concentration of dust a worker would be exposed to in a typical day. This average concentration of dust over an 8-hour time period is known as a time weighted average or TWA. Average wood dust exposures can then be compared to an occupational exposure limit or threshold limit value.

Various manufacturers make mechanical devices available for wood dust sampling. A typical set up includes a pump, which draws air across a filter.

There are many types of filters (and assemblies for the filters) based on what agent one is sampling. Collection of wood dust can be accomplished using area sampling or personal sampling techniques.

1.5.1 Area sampling

Ambient or area sampling involves placing a monitor in close proximity to a machine or area of interest. Measurements of ambient wood dust from that particular machine or area can then be obtained. Area sampling is relatively easy to perform, and will give a reasonable exposure assessment of the area that the monitor is placed. Considerations for local exhaust ventilation can then be planned when dust levels are too high. Area sampling however may not necessarily reflect the true dose of wood dust an individual worker is exposed to since the worker may move away from the machinery and the area monitor. If during an 8-hour work period the worker moves from Site A (with low dust exposure) into Site B (with higher dust exposure) the Area monitor from site A will underestimate the exposure of the worker. An area monitor at Site B might overestimate the worker's exposure if the majority of the worker's time was spent at Site A. In addition, if an area monitor was placed in very close proximity to a known heavy dust source, there may be an overestimation of a worker's exposure since it is unlikely that one would get that close to the dust source.

1.5.2 Personal sampling

In contrast to area sampling, personal sampling (which involves placing a monitor on the collar or close to the breathing zone of the worker) may more accurately document daily exposure since the monitor travels with the worker wherever he or she goes during their work shift.

1.5.3 Particle size-selective sampling

Wood dust particle size plays a role in determining health effects. The American Conference of Governmental Industrial Hygienists define a particle size-selective sampling criterion (ACGIH TLV and BEI's, 1999). "For chemical substances present in inhaled air as suspensions of solid particles or droplets, the potential hazard depends on particle size as well as mass concentration because of:

1) The effects of particle size on the deposition site within the respiratory tract.
2) The tendency for many occupational diseases to be associated with material deposited in particular regions of the respiratory tract".

Particulate mass fractions can be divided into inhalable, thoracic, and respirable categories. Respirable particulate mass fractions are fine particles capable of reaching the smallest airways responsible for gas exchange. Thoracic particulate mass fractions have particles that reach the lower airways (but not the gas exchange areas). Inhalable particulate mass fractions are the larger particles that are deposited mainly in the nose and throat. The inhalable mass fraction is of primary concern for nasal and sinus cancer. Particulate mass fractions are different from the traditional "total" dust collection methods.

1.5.4 "Total" dust collection

Historically wood dust collection did not use the particle size-selective sampling criteria as defined above. Dust measurements were made using a "total" dust sampler. A "total" dust sampler is not particle size-selective with respect to the wood dust particles. The name "total" dust sampler is a bit of a misnomer since "total" dust sampling does not measure total airborne particulate nor does it measure total particulate penetrating the airways (Davies, 2000). With the recognition of particle size and dependent deposition within the respiratory tract, total dust sampling may not be specific enough for the evaluation of workers exposed to airborne wood dust (Hinds, 1988). "Total" dust sampling is less efficient at capturing wood dust particles than inhalable fraction methods. It is suggested by investigators that the "total" dust sampling method underestimates the true total inhalable particulate mass concentrations (Vincent, Mark, 1986; Mark et al., 1994; Tsai et al., 1996). In sawmills, inhaled particulate mass (IPM) samples have been estimated to collect higher concentrations of wood dust by a factor of 4 times that of the "total" dust samples (Davies, 2000).

1.5.5 Inhalable Particulate Mass (IPM) or inhalable fraction

In the current 1999 ACGIH TLV's and 1999 Alberta OEL regulations, wood dusts are reported as "total" dust concentrations. Recall that it is recognized that particles are deposited in different anatomic sites of the respiratory tract depending on the size of the wood dust particles. IPM or inhalable particulate mass sampling is appropriate for measuring dust that would normally be deposited in the upper respiratory tract, which includes the nose and sinus. A sampling collection device can be called an IPM sampler if it can capture particles according to the collection efficiency given in Table 1-2 (regardless of sampler orientation with respect to wind direction).

Table 1-2. Collection efficiencies of particle sizes for the IPM fraction

Particle Aerodynamic Diameter (μm)	**Collection Efficiency (%) SI(d)**
0	100
1	97
2	94
5	87
10	77
20	65
30	58
40	54.5
50	52.5
100	50

*From ACGIH 1999 TLV's and BEIs

The mathematical equation for calculating SI(d) in Table 2 is: SI(d) = 50% X (1 + $e^{-0.06d}$).SI(d) is the collection efficiency for particles with aerodynamic diameter d in µm.

Sampling devices for inhalable particulate mass must be able to collect dust according to the above equation. For example, given an enclosed box with a known concentration of wood dust particles of a uniform diameter (say 10µm), an IPM sampler will collect 77% of the 10µm wood particles present in the enclosed box. By convention the IPM equation is only defined for particle sizes 0 to 100 µm.

There are many different manufacturers of IPM samplers such as the IOM (SKC), Seven-hole sampler (Casella, JS Holdings), GSP (Deha-Haan & Wittmer), PAS-6 (University of Wageningen), and Perspec (Lavoro e Ambiente). All of these samplers must still conform to the equation defined above to be classified as an inhalable sampler.

1.6 Exposure limits

1.6.1 ACGIH

The ACGIH is proposing the use of particle size-selective sampling techniques to quantify exposure levels. With the Notice of Intended Changes (NIC) for wood dust (ACGIH) there is a movement towards using inhalable particulate mass (IPM) limits (ACGIH TLV's and BEI'S, 1999). The proposed ACGIH NIC for wood dust suggest a threshold limit value (TLV) of 5 mg/m^3 TWA inhalable. This limit represents an average dust exposure over the course of an 8-hour workday for a 40-hour workweek that should not be exceeded. However it is quite possible that a worker will exceed this exposure level at certain times during the day. For some hazards (chemicals, physical, biological agents) a ceiling limit or a STEL (short-term exposure limit) is established in order to prevent adverse acute or chronic health effects. A ceiling limit is defined as a maximal exposure level that should not be exceeded at any point during the workday. In contrast, a

STEL is the maximum concentration of dust averaged over a 15-minute period that a worker should never exceed, even if the overall 8-hour TWA is within limits. The current ACGIH STEL for softwood dust is 10 mg/m^3 ("total" dust). The proposed ACGIH NIC (1999) for softwood dust will eliminate the STEL. It is important to note that the ACGIH TLV's refer to "airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects".

1.6.2 Alberta Labour Regulations

The current Alberta chemical hazards regulation (393/88) states the 8-hour occupational exposure limit (OEL) for softwood is 5 mg/m^3. Alberta's OEL is expressed as a TWA using "total" dust levels. Recall that "total" dust collection methods underestimate the exposure for particles of the inhalable fraction (Hinds, 1988). In other words inhalable particulate mass fractions are often higher than "total" wood dust levels. "Total" dust can be converted to IPM measurements using a conversion factor depending on the type of wood process which dictates the size predominance of the wood dust (Davies, 2000).

1.6.3 The Alberta Sawmill Study

In the Alberta Sawmill Study, wood dust was collected using a SKC brand of IPM sampler named IOM (Institute of Occupational Medicine). A conversion factor was required in order to compare the Alberta Sawmill Study IPM results to the Alberta OEL "total" dust. The magnitude of the conversion factor is variable. A conversion factor of 4X has been reported in sawmills (Davies, 1999). Another study has compared the IOM sampler with the traditional "total" dust collection methods (Martin and Zalk, 1998). At wood dust concentrations greater than 0.5 mg/m^3 the IPM/total dust ratio was in the range of 2 to 4, but at wood dust concentration below 0.5 mg/m^3 the IPM/total dust ratio ranges from 2.1 to 71 (Martin and Zalk, 1998). With this wide range of ratios at low dust concentrations there is a problem of estimating a conversion factor if wood dust samples are frequently in the 0.5 mg/m^3 range. The current Alberta occupational exposure limit (5 mg/m^3 total dust) is one order of magnitude greater than 0.5 mg/m^3, and therefore the conversion factor of 2 to 4 can be used. Using Martin and Zalk's study results, IPM levels will be on average 2-4 times greater than total wood dust levels. Thus the Alberta OEL of 5 mg/m^3 "total" dust is equivalent to approximately 10-20 mg/m^3 of IPM dust.

1.6.4 Summary

With the growing acceptance of particle size-selective sampling, the proposed ACGIH NIC TLV 5 mg/m^3 inhalable will be used for the purposes of analysis and comparison within this Masters thesis. The current Alberta OEL of 5 mg/m^3 "total" dust will be converted to IPM dust levels (using a conversion factor of 4X), and will also be used for comparison within this thesis. Both the TLV and OEL are time weighted averages (TWA). The concept of a threshold limit value is similar to the occupational exposure limit. Recall that the TLV refers to "airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects". For the purposes of this Masters thesis, TLV is the term used by the ACGIH, and OEL will refer to Alberta's regulation.

1.7 Literature review

Recall that IARC classifies all wood dust as a Group 1 or definite human carcinogen based on a marked excess of sino-nasal cancer among workers exposed primarily to hardwood dusts. What about the nasal cancer risks associated with softwood dust exposure? Currently the ACGIH designates softwood as A4 or "not classifiable as a human carcinogen". From the ACGIH Appendix A, Carcinogenicity, (A4) are "agents which cause concern that they could be carcinogenic for humans but which cannot be assessed conclusively because of a lack of data". Since there is an apparent discrepancy between IARC classifying all wood dust (including softwood) as a definite carcinogen and the ACGIH designating softwood as "not classifiable as a human carcinogen", a literature search was conducted to review and clarify the evidence.

1.7.1 Types of studies selected

To address the issue of softwood dust exposure and nasal cancer risks, a search of Medline, Toxline, Embase, and Current Contents was conducted. The initial search used the key-words sinonasal cancer; wood dust; occupational diseases; sawmills; and health effects. The search was limited to English language articles and human studies. Articles with a major focus on softwood dust exposure and estimates of nasal and paranasal cancer risk were selected to review.

Summarized in Table 1-3 are studies selected for use in this Masters thesis. These specific studies have either softwood dust exposure or at least have a subset of sawmill workers. They are as follows:

- 5 case-control studies (Elwood, 1981; Hernberg et al., 1983; Hayes et al., 1986; Vaughan and Davis, 1991; Leclerc et al., 1994;),
- 1 pooled case-control study (Demers et al., 1995a),
- 1 pooled cohort study (Demers et al., 1995b),
- 1 case-control study nested within a cohort study (Kauppinen et al., 1993),
- 1 case series (Voss et al., 1985).

1.7.2 Are softwood dust and nasal cancer associated?

From IARC's monograph, hardwoods have been implicated in the excess numbers of sinonasal cancer (mostly adenocarcinoma). In the following sections, the literature that reports softwood dust exposure is associated with nasal cancer will be presented.

Table 1-3. Summary of Literature Review

Study design	Exposure wood type / level	# of cases / & controls	Source of cases and (controls)	Control group	Health Outcome	Results
Case-control studies						
Elwood, 1981 (Canada)	softwood (presumed based on region) no levels given	121/ (120 X 3)	cancer clinic (same)	tumors related to smoking tumors related to outdoor exposure tumors not related to either	all nasal & paranasal cancers	OR = 2.5 P < 0.03
Hernberg et al., 1983 (Denmark, Finland, Sweden)	softwood (pine & spruce) hardwood (birch & aspen) (presumed based on region) no levels given	167/ 167	cancer registry & hospitals (same)	colonic and rectal cancer	all nasal and paranasal cancers	OR = 3.4 (for softwoods alone) 95% CI = 1.1 - 10.3
Hayes et al., 1986 (Netherlands)	mixed wood (based on region) low: gardeners, painters med: forestry, shoemakers, carpentry construction high: furniture makers, factory shoe carpenters	91/ 195	hospitals (city registries / death registries)	random sample of living / male residents and deceased (all causes)	squamous cell adenocarcinoma	OR = 2.5 (low level exposures) 90% CI = 1.1 - 5.2 OR = 0.5 (high level exposures) 90% CI = 0.1 - 1.9 OR = 26.3 (high level exposures) 90% CI = 3.4 - 25.4 no data for low level exposures
Vaughan & Davis, 1991 (United States)	softwood (presumed based on region) no levels given	53/ 552	population based tumor registry (random population)	random digit dial	squamous cell	OR = 2.4 95% CI = 0.8 - 6.7 OR = 7.3 (10+ years of exposure) 95% CI = 1.4 - 34.2
Leclerc et al., 1994 (France)	softwood, hardwood levels based on a formula using probability, frequency, and concentration	207/ 409	hospitals (case referral and hospitals)	cases selected individuals outside the hospital hospital cancer cases other than nasal cancer	squamous cell	OR = 1.7 (for softwood) 95% CI = 0.7 - 4.1 OR = 2.5 (for softwood in those exposed prior to 1945) 95% CI = 1.1 - 6.0

Table 1-3. Summary of Literature Review cont.

Study design	Exposure wood type / level	# of cases / & controls	Source of cases	Source of control group	Health Outcome	Results
Case-control studies cont.						
Demers et al., 1995a (pooled reanalysis from 12 case-control studies)	softwood & hardwood low (<1 mg/m^3) med (1-5 mg/m^3) high (>5 mg/m^3)	930 / 3136	as listed below	as listed below	nasal cancer in sawmill workers	OR = 1.1 (squamous cell) CI = 0.7 - 1.7 OR = 5.8 (all histologies) CI = 4.2 - 8.0
Zheng et al., 1992		60 / 414	tumor registry	resident registry		
Luce et al., 1991, 1992, 1993		207 / 409	hospital	hospital / friends		
Bolm-Audorf et al., 1989, 1990		54 / 54	hospital	hospitals		
Comba et al., 1992a		78 / 254	hospital	hospitals		
Comba et al., 1992b		34 / 102	hospital	hospitals		
Magnani et al., 1989, 1993		26 / 111	hospital	hospitals		
Merler et al., 1986		21 / 39	hospital	electoral registries / death registries		
Hardell et al., 1982		44 / 541	tumor registry	population / death registries		
Brinton et al., 1984		160 / 287	hospital	hospitals / death registries		
Mack and Prestin-Martin, in preparation		102 / 178	tumor registry	neighbourhood		
*Hayes et al., 1986a,b; 1987		91 / 195	hospital	city registries / death registries		
*Vaughan & Davis, 1991		53 / 552	tumor registry	random digit dialing		

* These studies are included in this literature review above

Study design	Exposure wood type / level	# of cases / & controls	Source of cases	Source of control group	Health Outcome	Results
Kauppinen et al., 1993 (nested case-control within a cohort study)	softwood and hardwood Levels: 0.1 - 1 mg/m^3 Levels: >1 mg/m^3	136 / 408 cohort of 7307 2531 sawmill 1775 plywood 1483 furniture 876 construction carpentry 630 particle board	cancer registry	from cohort without respiratory Ca	respiratory cancer including nasal cancer	OR = 1.19 95% CI = 0.74 - 1.89 for levels: 0.1 - 1 mg/m^3 OR = 0.64 95% CI = 0.30 - 1.37 for levels: >1 mg/m^3

Table 1-3. Summary of Literature Review cont.

