Occupational Exposure to Asbestos among Civic Workers:

A Risk Assessment of Low-dose Exposure

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Executive Summary

Asbestos is a human carcinogen and has been prohibited in many countries around the world. Long-term exposure to asbestos can lead to negative health outcomes including mesothelioma, asbestosis, pleural thickening, and lung cancer. The incidence of asbestos-related disease has been increasing in industrialized countries over the past decade. Exposure to asbestos and the risk for developing a serious health condition is dependent on the cumulative dose of exposure to asbestos, measured by the quantity of exposure and the length of time exposed. These diseases often do not present for 20 to 40 years after initial exposure and have poor prognoses. Asbestos poses a potential risk to the general population when it is used in buildings and infrastructure, however this risk is minimized if the dust fibres are left undisturbed.

In an occupational setting, asbestos fibres have an increased risk of friability (becoming airborne), and therefore pose greater risk to workers, necessitating protective efforts. Occupational exposure to asbestos is typically classified into three risk levels - low-, moderate-, and high-risk, and in recent years, the prevalence of asbestos exposure in the workforce has shifted from the mining and manufacturing professions, to those occupations involving construction, electrical work, and automobile repairs. WorkSafeBC recognizes that any person who repairs, renovates, or demolishes older buildings is at an increased risk for inhaling asbestos fibres.

This paper aims to summarize the available research related to asbestos exposure and asbestos-related disease and the estimated risk among British Columbian civic workers who are exposed to minimal doses of asbestos.

Main Findings

Across Canada in 2013, there were 24,395 newly diagnosed cases of lung and bronchus cancer, 580 cases of malignant mesothelioma, and 350 cases of other respiratory system cancers. Of these cases, 75 new cases of mesothelioma and 2,805 new cases of lung and bronchus occurred in British Columbia. According to WorkSafeBC statistics for the years 2006 to 2015, there were 584 work-related deaths claims in relation to occupational asbestos exposure in British Columbia. Sixty-six percent were for mesothelioma, 16% for asbestosis, and 15% were for malignant neoplasms and tumors of other sites. The highest number of work-related death claims occurred in general construction (28%), metal and non-metallic mineral products (17%), wood and paper products (12%), and transportation and related services (7%).

Multiple studies indicate that there is no safe dose of asbestos. In comparison, there is also evidence that argues that there is a safe threshold for asbestos exposure and validates the Threshold Limit Value (TLV) that is enforced by the Occupational Safety and Health Administration in the United States. The literature reviewed in this study does not indicate a significant prevalence of asbestos-related disease among civic workers, including fire fighters. In addition, WorkSafeBC data provides no evidence that this population of interest is at an increased risk for asbestos-related disease. The low prevalence of asbestos-related disease among this population likely indicates that the current practices in place to protect civic workers and firefighters are providing a high level of protection

from asbestos exposure, and that there is not a high level of exposure to asbestos in these professions.

Recommendations

The majority of the literature reviewed indicates that there is no safe limit for occupational asbestos exposure. While there is a small literature attempting to assess the evidence for an asbestos exposure threshold, there is insufficient research to date to support a definitive conclusion in favour of a safe threshold. Therefore, this review supports current policy in BC for a conservative approach to occupational protocols and regulations among civic workers and firefighters who may be exposed to asbestos at work. We recommend that the City of Surrey continue to abide by WorkSafeBC standards, as well as consider the following further recommendations arising from the research literature:

Asbestos air sampling protocol

These tests are used to reveal the quantity of asbestos fibres that are airborne in a workplace. While traditional tests require time to determine asbestos levels, two emerging technologies – Fibrous Aerosol Monitoring and spatial light scattering - address the need for rapid air quality assessment particularly in low-risk occupational settings.

Education on the combined effect of lung carcinogens

While it is unethical to force employees to discontinue their use of tobacco, educational programs informing workers of the multiplicative effects of tobacco use and asbestos exposure should be implemented. Educational initiatives are low-cost and can reduce the incidence of lung cancer and mesothelioma.

Documentation of past asbestos exposure

A database on asbestos-related disease should be created and include asbestosis as a reportable disease. An improved system to monitor the incidence of mesothelioma is necessary to observe and understand the trends in mesothelioma cases.

Occupational tool for past asbestos exposure

The Occupational Integrated Database Exposure Assessment System (OccIDEAS) from Australia is based on objective data such as job titles, specific worker tasks, and the performance on the job, in order to conduct individual exposure assessments. Currently, OccIDEAS contains a database of over 50 modules and agents to quantify the risk of asbestos exposure for research and prevention purposes. This tool has the potential to inform policy and prevention efforts in British Columbia.

Advocacy to senior levels of government

Local municipalities and the province can play a role in advocating for the development and implementation of an asbestos harm aid act. In 2011, South Korea became the first country in the world to ban the manufacture, import, sale, storage, transport, and use of all forms of products that contain more than 0.1% of asbestos fibres, thus, providing a model and precedence for other jurisdictions.

Further research required

Past studies have attempted to estimate dose-response relationship between asbestos exposure and risk for mesothelioma, asbestosis, or lung cancer. Continued research is needed to assess the impact of asbestos exposure on all populations, particularly occupational settings.

Concluding Remarks

Many industrialized countries have implemented occupational policies and regulations to combat the frequency of occupational asbestos exposure. Despite these regulations, cases of mesothelioma, asbestosis, and lung cancer due to asbestos exposure continue to emerge around the world. The present review of the literature and available data concludes that there is no safe limit for asbestos exposure. There is a small body of literature attempting to assess the evidence for an asbestos exposure threshold, but there is insufficient research to date to support a definitive conclusion in favour of a safe threshold. This review supports current policy in BC for a conservative approach to occupational protocols and regulations among civic workers and firefighters who may be exposed to asbestos at work.

Introduction

This paper summarizes the available research related to asbestos exposure and asbestos-related disease, including that related to exposure thresholds. Evidence related to asbestos exposure threshold and exposure limits will improve understanding of occupational risks and the development of protective policies and procedures. In this paper, we examine the research literature on occupational exposure to asbestos in order to better estimate the risk among British Columbian civic workers, in particular firefighters, who may be exposed to minimal doses of asbestos in the course of their work duties.

Asbestos is a material that was mined in abundance in Canada until 2012. Quebec was the first province to mine asbestos in Canada in the 1870's, with the largest asbestos mine worldwide located in eastern Quebec [26]. Today, asbestos is considered a human carcinogen by the International Agency for Research on Cancer [8]. The carcinogenicity of asbestos has prompted its prohibition in many countries, and strict regulation regarding its use in others. However, continued use of asbestos in developing countries, and its presence in buildings and other infrastructure, pose an ongoing risk for human exposure. In addition, asbestos is an attractive solution to many industrial objectives because of its relatively low cost, reducing the likelihood that asbestos-containing products will be replaced with safer alternative products [9].

The negative health implications of asbestos exposure have been extensively studied and defined. There is, however, uncertainty in the research and safety literature on whether a threshold exists below which asbestos exposure will not result in asbestos-related disease. The determination of an absolute threshold, and associated dose and frequency of an exposure threshold, would be beneficial for businesses and industry to appropriately determine worker related risk.

An Overview of Asbestos

Asbestos is the given term for six naturally occurring fibrous silicate minerals presenting in polyfilamentous bundles that are flexible, long, and small in diameter. These minerals are grouped into two different categories based on their physical and chemical properties: serpentine and amphibole [1].

Serpentine fibres are long, curved, flexible, and woven together [2], often referred to as 'sheet silicates' as they can be arranged to form sheets. A common form of serpentine fibre, chrysotile, is the principle asbestos fibre used in manufacturing industries [3]. In the United States, 95% of asbestos used is the chrysotile form and can be found in many buildings and equipment [5]. Chrysotile fibres are also known as white asbestos as they are white and light grey in colour [2,5].

Amphibole fibres are straight and rigid and have limited function in commercial materials. They can be further classified into five sub-types: crocidolite, amosite, actinolite, anthophyllite, and tremolite [2,4]. Crocidolite fibres, or blue asbestos, are often used to insulate steam engines, while amosite fibres, or brown asbestos, are used in cement and pipe insulation. Actinolite, anthophyllite, and tremolite asbestos fibres are the least commonly used amphibole fibres; however tremolite fibres have been previously found as a contaminant in chrysotile asbestos [5]. An overview of the history of asbestos production can be found in Appendix 1.

Health Impacts of Asbestos Exposure

Asbestos exposure occurs through two primary routes - inhalation and ingestion. Inhalation of asbestos fibres is the most common path of entry into the human body. In rare cases, asbestos fibres will enter through ingestion and cause negative health repercussions to the digestive system. The skin is typically not a primary contact source, however it can become a secondary form of exposure if asbestos fibres are transferred into the path of inhalation or ingestion [10].

Asbestos fibres can be easily inhaled in the form of dust [9,10], and carried into the lower lung regions where they can cause a range of health issues. Long-term exposure to asbestos yields negative health outcomes that will often not appear until 20 to 40 years after initial exposure [1,11]. Unsafe and accumulated exposure to asbestos can lead to fibrotic lung disease and damage to the lining of the chest cavity. Exposure to asbestos is a well-documented risk factor for malignant mesothelioma, lung cancer, and asbestosis [11]. For the purposes of this paper, the term asbestos-related disease is used to collectively identify the diseases of mesothelioma, asbestosis, pleural thickening, and lung cancer (Table 1, see Appendix 2 for more information about asbestos-related diseases).

Table 1: Asbestos-Related Diseases

Asbestos-related Disease	Description	Signs and Symptoms
Mesothelioma	A form of cancer caused by asbestos exposure that attacks the chest or abdominal cavity.	Pleural mesothelioma will produce shortness of breath, fever, fatigue, weight loss, trouble swallowing, pain in the side of the chest or lower back and a cough. [9]
Asbestosis	A condition that results in lung scarring making it difficult to breathe.	Signs and symptoms include shortness of breath, a dry cough, loss of appetite, weight loss, and chest tightness or pain. [12]
Pleural thickening	An inflammatory lung disease caused by fibres that embed themselves in one of two membranes surrounding the lung	Chest pain and difficult breathing may occur once the pleural thickening impedes the breathing function. At the advanced stages, most patients will experience breathlessness, which can lead to respiratory failure. [17, 18]
Lung cancer	A form of cancer that attacks the lungs.	Chest pain when breathing or coughing, shortness of breath, weight loss, fatigue, a long-lasting cough, and coughing up blood are all symptoms of lung cancer. [9]

Asbestos-related diseases often have poor prognoses. Asbestos-induced damage to the lungs is irreversible, and treatment options are often limited to pain management and supportive care [23].

Latency Period

Mesothelioma, lung cancer, pleural thickening, and asbestosis all have long latency periods; therefore asbestos-related disease most often presents many years after exposure has occurred [12,16]. The *latency period* is the time from exposure to asbestos to the development of an asbestos-related disease. The latency period varies depending on the exposure level of asbestos. In a study performed by Bianchi et al. (1997), latency periods for subjects varied from 29.6 years for insulators with the highest exposure, to 51.7 years in women with low domestic exposure [24].

Many studies have tried to determine the latency period between first exposure to asbestos and the onset of disease or death. The mean latency period is often stated to be 40 years, while latent periods of less than 15 years are extremely rare. There has been no proven upper limit for the latency period of asbestos-related disease [25].

Changes in asbestos-related disease rates over time

The incidence of asbestos-related disease has been increasing in industrialized countries over the past decade, resulting from an increased use of asbestos that occurred during the mid-1970's. Exposure to asbestos and the risk for developing a serious health condition is dependent on the cumulative dose of exposure of asbestos, measured by the quantity of exposure and the length of time exposed. Due to the long latency period, the majority of exposed workers in industries where asbestos exposure risk was high did not develop mesothelioma until decades later. In the United Kingdom, current mesothelioma death rates are the highest in the nation's history, and the highest in the world, accounting for one in forty of all male cancer deaths under the age of 80. To put this rate in perspective, it is estimated that 1 in 170 men born in Britain during the 1940's will die of mesothelioma [21,22].

Given the decline in asbestos production and use following its peak in the 1970's, it is likely that current mesothelioma and asbestosis rates represent the peak of cases in industrialized countries. Incidence rates are anticipated to decline in coming years, as subsequent birth cohorts were not exposed to the same degree as those in the 1940's and 1950's [23].

Asbestos Production and Environmental Presence

Prior to 1990, asbestos was regularly used for insulation and fireproofing both commercial and residential buildings [32]. Due to the long-lasting and fire-resistant nature of asbestos fibres, many industries used asbestos within their sectors. Products such as cement, heating systems, building insulation, floor and ceiling tiles, vehicle brake pads and clutches, and fire-proof garments are all common items that contained asbestos. In addition, prior to the regulation of asbestos, asbestos minerals were often combined with other materials such as plastics or cement, or woven as a textile and used as a loose fibre [29,32]. This has made the removal of all asbestos from products that pose a risk of human exposure and inhalation extremely difficult, even with the cessation of asbestos production.

The presence of asbestos is not a risk to human health if the fibres are contained behind walls or floorboards and importantly, left undisturbed [33]. However, when a home that contains asbestos is renovated or demolished, there is a risk that the asbestos fibres may be released into the air. Asbestos poses a health risk when the fibres become friable and enter into a location at risk for human inhalation. The natural breakdown of materials containing asbestos in the home can also pose a risk to human health; however, it is very rare that exposure in this context leads to an asbestos-related disease. The majority of asbestos-related disease cases occur from exposure to asbestos in the workplace [7,9].

When asbestos fibres are friable, the resulting dust particles can become easily airborne, which can then pose a significant risk to the human respiratory system if inhaled. Friable asbestos fibres can be easily crumbled with the fingers and inhaled due to their dust-like nature when released into the air [33]. Non-friable asbestos fibres are held together in a material with a binding agent, locking these fibres into the material and reducing the risk for human inhalation. If an asbestos-containing material is disturbed through cutting, drilling, grinding, or a similar action, then the fibres may become friable and airborne [34]. Asbestos-containing material that was originally installed in a non-friable condition can become friable with wear and tear, heat exposure, extreme weather, or through the addition of certain chemicals [33,34].

Asbestos poses a potential risk to the general population when used in buildings and infrastructure. Much of this risk is minimized within the general population since the asbestos dust fibres are often left undistributed and do not pose a threat for inhalation. Asbestos fibres have an increased risk of friability in an occupational setting, and the risk for fibre disruption is further enhanced with work tasks that destroy or use asbestos.

Occupational Risk for Exposure

In British Columbia, qualified personnel conduct risk assessments to determine the levels of exposure risk associated with a particular occupational task. While the risk for exposure can be classified into three categories, there are also general guidelines for reducing the risk of occupational exposure to asbestos, such as wetting product containing asbestos. Leaving an asbestos-containing product undisturbed, minimizing the duration of exposure, and wearing personal protective equipment (PPE) are all methods to reduce exposure to asbestos in an occupational setting [34,36,37].

