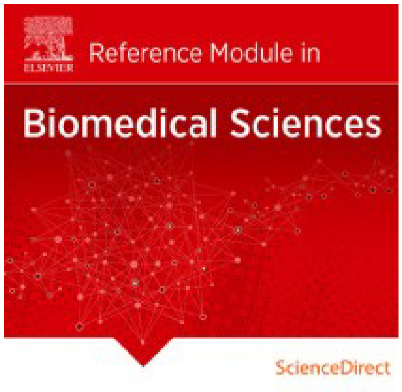

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Asbestos☆

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Introduction

Asbestos, although recognized as a curiosity and occasionally used since ancient times, was not exploited commercially until the industrial revolution in Europe and North America. Widespread use began in the twentieth century, with primary consumption occurring in countries with robust manufacturing sectors. As knowledge of the health consequences of asbestos exposure became widespread, use has been restricted or banned in many countries. Nevertheless, exposure in these countries continues during repair or removal of insulation and other asbestos-containing materials (ACM) (Landrigan and Kazemi, 1991). In addition, asbestos continues to be marketed and promoted for use in countries with few restrictions, thus raising the possibility of a continuing epidemic of serious disease among exposed workers and residents. In a growing movement 55 countries around the world have banned asbestos' further use (Kazan-Allen, 2014). Additionally one of the major producers of asbestos, Canada, has ceased all production as of 2012. Now the only major producers are Russia, China, Kazakhstan, and Brazil (USGS, 2013). The impact of asbestos on the World's health has been described as pandemic. The World Health Organization estimates that 107,000 people worldwide die each year from mesothelioma, lung cancer and asbestosis (Stayner et al., 2013).

Fiber Types

Traditionally commercial fibers known as asbestos have been classified based on chemical composition, physical properties, and appearance (**Table 1** and **Figure 1**).

All asbestos fiber types have been found to cause all major types of asbestos-related disease (Dupre et al., 1984; IPCS, 1998; IARC, 1977; IARC, 2012; IOM, 2006; WHO, 2006). In reality, most asbestos use involves either intentional mixing of different fiber types or inadvertent contamination of a fairly pure product with small quantities of another. For the discussion that follows, and for practical purposes, the single term 'asbestos' will be used to refer to naturally occurring inhalable, durable, bio-persistent fibers conferring disease risk to people exposed at work or in the general environment.

Exposure Settings

Occupational

The industries and occupations associated with asbestos exposure vary with the industrial profile of a region or country. Exposure occurs in the mining and milling of asbestos and of other minerals if they are contaminated with asbestos (**Figure 2**). Workers involved in the manufacture of any asbestos-containing materials such as pipes, roofing, friction materials, or cloth may be exposed during many points in the manufacturing process or while maintaining or cleaning plant or equipment.

☆*Change History:* August 2014. G Wagner and R Lemen separated out an abstract and have utilized and referenced updated and new scientific studies and policy papers. They have made minor text modifications and additions throughout to reflect the new studies and to add clarity.

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Table 1 Main commercial forms of asbestos

Category	*Name*	*Primary uses*	*Notes*
Amphibole	Anthophyllite $(Mg,Fe)_7Si_8O_{22}(OH)_2$	Insulation	Found primarily in Finland; no mining, marketing, or new use since 1974
Amphibole	Amosite $(Mg,Fe)Si_8O_2(OH)_2$	Asbestos-cement sheets (construction) thermal insulation roofing products	Known as brown asbestos
Amphibole	Crocidolite $NaFe_{32}Fe_{23}+Si_8O_{22}(OH)_2$	Ship insulation	Blue asbestos
Amphibole	Tremolite (tremolite-actinolite) $Ca_2Mg_5Si_8O_{22}(OH)_2$	Whitewash	Frequent contaminant of chrysotile, vermiculite, or talc; stronger association with mesothelioma than lung cancer
Serpentine	Chrysotile $MgSi_2O_5(OH)_2$	Woven materials; friction products; insulation; asbestos cement	'White asbestos'; 95% of asbestos used; finer and more flexible than amphiboles