Study design	Exposure wood type / level	Number in cohort	Cohort description	Health Outcome	# of deaths	Results
Cohort studies						
Demers et al., 1995b (pooled reanalysis from 5 cohorts listed below)	softwood & hardwood / classified into possible, probable, & definite exposure	28704	see below	cancer mortality of workers in wood-related industries	11 sinonasal cancers	SMR 3.1 (all histologies) 95% CI = 1.6 - 5.6
Acheson et al., 1984	as above	5106	British furniture			
Miller et al., 1989; 1994	as above	12158	American furniture			
Robinson et al., 1990	as above	2280	US plywood			
Blair et al., 1986; 1990	as above	2309	US plywood			
Roscoe et al., 1992	as above	2294	Wood model shop			

Study design	Exposure wood type / level	Study group	Control group	Study description	Health Outcome	Results
Case series						
Voss et al., 1985	softwood	70 patients from the Norway cancer registry	Norwegian Bureau of Statistics census 1946	compared the observed number of cancers with the expected to give a standard proprotional morbidity ratio	nasal cancer	SPMR = 300 $P < 0.001$

LEGEND
OR = Odds Ratio
CI = Confidence Interval
SMR = Standardized Mortality Rate
SPMR = Standardized Proportional Morbidity Ratio
P = P value

1.7.2.1 Case-control studies

The larger the magnitude of the risk, the more likely a true association exists between the exposure and the disease outcome. From the case-control studies selected the risk for developing nasal cancer ranged from OR = 2.5; P< 0.03 (Elwood, 1981) to OR = 3.4; 95% CI = 1.1 to 10 (Hernberg et al., 1983). In other words, wood dust exposed cases were 2.5 to 3.4 times more likely to develop nasal cancer than non-exposed controls. Greater risks were reported (OR = 7.3; 95% CI = 1.4 to 34) when a 10+ year duration of exposure was considered (Vaughan and Davis, 1991). Similarly Leclerc et al., (1994) found a significant association when workers were first exposed to wood dust prior to 1945, however the risk was lower (OR = 2.5; 95% CI = 1.1 to 6.0). When the OR is less than 1, this indicates a protective effect of the exposure (i.e. the exposure is associated with less risk of the disease). If the 95% CI (confidence interval) includes 1 then there is the potential that the observed association for the cases is not more likely to occur than it is for the controls. For example from the 95% confidence intervals in the Vaughan and Davis study (1991), the risk of nasal cancer could be as low as 1.4 and as high as 34.2. Since the 95% CI does not include 1, it is unlikely that the observed association is due to chance (i.e. this is statistically significant).

From the above studies, it is important to note that the predominant form of nasal cancer was squamous cell. In addition, no quantitative exposure levels were given. Two other case-control studies (Hayes et al., 1986; Demers et al., 1995a) were included in the literature review since the outcome measured was squamous cell cancer, and an attempt to quantify the level of exposure was completed. Note that the exposures however were mixed hardwood and softwood dusts. Low level exposures (based on job category) were reported (Hayes et al., 1986) to be associated with squamous cell nasal cancer OR = 2.5 (90% CI = 1.1 to 5.2). In the Hayes et al. (1986) study, there was no dose response with higher levels of exposure, and therefore an association is less likely. In Demers et al., (1995a) study, there was no significant risk of developing squamous cell cancer (OR = 1.1; 95% CI = 0.7 to 1.7). In the highest exposed group (> 5 mg/m^3 mixed wood) the risk for developing any type of nasal cancer was OR = 5.8 (95% CI = 4.2 to 8.0). Since the exposure included hardwood dust, it is possible that the increased risk observed may be due to an excess number of adenocarcinoma.

In the nested case-control study (Kauppinen et al., 1993), the softwood dust exposure was quantified into levels 0.1 – 1 mg/m^3 and > 1 mg/m^3. However there was no statistically significant increases in respiratory cancers compared with the control group. The OR's were 1.2 (95% CI = 0.7 to 1.9) and 0.6 (95% CI = 0.3 to 1.4) respectively.

In summary, softwood dust exposure is more likely to increase the risks of nasal cancer than in those not exposed. The risks vary from studies (2.5 to 3.4 times that of those not exposed to softwood dust). With dust exposures greater that 10+ years duration, the risks of nasal cancer may be as high as 7.3 times that of those not exposed to softwood dust. Squamous cell cancer (type of nasal cancer) is reported to be associated with softwood dust exposure. There is a lack of case-control studies that quantify softwood dust exposure and nasal cancer risks. "No recent studies have thus far examined the risk of sino-nasal cancer in relationship to quantitative estimates of softwood dust exposure" (ACGIH Wood dust draft, August 1999).

1.7.2.2 Cohort study

A pooled reanalysis of cancer mortality from 5 cohorts (Demers et al., 1995b) showed an increased risk of nasal cancer mortality (SMR = 3.1; 95% CI = 1.6 to 5.6) with exposure to wood dust. Classification of exposures were based on possible, probable, and definite exposure to wood dust. Unfortunately this study had exposures to both hardwood and softwood, and there was no differentiation between the types of nasal cancer.

1.7.2.3 Case-series

Voss et al. (1985) reviewed 70 cases of nasal cancer that presented to the National Hospital of Norway. Seventy % were squamous cell nasal cancer. Twelve of the 70 cases were found to have been exposed to wood dust in the past. Out of the 12 wood exposed cases, 11 of these were exposed exclusively to softwood dust. From this study, workers exposed to softwood dust were 3 times more likely to develop nasal cancer than those not exposed ($P<0.001$).

1.7.3 Strengths and weaknesses of study designs

The strongest feasible study designs to investigate an occupational exposure and an outcome are case-control and cohort studies. Cohort studies however are not ideally suited for investigating nasal cancer since this is a rare disease with a long latency period. One pooled cohort (Demers et al., 1995b) of 5 cohort studies (see Table 1-3) is included since there was some exposure to softwood dust, and the outcome of interest was nasal cancer. Unfortunately the proportion of hardwood and softwood dust exposure was not known.

Therefore in this literature review, the strongest evidence to suggest that softwood dust exposure is associated with nasal cancer is provided from the case-control studies (Elwood, 1981; Herberg et al., 1983; Hayes et al., 1986; Vaughan & Davis, 1991; Leclerc et al., 1994; Demers et al., 1995a). Unlike cohort studies, case-control studies are better suited for rare diseases or outcomes, and diseases with a long latency period. Cases (those with the disease of interest) were selected from cancer registries and hospitals. The disease was confirmed by pathological diagnosis. The comparison group (controls) were selected to be similar in age (usually within 5-10 years), and sex. Some of the control groups contained hospital patients with cancer (not nasal cancer). The other control groups were obtained by random digit dialing, calling city registries, or by referral to a person known by the case.

With most retrospective studies such as case-control studies there is the potential for cases to more likely recall an exposure due to increased vigilance (recall bias), or due to greater probing by an interviewer (interviewer bias). For example a patient (case) with a stomach ache is more likely to be able to recall what they had eaten that day compared to a person without a stomach ache (recall bias). If a doctor (interviewer) is aware of the stomachache, they may push harder for clues to the cause of the illness (interviewer bias). Attempts were made to minimize recall bias by using comparison subjects (controls) from patients in hospitals with cancer (Leclerc et al., 1994; Elwood, 1981; Hernberg et al., 1983). It is presumed that other hospital patients with non-nasal cancer may share similar characteristics with the nasal cancer cases except without being exposed to wood dust. The studies by Vaughan & Davis, 1991 and Hayes et al., 1986 used random digit dialing, calling city registries, and by referral to another person by the cases. These methods may not minimize recall bias.

Case series reports are descriptive studies intended to assist in generating hypotheses. Case series studies however lack information needed to assist in determining causation.

1.7.4 Temporal relationships and dose response

A true association between an exposure and an outcome is more likely when there is a temporal relationship and a dose-response. A temporal relationship means that the exposure occurred before the outcome or disease. For cohort studies a temporal relationship is presumed to exist since the study population is selected based on exposure prior to any study subjects having the disease. For case-control studies, the investigators look back in time to uncover exposures. For diseases with a long latency, such as cancer, it is necessary to look for remote exposures in the past. The latency or "time from first exposure to the time cancer (or disease) is detected" is variable in the case of wood dust. The latency time averages around 40 years (Nylander and Dement, 1993). However the range varies from 7 to 70 years (Caroyer and Van Dessel, 1987; Cecci et al., 1980).

A dose response refers to the fact that as one increases the duration or quantity of exposure the risks of the outcome or disease is also increased. For IARC, Demers and Boffetta (1998) recently conducted a pooled re-analysis of 12 case control studies. Approximate exposure cut points were chosen for low (<1 mg/m^3), moderate (1-5 mg/m^3), and high total dust exposure (>5 mg/m^3). The risks for all types of sino-nasal cancer were increased for high dust exposures (OR 5. 8, CI 4.2-8.0). The OR or Odds Ratio represents the likelihood of developing the disease or outcome. The confidence interval or CI is a range of values within which the true risk is likely to be with a specified level of confidence. When the confidence interval includes 1 then one concludes that the increase in risk is not statistically significant. For a specific type of cancer, namely adenocarcinoma, higher risks were associated with higher levels of dust (Table 1-4). For moderate exposure the likelihood (Odds Ratio or OR) of developing adenocarcinoma of the sinus and nasal passage was 3 times higher than the general population. For high exposure the risks of developing cancer of the sinus and nasal passages was greater than 45 times greater than background risks. It is important to note that the risks are for adenocarcinoma, and that adenocarcinoma has been reported to be more likely associated with hardwood dust exposure (IARC, 1994).

Table 1-4. Risks of sino-nasal cancer by level of exposure.

Exposure Category	**Adenocarcinoma OR (95% CI)**
Low exposure	0.6 (0.1-4.7)
Moderate exposure	3.1 (1.6-6.1)
High exposure	46(28-73)

Table from Demers and Boffetta, 1998

Longer duration of exposures are also associated with higher risks of sino-nasal cancer (Blot, 1997). For duration of exposures less than 5 years the risk of cancer is 1.5 times that of the normal population (95% CI = 1.0-2.2). For exposures greater than 30 years the risk of sino-nasal cancer is 3.9 times that of the normal population (95% CI = 2.8-5.6).

Demers and Boffetta (1998) have also confirmed a duration of exposure relationship. Part of their investigation looked at the risks of sino-nasal cancer in the primary wood industries, which included sawmills. For moderate and high exposure groups (see section above for definition of groups) there were increased risks of sino-nasal cancer with increased duration of exposure. Again, it important to note that the risks are for developing adenocarcinoma, and that adenocarcinoma has been reported to be associated with hardwood dust exposure (IARC, 1994).

Table 1-5. Risks of sino-nasal cancer by duration of exposure

Duration of Exposure	*Adenocarcinoma OR (95% CI)
Less than 5 years	14 (6.0 - 32)
5 to 9 years	12 (5.0 - 29)
10 to 19 years	10 (4.0 - 31)
20 to 29 years	23 (9.0 - 58)
30 or more years	30 (1.0 - 77)

Table from Demers and Boffetta, IARC 1998
* For moderate and high exposure groups (see text for definitions)

1.8 Summary

Although furniture workers were first discovered to be at risk for nasal cancer, other woodworkers such as loggers and sawyers have also been found to be at increased risk (Brinton et al, 1984; Hayes et al, 1986; Luce et al, 1992; Blot et al, 1997). Therefore it is possible that the "natural" wood or agents intrinsic to the wood itself may be responsible for nasal cancer. Sawmills in Alberta cut "natural" softwood such as pine, spruce, and fir.

The magnitude of the risk associated with softwood dust exposure ranges from OR 2.5 to 3.4. With longer durations of exposure the risk is higher (OR = 7.3). The risks associated with softwood dust is less than that of exposure risks to exclusively hardwoods (Demers, 1997).

Although wood dust itself has been implicated in causing nasal cancer, the dose of wood dust required has not always been measured. Surrogate exposure measurements such as job title or job description were often used when estimating risks of nasal cancer. Cabinetmakers and sawyers were presumed to have been exposed to a certain level of wood dust simply based on their job descriptions. There is a lack of case-control studies that quantitatively measure the exposure levels of softwood dust with respect to nasal cancer risks.

On a global scale by volume softwood is used more commonly than hardwood for industrial purposes (Demers, 1997; FAO, 1993). Alberta sawmills process predominantly softwood.

Softwood dust exposure is reported to be associated with squamous cell carcinoma (Elwood, 1981; Hernberg et al., 1983; Voss et al., 1985; Boysen et al., 1986; Vaughan and Davis, 1991; LeClerc et al., 1994). Squamous cell carcinoma is the most common type of nasal cancer in Alberta (Alberta Cancer Board, 2000). Therefore from a public health perspective, focussing attention to the most common type of nasal cancer deserves consideration even though the increased risk may not be as dramatic as the more uncommon adenocarcinoma.

2. STUDY OBJECTIVES

1. To analyze the results of personal inhalable wood dust levels collected from nine Alberta sawmills.
2. To estimate the percentage of inhalable dust samples from the nine Alberta sawmills that have wood dust exposures above the proposed ACGIH inhalable limits, and above Alberta's current occupational exposure limits using "total" dust.
3. To investigate occupational groups within the sawmills that may have higher levels of wood dust exposures.