Occupational levels of exposure to asbestos can be classified into categories according to different levels of risk. In British Columbia, these categories are classified as low-risk exposure, moderate-risk exposure, and high-risk exposure. Similarly in Manitoba, Ontario and New Brunswick, exposure levels are classified as Type I, for low-risk exposure, Type II for moderate-risk exposure, and Type III for high-risk exposure. While the classification of these exposure levels may vary by province, the three tiered system for categorizing asbestos exposure levels remains consistent across the country. Table 2 provides an overview of occupational levels of exposure to asbestos, based on the British Columbia classification model. Further overviews of these levels of exposure are described in Appendix 3.

Table 2: Occupational Levels of Exposure to Asbestos Classification

Exposure	Definition	Examples of work tasks	Protective Equipment
Low-risk	A work activity with a low risk for exposure to asbestos may involve, or be in proximity, to asbestos-containing material. The asbestos-containing material must be non-friable and therefore locked in by cement, vinyl, or another binding agent. If the asbestos-containing material is not cut, sanded, drilled, broken, ground down, fragmented, or disturbed to a degree where asbestos fibres may be released, then the work activity is considered a low risk for exposure [37].	• Tasks that involve materials that contain less than 0.5% asbestos, as long as the dust particles are not disturbed • Repairing drywall that contains asbestos in the drywall filler, as long as the filler is not disturbed • Inputting a nail or screw into drywall that contains asbestos-containing filler • Moving asbestos-containing waste that is sealed and double bagged	WorkSafeBC guidelines state: low risk activities do not carry the requirement for the use of PPE or engineering controls for the prevention of occupational exposure to asbestos [37].
Moderate-risk	Occupational tasks that are at a moderate risk for asbestos exposure involve direct work with asbestos-containing material that is being cut, sanded, drilled, broken, ground down or fragmented. These work activities disturb the fibres in the asbestos-containing material to release asbestos into the air. Workers who are in the proximity to any one of these tasks are at a moderate risk for exposure to airborne asbestos fibres [37].	• Using hand tools or power tools to grind, shape, or remove non-friable products that contain asbestos • Removing part of a ceiling that contains friable asbestos on the surface • Removing asphalt roofing material that contains asbestos	WorkSafeBC requires that PPE be worn when a worker is at a moderate risk for exposure to asbestos [37].
High-risk	Work tasks that are at a high risk for asbestos exposure are usually directly involved with asbestos-containing materials that are friable and large in size. These tasks require very strict protocols to ensure not only the workers safety, but also other individuals who may be affected by the high-risk activity [37].	• Removing materials that contain friable asbestos from a building, structure, or equipment • Cleaning equipment that has been sprayed with fireproofing materials containing asbestos • Using power tools, without wetting the product, to cut or drill into an asbestos-containing material • Removing asbestos-containing vermiculite insulation	WorkSafeBC requires that PPE be worn when a worker is at a high risk for exposure to asbestos [37].

Occupations at Risk

Each year, over 125 million people worldwide are exposed to asbestos in the workplace. The World Health Organization estimates that more than 100,000 individuals die every year from disease due to occupational exposure to asbestos [38].

Since the first use of asbestos in modern society there have been progressions in its regulation, altering the scope of occupational risks for exposure. Three waves of occupational trends and asbestos exposure are seen since the first uses of asbestos; the first cohort of exposed workers occurred among asbestos miners, the second wave of workers were exposed through the asbestos manufacturing industry, and the third and present wave is among secondary occupations in the building and construction industry [41].

In recent years, the prevalence of asbestos exposure in the "traditional" sectors of mining and manufacturing where asbestos exposure was high is disappearing. Professions that historically saw the highest rates of asbestos-related disease, such as insulation manufacturing and application, shipbuilding and repairs, and road paving are no longer the only occupations at risk [39]. Research has shown that exposure can come from unexpected occupational sources, with cases of mesothelioma occurring among construction workers, metal engineers, electricians, and automobile repair workers [39,40,41,42].

Recent studies have found that the occupations and industries with the highest rates of malignant mesothelioma are construction, automobile repair and direct work with asbestos [40,42,43]. Jung (2012) found that 36.8% of cases had occupational asbestos exposure histories, with 19.7% occurring among construction workers, and 5.9% occurring among automobile repair workers [40]. In comparison, Musk (2012) investigated the patterns of occupational asbestos exposure associated with malignant mesothelioma in Western Australia and concluded that rates of mesothelioma among construction works, electricians and welders have continued to increase over the past 50 years [42]. Additionally, the proportion of mesothelioma cases attributed to asbestos exposure among the armed forces, cement production, ship building and insulation workers all peaked and leveled off in the last 50 years [42]. Similarly, van Oyen (2015) estimated that out of 224 occupations in 60 industries, workers in the asbestos manufacturing, shipyard, and insulation industries have the highest exposure levels to asbestos [43]. In 2012, Villeneuve looked at over 15,000 occupations and found 801 that could have probable or definite exposure to asbestos [44]. Occupations most commonly exposed included mechanics and repairmen, stationary engine and utility workers, pipefitters, and construction workers. Results from Villeneuve's meta-analysis are provided in Appendix 4.

WorkSafeBC recognizes that any person who repairs, renovates, or demolishes older buildings is at an increased risk of inhaling asbestos fibres. Occupations with the highest risk include demolition and renovation contractors, carpenters, plumbers, electricians, building owners, home inspectors, insurance adjusters, and real estate agents [37]. Table 3 provides a summary of studies that describe occupations at risk for asbestos-related disease.

Exposure to asbestos in the workplace is not the only means of fibre inhalation risk. Family members indirectly exposed to asbestos are increasing as a proportion of the exposure cases among asbestos-related diseases [45]. Indirect cases of mesothelioma occur when asbestos fibres enter a home from clothing, skin or hair and are inadvertently transferred to other family members.

Another emerging trend is a phenomenon called the "third wave" of the mesothelioma epidemic, resulting from workers who were exposed in their place of work as a result of poorly maintained buildings containing asbestos [46]. Due to the high frequency of asbestos use in the construction of buildings prior to the 1970's, many work environments are situated in contaminated buildings. As discussed previously, properly maintained buildings do not pose a risk to the worker. However, asbestos fibres that become friable and airborne can have serious health repercussions for any person in the building, regardless of their specific occupation.

Table 3: Review of the Literature, Occupations at Risk for Occupational Exposure to Asbestos

Group	Occupation	Studies	Findings
Construction Trades	General construction Pipefitting Metal shaping Plaster Electrician Boilermaker Welder Insulation Metal engineering Carpenter Plumber	Jung (2012) [41] Musk (2012) [42] Corfiati (2015) [47] Roggli (2002) [49] Rushton (2010) [50] Salehpour (2011) [51] Romeo (2013) [52] Villeneuve (2012) [44] Marinaccio (2012) [39] Khatab (2014) [56] Pintos (2009) [57]	• 19.7% of mesothelioma cases surveyed were among construction workers, representing an occupation with the highest rates [41] • 56% of cancer registrations in men are attributable to work in the construction industry (mainly mesotheliomas, lung, stomach, bladder and non-melanoma skin cancers) [50] • General construction and insulation each represented 9.4% of studied asbestos exposed occupations [51] • The largest number of cases with occupational exposure was in the construction industry [52] • At present, construction is the most active industry within the MM surveillance program, where asbestos has been used as fireproofing and acoustic insulator, mixed with cements or plastics and also for the vinyl flooring [39] • Construction workers could be at risk from asbestos exposure during maintenance and restructuring activities [39] • Occupations in labouring/other elemental work, electrical work and plumbing were included in work histories of mesothelioma cases, each representing 10% [57] • Among the most frequent occupations classified as having a probable or definite exposure to asbestos, pipefitters represented 11% of cases, metalshapers 6%, plasters 2%, general construction 6% [44] • Elevated lung fiber burdens for commercial amphiboles, noncommercial amphiboles, and chrysotile among electricians, boilermakers, insulation, [49] • Mesothelioma cases have continued to increase in number and proportion among general construction workers, electricians, boilermakers, and welders [42] • Most mesothelioma victims have only had secondary links with asbestos, often as construction workers, carpenters, plumbers, or electricians [56]

Group	Occupation	Studies	Findings
	Decorator	van Oyen (2015) [43] Yenugadhati (2009) [53] Gilham (2016) [54]	• Insulators had levated risk of adenocarcinoma [53] • Workers in the insulation industry was among the occupations with the highest exposure to asbestos [43] • The majority of occupations with high-risk for exposure to asbestos included carpenters, plumbers, electricians or decorators. The highest amosite levels are predominantly in carpenters [54] • A major contribution to asbestos exposure was also provided by sectors with no direct use of asbestos [47]
Equipment Operators	Stationary engine and Utilities equipment	Villeneuve (2012) [44]	• Among the most frequent occupations classified as having a probable or definite exposure to asbestos, stationary engine and utilities equipment workers represented 15% of cases [44]
Fabricating & Related	Fabricating, assembling electrical and electronics Textile industry (non-asbestos)	Villeneuve (2012) [44] Corfiati (2015) [47]	• Among the most frequent occupations classified as having a probable or definite exposure to asbestos, fabricating and assembling electronic occupations represented 4.2% of cases [44] • A major contribution to asbestos exposure was also provided by sectors with no direct use of asbestos, such as non-asbestos textile industries [47]
Forestry/ Logging	Timber cutting	Pintos (2009) [57]	• The timber cutting industry occurred in at least 10% of work histories of mesothelioma cases [57]
Machining & Related	Maintenance Automobile repair	Villeneuve (2012) [44] Roggli (2002) [49] Jung (2012) [41] Carey (2014) [48]	• Among the most frequent occupations classified as having a probable or definite exposure to asbestos, mechanics and repair represented 26.7% of cases [44] • Elevated lung fiber burdens for commercial amphiboles, noncommercial amphiboles, and chrysotile found in maintenance workers [49] • 5.9% of mesothelioma cases surveyed were among automobile repair workers, representing an occupation with the highest rates [41] • Vehicle workers were among the occupations with the highest exposures for asbestos [48]
Material Handling Jobs	Powerplant Asbestos manufacture Asbestos-cement industries	Roggli (2002) [49] Jung (2012) [41] van Oyen (2015) [43] Fazzo (2012)[55]	• Elevated lung fiber burdens for commercial amphiboles, noncommercial amphiboles, and chrysotile was found among power plant workers [49] • One of the highest rates of mesothelioma was found among occupations with direct work with asbestos [41] • Workers in the asbestos manufacturing industry was among the occupations with the highest exposure to asbestos [43] • Asbestos-cement industries are associated with pleural neoplasm mortality [55]

Group	Occupation	Studies	Findings
Mining/Oil & Gas	Miner	Carey (2014) [48]	• Carey (2014) found that miners were among the occupations with the highest exposures for asbestos [48]
Service Jobs	Firefighter Emergency worker	Villeneuve (2012) [44] Carey (2014) [48]	• Among the most frequent occupations classified as having a probable or definite exposure to asbestos, firefighters represented 3.9% of cases [44] • Emergency workers were among the occupations with the highest exposures for asbestos [48]
Transport Operators	Water transport operating Shipyard Truck driver	Villeneuve (2012) [44] van Oyen (2015) [43] Roggli (2002) [49] Fazzo (2012) [55] Pintos (2009) [57]	• Among the most frequent occupations classified as having a probable or definite exposure to asbestos, water transport operating occupations represented 5.2% of cases [44] • The shipyard industry was among the occupations with the highest exposure to asbestos [43] • Elevated lung fiber burdens for commercial amphiboles, noncommercial amphiboles, and chrysotile was found among shipyard workers [49] • Shipyard industries are associated with pleural neoplasm mortality [55] • The timber cutting industry occurred in at least 10% of work histories of mesothelioma cases [57]

Data Review

Rates of Mesothelioma and Lung Cancer

According to Statistics Canada, there were 24,395 newly diagnosed cases of lung and bronchus cancer, 580 cases of malignant mesothelioma, and 350 cases of other respiratory system cancers in 2013 [58]. Mesothelioma had an incidence rate of 1.7[1] with the combined lung and bronchus cancer rate of 69.8 for comparison.

In 2013, British Columbia reported 75 new cases of mesothelioma, and 2,805 cases of lung and bronchus cancer. The incidence rate for lung and bronchus cancer (61.2) was lower than the national average, while the rate of malignant mesothelioma was similar to the national level (1.6). The highest rate of malignant mesothelioma in 2013 was in Quebec, where the incidence rate was 2.3 [58].

Chart 1 and Chart 2 detail trends of newly diagnosed malignant mesothelioma in Canada and British Columbia for the period 2000 to 2013. Nationwide, the number of new cases each year, as well as incident rates, have been increasing steadily since 2010, with the highest number of mesothelioma cases recorded in 2013. British Columbia saw the highest recorded numbers of cases of mesothelioma in 2006 (95 cases) and 2012 (90 cases), and the lowest number of new cases in 2000 (45 cases) [58].

Table 4 indicates that, in 2013, the incidence rate of mesothelioma was highest among Canadians aged 75 years and older. There are very few recorded cases of malignant mesothelioma occurring among individuals under 50 years of age, with most cases in Canada diagnosed between the ages of 75 and 79. In Quebec, the highest rate of mesothelioma was among 85 to 89 year olds (20.1) and in British Columbia the highest mesothelioma incidence rate was among individuals 90 years of age and older (27.6) [58].

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[1] *Rates are reported per 100,000 population, unless otherwise specified*

Chart 1: Number of New Mesothelioma Cases and Incidence Rate Per 100,000 Population in Canada, by Year, CANSIM, 2000-2013.

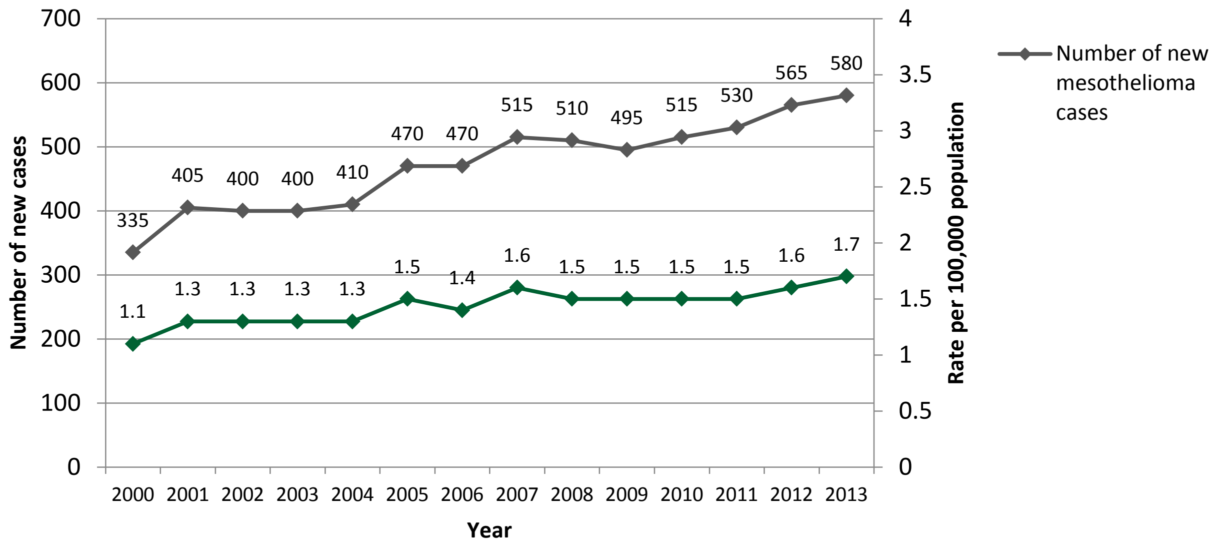


Chart 2: Number of New Mesothelioma Cases and Rate Per 100,000 Population in British Columbia, by Year, Cansim, 2000-2013.

