The Worldwide Pandemic of Asbestos-Related Diseases

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Abstract

Background: Asbestos-related diseases are still a major public health problem. The World Health Organization (WHO) has estimated that 107,000 people worldwide die each year from mesothelioma, lung cancer, and asbestosis. We review what is known about asbestos use, production, and exposure and asbestos-related diseases in the world today, and we offer predictions for the future. Although worldwide consumption of asbestos has decreased, consumption is increasing in many developing countries. The limited data available suggest that exposures may also be high in developing countries. Mesothelioma is still increasing in most European countries and in Japan but has peaked in the United States and Sweden. Although the epidemic of asbestos-related disease has plateaued or is expected to plateau in most of the developed world, little is known about the epidemic in developing countries. It is obvious that increased asbestos use by these countries will result in an increase in asbestos-related diseases in the future.

INTRODUCTION

IARC: International Agency for Research on Cancer

The usefulness of asbestos as an insulating material was recognized by the Egyptians and mentioned by Pliny in Roman times, but large-scale production of asbestos began only in the late nineteenth century (36). Asbestos is a term that has been used to describe a group of six commercially available silicate minerals with fibers that are generally long, thin, and flexible when separated. Asbestos fibers are classified into two types: serpentine and amphiboles. Serpentine asbestos is curly, whereas amphibole fibers are straight. Chrysotile is the only serpentine form of asbestos. The amphibole fibers that have been marketed in the past include crocidolite (riebeckite), amosite (cummingtonite-grunerite) and anthophyllite, tremolite asbestos, and actinolite asbestos. More than 90% of asbestos mined in the past century was chrysotile asbestos, and chrysotile presently accounts for more than 99% of production worldwide (41).

All forms of asbestos have been judged to be carcinogenic by the World Health Organization's International Program on Chemical Safety (22) and International Agency for Research on Cancer (19), and in the United States by the Environmental Protection Agency (12), the National Institute for Occupational Safety and Health (40), and the National Toxicology Program (42). The carcinogenicity of asbestos was reviewed most recently by a group of scientists at an International Agency for Research on Cancer (IARC) meeting in March 2009. The group concluded that all forms of asbestos (chrysotile, crocidolite, amosite, tremolite, actinolite, and anthophyllite) are associated with an increased risk of mesothelioma and lung, laryngeal, and ovarian cancers (21, 56).

It may seem peculiar to some readers that asbestos is the subject of this review, given that we have known about the hazards associated with asbestos use for many years. The first clinically recorded case of asbestos-induced lung disease, later known as asbestosis, was reported in London, in a 33-year-old man who worked in an asbestos textile plant for 14 years, by a Charing Cross Hospital physician Dr. M. Murray in 1906 (39). Numerous deaths (~50) were also reported in a French asbestos textile factory [Auribault 1906 cited in (54)]. Italian physicians reviewed the cases of 30 asbestos workers who had lung disease, seen in a Turin clinic, between 1894 and 1906 [Scarpa 1908 cited in (54)]. The name asbestosis was first applied in the medical literature to a case of lung fibrosis in a 33-year-old female asbestos textile worker published in 1927 (7). The first epidemiologic study of asbestos textile workers published on March 14, 1930, by Merewether & Price, both with the UK Government Home Office, established general causation between asbestos exposure and the lung disease asbestosis (37).

The first suspicion that asbestos exposure caused lung cancer came from Lynch & Smith (30) in the United States and Gloyne (13) in the United Kingdom, who reported three cases of lung cancer detected during autopsy studies of asbestos workers who had asbestosis. Sir Richard Doll published the first formal epidemiologic cohort study that demonstrated a large excess (11 observed versus 0.8 expected) of lung cancer among asbestos factory workers in Great Britain (10). The first persuasive report of a causal link between mesothelioma and asbestos was made in 1960 by Wagner, who identified 33 mesothelioma cases in individuals many of whom had either worked or lived in the vicinity of a South African crocidolite mine (64). A few years later, epidemiology studies confirmed mesothelioma's causal relationship to asbestos, first, with a study of a manufacturing plant in Ohio by Mancuso & Coulter (32) and, second, with a study of insulation workers by Selikoff and coworkers (53).

Sir Richard Doll in his landmark study in 1955 questioned, "Whether the specific industrial risk of lung cancer has yet been completely eliminated cannot be determined with certainty," owing to regulations that were instituted in 1931 (10). Studies since 1955 have demonstrated that the 1931 regulations did not eliminate the risk of cancer from asbestos, and

unfortunately, despite subsequent changes in regulatory and other policies, asbestos-related diseases and exposures remain a major public health concern today. In fact, the burden of asbestos-related diseases is increasing in most areas of the world. The use of asbestos has now been banned in 55 countries worldwide, but these bans are mostly recent and have not yet had a measureable impact on the incidence of asbestos-related diseases. Because of its widespread past use, the epidemic of asbestos-related diseases is known to be nearly worldwide and thus may be described as we have here as a pandemic rather than just an epidemic. The World Health Organization (WHO) recently estimated that ~107,000 people in the world die each year from asbestos-related diseases and those resulting from occupational exposures (68).