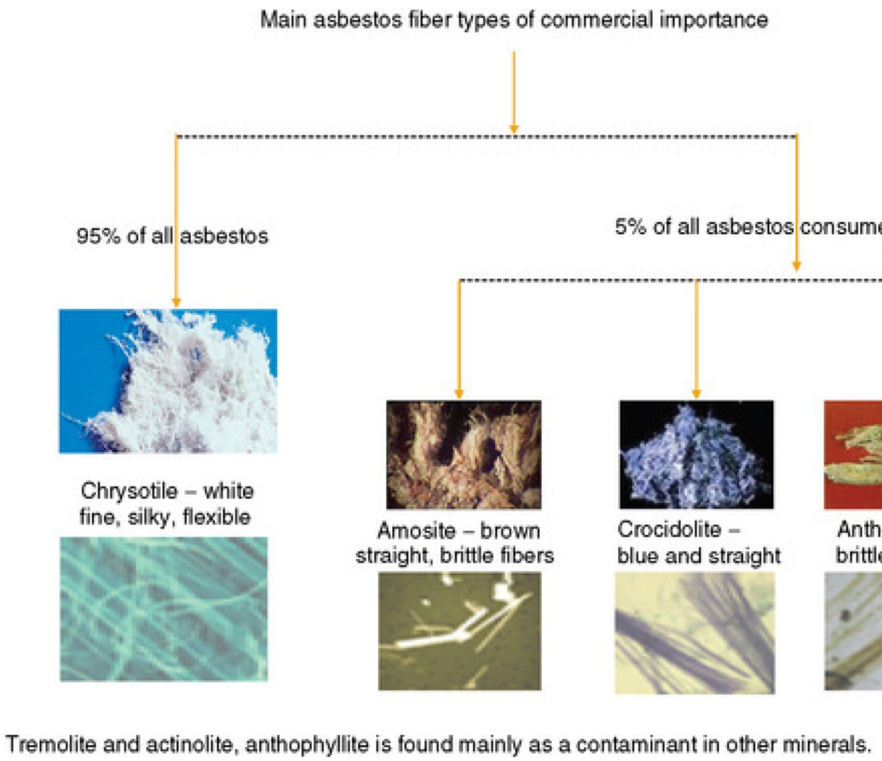

Figure 1 Asbestos fiber types of commercial importance.

Figure 2 Modern asbestos mine in Russia (NIOSH).

The application of asbestos for pipe or structural insulation has been the source of significant exposure both to the primary insulator and to bystanders. Thus not only insulators but also workers identified as pipe fitters, plumbers, and sheet metal workers have had documented disease from their occupational exposures. Any maintenance or repair workers involved in processes requiring the removal of asbestos-containing materials may be at risk. For example, pipe or boiler repair or replacement in a chemical plant may require removal of asbestos insulation and attendant exposure.

People working in proximity to others engaged in asbestos removal are at risk. For example, anyone working in railroad steam engine repair shops had potential asbestos exposure even if they were not directly involved in removal or application of asbestos 'lagging.' This was also true for workers in the general vicinity of insulation workers in other industries. Other trades with exposure to asbestos that have been studied include boilermakers; bakers; brake repairers; installation workers; bricklayers and mason; carpenters; custodial workers, laborers, and maintenance workers; decorators; electricians; jewelers; mechanics; merchant seamen; painters; petrochemical workers; plasterers and drywall workers; plumbers and pipefitters; power plant workers; railroad workers including steam engine repair personnel; roofers; rubber workers; shipyard workers; smelter workers; school teachers; steel workers; sulfate mill workers; and welders (Lemen, 2011).

Home

Family members of people with occupational exposure to asbestos may also experience exposure as the workers 'take home' asbestos that clings to the clothing or hair. Documented cases of asbestos-related diseases have occurred when the only apparent exposure has been shaking and laundering of the clothing of an exposed worker (Lemen, 2011; NIOSH, 1995).