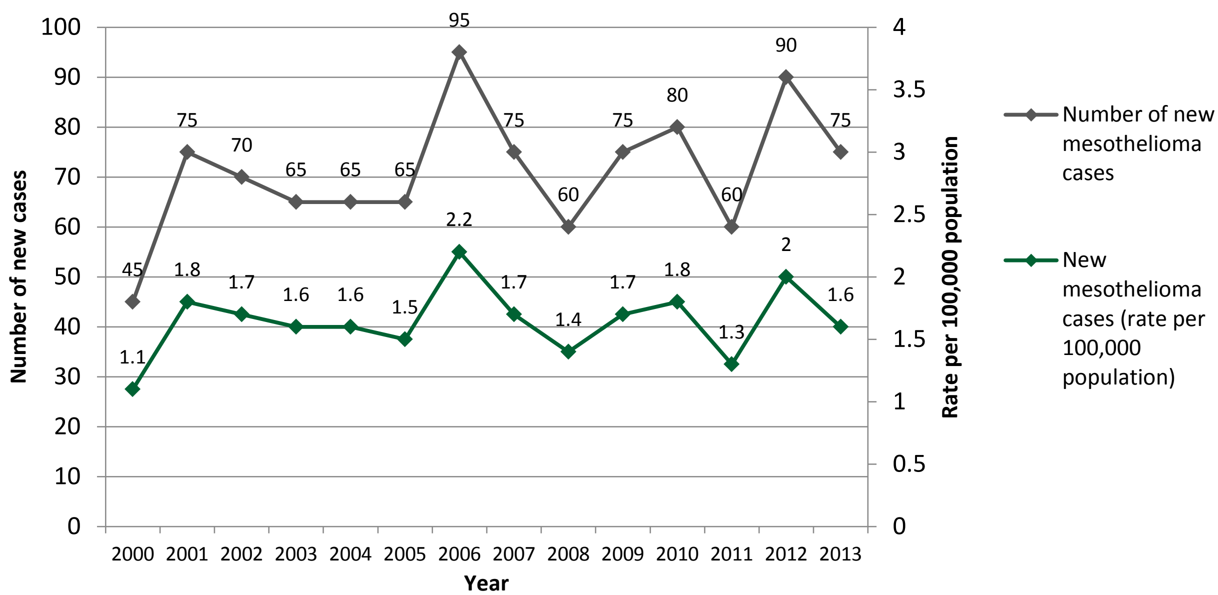


Table 4: Rate of Malignant Mesothelioma Cases Per 100,000 Population, by Age Group and Location, Cansim, 2013[58]

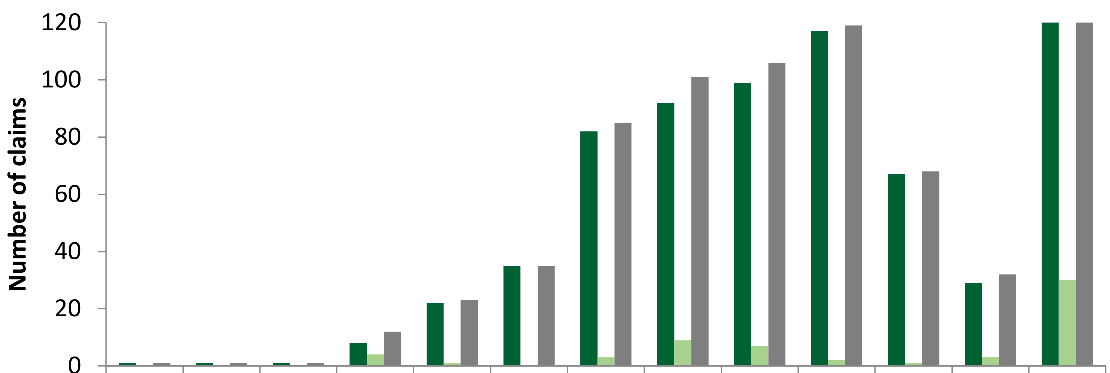
	Age Group (years)										
Location	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90+
Canada	0.2	0.4	0.7	1.0	2.6	5.0	7.4	12.7	11.9	12.5	10.5
Quebec	0	0	0	0.9	4.0	7.8	10.7	15.2	14.6	20.1	0
British Columbia	0	0	1.4	0	3.4	4.1	5.7	11.4	14.8	15.8	27.6

WorkSafeBC Claims Data

WorkSafeBC death claims data were analyzed to determine the burden of disease resulting from occupational exposure to asbestos in the province of British Columbia. These data include all claims approved between 2006 and 2015 that were made in relation to occupational asbestos exposure resulting in death caused by an asbestos-related disease. Further detail regarding the data source and analysis methodology is available in Appendix 5.

Between 2006 and 2015, there were a total of 584 work-related death claims in British Columbia; 71.3% represented individuals between 60 to 79 years of age (Chart 3).

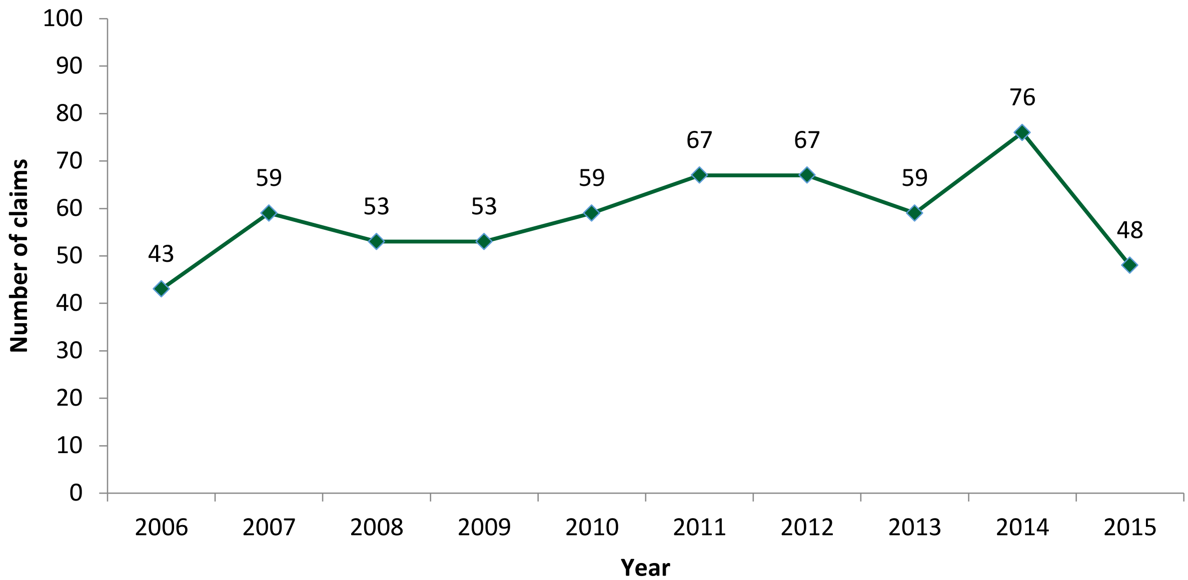
Chart 3: Work-Related Death Claims Associated with Asbestos Exposure by Age And Gender, WorkSafeBC 2006-2015.



	25 to 29	35 to 39	40 to 44	45 to 49	50 to 54	55 to 59	60 to 64	65 to 69	70 to 74	75 to 79	80 to 84	85+	Grand Total
Males	1	1	1	8	22	35	82	92	99	117	67	29	554
Females	0	0	0	4	1	0	3	9	7	2	1	3	30
Total	1	1	1	12	23	35	85	101	106	119	68	32	584

During this time period, death claims peaked in 2014 (76 claims), with a secondary peak in 2011-2012 (67 claims each) (Chart 4). WorkSafeBC reported lowest number of claims in 2006 (43 claims).

Chart 4: Work-Related Death Claims Associated with Asbestos Exposure by Year, WorkSafeBC, 2006-2015.



The primary cause of death related to occupational asbestos exposure in British Columbia was mesothelioma (388 claims) (Chart 5). Other leading causes were asbestosis (94 claims), and malignant neoplasms and tumors of other sites (88 claims). Most cases of asbestos-related disease (95.7%) originated in the chest (Chart 6). Other sites of disease affecting workers included the trunk (excluding the chest), face and ears, and other systems.

Chart 5: Work-Related Death Claims Associated with Asbestos Exposure by Disease, WorkSafeBC, 2006-2015.

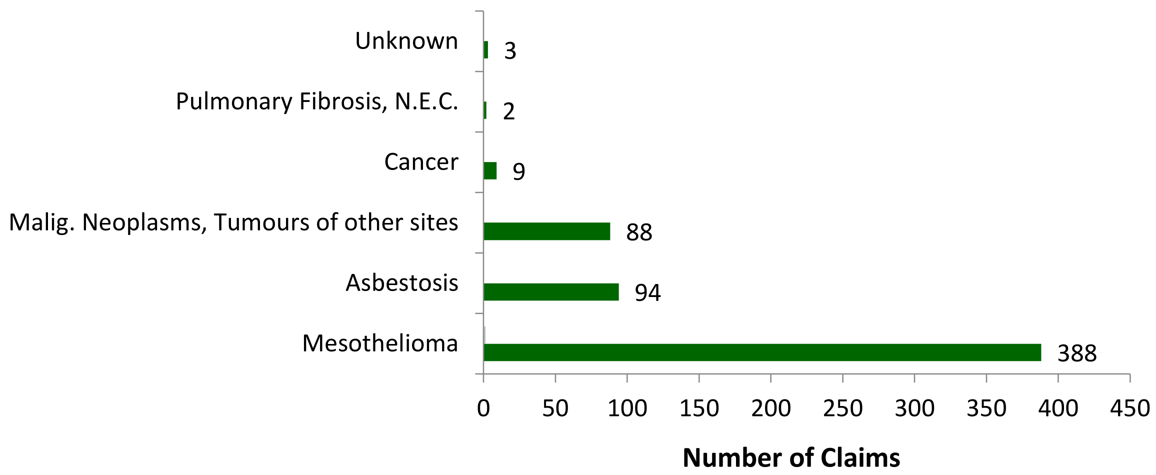
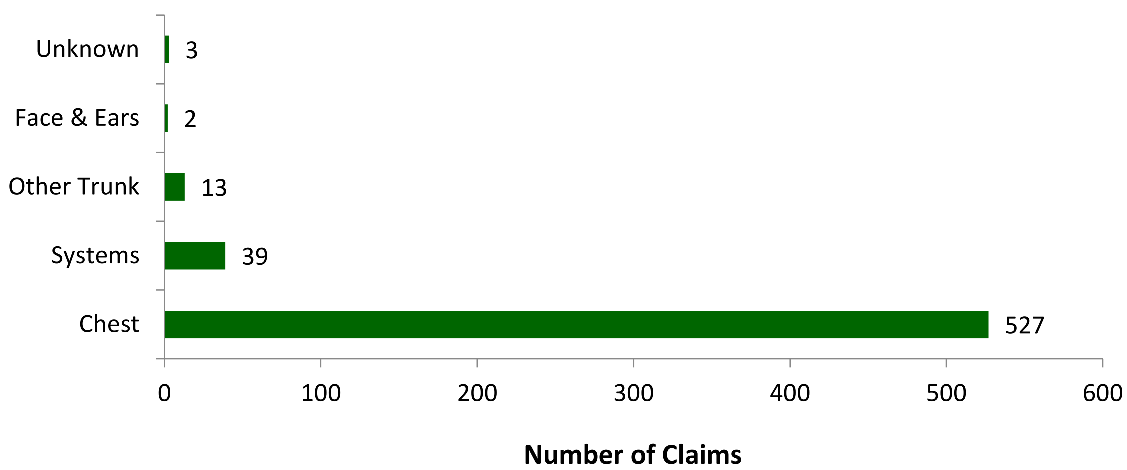


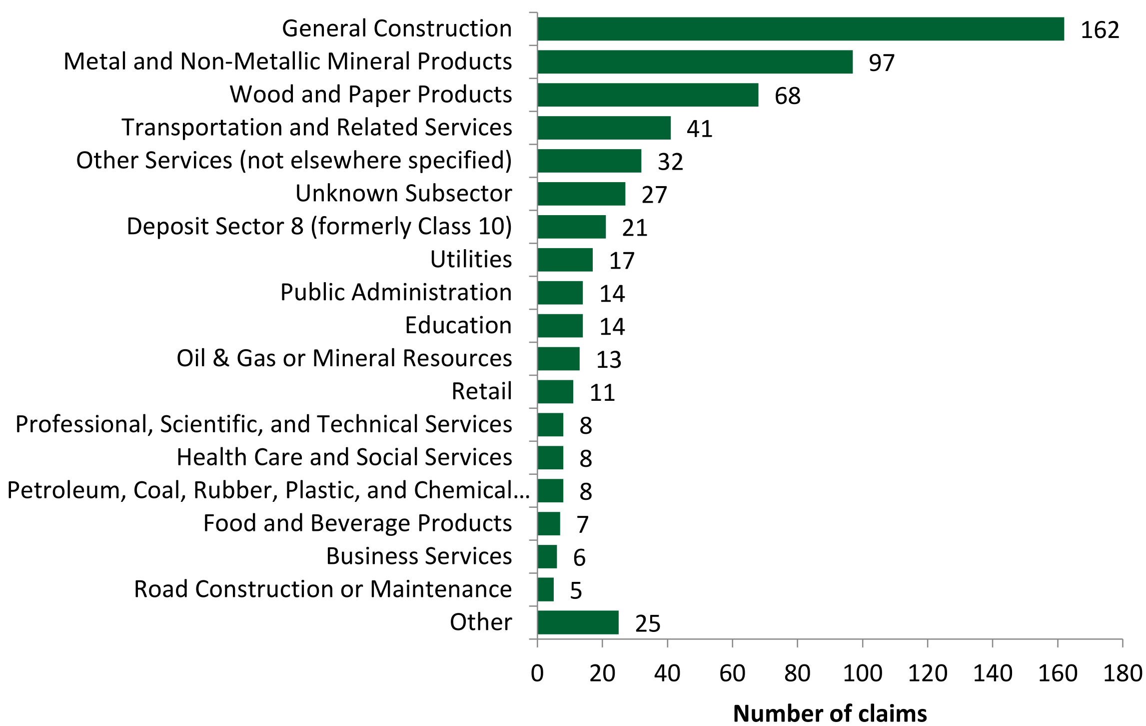
Chart 6: Work-Related Death Claims Associated with Asbestos Exposure by Physical Area of Body, WorkSafeBC, 2006-2015.