3. METHODS

3.1 Background to the sawmill survey

Alberta's forest products industry differs from that of British Columbia or eastern Canada in terms of predominant woods, end products, and conditions of moisture and temperature during cutting (Harman L, 1996). The objective of this survey was to collect and evaluate the wood dust exposure levels to gain an understanding of where the Alberta forest industry is positioned with respect to occupational exposure limits. An occupational hygiene survey to measure representative wood dust (and noise level) exposures in workers of the forest products industry in Alberta began in the winter of 1996/97. The project contact was Mr. Lloyd Harman, Director, Safety and Loss Management, AFPA (Alberta Forest Products Association). Mr. Harman and Dr. Tee L. Guidotti wrote the initial proposal and outlined the key elements of the study. Mr. Ken Wong wrote the draft of the hygiene protocol and was the senior occupational hygiene consultant to the AFPA. Occutech Services HSE Inc. refined the hygiene draft and carried out the study. Mr. Harman, Dr. Guidotti, and Mr. Wong monitored the project as it progressed. Initial analysis of the data was undertaken by Mr. Ken Wong, Occutech Services HSE Inc., and Mr. Paul Beaulne. The project was funded by the AFPA, the Alberta Department of Economic Development and Tourism (through the Office of Industry, Technology and Forestry Development, Forest Industry Development), Network of Centres of Excellence in Sustainable Forest Management, and each of the 9 participating sawmills.

3.2 Study subjects

Nine sawmill member companies of the Alberta Forest Products Association paid to have their sawmills surveyed on two separate occasions; one in the winter (1996) and one in the following summer (1997). For each winter and summer season, area monitoring and personal monitoring were conducted. Inhalable particulate fractions and respirable particulate dust were collected simultaneously using personal monitoring techniques (Figure 3-1).

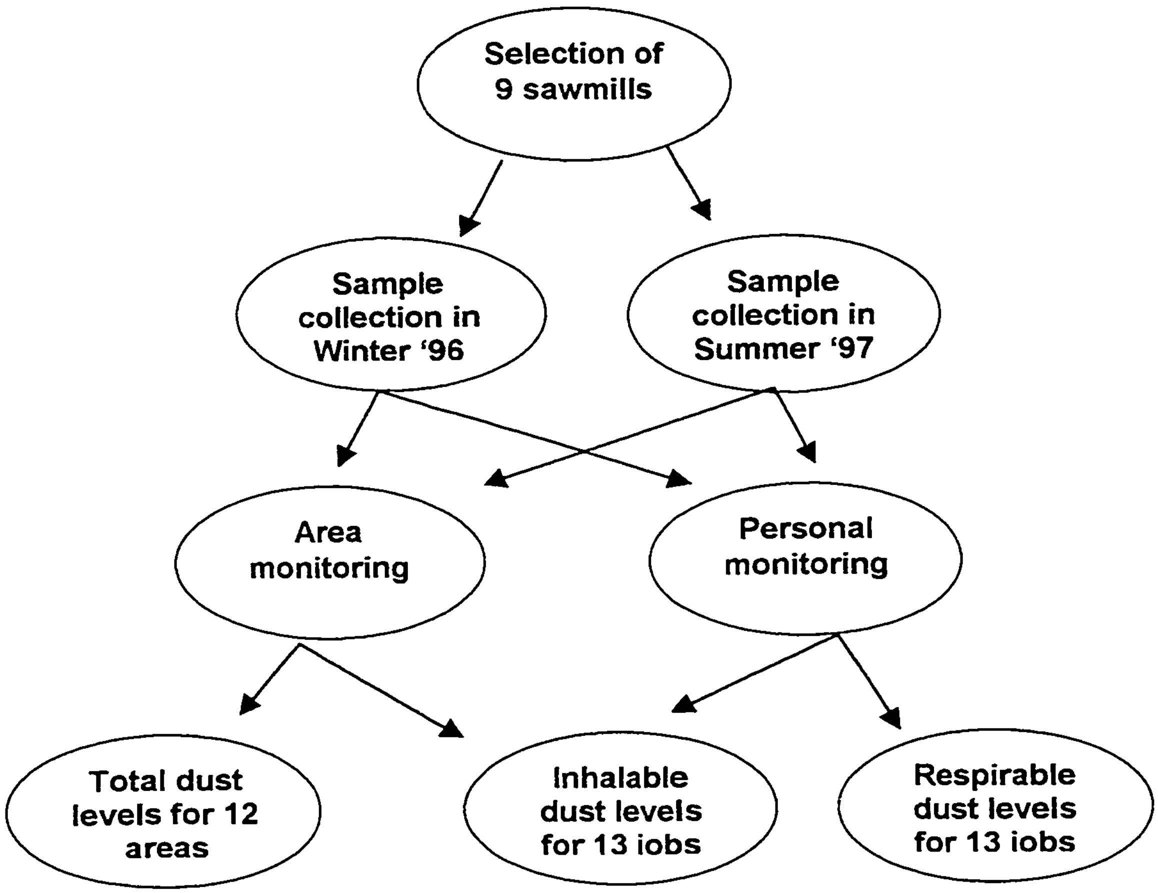


Figure 3-1. Overview of the wood dust exposure survey.

In addition "total" dust levels were collected using area monitoring techniques for inter mill comparison levels and intra mill ambient levels. However for the purposes of this study, only inhalable particulate mass measurements will be included.

The general processes that occur at a typical mill are shown in the flow chart (Figure 3-2). Wood dust measurements were taken from the sawmill and planermill areas represented in this flow chart. Figure 3-3 shows a more detailed schematic of the major components of the sawmill and planermill operations. Once the logs enter the debarker, the tree bark is removed in large pieces as the log moves though a series of rollers. Once the log is passed though the headsaw it is cut into cants (slices of wood). The edger will rip the edges off of the cant in a length-wise fashion. When the cant passes through the trimsaw, the ends of the lumber are cut off (cross-cut). The J-bar is a mechanical device that holds the various lumber by size in a large rack, and releases them onto a conveyor when signaled. Wood chips that fall off during the above processes are sent to the chip screen and sorted. Some of the wood chips will be sent to the pulp and paper mill, and some of the chips will be used for hog fuel. In the planermill operations, the planer will take a small surface layer off of the wood to make it smooth. The grader will sort the lumber by quality or condition of each piece of lumber. Lumber of the same grade or quality is bundled together for shipment. The finished product is strapped together and often wrapped in plastic before shipping.

Thirteen jobs were pre-selected for personal monitoring based on representation from all the work groups that included operators, maintenance, and support staff. Study subjects were those employees working the day the hygienist surveyed the sawmill, and volunteered to wear the dust monitor. Many of the workers had more than one job during the day, so four occupational groups were created for purposes of analysis to account for the change in the worker's daily activities

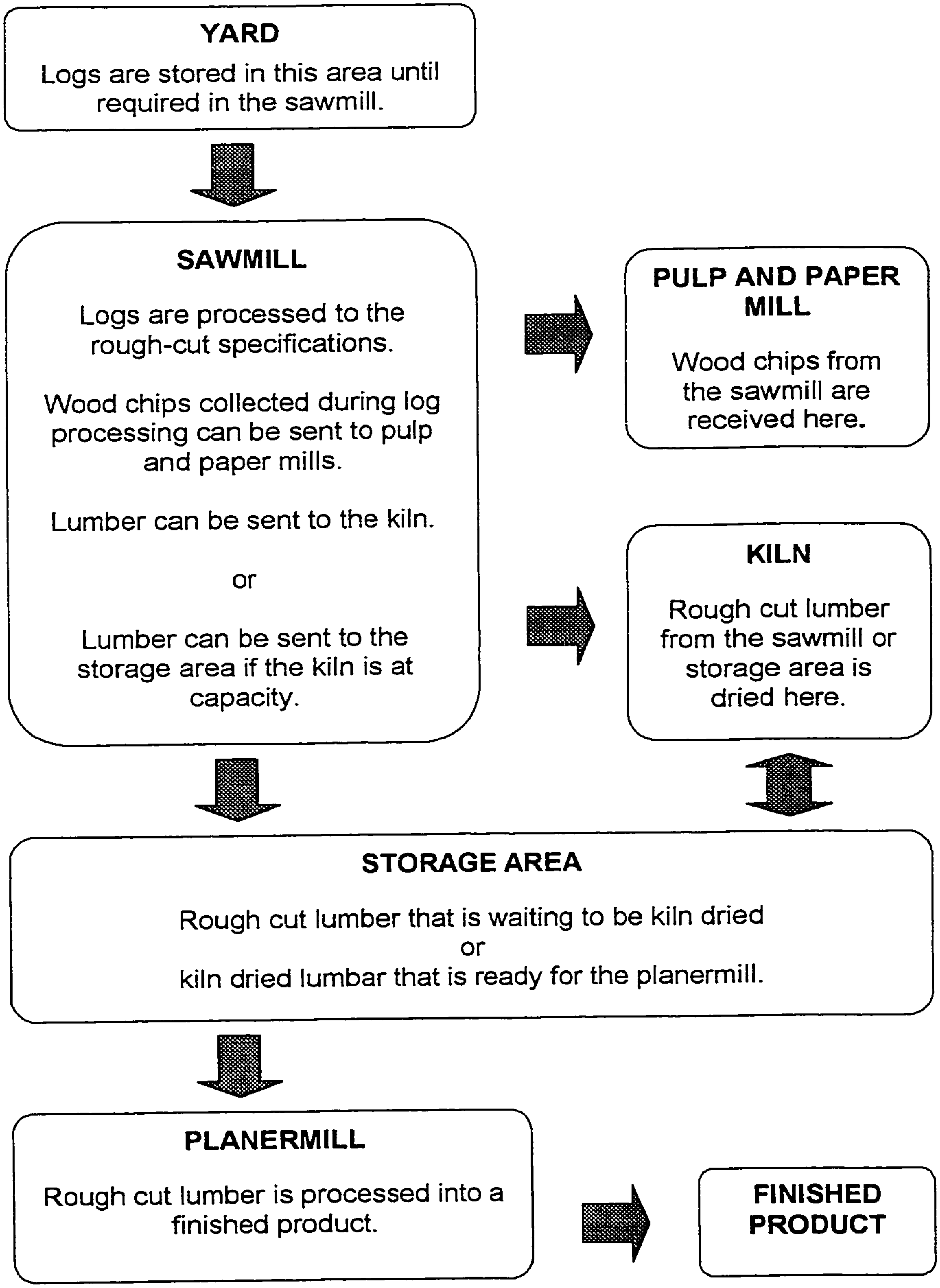
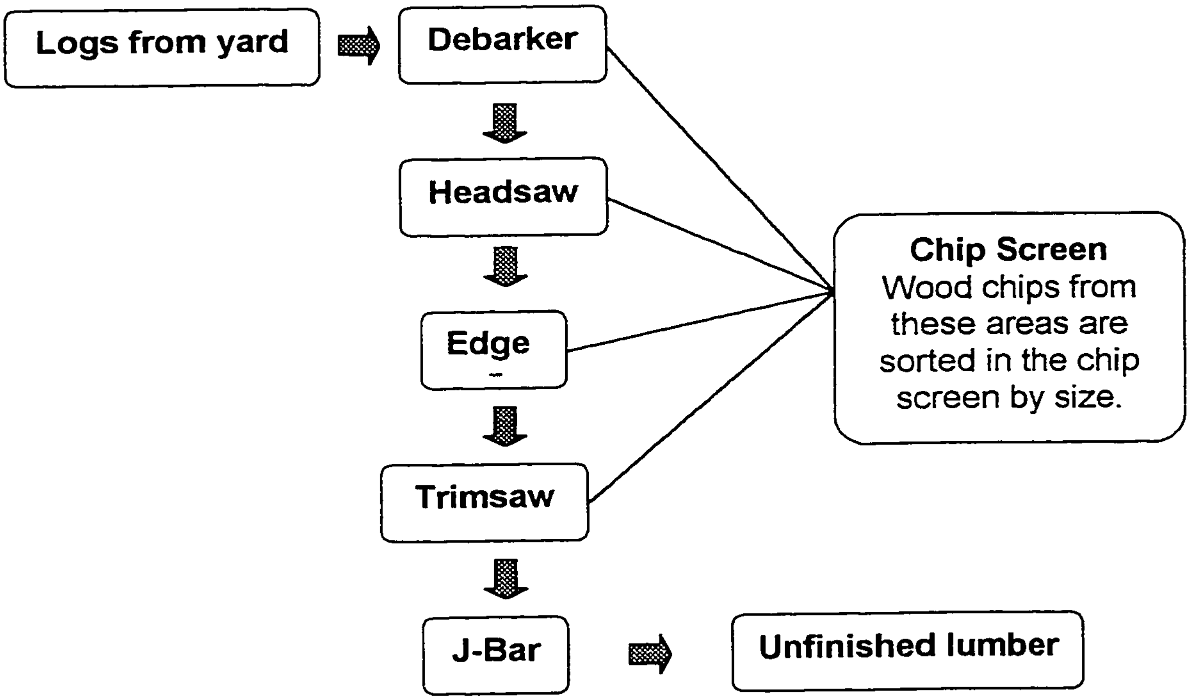


Figure 3-2. Flow chart of the processes in a typical mill.