Asbestos exposure may occur in homes as asbestos-containing construction materials such as pipe insulation, gaskets, and duct insulation deteriorate or need to be repaired or replaced. Consumer products such as hair driers, ironing board covers, and in one-instance cigarette filters have been documented to contain asbestos. People who maintain their own automobiles may be exposed during replacement of asbestos containing brakes pads. Vermiculite mined in Libby, Montana, that was used widely as loose-fill home insulation in the United States and elsewhere was contaminated with asbestos, creating risk not only to the residents of the mining area but to the users of the contaminated vermiculite when used for insulation. Restrictions in the use or labeling of asbestos in consumer products have varied over time and by jurisdiction, so exposure may occur without the knowledge needed for control.

Environmental Asbestos Exposure

Noncommercial environmental exposure to durable fibers conferring risk of asbestos-related diseases has been documented in regions of Turkey, where erionite is naturally occurring (Baris et al., 1988). This fibrous mineral has been used in whitewash and has resulted in high rates of characteristic diseases. Other minerals such as winchite and richterite, as well as tremolite asbestos, contaminated most of the vermiculite mined in the United States and contaminated the community surrounding the mining and milling operations. There has also been concern about disease risk in communities adjacent to quarries where small quantities of asbestos contaminate the mined minerals (Pan et al., 2005).

Diseases and Conditions from Asbestos Exposure

Asbestosis

Asbestosis is a chronic lung disease caused by the inhalation of asbestos fibers, characterized by diffuse interstitial parenchymal fibrosis (**Figure 3**). Asbestosis is frequently associated with pleural fibrosis or pleural calcification. Radiographic changes are usually small irregular opacities occurring mainly in the lower and middle lung fields. Pulmonary fibrosis usually develops slowly over years; radiographic detection is a direct correlate of the extent and profusion of fibrosis. In some cases, minor fibrosis with considerable respiratory impairment and disability can be present. Pulmonary hypertension may be associated with advanced asbestosis and in severe cases cor pulmonale (right-sided heart failure) may be a cause of death. Asbestosis is a progressive disease even after exposure has ceased. Individuals diagnosed with pulmonary asbestosis are at a higher risk of developing and dying of cancer. Most researchers believe that the probability of developing asbestosis is linearly related to cumulative exposure to asbestos. Asbestosis is generally recognized based on an abnormal radiograph consistent with asbestosis in an individual with a plausible history of asbestos exposure ten or more years previously with no more compelling alternate explanation for the X-ray changes (ATS, American Thoracic Society, 2004). An international method of classifying radiographs distributed by the International Labour Organization (ILO, 2011) is helpful in recognizing and classifying abnormalities; however, upwards of 18% of individuals with pathologically determinable fibrosis will have chest radiographs classified as showing no clear asbestosis (Kipen et al., 1987). The classification system has recently been updated to enable use of digital radiography for recognition and classification of pneumoconiosis.

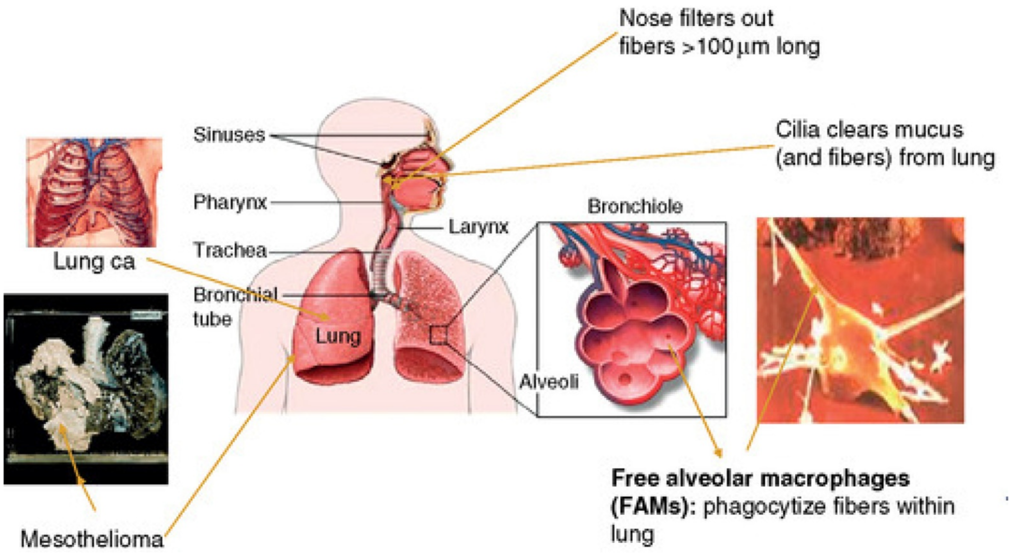

Figure 3 What happens to asbestos in the respiratory system.