Occupational groups with the highest number of work-related death claims in relation to occupational exposure to asbestos included: general construction (162 claims), metal and non-metallic mineral products (97 claims), wood and paper products (68 claims), and transportation and related services (41 claims) (Chart 7).

Table 5 displays the subcategories of occupational groups with the highest numbers of work-related death claims in British Columbia.

Chart 7: Work-Related Death Claims Associated with Asbestos Exposure by Occupation, WorkSafeBC, 2006-2015.



**Other includes: Forestry, Federal Government, Heavy Construction, Accommodation, Food and Leisure Services, Other Products, Deposit Sector, Special Accounting, Fishing, Wholesale, Warehousing*

Table 5: Leading Occupational Sub-Categories for Work-Related Death Claims Associated with Asbestos, WorkSafeBC, 2006-2015.

Occupational sub-category	Number of claims
Not Applicable	42
Carpenters	36
Construction trades helpers and labourers	32
Steamfitters, pipefitters and sprinkler system installers	30
Construction millwrights and industrial mechanics	21
Plumbers	20
Industrial electricians	17
Labourers in wood, pulp and paper processing	17
Heavy-duty equipment mechanics	14
Longshore workers	14
Power engineers and power systems operators	14
Structural metal and platework fabricators and fitters	14
Transport truck drivers	14
Welders and related machine operators	14

**Not Applicable is used to represent cases where a sub-category is not used to identify occupation.*

Policy Review

International Policy Review

The Resolution on Asbestos of the 95th International Labour Conference, implemented in 2006, asserts that elimination of all asbestos use is the most effective means to protect workers and prevent future asbestos-related deaths. In addition, identification and management of asbestos currently in place is necessary in order to eliminate future asbestos-related disease. The Resolution on Asbestos was implemented to amend the previous recommendations made by the Occupational Cancer Convention (1974) and the Asbestos Convention (1986). The Resolution on Asbestos promotes elimination of all future uses of asbestos – an important provision to past Convention recommendations. In addition, the Resolution on Asbestos encourages the development of national programs dedicated to occupational safety and health in order to protect workers from asbestos exposure [65,66].

The World Health Organization (WHO) and the International Labour Organization assert that elimination of all types of asbestos is the most efficient method to eliminate asbestos-related disease [38]. There are currently 52 countries that ban the use of asbestos worldwide [35,67]. Denmark was the first country to ban the use of asbestos for insulation in 1972, while Iceland and Norway were among the first countries to implement a national ban on all asbestos in 1983 and 1984, respectively. In the last five years, Serbia, Hong Kong and Nepal implemented a national ban on the use of all asbestos. Canada and the United States have yet to implement a full ban on the use of asbestos [99].

The WHO recommendation encourages countries to replace asbestos-containing products with safer substitutes, implement measures to prevent exposure to asbestos that currently exist, and improve early diagnosis, treatment and rehabilitation of asbestos-related disease. WHO also recognizes that there is a need for countries to establish registries of people with past or current asbestos exposure.

A more detailed review of countries that have regulated asbestos exposure is listed in Appendix 6. Appendix 7 reviews the use of asbestos and the implementation of national bans on a global scale.

Federal Regulations

The Government of Canada recognizes that asbestos fibres pose a significant risk to the public when inhaled. The federal government has prohibited the import, sale or advertising of pure asbestos products, in particular products with potential for friability. The sale of products that contain asbestos is regulated through the Asbestos Products Regulations under the Canada Consumer Product Safety Act [59]. Asbestos fibres that are released into the environment are regulated through the Asbestos Mines and Mills Release Regulations under the Canadian Environmental Protection Act (1999) [60].

The federal government, the Workplace Hazardous Materials Information System (WHMIS), and provincial occupational health and safety legislation all recognize asbestos as a carcinogenic health hazard. All three regulate the use of asbestos in every Canadian jurisdiction. The Federal Ingredient Disclosure List requires identification of any product containing 0.1% or more asbestos [62].

Until recently, non-friable asbestos was used according to the National Building Code in federal buildings for items such as resilient flooring, fire retardant boards, and piping. Public Services and Procurement Canada (PSPC) reviewed the use of asbestos in 2016 and determined that alternate materials could be used in place of asbestos. On April 1, 2016, PSPC prohibited the use of asbestos for any new construction or renovations on any federally owned building [61,62].

While federal regulations are implemented to minimize exposure to asbestos, its use is not completely banned in new products [61]. The government of Canada has taken a controlled-use approach to regulation, rather than prohibiting the use of asbestos altogether. With the controlled-use approach, the Canadian Asbestos Products Regulation allows the use of asbestos in some products, provided they meet the strict criteria for approval.

Provincial Regulations

Most provinces regulate asbestos exposure limits according to the American Conference of Governmental Industrial Hygienists (ACGIH) recommendation of 0.1 fibres per cubic centimeter (0.1f/cc). This occupational standard, also represented as 0.1 fibres per millilitre (0.1 f/ml), is used internationally. Some jurisdictions and provinces in Canada differ from the ACGIH recommendation, implementing their own limitations on occupational asbestos exposure [63].

In British Columbia, the current occupational exposure limit is 0.1 fibres per millilitre weighted over an 8-hour average work period [37]. WorkSafeBC regulates this limit in the workplace and recommends that occupational exposure to asbestos should be reduced below 0.1 fibre/ml whenever possible. This limit balances ACGIH recommendations with technical feasibility, established work practices, and engineering controls [37,64].

Analysis and Risk Assessment

While this report focuses on occupational exposure to asbestos, there is worldwide asbestos pollution occurring outside of an occupational setting. Evidence has shown that every citizen in the world has been exposed to asbestos to some extent and at some point in their lives [4,75]. Most autopsies after death have revealed some level of asbestos fibres in the lungs [76]. This can be a cause for concern among the general population, however mesothelioma is a rare disease even among the groups with the highest exposures. In addition, the long latency period of mesothelioma allows time for many individuals who have been highly exposed to asbestos to die of unrelated causes. For this reason, the risk for mesothelioma when exposed to concentration levels of very low magnitudes is very small – even impossible to measure.

Exposure to the General Public

The general public is exposed to asbestos through exposure to both indoor and outdoor air, or through ingestion of contaminated water. Secondary transmission of asbestos can occur through the transfer of asbestos fibres from clothing or hair to other individuals [75]. See Appendix 8 for further detail about airborne exposure.

Characteristics of Exposure

Many factors contribute to the development of disease following exposure to asbestos. Dosage and duration of exposure; size, shape, and chemical makeup of asbestos fibres; and distance from the exposure all determine the course of disease [78]. Asbestos exposure can be measured based on dose at a given point in time, fibres per cubic centimetre/millilitre (f/cc) or expressed as the total cumulative duration of exposure, fibres per cubic centimetre or millilitre years (f/cc-years) [82]. These characteristics are further detailed in Appendix 9. While there is conflicting evidence regarding the relationship between the magnitude of exposure to asbestos and increased risk for asbestos-related disease, other characteristics of exposure have been well documented [78]. Evidence for the threshold levels of asbestos exposure is discussed later in this report.

Occupational Thresholds for Exposure

There is an established link between occupational asbestos exposure and asbestos-related disease. Most research has been conducted with cohorts comprised of asbestos miners, or other occupations known to be exposed to high doses of asbestos. Very few studies have examined low-dose exposure to asbestos resulting in disease, or sought an exposure threshold below which disease does not occur.

A positive dose-response curve for mesothelioma and asbestos exposure indicates a positive relationship between level of exposure to asbestos and risk of disease. Doll and Peto (1985) created the "cubic residence-time model" to estimate the incidence of mesothelioma after exposure to asbestos [82]. This equation factored in the intensity of exposure (F), the duration of exposure (D), and the time after exposure (T).

$$I(T) = c \text{ x } F \text{ x } (T_4-(T-D))_4$$

Unfortunately, the total exposure (F) is often unknown or difficult to estimate. The exposure dose is likewise difficult to estimate, particularly at low levels, and so is not useful for determining the risk for disease in this context.

Evidence supporting no safe threshold for asbestos exposure

The relationship between malignant mesothelioma and asbestos is dose dependent; dose is the primary indicator for a zero tolerance model of asbestos exposure. According to Markowitz (2015), there is no dose of asbestos below which some risk of malignant mesothelioma does not exist [83]. Markowitz reviewed four large case-control studies and compiled relative odds ratios at given exposure levels. The results of the Markowtiz's (2015) review, displayed in Table 6, demonstrate evidence for mesothelioma occurring at low doses of asbestos exposure.

Table 6: Risk of Malignant Mesothelioma According to Levels of Occupational Asbestos Exposure: Results of Case–Control Studies[83]

Cumulative exposure (fiber/mL-year)	Cases/controls	Odds ratio	95% CI
French study no. 1			
Not exposed	95/154	1.0	–
0.001–0.49	77/109	1.2	0.8–1.8
0.5–0.99	29/12	4.2	2.0–8.8
1–9.9	80/27	5.2	3.1–8.8
≥ 10	49/10	8.7	4.1–18.5
*German study**			
Not exposed	11/67	1.0	–
> 0–0.15	14/12	7.9	2.1–30.0
> 0.15–1.5	38/25	21.9	5.7–83.8
> 1.5–15	46/16	47.1	11.5–193
> 15	16/5	45.4	8.1–257
			*99% CI
French study no. 2 (males only)			
Not exposed	28/327	1.0	–
> 0–0.1	54/181	4.0	1.9–8.3
> 0.1–1	68/121	8.3	3.8–17.7
> 1–10	115/68	22.5	10.4–48.7
> 10	97/27	67.0	25.6–175.1
Intensity of exposure	**Cases/Controls**	**Odds ratio**	**95% CI**
Spanish study			
Not exposed	30/127	1.0	–
Low	35/70	3.35	1.72–6.52
Medium	25/18	9.96	4.38–22.7
High	22/6	27.1	9.28–79.3

Stayner (1997) fit a Poisson regression model to estimate the lifetime risk of dying from lung cancer and asbestosis following exposure to chrysotile asbestos [84]. The author found that chrysotile asbestos exposure poses a risk to human health at any level of exposure. The exposure-response relationship between chrysotile fibre exposure and lung cancer was linear on a multiplicative scale, whereas chrysotile exposure and asbestosis was non-linear on a multiplicative scale. These relationships meant that, at a lower dose of exposure to asbestos, the risk of developing asbestosis was lower than the risk of developing lung cancer or mesothelioma.

The same study also estimated relative rates of death from an asbestos-related disease, based on an exposure of 0.1 fibre/ml. For a white, male worker exposed at this level for 45 years, the predicted excess lifetime risk of lung cancer was 5/1000, and the risk of asbestosis was 2/1000. These findings emphasize that chronic asbestos exposure can still result in adverse health consequences at the recommended national exposure limits. A review of the literature demonstrating evidence for no safe exposure limit to asbestos in the workplace is displayed in Table 7.

Table 7: Evidence in the Literature for No Safe Threshold for Asbestos Exposure

Title	Author	Findings
Asbestos and Man-Made Vitreous Fibers as Risk Factors for Diffuse Malignant Mesothelioma: Results From a German Hospital-Based Case-Control Study	Rodelsperger (2001) [85]	Results confirm a distinct dose-response relationship between mesothelioma and asbestos exposure, even for levels of cumulative exposure below 1 fibre-year.
Asbestos-related lung cancer and malignant mesothelioma of the pleura: selected current issues. [Review]	Markowitz (2015) [83]	No safe threshold for asbestos exposure has been established for lung cancer and mesothelioma.
Exposure-response analysis of risk of respiratory disease associated with occupational exposure to chrysotile asbestos.	Stayner (1997) [84]	There was no significant evidence for a threshold in models of either lung cancer or asbestosis.
Mesothelioma: cases associated with non-occupational and low dose exposures.	Hilerdal (1999) [86]	There is no evidence of a threshold level below which there is no risk of mesothelioma.
The four most pernicious myths in asbestos litigation: Part II: safe thresholds for exposure and Tyndall lighting as junk science	Meisenkothen (2014) [87]	There is no known safe threshold of exposure below which mesothelioma will not develop, as proven and accepted by the scientific and medical communities.
Asbestos Exposure- Quantitative Assessment of Risk	Hughes (1986) [88]	The risk to students exposed to 0.001 f/ml of mixed asbestos fibres over the course of 6 years will have an estimated 5 lifetime excess cancers per one million exposed. If this exposure is to pure chrysotile asbestos fibres, the estimated risk is 1.5 lifetime excess cancers per million.
Occupational and non-occupational attributable risk of asbestos exposure for malignant pleural mesothelioma	Lacourt (2014) [89]	Men exposed to less than 0.1 f/mL per year exhibited an odds ratio of 4.0 between asbestos exposure and pleural mesothelioma.
Pleural mesothelioma and occupational and non-occupational asbestos exposure: a case-control study with quantitative risk assessment	Ferrante (2015) [90]	The odds ratios with cumulative exposure index increased from 4.4 at less than one f/mL-years to 62.1 at more than 10 f/mL-years. Odds ratios of 2 were observed for low dose domestic exposure.

Evidence supporting a safe threshold for asbestos exposure

Most developed countries have regulated exposure to asbestos with occupational standards. Many countries, including Canada, mandate a threshold that exposure should not exceed. In British Columbia the time-weighted average exposure of a worker to airborne asbestos cannot exceed 0.1 f/cc [64]. This is equivalent to the Threshold Limit Value (TLV) that is enforced by the Occupational Safety and Health Administration in the United States [91]. This occupational threshold limit assumes the existence of an average airborne asbestos concentration that workers may be exposed over a lifetime without adverse health consequences [91].

A review of the literature describing a safe threshold for exposure to asbestos in the workplace is displayed in Table 8.