Sawmill operations



Planermill operations

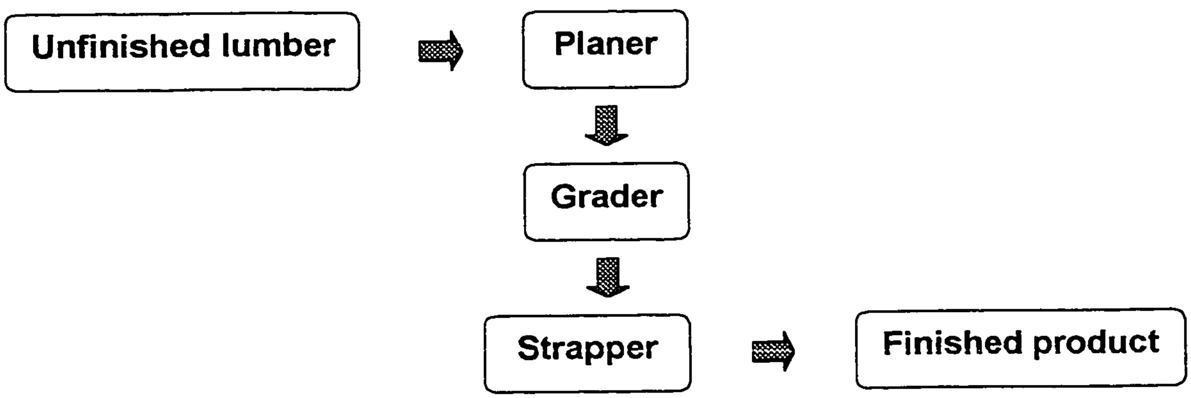


Figure 3-3. Flow chart of sawmill and planermill operations (see text)

The thirteen job titles are divided into four occupational groups as shown in Table 3-1. A brief description of the jobs is included here. The millwright is a "jack of all trades" and will attend to any problems with the machinery that requires attention in the sawmill. The planerman is an equivalent of the millwright except he works in the planermill and fixes any problems with the planer equipment. A sawfiler is responsible for the sharpening and maintenance of the saw blades in the sawmill. Cleaning the planermill of wood debris is the job of the cleanup personal. The basement attendant, who is the equivalent of the cleanup personal of the planermill, keeps the basement area of the sawmill tidy by sweeping up sawdust and removing pieces of wood debris. The log chaser ensures the flow of logs into the sawmill and attends to problems such as logjams that may occur along the conveyor leading from the yard to the debarker or headsaw area. The debarker operator controls the rotation and speed of the logs as it enters the debarker machine. The edger operator controls the saws to rip the edges off of the cant. The trimsaw operator controls the saw that cross cuts the ends of the lumber. The stacker controls the machinery to bundle the rough cut lumber before it leaves the sawmill. The infeed operator controls the machinery to plane the rough-cut lumber once it enters the planermill. The grader visually inspects and determines the "grade" or quality of the finished lumber in the planermill. The tilt hoist operator controls the machines to bundle the finished lumber products as it leaves the planermill.

3.3 Exposure assessment

For personal monitoring, inhalable dust samples were collected using an SKC brand IOM (Institute of Occupational Medicine) sampler following MDHS Method 14/2 and weighed following NIOSH Method (modified) 0500 (Handbook of Occupational Hygiene, 1993). Portable sample pumps were calibrated to a nominal flow rate of 2.0 litres/minute using a Matheson Gas #603 Rotameter (previously calibrated with a bubble tube primary standard). The sample pumps were run for the 8 hour work day and after completion the pump calibrations were rechecked to ensure consistent flow rates. The samples were collected on

Table 3-1. Classification of Job Titles into Occupational Groups

Job Title	Occupational Group
Millwright Sawfiler Planerman	Maintenance
Cleanup Basement Attendant	Cleanup
Edger Operator Trimsaw Operator Log Chaser Debarker Operator Stacker Operator	Sawmill
Grader Infeed Operator Tilt Hoist Operator	Planermill

25mm open-face, pre-weighed PVC filters cassettes with a pore size of 0.5 micrometers, and loaded into an SKC type IOM sampler head. A blank sample for correction factor purposes was provided for every six samples taken.

3.4 Geometric means, arithmetic means, medians

Geometric means, arithmetic means, and medians are measures of central tendency. Often it is valuable to give a summary value for a set of data in order to compare results and apply statistics. Geometric means will be used in this Masters thesis in order to compare the results to other published studies. Arithmetic means will be used to statistically compare data within the sawmills and occupational groups studied in this thesis. In addition arithmetic means are often used to relate health effects. Medians are included in this thesis to further elaborate on the distribution of data. Medians are often included in the literature however, occupational exposure limits and health related effects are not based on medians.

The geometric mean (GM) is defined by the following equation.

$$GM = (a1 \times a2 \times \ldots aN)^{1/N}$$

a1, ..., aN is a set of positive numbers

N is a positive integer.

The arithmetic mean is a simple average defined by the following equation.

$$AM = (X_1 + X_2 + \ldots X_n) / N$$

$X_1, \ldots, X_n$ is a set of numbers

N is the total number of entries in the set

The median is the middle most value in a data set and can be estimated by in the following manner.

Let $X_1, \ldots, X_n$ represent a set of numbers in rank order (either highest to lowest, or lowest to highest)

For data sets that have an odd number of samples, the median is the value obtained from the sample in position (N+1) / 2 of the rank order. For sets with an even number of samples, the median is the value obtained from the sample in position N / 2 of the rank order.

The following example will demonstrate the geometric mean, arithmetic mean and median. Column 1 represents 7 houses in a neighbourhood with a cost range from $50,000 to $5,000,000. Column 2 represents the same houses except listed in rank order from lowest to highest costs.

Column 1	**Column 2 (rank order)**	
House 1 = $50,000	#1	House 1 = $50,000
House 2 = $70,000	#2	House 3 = $55,000
House 3 = $55,000	#3	House 4 = $60,000
House 4 = $60,000	#4	House 7 = $63,000
House 5 = $5,000,000	#5	House 6 = $65,000
House 6 = $65,000	#6	House 2 = $70,000
House 7 = $63,000	#7	House 5 = $5,000,000

The geometric mean = $(50{,}000 \times 70{,}000 \times \ldots 63{,}000)^{1/7}$ = $113,083

Arithmetic mean or average = (50,000 + 70,000 + ...63,000) / 7 = $759,714

The median = value from the rank order (7+1) / 2 = House 6 = $65,000

House 5 brings up the average cost per house in the neighbourhood to approximately $750,000. This is over 10x the cost of House 2, which is the second most expensive house. The $750,000 is not a good estimate of what a home purchaser would expect to pay if looking for a house in the neighbourhood. One would more likely pay something closer to $60,000. Averages are sensitive to values that are extremely high, and therefore may not be the best representation for the cost of houses in the neighbourhood. The median is less sensitive to values that are very large since the median is estimated based on the rank ordering of the housing values. The geometric mean is also less sensitive to extremely high values, and will always be less than the arithmetic mean.

3.5 Data presentation

Simple bar graphs were used to show differences in arithmetic mean values. Boxplots were used to summarize data where median values and outliers were necessary to display. The boxplot summarizes information about the distribution of dust levels for each mill in a graph form (see Figure 4-2 for an example). By definition 50% of a mill's dust level data fall within the "box". The longer the box, the more variability or spread the dust levels have. Therefore a single number summarizing the dust levels, such as the arithmetic mean, is often less meaningful. The horizontal line within the box represents the median or middle most dust level. Unlike the mean, the median dust level is less sensitive to extreme dust levels and wide spreads or variability of the dust levels. Mean dust levels are also influenced by outliers and extreme outliers (denoted by "O" and "*" respectively), which represent dust level data 1.5 box-lengths and 3 box-lengths from the bottom of the box respectively. The outliers and extreme outliers represent dust level data that are higher than expected given the grouping of the rest of the dust level data. By reducing the outliers and extreme outliers (i.e. high levels), the mills may be left with a lower mean dust level. We will encounter the boxplot several times in this wood dust analysis.

3.6 Statistical Analysis

Analysis was completed using a statistical package for personal computers (SPSS 8.0 for Windows™ analytical software, Chicago, Illinois). The original wood dust data were not normally distributed. Normal distribution was checked using Kolmogorov-Smirnov and Shapiro-Wilk tests of normality. Since the original data was not normally distributed, non-parametric tests (Kruskal-Wallis H test) were used to determine if there were statistically significant differences in median IPM dust levels between the mills and between the occupational group. A P-value of <0.05 was considered to indicate statistical significance. Since the Kruskal-Wallice H test only compares medians, the data was also transformed in order to compare the arithmetic mean concentrations. .. After the natural log transformation, the data was checked for equality of variance and normal distribution. Equality of variance was tested using Levene's test for homogeneity of variance. Normal distribution was tested using Kolmogorov-Smirnov and Shapiro-Wilk tests of normality. The mean log concentrations for the mills and occupational groups were then tested for statistical significant differences using ANOVA.

Mill analysis: For the IPM dust data all thirteen jobs within a mill were first combined to obtain an overall arithmetic mean for each mill. Then summer and winter data were combined in order to double the sample size and allow for more statistical power. Before the summer and winter data were combined a Mann Whitney U Test was conducted and confirmed that the median summer and winter IPM dust levels were not statistically different from each other (P = 0.06). The median IPM dust levels for each of the nine mills were then compared using the Kruskal-Wallis H test. After log transformation the log mean IPM concentrations of the mills were also compared using AVOVA.

Occupational group analysis: Thirteen job titles were collapsed into four occupational groups (Maintenance, Cleanup, Sawmill, Planermill) in order to account for changes in a workers job duties in an average workday. Maintenance workers from each of the nine sawmills were combined together to pool the inhalable wood dust samples for this occupational group. The same procedure was completed for the Cleanup, Sawmill, and Planermill occupational groups. Summer and winter data were once again combined to double the sample size and increase the statistical power. Using non-parametric tests (Kruskal-Wallis H test) the IPM dust levels for each occupational group were first analyzed for statistically significant differences in medians. Recall that the Kruskal-Wallis H test will not identify which occupational group was significantly different from the others. It will only help show that there is a difference in median IPM levels. Further non-parametric tests (Mann-Whitney U Test) were completed to determine specifically which occupational groups had statistically significant difference in medians. The four occupational groups were compared in pairs using the Mann-Whitney U Test (6 pairs). Since multiple comparison tests were performed, the level of significance (P-value) needed to be more stringent. The Bonferroni adjustment was calculated (considering 6 pairs of comparison) to be 0.05 / 6 or 0.008. Using the Bonferroni adjustment, the Mann-Whitney U Tests required a P-value less than 0.008 to indicate a statistically significant difference.

3.7 Comparison of Study Data to Regulatory Standards.

For softwood dust, the TLV's and OEL's are not based on nasal cancer risks (ACGIH TLV's and BEI's, 1999). Nonetheless from the literature review there is evidence to suggest that softwood dust exposure is a risk factor for development of sinonasal cancer (Elwood, 1981; Hernberg et al., 1983; Hayes et al., 1986; Vaughan & Davis, 1991; Leclerc et al., 1994; Demers et al., 1995a). However it is not yet possible to quantify the exposure level necessary for development of sinonasal cancer since there is a lack of quantitative exposure data for such a risk assessment (Demers et al., 1997).

The data from this study is compared to the current TLV's and OEL's for the following reasons. First of all, although there is a lack of quantitative exposure data for softwood dust there is some quantitative exposure data to support an association between hardwood dust and nasal cancer (ACGIH TLV's and BEI's, 1999). Current recommendations by the ACGIH suggest a TWA TLV of 5 mg/m^3 inhalable for hardwood dust and are based on the effects of irritation, mucostasis and cancer (ACGIH TLV's and BEI's, 1999). Incidentally the proposed notice of intended change of the TWA TLV for softwood dust is also 5 mg/m^3 inhalable (ACGIH TLV's and BEI's, 1999). Secondly, the current OEL under Alberta regulations for softwood dust is 5 mg/m^3 TWA total dust (Alberta chemical hazards regulation 393/88). With the introduction of particle size selective sampling, and the movement toward inhalable fraction sampling for wood dust, an estimate of the number of study samples that would be affected by such a change would be important to investigate from a industry perspective.

In summary, for the purposes of this study the hardwood dust TLV of 5 mg/m^3 inhalable was adopted by analogy since there is a lack of quantitative exposure data for softwood. In addition, proposed changes to the ACGIH softwood TLV from 5 mg/m^3 "total" dust to 5 mg/m^3 inhalable prompted an investigation of our Alberta softwood dust samples.

4. RESULTS

4.1 IPM data

Tables 4-1 to 4-9 display the individual wood dust IPM levels from each of the nine sawmills. Within each table, there are 13 job titles that are listed in the rows. A line divides the 13 job titles into 4 different occupational groups (see Table 3-1 for classification). Dust levels are entered into either the winter or summer column based on when the dust was collected. For the purposes of this thesis a distinction between winter measurements and summer measurements will be discounted. Winter and summer measurements will simply represent two samples that were taken from the mill in one year.

Each entry within Tables 4-1 to 4-9 represents one IPM sample collected using personal sampling techniques. In some mills there were a duplication of samples collected from one job and therefore there are two entries in one slot. This represents two separate workers performing the same job during the same day. Some mills did not have all 13 jobs and therefore a blank will appear in the table for that particular job. If there was no worker available (absent or not willing to wear the monitor) on the date of the sampling, a blank will appear in the slot of the corresponding job.