The primary objective of this article is to present a review of what we currently know about the worldwide pandemic of asbestos-related diseases. To place this subject in its proper context, we start with a description of the current use, production, and potential exposures to asbestos. This discussion is followed by a review of what is known about the current incidence and mortality of asbestos-related diseases in the world. Finally, we consider what the future might hold for the global pandemic of asbestos-related diseases.

WHO: World Health Organization

CURRENT USE AND PRODUCTION

Worldwide consumption of asbestos has changed dramatically over the past century as illustrated in **Figure 1**. The consumption of asbestos greatly increased from the 1920s until its peak in the 1980s. Worldwide consumption rates continued to drop until the late 1990s when they stabilized at roughly 2 million metric tons per year, approximately half of what it was during the peak consumption in the 1980s. The most recent available data from 2010 indicate that worldwide consumption remains at about this level (R.L. Virta, USGS, personal communication, June 7, 2012). The drop in

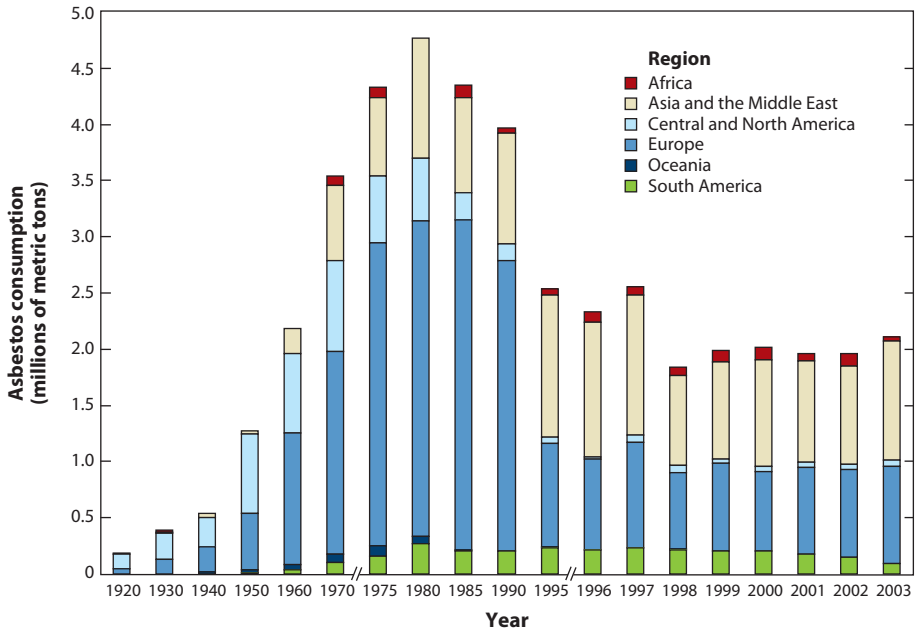

Figure 1

Worldwide consumption of asbestos by region, 1920–2003. From Reference 63.

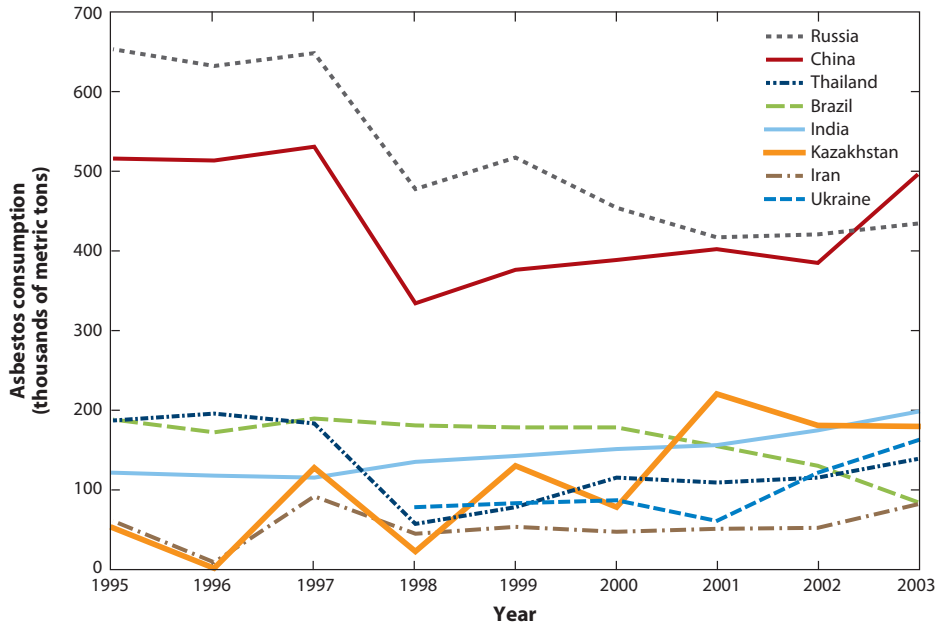

Figure 2

Worldwide consumption of asbestos by country, 1995–2003. From Reference 63.

consumption after the 1980s coincided with efforts in Western Europe and North America to limit asbestos use and, perhaps as importantly, with demonstrated liability of the manufacturers for cancers due to asbestos exposure.