Table 8: Evidence in the Literature for a Threshold for Asbestos Exposure

Title	Author	Threshold
A threshold for asbestos-related to lung cancer	Browne (1986) [93]	Increased risk of lung cancer: 25-100 f/cc-years Increased risk of clinical asbestosis: 25 f/cc years
Analysis of the asbestos permissible exposure level threshold standard	Peterson (1991) [94]	The threshold level may exist for no danger posed to humans at a range of 1.5-5.0 f/cc
Is asbestos or asbestosis the cause of the increased risk of lung cancer in asbestos workers?	Browne (1986) [95]	It is generally accepted that there is a threshold dose below which clinical asbestosis will not appear (the Ontario Royal Commission estimated a threshold of 25 f/ml-years)
Pleural mesothelioma and lung cancer risks in relation to occupational history and asbestos lung burden.	Gilham (2016) [54]	Lifetime mesothelioma risk is approximately 0.02% per 1000 amphibole fibres per gram of dry lung tissue over a more than 100-fold range
Asbestos, Asbestosis, and Cancer: Helsinki Criteria for Diagnosis and Attribution 2014	Finnish Institute of Occupational Health (2014) [92]	Risk for asbestos-related disease is present when an estimated cumulative exposure to asbestos 25 fibre-years or more occurs

Relationship between lung cancer, mesothelioma and asbestosis in determining an exposure threshold

To date, a causal relation between lung cancer and asbestosis cannot be fully established. If this relationship is possible, then certain prerequisites must be met. In 1984, the Ontario Royal Commission suggested that a threshold dose below which clinical asbestosis will not appear is accepted to be at 25 fibres/ml years. Browne (1986) believed that if a causal relationship were possible, a threshold should also exist below which there is no excess risk of lung cancer [95]. While Browne (1986) discovered results indicating that lung cancer only occurs after the presence of asbestosis, further evidence is required to establish a causal relationship between lung cancer and asbestosis and proof of a related threshold [95]

The Helsinki Criteria [92,100] for mesothelioma and lung cancer determined that there must be a minimum latency period of 10 years to establish a causal link between asbestos exposure and disease. In addition, one of the following four criteria must be met to infer a causal relationship between asbestos exposure and the disease:

1) The presence of asbestosis; and/or

2) A count of 5000 to 15000 asbestos bodies or more per gram dry lung tissue, or an equivalent uncoated fibre burden of 2.0 million or more amphibole fibres less than 5 μm in length per gram dry, or 5.0 million or more amphibole fibres less than 1 μm in length per gram dry; and/or

3) An estimated cumulative exposure to asbestos 25 fibre-years or more; and/or

4) An occupational history of 1 year[2] of heavy exposure to asbestos or 5-10 years of moderate exposure;

Personal Protective Equipment (PPE)

Current standards (BC)

WorkSafeBC standards stipulate that protective clothing must be worn when engaging in an occupational task that is at a moderate or high risk for asbestos exposure. Clothing material must cover the entire body and fit snugly at the neck, wrist, and ankles to avoid entry points for asbestos dust. Foot and head coverings must also be worn, and torn clothing must be replaced immediately. It is imperative that the clothing material resists any form of penetration from asbestos fibres. A respirator is also required when working in a moderate to high risk exposure situation. The respirator must be fitted with a P100 HEPA (high-efficiency particulate air/arrestance) filter [37].

Particulate filters are used in respirators to trap particles that may be harmful if inhaled. Most workplaces with risk of contact with contaminants only require a respirator that traps particles with 95% efficiency. For occupations with risk of asbestos fibre inhalation, "100" HEPA filters are required which trap particles with 99.97% efficiency. In the event that a worker is entering into a situation involving high-hazard asbestos abatement, an escape respirator is used. A full-face piece PAPR with "100" HEPA filters has a protective factor of 100, whereas a powered air purifying respirator (PAPR) helmet or hood has a protective factor of 1,000 [37]. For International Standards and Ontario Standards, see Appendix 10.

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[2] *Two-fold risk of lung cancer can be reached with exposures less than 1 year in duration if the exposure is of extremely high intensity*

Application to a Municipal Work Force

A key objective of this paper was to review the published literature on occupational exposure to asbestos fibres and asbestos-related disease, including an estimation of risk among British Columbian civic workers, in particular firefighters, who may be exposed to minimal doses of asbestos in the course of their work duties. Currently, municipal workforces in British Columbia protect their civic workers and firefighters from asbestos exposure through adherence to WorkSafeBC standards and guidelines, which are based upon the WorkSafeBC mandate to create healthy and safe workplaces through effective health and safety programs. The Occupational Health and Safety (OHS) Regulation and Part 3 of the *Workers Compensation Act* contain legal requirements for workplace health and safety that must be met by all workplace parties under the jurisdiction of WorkSafeBC.

The current review revealed occupations at increased risk of asbestos exposure and resulting illness, disease and death. Among these occupations, construction related trades were most often cited as having the highest asbestos exposure risks. The research literature did not reveal studies of asbestos-related exposure-risk, nor a significant incidence rate of asbestos-related disease among civic workers or firefighters. Further, data obtained from WorkSafeBC for the five-year period 2012-2016 does not provide evidence that civic workers or firefighters specifically are at increased risk for asbestos-related disease (Table 9).

Table 9: WorkSafeBC Asbestos-related claims, 2012-2016

Occupation	Number of Claims
Carpenters	16
Plumbers	15
Steamfitters, pipefitters, and sprinkler system installers	14
Construction trades helpers and labourers	12
Labourers in wood, pulp and paper processing	12
Longshore workers	11
Firefighters	1
Other	225
Total	**306**

The lack of research and claims data of asbestos-related disease among civic workers and firefighters suggests that the current practices to protect these workers are providing a high degree of protection from asbestos exposure that may occur, or that there are minimal levels of exposure to asbestos among these occupations. The combination of exemplary safety practices and low-dose or null exposure to asbestos among civic workers and firefighters is likely the case.

Conclusion and Recommendations

Research on asbestos-related disease and exposure to asbestos fibres has progressed over the past century. A review of the literature revealed that many industrialized countries implemented occupational policies and regulations to combat the frequency of occupational asbestos exposure. Despite these regulations, cases of mesothelioma, asbestosis, and lung cancer due to asbestos exposure continue to emerge around the world.

Quantifying the risk of asbestos-related disease among occupations exposed to low doses of asbestos is challenging. Any level of exposure to asbestos should be considered dangerous in light of a continued lack of evidence to support a safe exposure level. Minimal asbestos exposure, even at low frequencies, can combine with other cancer agents, such as tobacco, to increase the risk for mesothelioma, asbestosis and lung cancer. Occupational standards and regulations that prevent exposure to asbestos should apply to all professions that may be exposed to any dosage level of asbestos in the workplace. As there is no safe limit for occupational asbestos exposure, British Columbia, as well as the rest of Canada, should take the following measures to ensure that the risk for asbestos-related disease is minimized in the workplace.

Recommendations

The present review of the literature and available data concludes that there is no safe limit for asbestos exposure. There is a small body of literature attempting to assess the evidence for an asbestos exposure threshold, but there is insufficient research to date to support a definitive conclusion in favour of a safe threshold. This review supports current policy in BC for a conservative approach to occupational protocols and regulations among civic workers who may be exposed to asbestos at work. We recommend that the City of Surrey continue to abide by WorkSafeBC standards, as well as consider further recommendations outlined below.

Asbestos air sampling protocol

Air sampling is used around the world to test for the concentration of airborne asbestos that may be present in or near a workplace. Currently, the standard for air sampling involves capturing the airborne fibres on a filter and conducting a laboratory analysis to determine the presence of asbestos fibres in a setting [37]. These tests are used to reveal the quantity of asbestos fibres that are airborne in a workplace. While such techniques are useful, they require time to determine if a workplace is at risk for asbestos exposure and may not be effective for occupations requiring immediate confirmation.

Two emerging technologies address the need for rapid air quality assessment. The Fibrous Aerosol Monitor is a portable device that can instantly analyze asbestos fibre content in the air. This tool cannot differentiate between different asbestos fibres types, but gives a real time count of the quantity of asbestos in an occupational setting. Another evolving method to determine the presence of airborne asbestos is spatial light scattering. Research has shown that asbestos fibres can be detected through an analysis of the spatial light scattering patterns that result when a contaminated air sample is passed through a magnetic field [91]. Both of these evolving techniques make real time analysis of airborne asbestos concentration possible. The limitation to these tools is the increased risk for false positive readings, affecting the validity of the tool's results. While they should not be used as the sole method for determining asbestos fibre content and exposure, rapid techniques to monitor occupational air settings can be useful to prevent exposure to asbestos among low risk occupations.

Education on the combined effect of lung carcinogens

Tobacco is a known lung carcinogen that greatly increases an individual's risk of lung cancer [15]. However, many individuals are unaware that the use of tobacco and inhalation of asbestos fibres can have a multiplicative effect on the risk of lung cancer and mesothelioma. It is unethical to force employees to discontinue their use of tobacco, however educational programs can be put in place for occupations at risk. Workers who have known exposure to asbestos should be encouraged to quit the use of tobacco immediately, as it can significantly increase the risk of lung cancer if pleural plaques, pleural effusion, or asbestosis are already present. Educational initiatives are low-cost and can reduce the incidence of lung cancer and mesothelioma.

Documentation of past asbestos exposure

In British Columbia, physicians struggle to document occupational history for their patients with mesothelioma and other asbestos-related disease. Many patients do not volunteer information on their work history, and many do not seek compensation from WorkSafeBC because of the long latency period of asbestos-related disease [96]. It is difficult to gain information on the occupational source of asbestos exposure without a compensation record. In addition, malignant mesothelioma cases should trigger a mandatory taking of occupational history. However, if this information is to be useful, a database on asbestos-related disease must be created and include asbestosis as a reportable disease. An improved system to monitor the incidence of mesothelioma, such as a national mesothelioma registry, is necessary to observe and understand the trends in mesothelioma cases. Such information could help employers understand past asbestos exposure incidences and risk for future exposure in their workplace.

Occupational tool for past asbestos exposure

The Australian Mesothelioma Registry (AMR) assesses exposure to asbestos from environmental and occupational sources in Australia. This registry collects information on malignant mesothelioma cases from the mandatory cancer registries in each state and territory in the nation. The Occupational Integrated Database Exposure Assessment System (OccIDEAS) was created as a web application to compliment the AMR and assess occupational exposure to asbestos [97]. An important aspect of the OccIDEAS tool is that occupations are triaged for their risk for exposure and, combined with the AMR, individual exposure data are collected efficiently. OccIDEAS can automatically assess the exposure level for a selected agent and occupational category using preprogrammed algorithms. Unlike many other research studies and asbestos exposure tools, OccIDEAS is not subject to the limitations of self-reports. Rather, the exposure estimate is based on objective data such as job titles, specific worker tasks, and the performance on the job, in order to conduct individual exposure assessments. Currently, OccIDEAS contains a database of over 50 modules and agents to quantify the risk of asbestos exposure for research purposes. This tool has the potential to become useful for policy development in the workplace in British Columbia, or to inform employers about the risk for exposure in their workplace.

Advocacy to senior levels of government

The federal government must look to enacting an asbestos harm aid act, similar to that of South Korea. In 2009, the government of South Korea banned the manufacturing, importing, sale, storage, transport, and use of all forms of products that contain more than 0.1% of asbestos fibres. South Korea became one of the first countries in the world to implement an asbestos harm aid act in 2011. This act enables a Korean citizen to free lifetime medical care and monthly income, subsidized by the government, if diagnosed with an asbestos-related disease [67]. The province, and local municipalities, can play a role in advocating to senior levels of government for the implementation of an act to aid those diagnosed with an asbestos-related disease.

Further research required

Past studies have continually attempted to estimate dose-response relationship between asbestos exposure and risk for mesothelioma, asbestosis, or lung cancer. Many of these studies were performed on cohorts who sustained chronic high doses to asbestos in their occupation, such as workers from asbestos mines. These studies were predominately performed on white male workers, as this population made up the majority of the targeted industry cohorts. As a result, these results do not extend to describing the impact that occupational exposure to asbestos has on females or on individuals of different ethnicities. Continued research is needed to assess the impact of asbestos exposure on all populations.

Appendices

APPENDIX 1: HISTORY OF ASBESTOS PRODUCTION

Asbestos fibres are not a recent discovery. Among the first use of asbestos in the modern industrial world was in the Quebec chrysotile fields in the 1880's [6,7]. The next 50 years brought increased production and use of asbestos. The chemical and physical properties of asbestos made it an ideal mineral to use in many industries, serving a wide variety of functions. By the late 1930's, a cumulative total of over 5 billion kilograms of asbestos were mined, and by the time commercial use of asbestos peaked, there were more than 3000 applications for its uses [4].

Industrialized countries in Northern and Western Europe, Oceania, and North and Central America had the highest rates of asbestos use compared to to the rest of the world. Developed countries in these parts of the globe also used asbestos-containing products earlier and became leaders in the global trade of products containing asbestos. The highest rates of asbestos use were recorded in Australia (5.11 kg per capital/year), Denmark (4.80 kg per capita/year), Germany (4.44 kg per capita/year), and occurred throughout the 1960's and 1970's. Canada's production of asbestos peaked in the 1970's at 4.37 kg per capita/year [4].

Scientific studies began to demonstrate the negative health effects on the human body that all forms of asbestos fibres have on the human body many years after the increase in production levels. In the 1930's the Metropolitan organization commissioned one of the first studies on the potential long-term effects on individuals living with exposure to asbestos. Many years passed before the effects of large-scale use of asbestos began to emerge in the population [26,27]. In 1966, a McGill University study [28] looked at the effects of chrysotile mining in Canada. By the late 1960's many workers who worked directly in the asbestos mines in the early 1900's started to exhibit shortness of breath, fatigue and coughing up blood. In the 1960's, attempts were made to evaluate and measure the dose-response nature of asbestosis. An increasing number of studies of asbestos workers were initiated in the 1960's and 1970's as most industrialized countries began to recognize the health repercussions of asbestos exposure [29]. Many studies began to report a linear relationship between cumulative exposure to asbestos and lung cancer. Due to the long latency period of all types of asbestos-related disease, many analyses only studied exposure rates that were on the highest range of the spectrum.

In 2011, the last two asbestos mines in Canada were closed. Both of these asbestos mines were located in Quebec, which was a primary producer of asbestos on a global scale. In 2012, the Parti Québécois won the Quebec provincial election and followed through on a promise to halt all asbestos mining. This act persuaded the Canadian federal government to eliminate its opposition to efforts made to add asbestos to the list of hazardous substances under the international Rotterdam Convention. Prior to 2012, the Canadian federal government repeatedly blocked the procedure for asbestos to be listed as a hazardous chemical by the United Nations. Many activists around the world called for the removal of asbestos mining in Quebec, since much of this product was shipped to countries with no complete ban on asbestos [29].

While research studies reinforcing the link between asbestos exposure and asbestos-related disease began to accumulate, the mortality rates also began to increase [29]. One of the first studies on mortality of workers exposed to asbestos was conducted in 1955. At this time, the study found 11 deaths from lung cancer that were associated with asbestosis, and no cases of lung cancer that were not associated with asbestosis [30]. It was originally believed that lung cancer must follow a diagnosis of asbestosis, and in the United Kingdom, lung cancer among asbestos workers was made a prescribed disease only if accompanied by asbestosis [31]. Along with this theory came the hopeful belief that if asbestosis was eliminated as a disease, then the excess risk for lung cancer would be eliminated.

The discovery of the link between asbestos exposure, and lung cancer and asbestosis prompted the limitation of asbestos use. The production of materials containing asbestos peaked globally in the 1970's, and world production and consumption of asbestos quickly declined in the years following [4].