Table 4-1. Inhalable Particulate Mass by Job and Season for Mill 1

JOB	Inhalable Dust (mg/m³)	
	Winter	Summer
Millwright	N/A	6.64
Sawfiler	2.43	3.22
Planerman	4.85	3.13
Cleanup	5.69	4.61
Basement Attendant	26.19	11.08
Edger Operator	3.08	4.32
Trimsaw Operator	3.05	7.45
Log Chaser	3.28	4.00
Debarker Operator	0.44	0.92
Stacker Operator	4.78	2.15
Grader	4.80	2.76
Infeed Operator	3.96	3.91
Tilt Hoist Operator	N/A	N/A

Table 4-2. Inhalable Particulate Mass by Job and Season for Mill 2

JOB	Inhalable Dust (mg/m³)	
	Winter	Summer
Millwright	4.16	1.97
Sawfiler	1.75	2.35
Planerman	7.84	10.39
Cleanup	6.87	2.69
Basement Attendant	7.27	2.11
Edger Operator	1.54	2.12
Trimsaw Operator	0.82	1.79
Log Chaser	0.95	2.06
Debarker Operator	0.25	0.73
Stacker Operator	0.82	1.49
Grader	12.32	2.04
Infeed Operator	3.95	3.93
Tilt Hoist Operator	N/A	N/A

Table 4-3. Inhalable Particulate Mass by Job and Season for Mill 3

JOB	Inhalable Dust (mg/m^3)	
	Winter	Summer
Millwright	2.09	2.58
Sawfiler	0.86	1.46
Planerman	3.64	2.79
Cleanup	0.53	1.50
Basement Attendant	2.18	5.32
Edger Operator	1.58	1.66
Trimsaw Operator	1.46	1.73
Log Chaser	3.46	2.73
Debarker Operator	0.11	3.46
Stacker Operator	3.17	2.00
Grader	1.58	1.10
Infeed Operator	1.33	2.32
Tilt Hoist Operator	N/A	N/A

Table 4-4. Inhalable Particulate Mass by Job and Season for Mill 4

JOB	Inhalable Dust (mg/m^3)	
	Winter	Summer
Millwright	2.66	N/A
Sawfiler	1.26	1.75
Planerman	N/A	N/A
Cleanup	1.19	1.09
Basement Attendant	5.38	2.45
Edger Operator	1.16	1.25/.1.39
Trimsaw Operator	0.50	2.76
Log Chaser	1.66	0.89
Debarker Operator	0.11	0.63
Stacker Operator	1.11	0.99
Grader	0.87	1.21
Infeed Operator	2.71	N/A
Tilt Hoist Operator	N/A	1.54

Table 4-5. Inhalable Particulate Mass by Job and Season for Mill 5

JOB	Inhalable Dust (mg/m³)	
	Winter	Summer
Millwright	2.93	2.24
Sawfiler	N/A	N/A
Planerman	3.00	1.68
Cleanup	N/A	N/A
Basement Attendant	N/A	N/A
Edger Operator	2.17	1.11/1.23
Trimsaw Operator	0.87/0.56	1.42
Log Chaser	1.08	0.88
Debarker Operator	0.46	0.68
Stacker Operator	0.97	1.00
Grader	0.87	0.85
Infeed Operator	2.33	4.08
Tilt Hoist Operator	1.64	1.19

Table 4-6. Inhalable Particulate Mass by Job and Season for Mill 6

JOB	Inhalable Dust (mg/m³)	
	Winter	Summer
Millwright	4.77	2.33
Sawfiler	1.49	2.15
Planerman	2.71	1.80
Cleanup	1.36	1.31
Basement Attendant	12.55	1.85
Edger Operator	3.70	1.72
Trimsaw Operator	3.75	3.64
Log Chaser	0.97	2.58
Debarker Operator	0.73	1.13
Stacker Operator	1.24	1.39
Grader	1.57	3.20
Infeed Operator	0.63	1.32
Tilt Hoist Operator	N/A	N/A

Table 4-7. Inhalable Particulate Mass by Job and Season for Mill 7

JOB	Inhalable Dust (mg/m³)	
	Winter	Summer
Millwright	1.88	4.19
Sawfiler	0.83	4.44
Planerman	26.51	9.49
Cleanup	4.27	4.98
Basement Attendant	N/A	1.45
Edger Operator	2.17	4.88
Trimsaw Operator	1.19/1.76	3.60
Log Chaser	1.87	6.10
Debarker Operator	1.28	2.14
Stacker Operator	1.15	1.90
Grader	3.35	3.72
Infeed Operator	1.68	2.36
Tilt Hoist Operator	N/A	N/A

Table 4-8. Inhalable Particulate Mass by Job and Season for Mill 8

JOB	Inhalable Dust (mg/m³)	
	Winter	Summer
Millwright	0.87	2.27
Sawfiler	2.24	2.95
Planerman	3.08	2.49
Cleanup	N/A	N/A
Basement Attendant	3.07	2.66
Edger Operator	1.53	1.52
Trimsaw Operator	3.93	1.98
Log Chaser	1.82	4.34
Debarker Operator	1.84	6.54
Stacker Operator	0.94	1.79
Grader	0.57	1.76
Infeed Operator	3.55	4.12
Tilt Hoist Operator	3.98	4.43

Table 4-9. Inhalable Particulate Mass by Job and Season for Mill 9

JOB	Inhalable Dust (mg/m³)	
	Winter	Summer
Millwright	4.42	2.27
Sawfiler	1.06	2.84
Planerman	3.48	2.63
Cleanup	N/A	3.06
Basement Attendant	34.6	3.06
Edger Operator	1.00	2.09
Trimsaw Operator	N/A	1.98
Log Chaser	2.20	5.40
Debarker Operator	0.11	1.05
Stacker Operator	0.94	1.34
Grader	0.76	1.50
Infeed Operator	1.11	2.22
Tilt Hoist Operator	0.63	N/A

4.2 IPM dust levels by mill

4.2.1 Mills pooled:

Table 4-10 is a summary of the information contained in Tables 4-1 to 4-9. The overall summary statistics with all the mills pooled is listed along the bottom row. Inhalable dust levels among the 9 mills ranged from 0.11 to 34.6 mg/m^3. Approximately 9% (95% CI = 5.2% to 12.9%) of the 210 IPM samples collected were above the 1999 proposed ACGIH NIC TLV of 5 mg/m^3 inhalable. With the current Alberta OEL of 5 mg/m^3 "total" dust limits, 1% (95% CI = 0% to 2.6%) of the 210 IPM samples collected would be above the OEL. This estimate of 1% is based on a conversion factor of 4 between inhalable dust and "total" dust in sawmills (Davies et al., 1999). The overall geometric mean (2.04 mg/m^3) and median (2.08 mg/m^3) inhalable dust were less than the arithmetic mean (2.95 mg/m^3) levels. The geometric mean and median are measures of central tendency that are less influenced by extremely high dust measurements.

Mill 1 had the highest geometric mean (3.79 mg/m^3), arithmetic mean (5.08 mg/m^3), and median (3.96 mg/m^3) inhalable dust levels. Note the maximum dust level (26.2 mg/m^3) recorded from this mill.

Mill 7 had the 2nd highest geometric (2.83 mg/m^3) and arithmetic (4.05 mg/m^3) mean dust levels, but the 3rd highest median (2.27 mg/m^3) dust level. Note the maximum dust level recorded from the mill (26.5 mg/m^3).

Note the maximum dust level recorded from Mill 9 (34.6 mg/m^3). Also note that Mill 9 has the 3rd highest arithmetic mean (3.47 mg/m^3) dust level, but only the 6th highest geometric mean (1.83 mg/m^3), and 4th highest median (2.09 mg/m^3) dust levels. Arithmetic means are measures of central tendency, but can be influenced by large values (i.e. the 34.6 mg/m^3). Recall that geometric means and medians are also measures of central tendency, but are less influenced by high dust measurements.

Table 4-10. Descriptives for Inhalable Particulate Mass (IPM) Dust for each Mill

Mill	N	Geometric Mean (mg/m³)	Arithmetic Mean (mg/m³)	95% Confidence Interval for Mean (mg/m³)		Min. (mg/m³)	Max. (mg/m³)	Median (mg/m³)	Samples > 5 mg/m³		
				Lower Bound	Upper Bound				Number	Percent	95% Confidence Interval for %
1	23	3.79	5.08	2.87	7.28	0.44	26.19	3.96	5/23	22 %	4.9 to 38.6%
2	24	2.33	3.43	2.08	4.78	0.25	12.32	2.09	5/24	21 %	4.6 to 37.1%
3	24	1.73	2.11	1.62	2.59	0.11	5.32	1.86	1/24	4 %	0 to 12.2%
4	22	1.25	1.57	1.08	2.06	0.11	5.38	1.23	1/22	5 %	0 to 13.2%
5	22	1.29	1.51	1.10	1.92	0.46	4.08	1.15	0/22	0 %	0
6	24	1.95	2.49	1.48	3.51	0.63	12.55	1.76	1/24	4 %	0 to 12.2%
7	24	2.81	4.05	1.86	6.24	0.83	26.51	2.27	3/24	13 %	0 to 25.7%
8	24	2.32	2.68	2.09	3.27	0.57	6.54	2.38	1/24	4 %	0 to 12.2%
9	23	1.83	3.47	.48	6.45	0.11	34.59	2.09	2/23	9 %	0 to 20%
Total	210	2.04	2.95	2.43	3.46	0.11	34.59	2.08	19/210	9 %	5.2 to 12.9%

N is the number of samples collected

4.2.2 Comparison between the mills:

Using the data from Table 4-10, a bar graph (Figure 4-1) was constructed to compare arithmetic mean IPM dust levels between the nine sawmills.

Mills 1 and 7 had the highest mean IPM dust levels. Mills 4 and 5 had the lowest mean IPM dust levels. Note that the majority of the mills (excluding Mill 1) had mean IPM dust levels below the proposed ACGIH NIC TLV of 5 mg/m^3 inhalable. The bars in this figure represent average dust levels for each mill, therefore some individual dust samples within each mill may still exceed the proposed ACGIH TLV.

Using ANOVA there was a statistically significant difference (P<0.001) in mean log mean IPM dust concentrations from the 9 sawmills. Before the ANOVA was performed, the IPM dust data was natural log transformed. The distribution was normal, and the variance was equal (tests of normality, Levene's homogeneity of variance).

Figure 4-2 is known as a boxplot. IPM dust levels from the nine sawmills are displayed as box and whiskers (see methods 3.5 for complete description). Note the black bar within the boxes. This bar represents the median inhalable dust levels for each mill. None of the Mill's median dust levels are above the proposed TLV. Mill 1, which had the highest mean dust level, also has the highest median dust level.

Using non-parametric tests (Kruskal-Wallis H Test) there is a significant statistical difference (P<0.001) in median IPM dust levels from the 9 sawmills. With the Kruskal-Wallis H Test it is not possible to determine which particular mill is significantly different from another. Although it is not entirely known what is responsible for the differences in the 9 mills, the following observations are made.

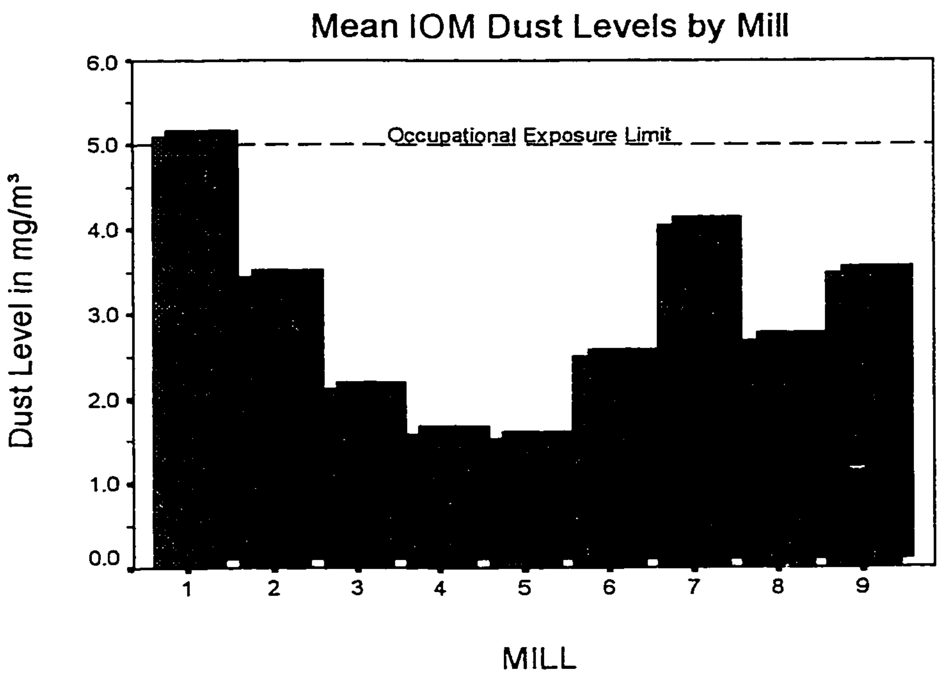


Figure 4-1. Comparison of dust levels between the mills.

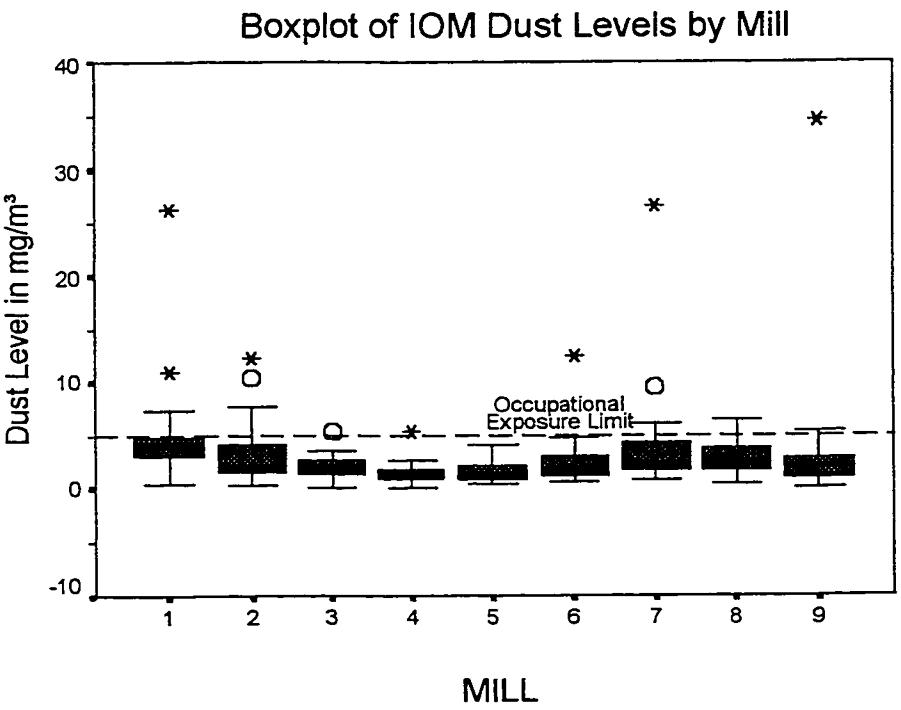


Figure 4-2. Distribution of dust levels within the mills. See Methods 3.5 for description of symbols.

Recall that the asterisk in a boxplot represents extreme outliers (dust levels higher than expected based on the distribution of the remaining dust measurements). The circles represent outliers (dust levels higher than expected, but not as high as extreme outliers). For Mill 1 there were two extreme outliers which both represent IPM samples obtained from basement attendants (Cleanup occupational group). These two IPM samples will contribute to the higher average IPM dust levels seen in Mill 1. Mill 7 had an outlier and an extreme outlier which both represent IPM samples from the planerman job (Maintenance occupational group). These planerman samples may elevate Mill 7's mean dust levels. Mill 9 had an extreme outlier, which represents an IPM sample from another basement attendant (cleanup occupational group). This basement attendants IPM sample will contribute to an elevated mean dust level for Mill 9.

4.2.3 Summary for the mills

In summary for the mill analysis, Mill 1 had the highest geometric mean (3.8 mg/m^3), arithmetic mean (5.1 mg/m^3), and median (3.9 mg/m^3) dust levels. The maximum IPM dust level obtained from this Mill was 26.2 mg/m^3. This measurement came from the basement attendant job, which is part of the cleanup occupational group. In addition 21.7% (95% CI = 4.9% to 38.6%) of the 23 IPM samples collected from Mill 1 were above the proposed ACGIH NIC TLV of 5 mg/m^3 inhalable.