Pleural Disease

Asbestos exposure can cause abnormal discrete or diffuse thickening of the lining of the chest wall or the lung or the dome of the diaphragm. These areas of thickening or plaques may become calcified. Pleural plaques, with or without calcification, are frequently bilateral and situated on the parietal pleura. Plaques are often the first indication of response to asbestos exposure, preceding fibrosis, and may or may not be associated with abnormal symptoms such as breathlessness or loss of lung function. Although plaques themselves are usually harmless, they indicate sufficient latency for the occurrence of asbestos-induced cancers. There is evidence that persons with pleural plaques are more likely to develop asbestos-induced parenchymal fibrosis than those without such plaques (Rosenstock, 1994). Individuals with asbestos-induced pleural plaques are at a markedly increased risk of developing and dying of lung cancer or malignant mesothelioma (Cullen et al., 2005; Edge, 1976; Fletcher, 1972).

In populations without exposure to naturally occurring asbestos in the environment, 80–90% of plaques found at autopsy are due to occupational exposures, including those with low-level exposure. People with pleural plaques in general have lower lung function.

Pleural effusions may also be an early indication of a response to asbestos exposure. Effusions often resolve spontaneously but may leave a residual diffuse pleural thickening that, itself, may be associated with abnormal chest symptoms and reduced pulmonary function.

Lung Cancer

Asbestos exposure increases the risk for all histological types of lung cancer (IARC, 2012; Karjalainen, 1994). Both those with asbestos exposure and also those with asbestosis have risks of lung cancer higher than found in the general population not exposed to asbestos (Broderick et al., 1992; Markowitz et al., 2013). Asbestosis is not a necessary precursor to lung cancer, but both asbestosis and lung cancer are diseases that increase as exposure to asbestos increases (Abraham, 1994; Jones et al., 1996; McDonald et al., 1994; Roggli et al., 1994). Thus workers with asbestosis are more likely to have lung cancer than those without visible fibrosis, although both have increased risk proportional to their asbestos exposure (Markowitz et al., 2013; Morinaga et al., 1993).

Lung cancer risk in asbestos workers who also smoke tobacco products is substantially greater than the risk from asbestos exposure alone. An analysis of 23 studies on asbestos exposure and smoking shows that asbestos multiplies the risk of lung cancer in nonsmokers and smokers by a similar factor and that risk resulting from exposure to both asbestos and smoking can be best described by a multiplicative rather than an additive model (Lee, 2001). One of the largest cohorts of asbestos workers to demonstrate this is that of the North American insulators studied by Selikoff and Hammond in the 1960s. They reported that when 12 051 insulation workers with more than 20 years of work experience were compared to a control population from the American Cancer Society cohort of 73,763 men with known smoking history, the relative risk of lung cancer (RR) went from 1 in the nonsmoking control group to 5.17 in nonsmoking asbestos workers to 10.85 in smokers without asbestos exposure up to 53.24 for smoking asbestos insulation workers (Hammond et al., 1979).

Efforts have been made to assess the relationship between fiber exposures over time with increase in lung cancer risk. In West Germany, a case–control study reported a doubling of lung cancer risk with 25 fiber-years of exposure. Other studies have shown elevated risk at lower levels of exposure (Gustavsson et al., 2002; Stayner et al., 1997). There is evidence of an increased number of multiple primary cancers at the same time among those exposed to asbestos compared with the general population (Selikoff and Hammond, 1979). Nevertheless, the overall poor prognosis in lung cancer outcome has meant that the prognosis and treatment of asbestos-induced lung cancer is no different than lung cancer having another etiology. It appears that all cell types of lung cancer can occur in asbestos workers and that the presence or absence of one cell type cannot be used to prove or disprove an association of asbestos exposure with the lung cancer (Churg, 1985).