However, during this same time period the consumption of asbestos by countries in Eastern Europe, South America, and Asia has increased. Asbestos consumption by country from 1995 to 2003 is presented in **Figure 2**. The leading consuming nations since 1995 have been Russia and China, but substantial amounts have also been consumed in Brazil, Thailand, Kazakhstan, India, Ukraine, and Iran. The upward trend that can be seen in India has continued and, according to the latest data from 2010, has reached approximately 420,000 metric tons, making India the second largest consumer after China (R.L. Virta, USGS, personal communication, June 7, 2012). Worldwide production of asbestos in 2011 by country is illustrated in **Figure 3**. Russia is currently the largest producer of asbestos in the world followed by China, Brazil, Kazakhstan, and Canada. Total worldwide production in 2011 was ~2,000,000 metric tons (62).

CURRENT POTENTIAL FOR EXPOSURE

The WHO estimates that 125 million people globally are exposed to asbestos in the workplace (68). The use of asbestos has been virtually eliminated in most but not all developed countries. The European Union has completely banned the use of asbestos since 1999. Although the United States has not banned asbestos, the use of asbestos by industry has been reduced to trivial levels because of a combination of regulation and litigation. The United States imported only ~800 metric tons in 2010 (R.L. Virta, USGS, personal communication, June 7, 2012). The US Occupational Safety and Health Administration (OSHA) has estimated that 1.3 million workers in general industry continue to be exposed to asbestos in the United States (41). Asbestos exposures in the United States and Western countries still

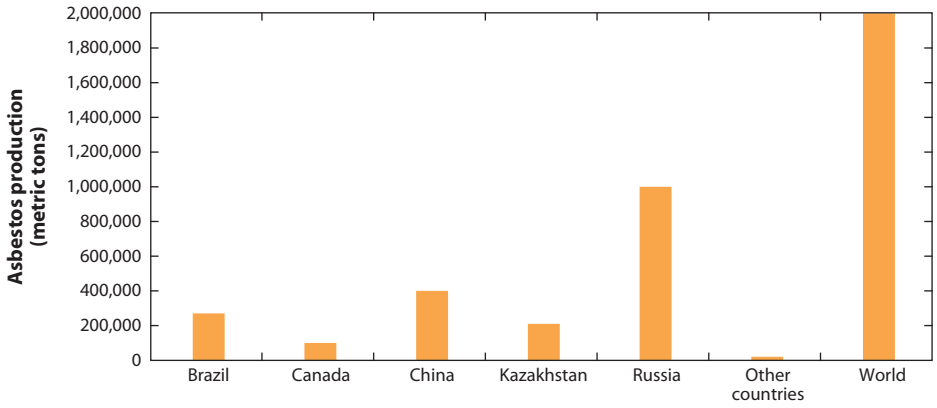

Figure 3

Worldwide production of asbestos in 2011 by country. From Reference 62.

occur from buildings containing asbestos. The most dramatic example is the destruction of the World Trade Centers on 9/11, which resulted in exposures to asbestos from the resulting dust cloud (29). Occupational exposures can occur in the maintenance and the abatement of asbestos in buildings (15). Community exposures also result from the contamination of the environment by past industrial production of materials containing asbestos. The most notable recent US example is in Libby, Montana, where significant rates of asbestos-related diseases have been observed among community residents who never worked in the vermiculite mining operations; the vermiculite ore was contaminated with as much as 25% amphibole asbestos. Asbestos-related disease has also been found in communities around industrial plants that produced vermiculite from the Libby ore (2, 57). An increase in mesothelioma has been documented in communities with asbestos mining in South Africa (48), Australia (14, 27), Italy (31) and Quebec (6). Finally, asbestos is a naturally occurring mineral, and excess mesotheliomas have been reported among residents living near deposits of asbestos in California (43), Greece (51), Turkey (4), Cyprus (34), Corsica (49), and Sicily (44).

Much less is known about the potential levels of asbestos exposures in developing countries, but the findings from a few published studies suggest that exposures may be high by today's standards. In India, Dave & Beckett (8) reported that in 1994 levels of 200–400 fibers/cubic centimeter (fb/cc) were found in asbestos mills (that subsequently have been reduced to 2 fb/cc in one of the mills), and as high as 100 fb/cc in textile facilities and 10 fb/cc in cement mills. By comparison, the current permissible exposure limit (PEL) in the United States and many western countries is 0.1 fb/cc and is 1.0 fb/cc in India.