Mills 7 had the 2nd highest geometric (2.8 mg/m^3) and arithmetic (4.0 mg/m^3) mean dust levels. The highest IPM dust level from Mill 7 was 26.5 mg/m^3 and was from the planerman job (maintenance occupational group). 13% (95% CI = 0 to 25.7%) of the 24 IPM samples collected from Mill 7 were above the 1999 proposed ACGIH NIC TLV of 5 mg/m^3 inhalable.

Mill 9 had the 3rd highest arithmetic mean IPM dust levels (3.5 mg/m^3). The basement attendant (cleanup occupational group) from Mill 9 had the highest IPM dust level in this Mill and in the entire Alberta sawmill study. Although there were only two IPM samples from Mill 9 that were above the proposed ACGIH TLV of 5 mg/m^3 inhalable this mill still had the 3rd highest mean IPM levels. The other sample (5.4 mg/m^3) came from a log chaser in the sawmill occupational group.

The major focus of this thesis was not on differences in mills, but was on differences in occupational groups. The statistically significant difference in mean and median dust levels seen in the mill analysis serve as a starting point to investigate the occupational groups within the mills.

4.3 IPM dust levels by occupational groups

4.3.1 Comparison between occupational groups

Table 4-11 is a summary of the IPM levels in the 4 occupational groups. Occupational groups can be compared using the geometric and arithmetic means, medians, ranges of IPM dust levels, and percentage of samples above the proposed TLV of 5 mg/m^3. Note that all nine mills were pooled and 13 jobs were combined into these 4 occupational groups. The cleanup occupational, which has the fewest number of samples collected, has the highest recorded dust levels (34.6 mg/m^3), and the highest percentage (32%; 95% CI = 14.8% to 49.4%) of IPM samples above the proposed ACGIH NIC TLV of 5 mg/m^3. The cleanup group had the highest geometric mean (3.5 mg/m^3), arithmetic mean (5.7 mg/m^3), and median (3.1 mg/m^3) dust levels, followed by the maintenance, planermill, and sawmill occupational groups.

Using non-parametric tests (Kruskal-Wallis H Test) it was found that there was a significant statistical difference ($P<0.001$) between the median IPM dust levels of the 4 occupational groups. Using ANOVA there was a statistically significant difference ($P<0.001$) in log mean IPM dust levels between the 4 occupational groups. Before the ANOVA was performed, the data was natural log

Table 4-11. Descriptives for Inhalable Particulate Mass Dust by Occupational Group

Occupational Group	N	Geometric Mean (mg/m^3)	Arithmetic Mean (mg/m^3)	95% Confidence Interval for Mean (mg/m^3)		Min. (mg/m^3)	Max. (mg/m^3)	Median (mg/m^3)	Samples > 5 mg/m^3		
				Lower Bound	Upper Bound				Number	%t	95% Confidence Interval for %
Cleanup	28	3.45	5.73	2.77	8.68	0.53	34.59	3.06	9/28	32%	14.8 to 49.4%
Maintenance	48	2.74	3.56	2.42	4.70	0.83	26.51	2.61	5/48	10%	1.8 to 19.1%
Planermill	41	2.01	2.53	1.89	3.17	0.57	12.32	2.04	1/41	2%	0 to 7.2%
Sawmill	93	1.50	1.97	1.68	2.27	0.11	7.45	1.54	4/93	4%	0 to 8.4%
Total	210	2.04	2.95	2.43	3.46	0.11	34.59	2.08	19/210	9%	5.2 to 12.9%

N is the number of samples collected

transformed. The distribution was normal, and the variance was equal using tests of normality and Levene's homogeneity of variance respectively.

These statistical tests do not allow one to determine which occupational groups are different from each other. The non-parametric test (Mann-Whitney U Test) was used to make comparisons between pairs of occupational groups (Table 4-12). Comparisons were completed for all possible pair combinations from the 4 occupational groups. Recall that the level of significance using the Bonferroni adjustment is P<0.008.

Table 4-12. Statistical differences in means between Occupational groups

Pairs of Occupational Groups		P Value
Cleanup	Maintenance	0.301
Cleanup	Planermill	0.020
Cleanup	Sawmill	*0.000
Maintenance	Planermill	0.061
Maintenance	Sawmill	*0.000
Planermill	Sawmill	0.077

* indicates statistically significant (P< 0.008)

The cleanup group had median dust levels significantly different (P<0.008) than the sawmill, but not the planermill and maintenance group. The maintenance group had median dust levels significantly different (P<0.008) than the sawmill, but not the planermill. The planermill did not have median dust levels significantly different than the sawmill.

4.3.2 Cleanup occupational group:

Figure 4-3 is a bar graph that shows average IPM dust levels in the four occupational groups using the combined data from the 9 sawmills. All of the occupational groups except the cleanup group have mean IPM levels below the proposed ACGIH NIC TLV of 5 mg/m^3 inhalable. Individual measurements within

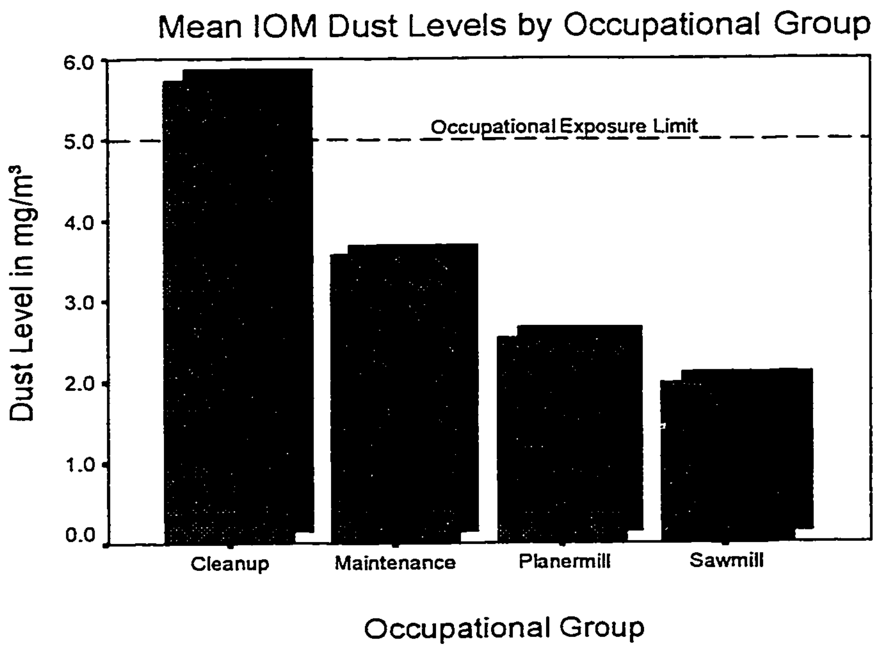


Figure 4-3. Comparison of dust levels between the occupational groups

each occupational group may still exceed the TLV since the bars represent average IPM levels.

For the cleanup group, recall that the basement attendant from Mill 9 had had an IPM sample of 34.6 mg/m^3, and the basement attendant from Mill 1 had an IPM sample of 26.2 mg/m^3. These two values represent the highest and 3rd highest values for the entire study. Extreme high values will influence the arithmetic means. Also recall that the cleanup group has the smallest sample number. Small sample sizes (versus large sample sizes) will be more influenced by large values.

Although 32% (95% CI = 14.8% to 49.4%) of the IPM samples were above the proposed ACGIH NIC TLV of 5 mg/m^3, 2% (95% CI = 0% to 16.7%) of the IPM samples were above the current Alberta OEL of 5 mg/m^3 "total" dust (approx. equal to 20 mg/m^3 inhalable).

4.3.3 Maintenance occupational group:

The maintenance occupational group had the 2nd highest geometric mean (2.7 mg/m^3), arithmetic mean (3.6 mg/m^3), and median (2.6 mg/m^3) IPM dust levels. The highest IPM dust level in this group came from Mill 7's planerman (26.5 mg/m^3). This IPM dust level was 2nd highest of all the IPM samples. Of the 48 IPM samples from the maintenance group 10% (95% CI = 1.8% to 19.1%) were above the proposed ACGIH NIC TLV of 5 mg/m^3 inhalable. Approximately 2% (95% CI = 0% to 6%) of the 48 IPM dust samples were above the current Alberta OEL of 5 mg/m^3 "total" dust.

4.3.4 Planermill occupational group:

The planermill had the 3rd highest geometric mean (2.0 mg/m^3), arithmetic mean (2.5 mg/m^3), and median (2.04 mg/m^3) IPM dust levels. The highest IPM dust level came from Mill 2's grader (12.32 mg/m^3). Using the proposed TLV of 5 mg/m^3, 2% (95% CI = 0% to 7.2%) of the 41 IPM samples exceeded this limit. In contrast there are no IPM samples above the current Alberta OEL of 5 mg/m^3 "total" dust.

4.3.5 Sawmill occupational group:

The "sawmill" occupational group reported the lowest IPM dust levels (0.11 mg/m^3). Approximately 4% (95% CI = 0% to 8.4%) of the 93 IPM dust samples were above the proposed ACGIH NIC TLV of 5 mg/m^3 inhalable. None of the IPM samples exceeded the current Alberta OEL of 5 mg/m^3 "total" dust. The median dust levels from the "sawmill" group were significantly different from the cleanup group and maintenance groups.

4.3.6 Summary for the occupational groups:

In summary the cleanup group had the highest geometric mean (3.5 mg/m^3), arithmetic mean (5.7 mg/m^3), median (3.1 mg/m^3), and percentage of samples (32%: 95% CI = 14.8% to 49.4%) above the proposed ACGIH TLV of 5 mg/m^3 (inhalable). In contrast, 2% (95% CI = 0% to 16.7%) of the cleanup group's IPM samples were above the current Alberta OEL of 5 mg/m^3 "total" dust (approx. equal to 20 mg/m^3 inhalable). The highest and 3rd highest IPM samples from this study came from the cleanup occupational group, and these levels were more than twice that of the 4th highest IPM level.

There was a statistically significant difference in mean and median inhalable dust levels between the occupational groups. For the cleanup group, there was a statistically significant difference in medians from the sawmill group. The cleanup group did not have a statistically significant difference in medians from the maintenance or planermill occupational groups. For the maintenance group, there was also a statistically significant difference in medians from the sawmill group.

4.4 Mean IPM levels by job title

Figure 4-4 is a bar graph that illustrates the breakdown of the occupational groups into the 13 job titles. Average IPM dust levels were generally below the proposed ACGIH NIC TLV of 5 mg/m^3 except for the basement attendant and the planerman jobs. Caution must be exercised when reading this bar graph since there is an unequal distribution of samples within the 13 jobs. The edger operator's mean dust level is calculated using 18 IPM samples. In contrast, for the tilt hoist operator, 6 samples were used to calculate the average IPM levels. In some mills there was no job position titled tilt hoist operator. In some instances the worker may have refused to wear the personal monitor. However by combining jobs into occupational groups, this drawback of small sample sizes among some of the job titles is minimized. The lowest mean IPM dust levels were observed in the debarker operator job. It is important to note that some debarker operators are in enclosed booths. Note the bar representing the dust levels from the grader job. Recall that Mill 2 had a grader with an IPM level of 12.3mg/m^3. The average inhalable dust level for the grader remains below the proposed TLV of 5 mg/m^3.

4.5 Comparison with other studies

Table 4-13 is a summary of wood dust measurements from various sawmill studies in Canada and Internationally. The Australian sawmill investigation by Alwis et al. (1999) is of particular interest with regards to this thesis since personal sampling for inhalable particulate mass was also used. The geometric mean dust levels in Alberta sawmills was 2.04 mg/m^3. The corresponding dust levels collected in Australia's sawmills was 1.59 mg/m^3. Alwis et al. recorded higher arithmetic means than in the Alberta sawmill study (4.81 mg/m^3 versus 2.95 mg/m^3 respectively). Recall that arithmetic means are influenced by high values. The maximum IPM level in Alwis's study was 74.1 mg/m^3. This high value could account for the difference in arithmetic means between Alwis's study and this thesis. Alwis et al. did not report the percentage of samples > 5 mg/m^3, which would be helpful when interpreting the arithmetic mean.

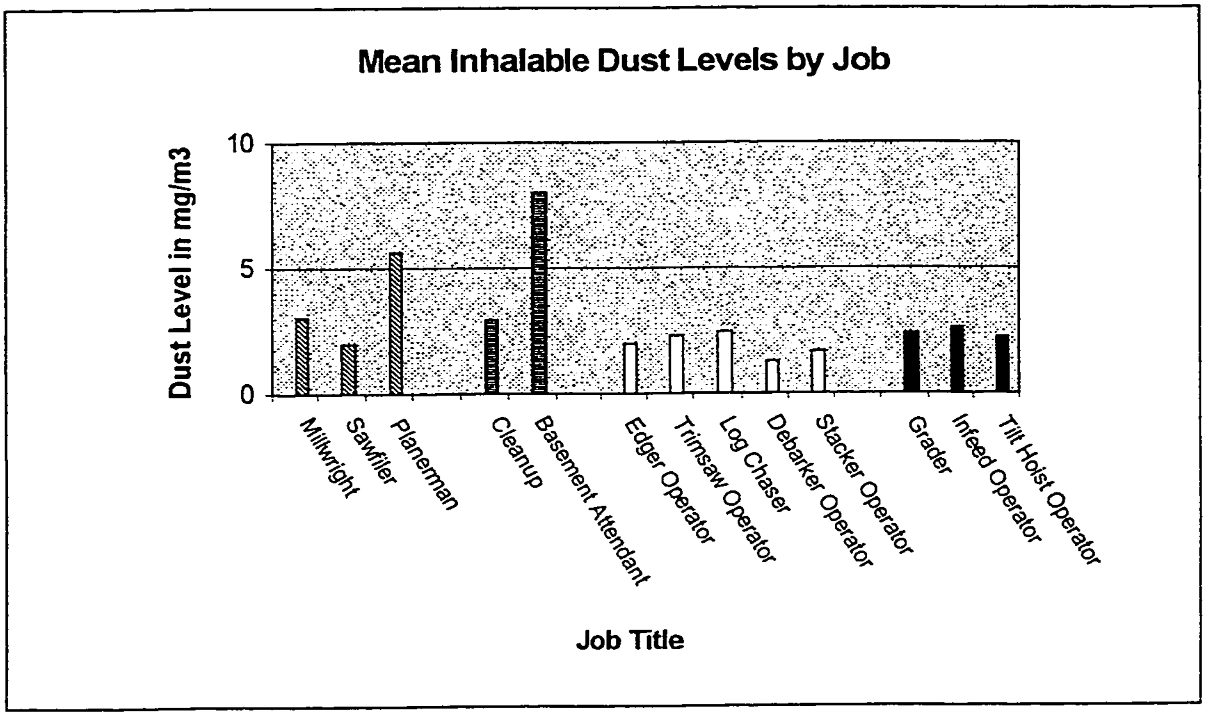


Figure 4-4. Comparison of dust levels between the jobs. Note that the jobs are arranged into the 4 occupational groups according to bar pattern. The maintenance group is represented by the barber pole; the cleanup group is the horizontal stripe; the sawmill group has no shading; the planermill group is the dark shading.