Since 1997, asbestos has been the leading cause of occupationally induced lung cancer in Japan (Morinaga et al., 2001). The World Health Organization has estimated that worldwide 107,000 lung cancers, mesotheliomas, and asbestosis deaths are attributable to occupational asbestos exposure annually. As tobacco use declines, the percentage of lung cancers attributable to asbestos exposure in areas where asbestos is in use will climb.

Mesothelioma

Mesothelioma is a cancer of the mesothelium, the thin lining that covers the major internal organs of the body. The rarity of this tumor and its strong association with asbestos exposure make it a 'signal tumor,' that is, it is considered an epidemiological marker for exposure to asbestos (Mullan and Murthy, 1991; Roggli et al., 1992). Although pleural tumors were recognized in the late nineteenth century, modern concepts concerning the pathology and diagnosis of mesothelioma were set forth in 1931 by Kemperer and Rabin (Klemperer and Rabin, 1931). An exposure–response relationship for mesothelioma was first demonstrated among textile workers exposed to asbestos and then subsequently among gas mask workers, miners and millers, and shipyard workers (Hobbs et al., 1979; Jones et al., 1979; Newhouse and Berry, 1976; Sheers and Coles, 1980).

Mesothelioma is reported in almost every major study of people exposed to asbestos. Pleural mesothelioma incidence has been increasing in all asbestos-using countries despite control measures put in place since the 1970s (McDonald and McDonald, 1981). Peritoneal mesothelioma is a much rarer tumor than pleural. The U.S. National Institute for Occupational Safety and Health, in conjunction with the National Center for Health Statistics, reports between 1987 and 1996 that various occupational groups had extremely elevated proportionate mortality ratios (PMR) for pleural malignancies such as insulation workers at 23.08 (95% CI 1059–43.80); boilermakers at 15.37 (95% CI 7.68–27.50); plasterers 11.61 (95% CI 3.76–27.13); sheet metal workers 10.35 (95% CI 6.55–15.54); plumbers, pipe fitters, and steamfitters 7.02 (95% CI 5.12–9.40), as well as 13 other specific occupations with PMRs of 2 or greater. They also report elevations in several industries, including ship and boat building and repairing, with a PMR for pleural tumors of 12.60 (95% CI 8.75–17.52) and petroleum refining with a PMR of 5.76 (95% CI 3.29–9.35). Another 15 industries also had PMRs over 2 (NIOSH, 1999).

Among the large occupationally exposed groups studied, approximately 5–10% of deaths have been due to mesothelioma (Lemen, 2006; Lemen, 2011). After initial exposure to asbestos, risk of both pleural and peritoneal mesothelioma increase over time, even after cessation of exposure (Reid et al, 2014).

Death-certificate-derived data generally underestimate mesothelioma mortality, as there has not been a unique *International Classification of Diseases* (ICD) code to allow adequate coding for mortality analysis until recently. As countries adopt the tenth revision of the ICD (ICD-10) with unique codes for pleural and peritoneal mesothelioma, recording of mesothelioma as a cause of death will become more accurate.

The association of mesotheliomas with recollection of asbestos exposure is very high, generally over 80%. Where exposure has not been recognized on initial questioning, careful follow-up often identifies a past exposure. In Scotland, only 5% of people with mesotheliomas gave no history of asbestos exposure, but in other studies up to 23% have not recalled exposure (Lemen, 2006; Lemen, 2011).

Since mesotheliomas are so closely associated with asbestos exposure and lung cancers from asbestos are indistinguishable from those caused by other exposures such as tobacco or other carcinogens, the ratio of mesotheliomas to increased lung cancers is of interest in assessing the overall disease burden from asbestos use. The ratio of mesotheliomas to lung cancers varies by cohort studied. One review found estimates of excess lung cancers to mesothelioma between 0.3 and 18.5, with most in the range of 2 to 4 (McDonald and McDonald, 1981). Between 1995 and 2000 the ratio for lung cancer attributed to asbestos exposure to mesothelioma reported in Germany was 1.24:1 (Henderson and Leigh, 2011). The ratios reported depend on the criteria used to determine what lung cancers are deemed asbestos-related.

Asbestos is a complete carcinogen in that it can both initiate and promote cancer. The persistence of fibers in the body following exposure lend credence to concerns of continuing exposure-related cancer risk after exposure cessation (Tomatis et al., 2007).