Several epidemiologic studies in China have reported on asbestos exposure levels. Yano et al. (69) reported in an epidemiologic study of an asbestos mixed products company that average asbestos exposures in 1999 were 7.6 fb/cc (range 5.2–58) and 4.5 fb/cc (range 0.7–17.0) in the raw material and textile sections of the plant. Wang et al. recently reported average exposures of 29.0 fb/cc (range 2.9–63.8 fb/cc) in a Chinese chrysotile asbestos mine (65) and 2.3 fb/cc (range 1.5–3.6 fb/cc) in a separate study (66) in a textile factory. It is noteworthy that a large excess of lung cancer and nonmalignant respiratory diseases was also observed in these studies, supporting the likely presence of relatively high exposures in these industries in the past. One paper on a chrysotile mine in Russia reported low average concentrations of between 0.02 and 0.17 fb/cc with a maximum of 2.7 fb/cc (23). No data are available for

fb/cc: fibers per cubic centimeter

other countries that produce or use asbestos in Asia, Africa, Eastern Europe, and Latin America.

Some recent efforts have aimed to limit the use of and the potential for exposure to asbestos in the developing world. In 2005, China banned all export and import of amphibole asbestos and, in 2011, banned all asbestos fiber types from use in siding and other wall construction products. Turkey and Thailand recently banned all uses of asbestos, and Taiwan has eliminated most uses of asbestos (24).

CURRENT WORLDWIDE INCIDENCE AND MORTALITY OF ASBESTOS-RELATED DISEASES

The best data we have on the worldwide incidence and mortality from asbestos-related diseases are for mesothelioma. Driscoll et al. (11) estimated that 43,000 people worldwide die each year from mesothelioma. Pathologic diagnosis of mesothelioma can be difficult, and the disease may therefore be underreported in many countries. A specific International Classification of Diseases (ICD) code for mesothelioma has been available only since the tenth revision (ICD10), which was first implemented in 1994. Many countries have not implemented ICD10 yet, and the accuracy of coding varies by countries.

Although the proportion of mesothelioma attributable to asbestos exposure varies, an attributable fraction of 80% is often cited (60). Only 19% of mesothelioma cases in the Australian registry had no known history, and of this "no known history" group, 81% had fiber counts >200,000 fibers/g dry lung, 30% with more than 106 fibers/g >2 μm, including "long" (>10 μm) fibers, suggesting that nearly all cases had been exposed (27). For every one case of mesothelioma, we have observed several cases of lung cancer in epidemiologic studies of asbestos-exposed workers for all types of asbestos except crocidolite (35, 55). Thus it is appropriate to view mesothelioma incidence as a useful marker of asbestos-related diseases in general as well as a marker of what is generally a fatal disease.

A map of the distribution of age-standardized mesothelioma incidence rates for males by country for 1998–2002 is presented in **Figure 4**. The data for this map come from

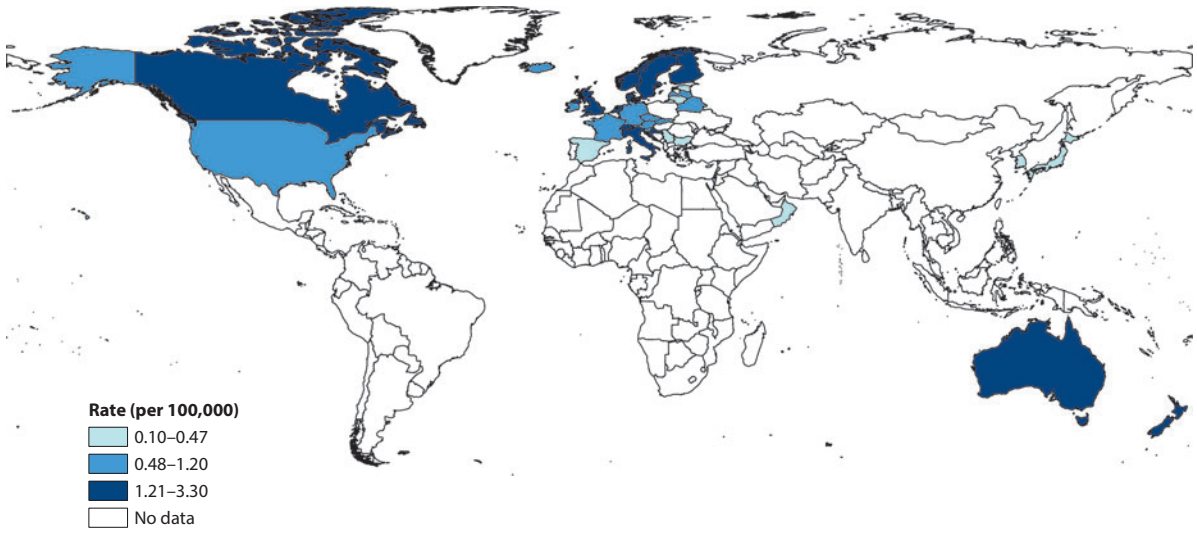

Figure 4

Worldwide age standardized mesothelioma incidence rates (per 100,000) for males in 1998–2002. Data from Reference 20.

a subset of data[1] in the IARC report, *Cancer in Five Continents* (20). As noted in another review (5), perhaps the most remarkable features of this map are the vast areas of the world for which we do not have any information on mesothelioma incidence. The rates also vary tremendously, spanning more than 3 orders of magnitude. The highest incidence of mesothelioma in the world was reported in the Italian Genoa Province (5.8 per 100,000). Other areas of the world reporting high rates include the West Cape of Australia (4.7 per 100,000), the Northern Yorkshire (4.2 per 100,000) area of the United Kingdom, Northern Ireland (4.0 per 100,000), and Scotland (3.6 per 100,000). Approximately 95% of the participating cancer registries have reported cases of mesothelioma to the IARC program.