Table 4-13. Comparison of wood dust levels measured from other sawmill studies

Study	Wood type	Measurement	Sawmills	Samples	Arithmetic Mean (in mg/m^3)	Geometric Mean (in mg/m^3)	Minimum level (in mg/m^3)	Maximum level (in mg/m^3)	% of sample > 5 mg/m^3
Alwis et al., 1999	mixed	inhalable, personal	c	22	0.83	0.74	0.25	2.63	
			d	29	2.99	1.91	0.55	11.2	
			e	25	12.32	2.44	0.26	74.1	
			f	17	2.02	1.68	0.56	4.55	
			4 total	93	4.81	1.59	0.25	74.1	
Holliday et al., 1986	softwood	total dust	2	18	1.5	1.1	0.31	6	6
		* IPM conversion (4 X)			* 6	* 4.4	* 1.24	* 24	
Kauppinen et al., 1984	mixed	total dust, area	6	80	2.1	1.3	0.1	15	10
		* IPM conversion (4 X)			* 8.4	* 5.2	* 0.4	* 60	
Mazurkiewicz et al., 1989	mixed	total, personal	12	193	x	0.71	< 0.1	410	8
		* IPM conversion (4 X)			x	* 2.84	x	x	
Vedal et al., 1986	softwood	total, personal/area	1	78	0.46	0.21	< 0.1	6	< 4
		* IPM conversion (4 X)			* 1.84	* 0.84	x	* 24	
Teschke et al., 1994	softwood	respirable, personal	2	224	0.51	0.12	< 0.08	52	1
Thesis, 2000	softwood	inhalable, personal	1	23	5.08	3.79	0.44	26.2	22
			2	24	3.43	2.33	0.25	12.3	21
			3	24	2.11	1.73	0.11	5.32	4
			4	22	1.57	1.25	0.11	5.38	5
			5	22	1.51	1.29	0.46	4.08	0
			6	24	2.5	1.95	0.63	12.6	4
			7	24	4.05	2.81	0.83	26.5	13
			8	24	2.68	2.32	0.57	6.54	4
			9	23	3.47	1.83	0.11	34.6	9
			9 total	210	2.95	2.04	0.11	34.6	10

Kauppinen et al. (1984) investigated sawmills in Europe. The geometric mean and arithmetic mean dust levels found in Kauppinen's study (1.3 mg/m^3, 2.1 mg/m^3) are lower than in the Alberta sawmills (2.04 mg/m^3, 2.95 mg/m^3). The results may not be directly comparable since area sampling was conducted, and in addition the "total" dust fraction was measured. Kauppinen's test results may be lower since it is known that "total" dust measures underestimate IPM fractions. In addition, area sampling may underestimate or overestimate personal sampling in certain conditions (see Introduction 1.7). A conversion factor (4X) was used to transform the "total" dust to IPM dust levels (Davies, 1999). The estimated GM (5.2 mg/m^3) and AM (8.0 mg/m^3) levels were now higher than the results from this thesis. The results may still not be comparable since area sampling techniques were used in Kauppinen's study.

Holliday et al. (1986) investigated softwood sawmills and reported geometric (1.1 mg/m^3) and arithmetic (1.5 mg/m^3) mean dust levels that were approximately half of the corresponding levels from the Alberta sawmills (2.04 mg/m^3 and 2.95 mg/m^3). The difference again may be accounted for by the fact that total dust was measured, and not inhalable dust. With the conversion (4X) to IPM measurements the estimated GM (4.4 mg/m^3) and AM (6.0 mg/m^3) were higher than the results of this thesis (2.04 mg/m^3 GM, and 2.95 mg/m^3 AM).

Teschke et al. (1994) investigated sawmill dust levels in British Columbia, which processes mainly softwood. The geometric mean dust levels (0.12 mg/m^3) are 20 times lower than Alberta sawmills (2.04 mg/m^3). The mass fractions measured may account for the difference. Cyclones were used, and the fraction of dust collected was reported to be respirable (particles capable of reaching the small terminal lung pathways responsible for gas exchange). Respirable dust and inhalable dust may not be directly comparable since the mass fractions are different sizes.

The studies by Vedal et al. (1986), and Mazurkiewicz et al. (1989) report GM dust levels of 0.21 and 0.71 mg/m^3 respectively. These levels are lower than that reported in this thesis (2.04 mg/m^3). With the conversion to IPM measurements the estimated GM's are 0.84 mg/m3 and 2.84 mg/m3 (for Vedal et al. and Mazurkiewicz et al. respectively). In Vedal's study it is not reported the percentage of samples taken by area monitoring. The samples obtained from area monitoring could contribute to the difference seen in geometric mean dust levels.

In summary, the mean inhalable wood dust levels from the 210 IPM samples taken from 9 Alberta sawmills are within the range of levels that other sawmill studies have found. There are other sawmill studies that have geometric and arithmetic mean dust levels that are either higher, lower or similar to the results found in this study (Kauppinen et al., 1984, Vedal et al., 1986, and Alwis et al., 1999).

5. DISCUSSION AND CONCLUSIONS

From the literature review there is evidence that softwood dust exposure is associated with nasal cancer, however the risks are less than that of exposure to hardwoods. Squamous cell carcinoma is the histological type most closely associated with softwood dust exposure. There is a paucity of studies that exclusively evaluate softwood dust exposure and squamous cell carcinoma. Cross-sectional studies that estimate exposure limits were based on mucostasis. Even with the inclusion of mixed wood studies, there is a lack of quantitative exposure data to estimate an occupational exposure limit based on nasal cancer risks.

5.1 Summary of results

There were statistically significant differences in the median and log mean IPM dust levels for the 9 sawmill studied. One can speculate that the mills with higher average dust levels had higher production volumes, older machinery, or inadequate ventilation. Mills with lower average dust levels may alternatively have lower production volumes, and newer "cleaner" machinery with proper ventilation. However the major focus of this thesis was not to speculate on causes but rather to investigate which groups of workers may be at increased risk for developing an adverse health outcome such as nasal cancer.

In summary, approximately 9% (95% CI = 5.2 to 12.9%) of the samples in the 9 sawmills had exposures above the proposed ACGIH NIC TLV of 5 mg/m^3 TWA inhalable dust. Using the current Alberta OEL (5 mg/m^3 TWA total dust) and using an inhalable to total dust conversion factor of 4 (Davies, 2000), only 1% (95% CI = 0 to 2.6%) of the samples in the 9 sawmills were above the OEL. Statistically significant differences in median and log mean inhalable dust levels were found among the 4 occupational groups. The cleanup occupational group had the highest geometric mean (3.45 mg/m^3), arithmetic mean (5.73 mg/m^3), and median (3.06 mg/m^3) inhalable dust levels. Approximately 32% (95% CI = 14.8 to 49.4%) of the cleanup occupational group samples were above the proposed ACGIH NIC TLV of 5 mg/m^3 TWA inhalable dust. However, only approximately 2% (95% CI = 0% to 16.7%) of the IPM samples from the cleanup occupational group were above the current Alberta OEL of 5 mg/m^3 "total" dust (approx. equal to 20 mg/m^3 inhalable).

5.2 Comparison of the Alberta Sawmill Study with other studies

A comparison of the results from this Alberta Sawmill Study and other sawmill studies has been addressed in the results section already. Briefly, the geometric mean (2.04 mg/m^3), arithmetic mean (2.95 mg/m^3), and maximum dust level (34.6 mg/m^3) from the Alberta Sawmill Study were neither the highest nor the lowest compared with the other sawmill studies (Alwis et al., 1999; Holliday et al., 1986; Kauppinen et al., 1984; Mazukiewicz et al., 1989; Vedal et al., 1986; Teschke et al., 1994). There were some differences in the collection methods (area vs personal, "total" vs IPM and respirable) that had to be considered. It is difficult to directly compare each of the various sawmill results without knowing more about the methods (including the sampling strategies used) and the characteristics of each mill. In summary the mean and median levels from the Alberta Sawmill Study were not out of the range that other studies have found.

5.3 Limitations/strengths of the study

5.3.1 Selection

The 9 Alberta sawmills in this thesis were not enrolled by random selection. Random selection was not possible since most of the sawmills were independently run, and there was no regulatory requirement for this study. Therefore even if a sawmill were randomly selected there would be no obligation to participate in the study. In addition there was a cost associated with conducting the study. It would be unfair to request a company to incur a financial cost for dust level monitoring since it is not a requirement; especially if the sawmill was already under financial stress. Testing sawmills that volunteer may however introduce a selection bias. Selection bias occurs when there is a systematic error during recruitment of study subjects that is repeated and may cause a false observation or outcome to occur. For example if only clean sawmills or sawmills with very low dust levels volunteered, then the study results may show low wood dust levels. If the results were generalized to all Alberta sawmills, a false representation would be created since dirty sawmills or sawmills with high wood dust levels were not included in the study. An example of how selection bias may occur is as follows. Sawmills are in business to make a profit, and controlling costs will maximize profit. If a sawmill has or is suspected to have high dust levels, then this will cost the sawmill money for the following reasons. First of all, the company will have to pay for the survey. Secondly when the test results come back, the levels are likely to show up high. More money must be spent to control the elevated dust levels either by upgrading machinery or installing ventilation measures. Therefore a company is not likely willing to pay the full costs of a dust survey that will inevitably show high dust levels. In contrast, a sawmill that has low dust levels may volunteer since apart from the cost of the initial study, there are no further costs. Therefore with the dust study, the sawmill can show its workers that the mill is “clean” and “efficient”. This may increase worker morale, worker productivity, and may translate into increased profit for that sawmill.

The incentive for all sawmills to volunteer was that instead of each company funding the entire cost to conduct the dust survey, part of the survey was paid for by the AFPA, and part was paid for by the Alberta Department of Economic Development and Tourism. Using this incentive, sawmills with higher dust levels would be encouraged to participate since a proportion of the costs would be covered.

With time considerations for completion of the study, the first 9 sawmills (38 sawmill members of the AFPA) were enrolled. Almost 25% of the AFPA sawmills were sampled. Approximately 95% of Alberta sawmill wood production is produced from these 38 sawmills (Harmon, 2000). Therefore the majority of softwood sawmill production comes from AFPA sawmill members. It can be postulated that smaller sawmills not enrolled with the AFPA may have wood dust exposure limits higher than that found in AFPA sawmill member companies. However these smaller sawmills represent only 5% of Alberta's softwood sawmill production, and therefore only a small percentage of the provinces softwood sawmill production.

5.3.2 Measurements

IPM fractions were measured using an IOM (SKC) inhalable dust sampler. There are other IPM samplers available such as the GSP (Deha-Haan & Witmer), seven-hole sampler (Casella, JS Holdings), PAS-6 (University of Wageningen), and Perspec (Lavoro e Ambiente). The IOM dust sampler was selected since it is the standard used in the United Kingdom, and it was the sampler most familiar to the industrial hygienist conducting the survey. Potential errors with the use of IPM (IOM) sampling in this particular study will be addressed.

With personal sampling, the IOM monitor is clipped onto the lapel or collar of the worker as close to the breathing zone as possible. The IOM dust sampler has a 15 mm opening and is facing forward away from the wearer. An IPM dust sampler is designed to collect or capture airborne material; in essence, wood dust that can be captured or drawn in from the ambient air by vacuum or inhalation. In sawmills, machinery with rotating blades can shoot small particles of wood (projectiles) through the air. Particles of wood that are projectiles are not normally suspended in air as opposed to finer particles of wood that are suspended. The rotating blades will give some wood dust particles sufficient momentum that the projectiles shoot directly into the 15 mm opening of the forward facing IOM sampler. In a normal breathing individual, projectiles are unlikely to pass the protective barriers of the upper respiratory tract (angle to enter the nose, nasal hair, outer skin covered part of the nose). The effect of projectiles on IOM sampling is that the measured wood dust levels may be falsely elevated with respect to the true IPM fraction. The distance a projectile will travel (stop distance) is related to the wood particle diameter, and the initial velocity (speed of the turning blade). The larger the particles, and the faster the initial velocity, the further (longer stop distance) a projectile will travel (Hamill et al., 1991). It is difficult to estimate the amount of contamination from projectiles in IPM sampling unless one counts the particles greater than 100 µm on the filter (which is not practical). Since the operator will move location during the work shift, estimating contamination by measuring the distance of the operator from the wood dust source, and the velocity of the machinery would not be useful either

According to Liden and Kenny, "the sampling convention for inhalable dust is undefined for particle sizes larger than 100 µm owing to experimental difficulties in its measurement" (Liden & Kenny, 1994). The data for the sampling convention were made in a wind tunnel with a simulated breathing dummy, and only particles between 0 and 100 µm were investigated. Particles greater than 100 µm are collected by the IPM sampler, but the efficiency and more importantly the health effects due to these larger particles is not known (Liden & Kenny, 1994). According to these investigators, to ensure that the amount of dust collected by the IPM sampler is in the 0 to 100 µm range, the size distribution of the wood dust should be measured. If the mass median aerodynamic diameter (MMAD) of the dust is less than 25 µm, then the inhalable mass above 100 µm is negligible (Liden & Kenny, 1994). The MMAD is defined as "the diameter at which 50% of the mass is contained within smaller particles and 50% is contained within larger particles" (Davies, 2000). The MMAD was not measured in this study.