APPENDIX 2: ASBESTOS RELATED DISEASES

Asbestosis

Asbestosis is a condition that results in lung scarring making it difficult to breathe. Signs and symptoms of asbestosis include shortness of breath, a dry cough, loss of appetite, weight loss, and chest tightness or pain [12]. Asbestosis is often difficult to diagnosis because the symptoms are similar to those of many other respiratory diseases. As asbestosis progresses, the tissue in the lungs becomes increasingly scarred. In advanced disease, the lung tissue becomes so stiff that the lungs can no longer contract and expand normally [12,13]. The diagnosis of asbestosis often precedes the advancement of more serious health complications such as lung cancer or mesothelioma.

Lung cancer

In Canada, lung cancer is the leading type of cancer among men, accounting for an estimated 10,900 deaths each year among men and 9,800 deaths among women [14]. It is commonly understood that most lung cancer cases are linked to tobacco use - the leading cause of lung cancer worldwide. However, exposure to asbestos is also a risk factor for lung cancer. Asbestos and cigarette smoke are equally recognized as lung carcinogens, and can interact with one another to further increase the risk of lung cancer [15].

Pleural Thickening

Pleural thickening is an inflammatory lung disease. It is one of the most common outcomes of asbestos exposure resulting from fibres that embed themselves in the pleura. This disease occurs when scarring thickens the lung pleura - one of two membranes surrounding the lung - thus eliminating the space between the lungs and the pleura [16]. Similar to most asbestos-related diseases, symptoms may not occur for many years after the initial exposure. Once the pleural thickening impedes breathing function, chest pain and difficulty breathing may be experienced. Once the disease reaches the advanced stages, most patients will experience breathlessness, which can lead to respiratory failure [17,18]. Among occupations where there is a risk of asbestos-exposure, studies have shown that pleural thickening occurs in 5 to 13.5% of workers, and on average has an average latency period of 15 to 20 years [16].

Mesothelioma

Malignant mesothelioma is a form of cancer with low survival rates that attacks the chest or abdominal cavity. It is diagnosed when a tumour arises from the mesothelioma or sub-mesothelial cells of the pleura, peritoneum, or on rare occasions, the pericardium [19]. Cases of peritoneal mesothelioma with asbestos exposure are relatively rare, as not all fibres inhaled proceed to the respiratory system if expelled by coughing or swallowing, [9]. Research estimates that 95% of all malignant mesothelioma cases in industrialized countries are due to asbestos exposure. For individuals with no identified exposure to asbestos, mortality rates from mesothelioma are estimated to be as low as 1 in 10,000. However, employees working in the insulating industry who were first exposed to asbestos before the age of 20 years have been estimated to have a mortality risk of one in seven by the time they are 80 years of age [20]. Similar to lung cancer, smoking tobacco can increase the risk for advanced progression of the disease [13].

APPENDIX 3: LEVELS OF ASBESTOS EXPOSURE RISK

Low risk exposure

A work activity that would have a low risk for exposure to asbestos may involve, or be in proximity, to asbestos-containing material where no asbestos fibres are released during the work task. If the asbestos-containing material is not cut, sanded, drilled, broken, ground down, fragmented, or disturbed to a degree where asbestos fibres may be released, then the work activity is considered a low risk for exposure. In order to be considered an operation with low risk for asbestos exposure, the asbestos-containing material must be non-friable and therefore locked in by cement, vinyl, or another binding agent [37].

As stated by the WorkSafeBC guidelines [37], low risk activities do not carry the requirement for the use of PPE or engineering controls for the prevention of occupational exposure to asbestos. Some examples of low risk activities include:

- Tasks that involve materials that contain less than 0.5% asbestos, as long as the dust particles are not disturbed
- Repairing drywall that contains asbestos in the drywall filler, as long as the filler is not disturbed
- Inputting a nail or screw into drywall that contains asbestos-containing filler
- Moving asbestos-containing waste that is sealed and double bagged

The provinces of Manitoba, Ontario and New Brunswick closely regulate asbestos in workplace. These provinces classify occupational tasks that pose a low risk of asbestos exposure as Type I activities. Type I activities include installing or removing ceiling tiles that are less than 7.5 square metres, installing or removing non-friable asbestos containing materials, and removing less than one square metre of drywall that contains asbestos in the joint-filling compounds. The act of breaking, cutting, drilling, grinding, sanding, or vibrating non-friable asbestos-containing material is also considered a Type I activity when the material is wetted to control the spread of fibres [34].

Moderate risk exposure

Occupational tasks that are at a moderate risk for asbestos exposure involve direct work with asbestos-containing material that is being cut, sanded, drilled, broken, ground down or fragmented. These work activities disturb the fibres in the asbestos-containing material to release asbestos into the air. Workers who are in the proximity to any one of these tasks are at a moderate risk for exposure to airborne asbestos fibres [37].

WorkSafeBC [37] requires that PPE be worn when a worker is at a moderate risk for exposure to asbestos. Activities in the workplace that pose a moderate risk for asbestos exposure include:

- Using hand tools or power tools to grind, shape, or remove non-friable products that contain asbestos
- Removing part of a ceiling that contains friable asbestos on the surface
- Removing asphalt roofing material that contains asbestos

In Manitoba, Ontario and New Brunswick, type II classified work tasks in Ontario are considered a medium risk for asbestos exposure. These tasks include the removal or disturbance of friable asbestos-containing materials that are equal to or less than one square metre. Type II activities also include the installation or removal of ceiling tiles that contain asbestos and are greater than 7.5 square metres. Moderate risk activities in the workplace pose a higher risk than low risk exposure activities as they involve tasks with friable asbestos and large materials that contain asbestos [36].

High risk exposure

Work tasks that are at a high risk for asbestos exposure are usually directly involved with asbestos-containing materials that are friable and large in size. These tasks require very strict protocols to ensure not only the workers safety, but also other individuals who may be affected by the high-risk activity [37].

WorkSafeBC [37] requires that PPE be worn when a worker is at a high risk for exposure to asbestos. Activities in the workplace that pose a high risk for asbestos exposure include:

- Removing materials that contain friable asbestos from a building, structure, or equipment
- Cleaning equipment that has been sprayed with fireproofing materials containing asbestos
- Using power tools, without wetting the product, to cut or drill into an asbestos-containing material
- Removing asbestos-containing vermiculite insulation

The provinces of Manitoba, Ontario and New Brunswick classify asbestos operations in Ontario at a high risk for exposure as Type III in the workplace. These tasks involve frequent or chronic exposure to friable asbestos. Frequent examples of these tasks include the installation or removal of asbestos-containing materials that are greater than one square metre in size, the spray application of a sealant to a friable asbestos-containing material, and altering a part of a building where asbestos has been used [98].

Other high risk exposure tasks occur when disturbing friable or non-friable asbestos-containing materials by drilling or cutting with a power tool that does not have a dust-collection device equipped with a high-efficiency particulate air (HEPA) filter [37].

APPENDIX 4: EXAMPLE OF AN ASBESTOS META-ANALYSIS

Table 10: Results from the 2012 Study by Villeneuve[44]

Table 1 Most frequent occupations among the 801 jobs held by subjects that were classified as having probable or definite exposure to asbestos

	SOC	Number of jobs	%	Most common exposure coding[A]		
				Confidence	Frequency	Concentration
Mechanics and Repairmen (except electrical)	8580 – 8589	214	26.7	Probable	Low	Low
Stationary Engine and Utilities Equipment	9530 - 9539	124	15.0	Probable	Medium	Low
Pipefitting	8791	89	11.1	Probable	Low	Low
Construction	8733	79	9.9	Probable	Low	Low
Metal shaping occupations	8330 – 8339	48	6.0	Probable	Medium	Low
Fabricating, assembling electrical and electronics	8530 – 8539	34	4.2	Probable	Medium	Low
Water Transport Operating Occupations	9151 – 9159	42	5.2	Probable	High	Low
Firefighters	6111	31	3.9	Definite	Medium	Low
Plasterers	8784	23	2.9	Probable	Medium	Low
Total		801	84.5			

A – defined by highest percentage.

APPENDIX 5: METHODOLOGY

Data Sources

Mortality data was collected from CANSIM (Statistics Canada) and was used to report data on the number of deaths and mortality rates of malignant mesothelioma, lung and bronchus cancer, and other respiratory system cancers. Data was filtered based on location, age range, and year. Results were displayed by number of new cases and the rate of new cases per 100,000 population.

Work-related death claims data were retrieved from WorkSafeBC. This dataset included claims from 2006 to 2015. Work-related death claims are claims accepted for survivor benefits in a given period, regardless of whether a payment is made. This dataset included detailed claim characteristics on subsector, accident type, source of injury, nature of injury, body part, occupation, age and gender.

Literature Review

A literature review was conducted to gather evidence supporting a threshold model for exposure to asbestos. A search was initially conducted on the UBC Library database using the keywords: *Asbestos AND exposure AND threshold*. On this database, a search was also done to include the terms: *Mesothelioma AND asbestosis* as many studies include the negative health impacts of asbestos exposure as key terms in their threshold models. A third general literature search was performed to incorporate the keyword *occupation** to filter results pertaining to the work force. These initial search results brought up over 1,000 journal articles, with many pertaining to high-dose exposure to asbestos.

A search was then performed on three health science databases (MEDLINE, PubMed and EMBASE). The same search keywords that were used with the UBC Library database were used across all health science databases: *asbestos AND occupation* AND low dose AND/OR threshold.* On all three health science databases, the keywords “asbestos” and “mesothelioma” were included as “exploded” terms using the advance keyword searches pertaining to each database.

APPENDIX 6: INTERNATIONAL POLICY REVIEW

Australia

The current Australian exposure standard is 0.1 f/ml. This regulated workplace limit is equivalent to 100 fibres per litre of air over an eight hour period of time. In comparison to regular population exposure rates of 0.01 to 0.2 fibres per litre of air, this occupational exposure limit is between 500 to 10,000 times the average general exposure rate. Prior to 1986, 46 occupations were considered to have had exposures exceeding this exposure standard of 0.1 f/ml, with over 90% of occupations with exposure to a mixture of asbestos fibre types [43].

In Australia, a qualified occupational designated leader has the authority to identify a material that contains asbestos. This eliminates the need to take samples from material to determine whether asbestos is present. A qualified occupational health specialist can presume that a material contains asbestos, and work practices and disposal criteria must then follow strict regulations [68].

In 2003, a nationwide ban on the use and importation of all forms of asbestos took effect. Following this ban, the National Occupational Health and Safety Commission promoted a consistent approach to managing occupation asbestos exposure and introduced health and safety measures of the management, control and removal of asbestos. At the time this ban was implemented, there was no ban or management of asbestos materials and products that were currently in use [68,43]. Australia has a mortality rate from asbestos-related diseases of more than 3,000 people per year. This compares to Britain's mortality rate, which has almost three times the population of Australia [67].

New Zealand

The government of New Zealand enforces occupational limitations on chrysotile asbestos fibres of 1 fibre per millilitre of air over any 4 hour period of time [67,69]. The average concentration of over a 10 minute period of time cannot exceed six fibres per millitre of air. The regulation of amosite, crocidolite, and fibrous actinolite, anthophyllite and tremolite in New Zealand is an occupational limit of an average concentration of 0.1 fibres per millilitre of air over a 4-hour period. The average concentration cannot exceed 0.6 fibres per millilitre of air over a 10 minute period [69].

Occupational health expert's state that any building built prior to January 1, 2000 is likely to contain asbestos in the infrastructure, and that new buildings are not exempt from asbestos use [69]. As of 2016, if the removal of more than 10 m^2 of non-friable asbestos occurs over the course of a project, a licensed asbestos removalist must be brought in to perform the work. A licensed asbestos removalist must also be contracted to remove any friable asbestos on a project. Licensed asbestos removalists have completed training and received a certificate of competence to safety remove asbestos in any project site [69,70].

France

In 1996, France banned the use of all asbestos fibre types in the manufacturing and construction industries. A complete ban on asbestos was completed in 2007, and the country called for a worldwide ban on the use of all asbestos types [67,71]. The current limit on occupational exposure in the workplace to asbestos is 0.1 f/cm for a one hour period of time. In 2012, the French Ministry for Work, Employment and Health began a three year plan to reduce the permissible limits of asbestos in the air from 100 fibres per litre to 10 fibre per litre. This plan was a result of a study that found that asbestos dust levels in various workplaces were considerably higher than expected, and posed a risk to many occupations [71,72].

India

Asbestos usage is prevalent in India even with governing rules that have been implemented for safe usage of asbestos products. Policies in India state that Pictorial Warnings must be implemented in the workplace, and there are guidelines that all employers must follow if workers are using asbestos in an occupational setting. Unfortunately, there is no enforcement of these standards or rules and asbestos usage is prevalent with no use of basic safety regulations. In 2011, asbestos was banned by the supreme court of India, which was motivated by a case filed by a non-governmental organization in 2004 [67].

Italy

A full ban of asbestos occurred in 1992 and the government has implemented a detailed plan to decontaminate many industries and housing from asbestos [67,72].

Japan

Japan is a country that did not fully ban asbestos until 2004 and because of this delay in a national ban, the government has been held responsible for many asbestos-related diseases in their population [67].

South Korea

The production and use of crocidolite and amosite asbestos was banned in South Korea in 1997. It wasn't until over 10 years later in 2009 that the government implemented a full-fledged ban on all types of asbestos [67]. This ban included the manufacture, importing, sale, storage, transportation, or usage of any product containing more than 0.1% asbestos. In 2011, South Korea enacted an asbestos harm aid act which entitles a Korean citizen to free medical care and monthly income for the rest of an individual's life if diagnosed with an asbestos-related disease [73]. South Korea became the sixth country in the world to enact an asbestos harm aid act that aims to reduce the lifetime burden that asbestos-related diseases has on a population [67,73].

For each building in South Korea, a safety supervisor is chosen by the landlord to complete education on asbestos and regulate the status of asbestos in the building. This safety supervisor also ensures safety requirements are met in the building and that any removal of asbestos is completed properly. These new regulations also ensure that if a building is to undergo renovation, the safety supervisor must be present to monitor the removal of asbestos[67].

United Kingdom

The United Kingdom exhibits one of the highest rates of mesothelioma in the world. This is due in part to the country's delay in halting the use of asbestos in products and manufacturing. The United Kingdom continued to use asbestos in their construction industry into the late 1990's, and so many homes build or renovated prior to 2000 are at risk for containing asbestos [67]. In comparison, homes in Canada are largely at risk if built or renovated before the year 1980.

The limit for asbestos exposure in an occupational setting in the United Kingdom is 0.1 asbestos fibres per cubic centimeter of air (0.1 f/ml). The government does not believe that this limit should be considered a safe level of exposure and that any exposure to asbestos should be reduced as much as possible [75].