Delgermaa et al. (9) recently presented an analysis of worldwide mesothelioma mortality data based on the WHO mortality database. A total of 92,253 mesothelioma deaths reported by 83 countries between 1994 and 2008 were included in the analysis. The worldwide age-adjusted rate for mesothelioma mortality was 4.9 per million. The United Kingdom was found to have the highest age-adjusted mortality rate (17.8 per million), followed by Australia (16.5 per million), and Italy (10.3 per million). Trend analyses were also conducted based on a subset of the data from countries ($n = 46$) reporting at least 5 years of data. Age-adjusted mesothelioma mortality was found to be increasing ~5% per year, and it more than doubled over the 15-year study time period. Analysis of trends in different continents revealed a significant annual increase in Asia (3.7%) and in Europe (3.4%). Analysis by country revealed a significant annual increase in Japan (3.5%) and a decrease in the United States (0.8%). On the basis of their findings, the authors suggest, "The different time trends observed between the countries may be an early indication that the disease burden is slowly shifting toward those that have used asbestos more recently" (p. 716).

The data sets on trends in mortality and incidence of mesothelioma discussed above are missing data from many underdeveloped countries, some of which are currently heavy users and/or producers of asbestos. Upper-income countries contributed more than 88% of all the mesothelioma cases to the WHO mortality database. An increasing trend from 1980 to 2003 in mesothelioma mortality has been reported in Brazil (46), which is the third largest producer and a major consumer of chrysotile asbestos (**Figures 2** and **3**). An increasing trend in mortality from mesothelioma has also been reported in Mexico between 1979 and 2000 (1). Takahashi & Karjalainen (59) have reported an annual rate of ~45 cases of mesothelioma in South Korea and 2 deaths per year in Singapore. No data are available for Russia, Kazakhstan, China, India, or Thailand, which, as discussed above, have used substantial amounts of asbestos in recent years.

Asbestosis and pleural plaques are also common findings among asbestos workers. Both of these outcomes could be considered "sentinel" events of asbestos exposure that are useful to observe asbestos-related diseases (50). In the United States, asbestosis mortality peaked in 2000 at 1,493 deaths and declined slightly to 1,470 deaths in 2004 (50). A study of asbestos miners and millers in India reported that the overall prevalence of asbestosis was 11.5% (8). Cases of asbestosis have also been reported from compensation systems in China, Indonesia, Japan, Korea, Malaysia, Philippines, Singapore, and Thailand (59).

THE FUTURE OF THE ASBESTOS PANDEMIC

Peto et al. (47) published the first attempt to develop predictions of the future direction of the mesothelioma epidemic in Great Britain. On the basis of their analyses of age and birth cohort rates for mesothelioma, they projected that the peak of the mesothelioma epidemic would

[1]The data include only cancer registries that have at least 15 years of data and that agreed to allow their data to be published annually.

reach 2,700–3,300 deaths in the year 2020. Using a dosimetric model and Bayesian methods, the Health Safety Executive (HSE) of Great Britain has more recently predicted that the epidemic in Great Britain will peak in 2016 at 2,038 cases (16). Similar efforts have been made to predict the future course of the mesothelioma epidemic in several other European countries, including Denmark (25), France (3, 18), the Netherlands (52), and Italy (33). These analyses have all indicated that the mesothelioma epidemic will not peak for a few more years. For Europe as a whole, La Vecchia et al. (26) predicted that the peak will occur sometime between 2010 and 2020. One exception is Sweden, where mesothelioma rates peaked in 1995 (17). This earlier peak reflects the fact that, in 1976, Sweden became the first country in Europe to place a nearly total ban on asbestos use. Mesothelioma mortality rates have, in fact, begun to decline in the United States (9), which is most likely due to the significant reduction in asbestos use in the United States during the 1970s. Leigh & Driscoll (27) predict that mesothelioma rates in Australia have also peaked.

In contrast with Europe, the United States, and Australia, mesothelioma rates in Japan have been rising and are predicted to peak only sometime between 2030 and 2039 (38). Japan began to use asbestos in significant quantities after World War II, and heavy consumption of asbestos continued until 1990 and ended in 2003 with a ban.