In this study there were three samples that had dust concentrations (34.6 mg/m^3, 26.5 mg/m^3, 26.2 mg/m^3) greater than twice that of the 4th and 5th ranked dust samples (12.6 mg/m^3 and 12.3 mg/m^3). There was no reason to suspect tampering and no evidence of contamination of the IOM sampler. Since the samples were collected from three different mills, it is unlikely these high levels are due to some error in the collection method from that day. Projectiles may account for the elevated levels, but it is difficult to prove without measuring the mass median aerodynamic diameters. However these three high dust level results are not as elevated as some sawmill investigators have found (Alwis et al., 1999; Teschke et al., 1994; Mazurkiewicz et al., 1989). In the Australian sawmill study, personal inhalable dust levels were reported to be as high as 74.1 mg/m^3 (Alwis et al., 1999). Teschke (1994) reported mean respirable dust levels as high as 52 mg/m^3. It is important to note that this was respirable dust, and the conversion to inhalable dust is not clearly defined. Mazurkiewicz (1989) reported total dust levels up to 410 mg/m^3. This is total dust and therefore the IPM equivalent may be even higher. Therefore the three high IPM dust levels collected from the 9 sawmills are likely to represent true dust levels.

5.3.3 Occupational groups

Although occupational exposure limits are time weighted averages and are applied to each individual worker, it was necessary to group workers in order to investigate or generate ideas of where to focus the attention on dust control. 13 job categories were identified, however each sawmill did not necessarily have all 13 job categories. In addition with job rotation strategies to reduce repetitive strain injuries, a worker may rotate to different jobs during their work shift. Therefore 4 occupational groups (cleanup, maintenance, sawmill, and planermill) were artificially created in order to account for job rotation, and in order to assist with statistical analysis. By combining the 13 jobs into 4 occupational groups there is the potential that statistical differences in means will be obscured by the averaging effect. Statistical difference in means between the jobs may be lost when the jobs are combined to form occupational groups. For example if 4 jobs (equal means and sample size) are combined with 1 job (equal sample size, but higher mean) to form an occupational group, the average dust level may not be statistically different compared with another occupational group due to the effects of averaging. The single job by itself may have had a statistically significant difference in means from the other jobs.

Although the effect of combining jobs into occupational groups has the potential effect of obscuring differences in mean dust levels, there were still statistically significant differences found in the occupational groups.

It is also possible to increase an occupational group's mean dust level by including a job with an extremely high mean dust level. Recall that means are influenced by high values. Also recall that medians are not influenced by the high values and are dependent on rank order. In this thesis study there were statistically significant differences in mean inhalable dusts. The cleanup occupational groups had the highest geometric and arithmetic means, but also the highest median dust level. Therefore it is likely that there were many high dust samples in the cleanup occupational group compared with other occupational groups (as opposed to just 1 extremely high level).

5.4 Confidence in the results

Wood dust is generated continuously by machinery along the production line from the sawmill to the planermill. This dust will settle on the floor and machinery. The cleanup occupational group is responsible for keeping the mill tidy of wood dust and debris. The basement attendant and cleanup attendant perform these duties. Often it is the new hires that are recruited to do these tasks (Summer students, lower seniority workers). It is reasonable to expect that workers in this occupational group would have exposures greater than other occupational groups in the mill.

In this study it was shown that the cleanup group has mean dust levels that are significantly different than the sawmill group. The sawmill group consists of jobs that have relatively low dust exposures. The debarker operator usually sits in a booth. The log chaser is out on the deck and not in the mill. The stacker operator job does not involve sawing or cutting the wood. The trimsaw and edger operators do involve cutting the wood but it is the edges and the ends of the wood. The finding that the dustiest jobs (cleanup group) had statistically significant higher mean dust levels than the sawmill group is expected.

An IPM sample of 5.40 mg/m^3 collected from a log chaser in Mill 9 was an unexpected finding. The log chaser (sawmill occupational group) works out on the deck before the log is processed through the debarker. One would not expect this level of wood dust for this job. No job change was recorded in the log sheet that accompanied the industrial hygienists that conducted the study. A possible explanation is that while in the sawmill yard other dusts may be collected on the filter since the IPM dust sampler is not specific for wood dust. The cleanup group and maintenance group did not have different mean dust levels that were statistically significant. The maintenance group is required to repair and maintain machinery (blades must be changed and sharpened, equipment must be maintained, etc.). The maintenance group may have to clean the machinery of wood dust before access can be obtained. It is possible that this may contribute to the fact that no differences in mean dust levels were seen between these two groups.

A planerman had an IPM dust level of 26.5 mg/m^3. This extremely high level was unexpected since the planerman is responsible for general repairs to machinery in the planermill. A possible explanation for this high level is as follows. It is a common practice (not condoned) to use compressed air to clean off machinery before repairs are done. This procedure is known as blow down. Therefore this planerman may have used blow down before working pieces of equipment in the planermill.

5.5 Generalizability/implications of results

The AFPA sawmill members are responsible for 95% of the softwood sawmill wood production. In this thesis approximately 25% (9/38) of the AFPA sawmills were surveyed. All 38 sawmills were offered financial incentives (part of the hygiene survey would be paid) if they were recruited into the study. With this financial incentive, an attempt was made to allow equal opportunity for sawmills to have an industrial hygiene survey conducted at their mill. With financial incentives, companies with restricted budgets could then afford the expense of an industrial hygiene survey. In summary, it would be difficult to generalize the results of this study to all of Alberta sawmills since mills were not selected to participate in the study by random selection.

With the proposed ACGIH NIC TLV change from limits based on "total" dust to TLV's based on inhalable measurements, a greater percentage of samples will be above the exposure limit (1%; 95% CI = 0 to 2.6% versus 9%; 95% CI = 5.2 to 12.9%). Financially this has implications for the sawmills since upgrades to machinery, ventilation improvements, and personal protective equipment may have to be considered. For sawmills that are already on a tight financial budget, the additional costs for wood dust control measures may be problematic. From a health perspective, with a greater proportion of samples above the OEL it is possible that more workers may be at risk. Recall that a TLV refers to "airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects" (ACGIH TLV's and BEI's, 1999). Although there are studies that report softwood dust exposure may be associated with nasal cancer (Elwood, 1981; Hernberg et al., 1983; Vaughan and Davis, 1991; Voss et al., 1985; Leclerc et al., 1994), there are no reported quantitative exposure levels. Irrespective of quantifying the lowest level of wood dust exposure needed to cause cancer, groups of workers with higher wood dust exposures (assuming a dose response relationship of cancer) will be at higher risk than for those with low levels of exposure. The cleanup occupational group has statistically significant different mean and median dust levels than the other occupational groups.

It has been identified that 32% (95% CI = 14.8 to 49.4%) of the samples from the cleanup occupational group were above the proposed ACGIH NIC TLV of 5 mg/m^3 inhalable. Since unweighted samples were used, this does not necessarily mean that 32% of the cleanup workers in the mills in the study were above the proposed ACGIH NIC TLV of 5 mg/m^3 inhalable. Caution must be used if extrapolating the study sample results to actual workers. In addition personal protective equipment (PPE) such as respirators or filtering face pieces (dust filter masks) were not taken into account. It is important to note that if the operators were wearing respirators, then the inhalable dust samples measured would overestimate the true personal exposure levels.

Although it is considered standard practice (from a hygiene perspective) that each sawmill review and update the wood dust control measures for all occupational group, the cleanup occupational group deserves extra attention since this group has the greatest proportion of measurements above the TLV. Current best practices or methods for cleaning the mills may be learned from those mills that have lower mean inhalable dust measurements from their cleanup occupational group. Alternatively, mills with higher mean dust levels from the cleanup occupational group may have to review their current work practices in order to identify methods and practices that may be contributing to higher dust levels. Engineering controls such as ventilation could be retrofitted or alternatively new machinery could be acquired if financially feasible. Administrative controls (job rotation), and the use of personal protective equipment (respirators, dust masks) are alternative options.

If a new sawmill was being planned, the designers and engineers may try to incorporate better dust control measures in order to reduce the amount of wood dust generated by the machinery. In addition methods to collect fugitive wood dust from the sawmill machinery would be an advantage.

6 RECOMMENDATIONS FOR MEASURES TO REDUCE RISK AND FOR FUTURE RESEARCH

6.1 Recommendations for measures to reduce risk

By identifying occupational groups at risk, measures can be put in place to reduce or control the level of dust exposure. The cleanup group has the highest dust (Geometric Mean, Arithmetic Mean, median) levels. General hygiene principles for controlling wood dust follow a hierarchy, and include engineering controls, administrative procedures, and personal protective equipment.

Controlling dust from the source is a number one priority. For engineering controls from a hygiene perspective, local exhaust controls to reduce the amount of dust circulated into the air can be adopted. Maintenance of equipment (blades, belts, motors, and guards) may reduce dust emissions. Enclosing the machine or placing the operators in booths may also reduce the amount of personal dust exposure.

Job rotation during the day is a form of administrative controls and has the effect of decreasing the exposure time to wood dust (assuming that the worker is rotated to an area of less dust).

When engineering methods and administrative controls are not feasible or practical, personal protective equipment can be used. A disposable dust filtration mask (also known as a filtering face piece) is lightweight, requires minimal adjustment, and is relatively inexpensive. A respirator (half mask or full mask) with filter cartridges may be more cumbersome, expensive, and requires adjustment to ensure that the respirator seals over the nose and mouth (fit testing). SCBA or self-contained breathing apparatus are sometimes used as well as supplied air hoods.

Within the cleanup occupational group is the basement attendant job. Particular attention to this job is warranted since two of the highest dust levels were measured from this group of workers. Recall that the basement attendant is responsible for manual removal of accumulated wood dust and debris from the machinery. In the course of sweeping or cleaning, wood dust may be aerosolized again. Work procedures such as blow down are discouraged. Blow down is a method of using compressed air to clean off or blow wood dust off of machinery or areas. This procedure will aerosolize dust particles that have already settled out once. Vacuuming, suctioning, dry sweeping or sweeping wood dust that has been wetted are control measures to minimize re-suspension of dust particles. Wetting wood dust has its own problems though, such as being a source for mold, water source for rodents, added weight during removal, rust potential near machines, and hazard potential near electrical sources.

Any combination of the above dust control measures could be implemented provided worker preference and cost are taken into account. Engineering controls for dust and replacement of old equipment may be costly. Compliance with wearing personal protective equipment may be low if the PPE is bulky, difficult to wear, or difficult to breathe though. Changes in work practice (wet sweeping), vacuuming may result in ergonomic issues such as back, shoulder, or wrist strain from incorrect posture or movement associated with removal of the heavier wet dust. Therefore an assessment of all dust control options should be reviewed before implementing.

6.2 Recommendations for future research

There is a lack of quantitative IPM exposure data with respect to nasal cancer risks (hardwood and softwood). More research is required to investigate the dose-response of wood dust and nasal cancer. Estimates of risk based on exposure limits would then be possible. The results of the IPM levels measured in this Alberta Sawmill Study may provide quantitative wood dust exposure levels for future investigations. Case-control or cohort studies involving softwood sawmills could use this exposure data to investigate not only nasal cancer, but other associated health outcomes (skin, eye, nasal irritation, and other non-malignant effects).

With respect to IPM measurements, the effects of projectiles and dust particles greater than 100 µm needs further investigation. The equation that defines inhalable dusts only regards particles 0 – 100 µm. The health effects of particles > 100 µm was not investigated with the experimental model during the development of the equation due to mechanical/technical constraints.

In this thesis study, there were statistical differences in mean and median dust levels between the mills. An analysis could be completed to determine if there were any predictors or characteristics of the mill (such as production volume, type and age of machinery, blade speed or width, types of softwood tree, etc) that could account for these statistical differences.

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CURRICULUM VITAE

ACADEMIC AND PROFESSIONAL DEVELOPMENT

1989 BSc. Biology Major (Honours), specialising in marine biology
University of British Columbia, Vancouver, BC

1995 M.D. Doctor of Medicine
University of British Columbia, Vancouver, BC

1997 General Licensure
College of Physicians and Surgeons of British Columbia

2000 MSc. Medical Sciences, Public Health Sciences
University of Alberta, Edmonton, AB

2000 Specialist in Occupational Medicine (FRCPC)
The Royal College of Physicians and Surgeons of Canada

PROFESSIONAL MEMBERSHIPS AND COURSES

1995 to present	Alberta College of Physicians and Surgeons
1995 to present	Royal College of Physicians and Surgeons of Canada
1997 to 1998	MSc. Public Health Sciences. Courses in Epidemiology, Biostatistics, Industrial Hygiene, Toxicology, Occupational and Environmental Diseases, Public Health, and Health Policy.
1997 to present	BC College of Physicians and Surgeons
1998 to present	BC, Alberta, and Canadian Medical Association

CLINICAL EXPERIENCE

July 1995/96	General "rotating" internship at the Royal Alexandra Hospital, University of Alberta Hospital, and Grey Nuns Hospital.
July 1996/97	Seconded to Internal Medicine, University of Alberta Hospital. Training included Pulmonary Medicine, Rheumatology, Dermatology, Neurology, and General Internal Medicine clinics.
August 1997 to present	General Practitioner in Vancouver, British Columbia. Performed locums in the Family Medical Centre, Coquitlam and in the New Westminster Medical Clinic, New Westminster.

CLINICAL EXPERIENCE cont.

May 1999 to October 1999	Workers' Compensation Board of British Columbia. Training with: Occupational Health and Safety Division. (Prevention, Hygiene & Safety) Occupational Disease Claims Rehabilitation Medicine, Disability Assessments Medical Advisor training
Oct/Dec. 1999	BC Research Inc. (Risk assessment and management consulting firm). Provided medical expertise and worked with industrial hygienists and environmental engineers on projects for the lower mainland (Vancouver).
Jan/Apr. 2000	Shell Canada Ltd. Worked with the Corporate Medical Director in the Occupational Health Centre (Calgary). Health policy development and disability management were key areas of focus.
April 2000	Concept Health Services Ltd. Mentorship at this health clinic that provided Executive, Aviation, Insurance, and Pre-placement Medicals, as well as "Wellness Programs" to industry in the Calgary Business Community.
May/Jun 2000	University of Alberta Occupational Medicine Dept. Trained in the general occupational medicine clinics in Edmonton, Alberta.

RESEARCH EXPERIENCE

Sept. 1997	Masters Thesis: Wood dust exposure in Alberta Sawmills. The carcinogenic risks of wood dust exposure prompted a study on the levels of inhalable softwood dust levels in 9 Alberta Sawmills.

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