The British Government's Health and Safety Executive (HSE) does not believe that a minimum threshold for asbestos exposure and the development of mesothelioma exists. The HSE cites evidence from many epidemiological studies that support the theory that if a threshold for mesothelioma were to exist, it must be at such a low level that exposure groups would not exist. The HSE has implemented standards on asbestos handling, and the Control of Asbestos Regulations was introduced in 2006 to minimize the use of asbestos containing products in the workplace. This Regulation banned the import of most asbestos products and its use in the United Kingdom. It also set out guidelines to manage any asbestos containing material that was currently in use [67,75].

APPENDIX 7: HISTORICAL TREND IN ASBESTOS USE

Table 11: Historical trend in asbestos use per capital and status of national ban[67]

Country	Use of asbestos (kg per capita/year)					
	1960	1970	1980	1990	2000	National ban
Norway	2.00	1.16	0.03	0.00	0.00	1984
Denmark	4.80	4.42	1.62	0.09	NA	1986
Germany	2.60	4.44	2.43	0.10	0.00	1993
France	2.41	2.64	1.53	0.73	0.00	1996
Poland	1.24	2.36	2.09	1.05	0.01	1997
United Kingdom	2.90	2.27	0.87	0.18	0.00	1999
Spain	1.37	2.23	1.26	0.80	0.18	2002
Australia	4.84	5.11	1.82	0.09	0.03	2003
Japan	2.02	2.92	2.66	1.81	0.46	2004
USA	3.32	2.40	0.77	0.08	0.01	No ban
Canada	3.46	4.37	2.74	1.96	0.32	No ban

APPENDIX 8: EXPOSURE TO THE GENERAL PUBLIC

Environmental exposure to asbestos begins at birth, and the risk of pleural fibrosis and plaques is likely to be linearly dependent from time since first exposure. The risk of lung cancer seems to be linearly related to cumulative asbestos exposure, with an estimated increase in risk of 1% for each fibre/ml-year of exposure. The risk of pleural mesothelioma is linked with the cubic power of time since first exposure, after allowing for a latency period of 10 years, and depends on the fibre type, as the risk is about three times higher for amphiboles as compare to chrysotile [77].

Rural locations have lower rates of airborne asbestos fibres than urban cities. Typical concentration levels in rural locations are 10 fibres/m^3; tenfold higher concentration levels are common in urban locations. When the outdoor air is in close proximity to a direct asbestos source, concentration levels can be one thousand times higher than in rural areas [4].

Indoor air asbestos concentration levels can range from 30-6000 fibres/m^3. Ambient air usually contains between 10 to 200 asbestos fibres in approximately 1000 litres of air. This is equivalent to a range of 0.01 to 0.20 fibres per litre of air, which does not pose a high risk to the public and most individuals exposed to this level of asbestos will never experience asbestos-related symptoms [4].

APPENDIX 9: CHARACTERISTICS OF ASBESTOS EXPOSURE

Duration of exposure

It has been proven that there is an increased risk of mesothelioma, asbestosis, or lung cancer as the intensity and duration of asbestos exposure increases. Chronic exposure to asbestos increases the risk for asbestos-related disease as there is an increased likelihood for asbestos fibres to enter the respiratory system and cause damage. However, cases of mesothelioma have arisen in subjects with durations of crocidolite exposure as short as 2 months and estimated cumulative exposure as low as 0.53 fibers/ml. In one study, the median duration of exposure to asbestos for cases of mesothelioma was reported as 60 months, with a range of 2 months to 17 years [79].

Fibre Size

The surface area, diameter and length of asbestos fibres all play a role in determining the risk for the development of asbestos-related disease. Studies have demonstrated that the risk for asbestosis is related to the surface area of retained asbestos fibres. Asbestos fibres that are longer than 5 μm and thinner than 0.1 μm are associated with an increased risk for mesothelioma. In contrast, the development of lung cancer is closely associated with fibres longer than 10 μm [4].

After exposure to asbestos, the risk for long-term health repercussions depends largely on the diameter of the asbestos fibre inhaled or ingested. Thin fibres have the highest risk for deep lung deposition and therefore, future negative health consequences. According to a study by Antman [80], a 10:1 length-to-width fibre ratio has the highest association with carcinogenesis. The risk for carcinogenicity is further amplified the finer the asbestos fibres are in nature. The World Health Organization only regulates asbestos fibres that are thinner than 3μm, longer than 5 μm, and maintain a length-width ratio above 3:1 [41].

Fibre Type

As discussed earlier, there are many different types of fibres within the broad term of asbestos. Studies have aimed to determine which types of fibres may induce a higher risk for mesothelioma and other types of asbestos-related disease.

Amphibole fibres are the most potent asbestos fibre as a cause of mesothelioma. While chrysotile fibres are the most common asbestos fibres found in occupational and environmental settings, chrysotile fibres are cleared quickly from the lungs, resulting in a lower carcinogenic potential than amphiboles. There is a hypothesis, referred to as the "amphibole hypothesis" [4], that even when an individual is exposed exclusively to commercial chrysotile asbestos fibres, mesothelioma develops due to a small quantity of amphibole contamination within the chrysotile fibres. Tremolite, an amphibole, has been shown to exist in extremely small quantities in asbestos that is believed to be chrysotile fibres.

Exposure to crocidolite asbestos fibres is associated with the highest risk of mesothelioma, in comparison to both chrysotile and amosite asbestos fibres. A study by Nicholson found that crocidolite asbestos fibres were 4 to 10 times more harmful than chrysotile fibres. Hodgson and Darnton found a similar result, and estimated that the potency ratio for crocidolite:amosite:chrysotile is 500:100:1 [4].

Proximity to exposure

Studies have shown that proximity to asbestos exposure plays a role in the development of mesothelioma, asbestosis, and lung cancer. According to Pan, the odds of developing mesothelioma decreased by approximately 6.3% for every 10 km removed from the source of asbestos exposure [81].

APPENDIX 10: PERSONAL PROTECTIVE EQUIPMENT STANDARDS

International standards

The majority of industrialized countries require the use of personal protective equipment (PPE) when handling any product containing asbestos in an occupational setting. Coveralls, adequate footwear, gloves and respirators are among the mandatory requirements for workers who are at a moderate to high risk for occupational exposure to asbestos. In Australia, decontamination is one of the primary factors considered when selecting equipment and it is recommended to use disposable PPE where possible [68]. New Zealand also recommends disposable equipment and requires footwear that that is non-laced or can be fit under disposable boot covers [69].

France has taken a proactive approach to preventing asbestos exposure by creating multiple regulations in the workplace. An employer with work activities involving asbestos must implement an initial risk assessment, train their staff on asbestos procedures, and provide regular information sessions to their employees. In addition, the control of asbestos dust accumulation is monitored by transmission electron microscopy (TEM) to guarantee compliance with federal limits [67,72].

Current standards (Ontario)

The province of Ontario classifies risk for exposure to asbestos in work activities by Type I activities (low risk), Type II activities (medium risk), and Type III activities (high risk). Type I work activities that pose a low risk for occupational exposure do not require protective equipment, although it is offered as a choice to the worker {34,36]. Some of the basic standards for Type I work tasks include {34,36]:

- Use a damp cloth or HEPA vacuum to clean up any dust in the work area
- Wet non-friable asbestos material with a wetting agent
- Do not use any powered hand tools on any material containing asbestos
- Do not use compressed air to clean the work area
- Regularly clean up dust or waste that may contain asbestos with a HEPA vacuum or damp mop
- If a respirator or protective coveralls are used, damp wipe or HEPA vacuum these materials before leaving the work area
- Dispose of all waste that may contain asbestos in dust-tight containers with a warning label
- Wash hands and face prior to departing the work area

Type II activities in the workplace are considered a medium risk for exposure and employers are required to follow occupational protocols to eliminate exposure to asbestos for their workers. Disposable coveralls that are tight around the wrists, ankles and neck and contain no rips or holes must be worn at all times. A NIOSH- approved (National Institute for Occupational Health and Safety, U.S. Centers for Disease Control and Prevention) respirator must be worn, as well as rubber boots {34,36]. In addition to standards outlined in Type I tasks, other standards for Type II work tasks include {34,36]:

- Do not eat, drink, or smoke in the work area
- Ensure warning signs are set up in the work area and mandate everyone to wear PPE

- Any disturbance of friable asbestos (must be less than one square metre) must be done inside an enclosure
- Once all disposable clothing, waste, and other contaminated materials are placed into a labelled, dust-tight container, damp wipe or HEPA vacuum the container prior to removing it from the work area

Type III activities are considered the highest risk for occupational exposure to asbestos. These tasks involve work with friable asbestos-containing material that has the ability to produce high amounts of dust fibres in the air. On top of procedures and standards outlined in Type II activities, Type III activities require a designated isolate asbestos work area for all tasks [98].

APPENDIX 11

BC INJURY research and prevention unit

The British Columbia Injury Research and Prevention Unit (BCIRPU) was established by the Ministry of Health and the Minister's Injury Prevention Advisory Committee in August 1997. BCIRPU is housed within the Evidence to Innovation research theme at BC Children's Hospital (BCCH) and supported by the Provincial Health Services Authority (PHSA) and the University of British Columbia (UBC). BCIRPU's vision is, *to be a leader in the production and transfer of injury prevention knowledge and the integration of evidence-based injury prevention practices into the daily lives of those at risk, those who care for them, and those with a mandate for public health and safety in British Columbia*.

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REFERENCES

1. Kanarek M. Mesothelioma from Chrysotile Asbestos: Update. *Annals of Epidemiology.* September 2011;21(9):688-697.
2. Bernstein D, Dunnigan J, Hesterberg T, Brown, R, Velasco JA, Barrera R, et al. Health risk of chrysotile revisited. *Critical Reviews in Toxicology.* 2013: 43(2): 154–183.
3. Berstein DM, Hoskins JA. The health effects of chrysotile: Current perspective based upon recent data. *Regulatory Toxicology and Pharmacology.* 2005: 45: 252-264
4. IARC Working Group on the Evaluation of Carcinogenic Risk to Humans. ASBESTOS (CHRYSOTILE, AMOSITE, CROCIDOLITE, TREMOLITE, ACTINOLITE AND ANTHOPHYLLITE). *International Agency for Research on Cancer.* 2012. Available from: https://www.ncbi.nlm.nih.gov/books/NBK304374/
5. The Mesothelioma Center. Types of Asbestos. Modified October 13, 2016. Visited on October 20, 2016. Available from: https://www.asbestos.com/asbestos/types/
6. Raymond B, Gauthier J, Desmeules M, Ostiguy G. Work-related mesothelioma in Quebec, 1967-1990. *American Journal of Industrial Medicine.* 1992:22(4): 521-542
7. Ross M, Nolan RP. History of asbestos discovery and use and asbestos-related disease in context with the occurrence of asbestos within ophiolite complexes. *Geological Society of America*. 2003. Special paper 373
8. Boffetta P. Human cancer from environmental pollutants: The epidemiological evidence. *Environmental Genotoxins in Children and Adults. 2006:*608(2): *157-162*
9. Offermans, N, Vermeulen, R, Burdorft A, Goldbohm RA, Kauppinen, T, Kromhout, H, van den Brandt PA. Occupational Asbestos Exposure and Risk of Pleural Mesothelioma, Lung Cancer and Laryngeal Cancer in the Prospective Netherlands Cohort Study. *Journal of Occupational and Environmental Medicine.* 2014: 56(1): 6-19
10. Smith AH, Ercument A, Yan Y, Steinmaus CM. Increased lung cancer risk are similar whether arsenic is ingested or inhaled. *Journal of Exposure Science and Environmental Epidemiology*. 2009:19, 343-348
11. Agudo A, González CA, Bleda MJ , Ramirez J, Hernandez S, Lopez F, et al. Occupation and risk of malignant pleural mesothelioma: a case-control study in Spain. *American Journal of Industrial Medicine*. 2000; 37(2): 159-168
12. The Mesothelioma Center. Asbestosis. Last updated October 10, 2016. Visited October 20, 2016. Available from: https://www.asbestos.com/asbestosis/
13. The Lung Association. Diseases: Asbestosis. Visited October 12, 2016. Available from: http://sct.poumon.ca/diseases-maladies/a-z/asbestosis-asbestose/index_e.php
14. The Canadian Cancer Society. Lung Cancer Statistics. Visited September 27, 2016. Available from: http://www.cancer.ca/en/cancer-information/cancer-type/lung/statistics/?region=on
15. Case BW. Asbestos, smoking, and lung cancer: interaction and attribution. *Occupational and Environmental Medicine.* August 2006: 63(8): 507-508
16. The Mesothelioma Center. Pleural Thickening and Asbestos. Visited October 12, 2016. Available from: https://www.asbestos.com/mesothelioma/pleural-thickening.php
17. Ahuja A, Gothi D, Amonkar G, Joshi JM. 25- Year Old Male with Pleural Thickening. *Lung India : Official Organ of Indian Chest Society.* 2008: 25(2): 82-84
18. Downer NJ, Ali NJ, Au-Yong IT. Investigating pleural thickening. *BMJ.* 2013: 346:e8376
19. Rudd R. Malignant mesothelioma. *Journal of the Royal Society of Medicine*. March 1989:82(3): 126-9

20. McDonald JC, McDonald AD. The epidemiology of mesothelioma in historical context. *European Respiratory Society*. 1996:9: 1932-1942

21. Rake C, GIlham C, Hatch J, Darnton A, Hodgson J, Peto J. Occupational, domestic and environmental mesothelioma risk in the British population: a case-control study. *British Journal of Cancer.* 2009: 100(7): 1175-83

22. Hodgson JT, McElvenny DM, Darnton AJ, Price MJ, Peto J. The expected burden of mesothelioma mortality in Great Britain from 2002 to 2050. *British Journal of Cancer*. 2005:92(3): 587-93

23. Markowitz S. Asbestos-related lung cancer and malignant mesothelioma of the pleura: selected current issues. *Seminars in Respiratory and Critical Care Medicine.* 2015:36: 334–346

24. Bianchi C, Giarelli L, Brollo A, Ramani L, Zuch C. Latency periods in asbestos-related mesothelioma of the pleura. European Journal of Cancer Prevention. 1997:6: 162-166

25. Lanphear BP, Buncher CR. Latent period for malignant mesothelioma of occupational origin. *Journal of Occupational Medicine.* July 1992: 34(7): 718-21

26. The Mesothelioma Center. Mesothelioma in Canada. Visited October 12, 2016. Available from: https://www.asbestos.com/mesothelioma/canada/

27. Canadian Environmental Health Atlas. Asbestos Production in Canada. Visited October 12, 2016 Available from: http://www.ehatlas.ca/asbestos/trends/asbestos-production-canada-0

28. McDonald JC. Mortality in Canadian Miners and Millers Exposed to Chrysotile. *Annals of the New York Academy of Sciences.* December 1979: 220: 1-9

29. Canadian Labour Congress. Asbestos in Canada: A Timeline. Visited October 12, 2016. Available from: http://canadianlabour.ca/asbestos-canada-timeline