Predicting the future course of the asbestos epidemic in developing countries is severely hampered by the paucity of data on exposures and disease occurrence from these areas of the world. A strong correlation between asbestos-related diseases and past national consumption of asbestos has been reported in several publications (28, 45, 58, 61). Most recently, Lin published an ecologic analysis of mesothelioma and asbestosis mortality data for 2000–2004 from the WHO and the mean per capita consumption of asbestos in 1960–1969 (28). Historical use of asbestos was found to be a strong predictor ($R^2 = 0.74$, $p < 0.0001$) of mesothelioma mortality in both sexes and of asbestosis ($R^2 = 0.79$, $p < 0.0001$) among males in regression models of the log of the age-standardized mortality rates weighted by population size. It would be hazardous to use these models to predict the future epidemic in developing countries such as India that have recently increased their asbestos consumption. The models are based on ecologic analyses, which may be biased by individual population characteristics. In addition, the models do not account for changes in the type of asbestos consumed, which is currently nearly exclusively chrysotile. Nonetheless, these analyses clearly indicate that increased asbestos use will result in an increase in asbestos-related diseases in the future.

DISCUSSION

The pandemic of asbestos-related diseases shows some signs of abating in the developed world, whereas the pandemic is increasing in the developing world. One hopeful sign is that worldwide production and use of asbestos have declined, although by only about one-half of the peak in the late 1970s. The decline is clearly attributable to a cessation of use mostly by developed countries. The use of asbestos has currently been banned in 55 countries (24). Some other countries, such as the United States, have not banned asbestos but have greatly reduced their consumption owing to legal liability concerns. Unfortunately, asbestos consumption is increasing in other parts of the world such as India and much of Asia.

Exposures in the developed world have been greatly reduced or eliminated in industrial operations, but exposures do still occur from asbestos remaining in existing buildings, from old industrial sites and from naturally occurring asbestos. Little is known about the level of asbestos exposures in developing countries, but what has been reported suggests that the levels may be quite high in India and China. The mere fact that asbestos exposure does not seem to be monitored, or at least is not being reported, in many of the countries

that are currently producing or using asbestos is worrying. It suggests that these countries do not have the technology and expertise to cope with these very hazardous materials.

The prognosis for the world pandemic of asbestos disease is very different for the developed and developing economies of the world. The incidence of mesothelioma and other asbestos-related diseases has begun to decline in Sweden (17), Australia (27), and the United States (9) and is projected to decline in most of Europe within the next decade. These declines reflect dramatic changes in asbestos consumption by these countries owing either to regulatory policies to prohibit asbestos use (i.e., Sweden) or to liability concerns (i.e., the United States) that have occurred over the past 40 years. Very few data are available on which to base predictions for the developing world. However, it is quite obvious that the current rise in consumption and the likely poor control of asbestos exposures will translate to a rise in the rates of asbestos-related diseases in these nations in the future.

What can be done to stop the asbestos pandemic from spreading? In 2006, the WHO published a statement that "the most efficient way to eliminate asbestos-related diseases is to stop using all types of asbestos" (68, p. 1). Although this is a very useful statement, it may not go far enough. Eliminating asbestos use is not just the most efficient way to prevent asbestos-related diseases; based on our experience, it is, indeed, the only way to prevent disease. As is evident from the history of asbestos use and control described here, the risks of exposure to asbestos cannot be adequately controlled by technology or by regulation of work practices. Even the best workplace controls cannot prevent exposure to asbestos products once they are in use or when they join the waste stream. Safer substitutes for asbestos exist and are feasible for use in developing countries (67). In recent years, some countries using asbestos, such as China, have begun to control its use, and we can only hope that this trend continues worldwide.

Eliminating the scourge of asbestos-related diseases will also require continued vigilance and control of exposures from asbestos that is still in buildings or is naturally occurring and from former mining and industrial sites. Unfortunately, even if a total worldwide ban were instituted today we would still be faced with this legacy and this epidemic 20–40 years from now because of current and past use. Meanwhile societies need to do everything possible, including a ban on usage, to reduce exposures and to offer care to the unfortunate victims of asbestos-related diseases.

DISCLOSURE STATEMENT

The authors have served as consultants and expert witnesses for individuals with asbestos-related diseases in asbestos litigation and bankruptcy cases.

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LITERATURE CITED

1. Aguilar-Madrid G, Juárez-Pérez CA, Markowitz S, Hernández-Avila M, Sanchez Roman FR, Vázquez Grameix JH. 2003. Globalization and the transfer of hazardous industry: asbestos in Mexico, 1979–2000. *Int. J. Occup. Environ. Health* 9(3):272–79