Other Cancers

A recent comprehensive review of scientific literature concerning malignant diseases associated with asbestos exposure concluded that in addition to lung cancer and mesothelioma, asbestos exposure causes laryngeal cancer and perhaps gastrointestinal cancers. The review panel found that some other cancers such as kidney cancer were inconsistently associated with asbestos and the evidence was inadequate to confirm this relationship (National Research Council, 2006).

Despite the panel findings, and because of the diversity of studies in the scientific literature, controversy remains concerning the possible association of asbestos exposure with gastrointestinal tract cancers. Studies show a range of relative risk from 0.5 (Edge, 1976) to 3.1 (Mancuso and El-Atar, 1967; Selikoff, 1974). Reports of gastrointestinal tract cancers associated with asbestos exposure have been reviewed by the World Health Organization (WHO); they have concluded that "overall, there seems that

Figure 4 Refugee housing in the Philippines with asbestos cement roof (photo by R. Lemen).

Figure 5 Shipbreaking in Chittagong, Bangladesh's largest port. Source: Photo by Edward Burtynsky and Brendan Corr (ArkiBlog-info@arkiblog.net).

there is a correlation between lung cancer and gastrointestinal cancer rates in occupational cohorts [exposed to asbestos] which is not due to chance" (WHO, 1989).

Prevention Strategies

There is a clear linear relationship between national consumption of asbestos and mesothelioma incidence. Use of an average of 2.8 kg of asbestos per capita can be expected to cause about 22 mesothelioma cases/million or about 130 tons of asbestos will cause one death from pleural or peritoneal mesothelioma (Tossavainen, 2005). Most of the asbestos used worldwide is in the production of asbestos-cement products along with other major uses including friction material, gaskets, floor tiles, insulation boards, and textiles (Tossavainen, 2005). Asbestos-cement roofing is in common use in developing countries (**Figure 4**).

Although mesothelioma is the disease of most interest in Western Europe and North America, asbestosis is still a disease of concern in developing countries where uncontrolled exposures to asbestos continue to occur.

Shipbreaking – the industry that demolishes old ships for scrap metal and recyclable parts – is of particular concern, since the average ship contains 6 tons of asbestos (**Figure 5**). Shipbreaking often takes place in low-resource countries such as Bangladesh and is often not covered by labor laws. Child labor and high exposures are not uncommon. The ILO has prepared safety and health guidelines for shipbreaking (ILO, 2003). These guidelines point out that the waste from such ship breaking can also carry a risk to the communities where the waste is deposited.

Public health advocates have called for bans on mining, importation, and new use of asbestos as the only effective way to prevent future health effects. Noting that lung cancers and mesotheliomas have resulted from low levels of asbestos exposure, the WHO recommends cessation of use of asbestos. With this recommendation they also not that approximately 125 million are still occupationally exposed to asbestos throughout the world (WHO, 2014).

Even in the absence of new use, extreme care must be taken in work processes that involve contact with existing asbestos-containing materials. Traditional occupational hygiene measures include isolation of any areas where asbestos fibers may be liberated, wet methods of dust suppression, enclosure of all friable materials, continual environmental monitoring, aggressive workplace hygiene, and separate changing facilities and on-site disposal or laundry for potentially contaminated work clothes. Nevertheless, these measures, even if combined with labeling both asbestos-containing materials and work areas where asbestos may be liberated, can only reduce but not eliminate risk. Workers who must contact airborne asbestos fibers should be educated about the hazard and trained in the means to control risk. They should wear properly fitting respirators providing a high level of protection as part of an ongoing respiratory protection program. Exposed workers should be offered ongoing medical monitoring. Asbestos-containing materials that have been removed from their original use must be enclosed and disposed of in a manner that avoids additional human exposure and environmental contamination.

In general, the kinds of aggressive programs needed to reduce risk from asbestos are extremely expensive, require a fair level of technical sophistication, and are difficult to sustain, thus arguing for elimination of new use whenever possible.

Disclaimer: The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health, or The Rollins School of Public Health.

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Relevant Website

http://www.ilo.org – International Labour Organization.