30. Doll R. Mortality from Lung Cancer in Asbestos Workers. *British Journal of Industrial Medicine.* 1955:12: 81

31. Peto J, Rake C, Gilham C, Hatch J. Occupational, Domestic and Environmental Mesothelioma Risks in Britain: a case-control study. *British Journal of Cancer.* April 7 2009: 100(7): 1175-83

32. Alleman JE, Mossman BT. Asbestos Revisited. *Scientific American*. July 1997: 70-75

33. Dyer JS. An Asbestos Hazard Index for Managing Friable Asbestos Insulating Material. *Review of Policy Research.* May 1982: 1(4): 656-665

34. Infrastructure Health and Safety Association. Asbestos-Type 1 Operations (low risk). Retrieved on October 28, 2016. Available from: https://www.ihsa.ca/pdfs/safety_talks/asbestos_type_1_operations.pdf

35. Environmental Working Group Action Fund. Asbestos bans around the world. Retrieved on November 3, 2016. Available from: http://www.asbestosnation.org/facts/asbestos-bans-around-the-world/

36. Infrastructure Health and Safety Association. Asbestos-Type 2 Operations (medium risk). Retrieved on October 28, 2016. Available from: https://www.ihsa.ca/pdfs/safety_talks/asbestos_type_2_operations.pdf

37. WorkSafeBC. Safe Work Practice for Handling Asbestos. *Workers' Compensation Board of B.C.* 2012: 11, 45-53

38. World Health Organization. Asbestos: elimination of asbestos-related diseases. Last updated June 2016. Retrieved September 25, 2016. Available from: http://www.who.int/mediacentre/factsheets/fs343/en/

39. Marinaccio A, Binazzi A, Marzio DD, Scarselli A, Verardo M, Mirabelli D. Pleural malignant mesothelioma epidemic: incidence, modalitites of asbestos exposure and occupations involved from the Italian National Register. *International Journal of Cancer.* May 2012: 130(9): 2146-54

40. Jung SH, Kim HR, Koh SB, Yong SJ, Chung MJ, Lee CH, Han J, Eom MS, Oh SS. (2012) A decade a malignant mesothelioma surveillance in Korea. *American Journal of Industrial Medicine.* 55(10): 869-75

41. Boulanger G, Andujar, P, Pairon JC, Billon-Galland MA, Dion C, Dumortier P, et al. Quantification of short and long asbestos fibers to assess asbestos exposure: a review of fiber size toxicity. *Environmental Health.* 2014: 13:59

42. Musk A, Olsen N, Shilkin K, Threfall T, Reid A, Lee E, et al. Changing Pattern of Occupational Asbestos Exposure in People with Malignant Mesothelioma in Western Australia. *American Journal of Respiratory and Critical Care Medicine.* 2012: 17: 70

43. van Oyen SC, Peters S, Alfonso H, Fritschi L, de Klerk NH, Reid A, Franklin P, Gordon L, Benke G, Musk AW. Development of a Job-Exposure Matrix (AsbJEM) to Estimate Occupational Exposure to Asbestos in Australia. *The Annals of Occupational Hygiene.* 2015: 59(6): 737-48

44. Villeneuve PJ, Parent ME, Harris SA, Johnson KC, The Canadian Cancer Registries Epidemiology Research Group. *BMC Cancer. 2012:*12: 595

45. The Mesothelioma Center. Asbestos Exposure. Last updated September 15, 2016. Retrieved September 30, 2016. Available from: https://www.asbestos.com/exposure/

46. Robinson BM. Malignant pleural mesothelioma: an epidemiological perspective. *Annals of Cardiothoracic Surgery.* November 2012: 1(4): 491-496

47. Corfiati M, Scarselli A, Binazzi A, Di Marzio D, Verardo M, Mirabelli D, et al. Epidemiological patterns of asbestos exposure and spatial clusters of incent cases of malignant mesothelioma from the Italian national registry. *BMC Cancer.* 2015:15: 286

48. Carey RN, Driscoll TR, Peters S, Glass DC, Reid A, Benke G. Estimated prevalence of exposure to occupational carcinogens in Australia (2011-2012). *Occupational and Environmental Medicine.* January 2014:71(1): 55-62

49. Roggli VL, Sharma A, Butnor KJ, Sporn T, Vollmer RT. Malignant mesothelioma and occupational exposure to asbestos: a clinicopathological correlation of 1445 cases. *Ultrastructural Pathology.* March-April 2002:26(2): 55-65

50. Rushton L, Bagga S, Bevan R, Brown TP, Cherrie JW, Holmes P. Occupation and cancer in Britain. *British Journal of Cancer.* April 27 2010: 102(9): 1428-37

51. Salehpour S, Azin SA, Cheraghvandi A, Heidari MM, Saadeghi SMM. Occupational and environmental determinants of exposure to asbestos in malignant mesothelioma cases. *European Respiratory Jounral.* 2011: 38: 1067

52. Romeo E, Ascoli V, Ancona L, Balestri A, Scalzo CC, Cavariani F. Occupational exposure to asbestos and incidence of malignant mesothelioma in the Lazio region, years 2001-2009: results of the activities of the regional register. *La Medicina del Lavoro.* March-April 2013:104(2): 115-125

53. Yenugadhati N, Birkett NJ, Momoli F, Krewski D. Occupations and lung cancer: a population-based case-control study in British Columbia. *Journal of toxicology and environmental health.* 2009:72(10): 658-75

54. Gilham C, Rake C, Burdett G, Nicholson AG, Davison L, Franchini A, et al. Pleural mesothelioma and lung cancer risks in relation to occupational history and asbestos lung burden. *Occupational and environmental medicine.* May 2016:73(5): 290-9

55. Fazzo L, De Santis M, Minelli G, Bruno C, Zona A, Marinaccio A, Conti S, Comba P. Pleural mortality and asbestos exposure mapping in Italy. *American Journal of Industrial Medicine.* January 2012:55(1): 11-24

56. Khatab K, Felten MK, Kandala NB, Ghilagaber G, Gumber A, Kraus T. Risk factors associated with asbestos-related diseases: results of the asbestos surveillance programme aachen. *EMJ.* December 12, 2004

57. Pintos J, Parent ME, Case BW, Rousseau MC, Siemiatychi J. Risk of mesothelioma and occupational exposure to asbestos and man-made vitreaous fibers: evidence form two case-control studies in Montreal, Canada. *Journal of Occupational and Environmental Medicine.* October 2009:51(10): 1177-84

58. Statistics Canada, Canadian Socio-Economic Information Management System. *Table 103-0550 -New cases of primary cancer (based on the August 2015 CCR tabulation file), by cancer type, age group and sex, Canada, provinces and territories, annual,* CANSIM (database). Last updated March 15, 2016. Retrieved on October 28, 2016

59. Government of Canada. Canada Consumer Product Safety Act. S.C. 2010, c.21. Last updated on October 23, 2014. Retrieved on November 11, 2016. Available from: http://laws-lois.justice.gc.ca/eng/acts/C-1.68/

60. Government of Canada. Asbestos Mines and Mills Release Regulations. SOR/90-341. Last updated on November 7, 2016. Retrieved on November 11, 2016. Available from: https://www.ec.gc.ca/lcpe-cepa/eng/regulations/detailReg.cfm?intReg=56

61. Canadian Environmental Law Association. Asbestos: FAQ's. January 11, 2012. Retrieved on September 7, 2016.

62. Government of Canada. Asbestos in Public Services and Procurement Canada-owned buildings. Last updated on August 31, 2016. Retrieved on September 9, 2016. Available from: http://www.tpsgc-pwgsc.gc.ca/biens-property/amiante-asbestos-eng.html

63. Canadian Centre for Occupational Health and Safety. Asbestos- Control Strategies for Workplaces. Last modified November 11, 2016. Retrieved on November 11, 2016. Available from: http://www.ccohs.ca/oshanswers/chemicals/asbestos/control.html

64. WorkSafeBC. Part 06 Substance Specific Requirements: Asbestos. Retrieved on November 11, 2016. Available from: https://www.worksafebc.com/en/law-policy/occupational-health-safety/searchable-ohs-regulation/ohs-regulation/part-06-substance-specific-requirements

65. International Labour Office, Geneva. Safety in the use of asbestos. 1984. Retrieved on November 10, 2016.

66. International Labour Office. The ILO position on safety in the use of asbestos. Retrieved on November 10, 2016. Available from: http://www.ilo.org/safework/areasofwork/occupational-health/WCMS_360580/lang--en/index.htm

67. Nishikawa K, Takahashi K, Karjalainen A, Wen CP, Furuya S, Hoshuyama T, et al. Recent Mortality from Pleural Mesothelioma, Historical Patterns of Asbestos Use, and Adoption of Bans: A Global Assessment

68. Australian Government, National Occupational Health and Safety Commission. Code of Practice for the Management and Control of Asbestos in the Workplace. *Canberra: April 2005.*

69. Work Safe New Zealand. Asbestos. Retrieved on October 22, 2016. Available from: http://www.worksafe.govt.nz/worksafe/information-guidance/guidance-by-hazard-type/asbestos

70. Ministry of Business, Innovation, and Employment, New Zealand Government. Health and Safety at Work (Asbestos) Regulations 2016. February 2016.

71. ANSES. ANSES- French Agency for Food, Environmental and Occupational Health and Safety-Asbestos. Last updated on August 4, 2016. Retrieved on September 15, 2016. Available from: https://www.anses.fr/en/content/asbestos

72. European Agency for Safety and Health at Work. Safe Maintenance- Asbestos in Building Maintenance. Retrieved on September 15, 2016. Available from: http://osha.europa.eu

73. Hwang SH, Park WM. Evaluation of asbestos-containing products and released fibers in home appliances. *Journal of the Air & Waste Management Association.* 2016:66(9): 922-929

74. Health and Safety Executive. Asbestos Health and Safety: Control of Asbestos Regulations 2012. Retrieved on September 8, 2016. Available from: http://www.hse.gov.uk/asbestos/regulations.htm
75. Goldberg M, Luce D. The health impact of nonoccupational exposure to asbestos: what do we know? *European Journal of Cancer Prevention.* November 2012:18(6): 489-503
76. Goswami E, Craven V, Dahlstorm DL, Alexander D, Mowat F. Domestic Asbestos Exposure: A Review of Epidemiologic and Exposure Data. *International Journal of Environmental Research and Public Health.* November 2013:10(11): 5629-5670
77. Boffetta P. Health effects of asbestos exposure in humans: a quantitative assessment. *La Medicina del Lavoro.* November- December 1998:89(6):471-480
78. National Cancer Institute. Asbestos Exposure and Cancer Risk. Updated May 1, 2009. Retrieved on September 29, 2016. Available from: https://www.cancer.gov/about-cancer/causes-prevention/risk/substances/asbestos/asbestos-fact-sheet
79. Hansen J, de Klerk NH, Musk AW, Hobbs MST. Environmental Exposure to Crocidolite and Mesothelioma. *American Journal of Respiratory and Critical Care Medicine.* January 1998:157(1)
80. Antman KH. Natural history and epidemiology of malignant mesothelioma. *Chest.* April 1993:103(4): 373S-376S
81. Pan XL, Day HW, Wang W, Beckett LA, Schenker MB. Residential proximity to naturally occurring asbestos and mesothelioma risk in California. *American Journal of Respiratory and Critical Care Medicine.* October 2015:172(8): 1019-1025
82. Doll R, Peto J. Asbestos: Effects on health of exposure to asbestos. *Health and Safety Commission:HMSO*: London. 1985
83. Markowitz S. Asbestos-related lung cancer and malignant mesothelioma of the pleura: selected current issues. *Seminars in Respiratory and Critical Care Medicine.* June 2015:36(3): 334-346
84. Stayner L, Smith R, Bailer J, Gilbert S, Steenland K., Dement J, et al. Exposure-response analysis of risk of respiratory disease associated with occupational exposure to chrysotile asbestos. *Occupational and Environmental Medicine*. 1997:54(9): 646–652.
85. Rödelsperger K, Jöckel KH, Pohlabeln H, Römer W, Woitowitz HJ. Asbestos and man-made vitreous fibers as risk factors for diffuse malignant mesothelioma: results from a German hospital-based case-control study. *American Journal of Industrial Medicine*. 2001:39(3): 262-275
86. Hillerdal G. Mesothelioma: cases associated with non-occupational and low dose exposures. *Occupational and Environmental Medicine.* August 1999:56(8)L 505-13
87. Meisenkothen C. The four most pernicious myths in asbestos litigation: Part II: safe thresholds for exposure and Tyndall lighting as junk science. *New Solutions.* 2014:24(1): 27-55
88. Hughes HM, Weill H. Asbestos exposure- quantitative assessment of risk. *The American Review of Respiratory Disease.* January 1986:133(1):5-13
89. Lacourt A, Gramond C, Rolland P, Ducamp S, Audignon S, Astoul P. Occupational and non-occupational attributable risk of asbestos exposure for malignant pleural mesothelioma. *Thorax.* 2014:69:532-9
90. Ferrante D, Mirabelli D, Tunesi S, Terracini B, Magnani C. Pleural mesothelioma and occupational and non-occupational asbestos exposure: a case-control study with quantitative risk assessment.
91. York University. York University Asbestos Air Sampling Protocol. June 14, 2006. Retrieved on October 29, 2016.
92. Finnish Institute of Occupational Health. Asbestos, Asbestosis, and Cancer: Helsinki Criteria for Diagnosis and Attribution 2014. Retrieved on October 22, 2016.

93. Browne, K. (1986). A threshold for asbestos-related lung cancer. *British Journal of Industrial Medicine*, *43*(8), 556–558.

94. Peterson MW. Analysis of the Asbestos Permissible Exposure Level Threshold Standard. *Thesis: Naval Postgraduate School.* June 1991

95. Browne K. Is asbestos or asbestosis the cause of the increased risk of lung cancer in asbestos workers? *British Journal of Industrial Medicine.* March 1986:43(3):145-149

96. Kirkham, T.L., Koehoorn, M.W., McLeod, C.B., Demers, P.A. Surveillance of mesothelioma and workers' compensation in British Columbia, Canada. Occupational and Environmental Medicine, 2011; 68(1): 30-35.

97. Fritschi L, Friesen MC, Glass D, Benke G, Girschik J, Sadkowsky T. OccIDEAS: Retrospective Occupational Exposure Assessment in Community-Based Studies Made Easier. *Journal of Environmental and Public Health.* 2009: ID957023: 5

98. Canadian Centre for Occupational Health and Safety. Asbestos- Control Strategies for Workplaces. Retrieved on October 22, 2016. Last updated on October 20, 2016. Available from: http://www.ccohs.ca/oshanswers/chemicals/asbestos/control.html

99. Kazan-Allen. Chronology of National Asbestos Bans. Retrieved on December 14, 2016. Available from: http://www.ibasecretariat.org/chron_ban_list.php

100. The Mesothelioma Center. Asbestos Lung Cancer. Last updated on November 14, 2016. Retrieved on December 15, 2016. Available from: https://www.asbestos.com/cancer/lung-cancer/

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