2. Alexander BH, Raleigh KK, Johnson J, Mandel JH, Adgate JL, et al. 2012. Radiographic evidence of nonoccupational asbestos exposure from processing Libby vermiculite in Minneapolis, Minnesota. *Environ. Health Perspect.* 120(1):44–49
3. Banaei A, Auvert B, Goldberg M, Gueguen A, Luce D, Goldberg S. 2000. Future trends in mortality of French men from mesothelioma. *Occup. Environ. Med.* 57(7):488–94
4. Baris YI, Bilir N, Artvilni M, Sahin AA, Kalyoncu F, Sebastien P. 1988. An epidemiological study in an Anatolian village environmentally exposed to tremolite asbestos. *Br. J. Ind. Med.* 45:838–40
5. Bianchi C, Bianchi T. 2007. Malignant mesothelioma: global incidence and relationship with asbestos. *Ind. Health* 45(3):379–87
6. Camus M, Siemiatycki J, Meek B. 1998. Non-occupational exposure to chrysotile asbestos and the risk of lung cancer. *N. Engl. J. Med.* 338(22):1565–71
7. Cooke WE. 1924. Fibrosis of the lungs due to the inhalation of asbestos dust. *Br. Med. J.* 2(3317):140–2, 147
8. Cooke WE. 1927. Pulmonary asbestosis. *Br. Med. J.* 2:1024–25
9. Delgermaa V, Takahashi K, Park E-K, Le GV, Hara T, Sorahan T. 2011. Global mesothelioma deaths reported to the World Health Organization between 1994 and 2008. *Bull. World Health Organ.* 89:716–24C
10. Doll R. 1955. Mortality from lung cancer in asbestos workers. *Br. J. Ind. Med.* 12(2):81–86
11. Driscoll T, Nelson DI, Steenland K, Leigh J, Concha-Barrientos M, et al. 2005. The global burden of disease due to occupational carcinogens. *Am. J. Ind. Med.* 48:419–31
12. Environ. Prot. Agency (EPA). 1986. *Airborne Asbestos Health Assessment Update*. EPA/600/8-84/003F. Washington, DC: US EPA, Off. Health Environ. Assess.
13. Gloyne SR. 1935. Two cases of squamous carcinoma of the lung occurring in asbestosis. *Tubercle* 17:5–10
14. Hansen J, de Klerk NH, Musk AW, Hobbs MS. 1998. Environmental exposure to crocidolite and mesothelioma: exposure-response relationships. *Am. J. Respir. Crit. Care Med.* 157(1):69–75
15. Health Effects Inst.-Asbestos Res. (HEI-AR). 1991. *Asbestos in Public and Commercial Buildings: A Literature Review and Synthesis of Current Knowledge*. Cambridge, MA: HEI-AR
16. Health Safety Executive (HSE). 2009. *Projection of Mesothelioma Mortality in Great Britain.* Derbyshire, UK: HSE. **http://www.hse.gov.uk/research/rrpdf/rr728.pdf**
17. Hemminki K, Li X. 2003. Time trends and occupational risk factors for pleural mesothelioma in Sweden. *J. Occup. Environ. Med.* 45(4):456–61
18. Ilg AG, Bignon J, Valleron AJ. 1998. Estimation of the past and future burden of mortality from mesothelioma in France. *Occup. Environ. Med.* 55(11):760–65
19. Int. Agency Res. Cancer (IARC). 1977. *Asbestos*, Vol. 14. Lyon, Fr.: IARC
20. Int. Agency Res. Cancer (IARC). 2007. *Cancer Incidence in Five Continents:* Vol. IX, ed. MP Curado, B Edwards, HR Shin, H Storm, J Ferlay, et al. IARC Sci. Publ. No. 160. Lyon, Fr.: IARC
21. Int. Agency Res. Cancer (IARC). 2012. *A Review of Human Carcinogens: Arsenic, Metals, Fibres, and Dusts.* IARC Monogr. Eval. Carcinog. Risks Hum., Vol. 100C. Geneva, Switz.: WHO
22. Int. Programme Chem. Saf. (IPCS). 1988. *Chrysotile*. Geneva: WHO
23. Kashansky SV, Domnin SG, Kochelayev VA, Monakhov DD, Kogan FM. 2001. Retrospective view of airborne dust levels in workplace of a chrysotile mine in Ural, Russia. *Ind. Health* 39(2):51–56
24. Kazan-Allen L. 2012. *Current Asbestos Bans and Restrictions*. London: Int. Ban Asbestos Secr. (IBAS). **http://www.ibasecretariat.org/alpha_ban_list.php**
25. Kjaergaard J, Andersson M. 2000. Incidence rates of malignant mesothelioma in Denmark and predicted future number of cases among men. *Scand. J. Work Environ. Health* 26:112–17
26. La Vecchia C, Decarli A, Peto J, Levi F, Tomei F, Negri E. 2000. An age, period and cohort analysis of pleural cancer mortality in Europe. *Eur. J. Cancer Prev.* 9(3):179–84
27. Leigh J, Driscoll T. 2003. Malignant mesothelioma in Australia, 1945–2002. *Int. J. Occup. Environ. Health* 9:206–17
28. Lin RT, Takahashi K, Karjalainen A, Hoshuyama T, Wilson D, et al. 2007. Ecological association between asbestos-related diseases and historical asbestos consumption: an international analysis. *Lancet* 369(9564):844–49

29. Lorber M, Gibb H, Grant L, Pinto J, Pleil J, Cleverly D. 2007. Assessment of inhalation exposures and potential health risks to the general population that resulted from the collapse of the World Trade Center towers. *Risk Anal.* 27(5):1203–21
30. Lynch KM, Smith WA. 1935. Pulmonary asbestosis III. Carcinoma of lung in asbesto-silicosis. *Am. J. Cancer* 14:56
31. Magnani C, Terracini B, Ivaldi C, Botta M, Mancini A, Andrion A. 1995. Pleural malignant mesothelioma and non-occupational exposure to asbestos in Casale Monferrato, Italy. *Occup. Environ. Med.* 52:362–67
32. Mancuso TF, Coulter EJ. 1963. Methodology in industrial health studies. The cohort approach, with special reference to an asbestos company. *Arch. Environ. Health* 6:210–26
33. Marinaccio A, Montanaro F, Mastrantonio M, Uccelli R, Altavista P, et al. 2005. Predictions of mortality from pleural mesothelioma in Italy: a model based on asbestos consumption figures supports results from age-period cohort models. *Int. J. Cancer* 115:142–47
34. McConnochie K, Simonato L, Mavrides P, Christofides P, Pooley FD, Wagner JC. 1987. Mesothelioma in Cyprus: the role of tremolite. *Thorax* 42(5):342–47
35. Henderson DW, Rödelsperger K, Woitowitz HJ, Leigh J. 2004. After Helsinki: a multidisciplinary review of the relationship between asbestos exposure and lung cancer, with emphasis on studies published during 1997–2004. *Pathology* 36(6):517–50
36. McDonald JC, McDonald AD. 1996. The epidemiology of mesothelioma in historical context. *Eur. Respir. J.* 9(9):1932–42
37. Merewether ERA, Price CW. 1930. *Report on the Effects of Asbestos Dust on the Lungs and Dust Suppression in the Asbestos Industry.* London: HMSO
38. Murayama T, Takahashi K, Natori Y, Kurumatani N. 2006. Estimation of future mortality from pleural malignant mesothelioma in Japan based on an age-cohort model. *Am. J. Ind. Med.* 49(1):1–7
39. Murray HW. 1907. Statement before the committee in the minutes of evidence. In *Report of the Departmental Committee on Compensation for Industrial Disease*, pp. 127–28. London: HMSO
40. Natl. Inst. Occup. Saf. Health (NIOSH). 1972. Criteria for a recommended standard: occupational exposure to asbestos. *NIOSH Publ. No.* 72-10267, US Dep. Health, Educ. Welf., Atlanta, Ga.
41. Natl. Inst. Occup. Saf. Health (NIOSH). 2011. Asbestos fibers and other elongate mineral particles: state of the science and roadmap for research. *Curr. Intell. Bull. 62. DHHS (NIOSH) Publ. No.2011-159.* NIOSH, Atlanta, Ga.
42. Natl. Toxicol. Progr. (NTP). 2011. *Report on Carcinogens: Asbestos*. CAS No. 1332-21-4. Washington, DC: US Dep. Health Hum. Serv., Public Health Serv., NTP. 12th ed. **http://ntp.niehs.nih.gov/ntp/roc/twelfth/profiles/Asbestos.pdf**
43. Pan XL, Day HW, Wang W, Beckett LA, Schenker MB. 2005. Residential proximity to naturally occurring asbestos and mesothelioma risk in California. *Am. J. Respir. Crit. Care Med.* 172(8):1019–25
44. Paoletti L, Batisti D, Bruno C, Di Paola M, Gianfagna A, et al. 2000. Unusually high incidence of malignant pleural mesothelioma in a town of eastern Sicily: an epidemiological and environmental study. *Arch. Environ. Health* 55(6):392–98
45. Park EK, Takahashi K, Hoshuyama T, Cheng TJ, Delgermaa V, et al. 2011. Global magnitude of reported and unreported mesothelioma. *Environ. Health Perspect.* 119:514–18
46. Pedra F, Tambellini AT, Pereira BB, da Costa AC, de Castro HA. 2008. Mesothelioma mortality in Brazil, 1980–2003. *Int. J. Occup. Environ. Health* 14(3):170–75
47. Peto J, Matthews F, Hodgson J, Jones J. 1995. Continuing increase in mesothelioma mortality in Britain. *Lancet* 345:535–39
48. Rees D, Myers JE, Goodman K, Fourie E, Blignaut C, et al. 1999. Case-control study of mesothelioma in South Africa. *Am. J. Ind. Med.* 35:213–22
49. Rey F, Viallat JR, Boutin C, Farisse P, Billon-Galland MA, et al. 1993. Environmental mesotheliomas in northeast Corsica. *Rev. Mal. Respir.* 10(4):339–45
50. Rutstein DD, Mullan RJ, Frazier TM, Halperin WE, Melius JM, Sestito JP. 1983. Sentinel health events (occupational): a basis for physician recognition and public health surveillance. *Am. J. Public Health* 73(9):1054–62

51. Sakellariou K, Malamou-Mitsi V, Haritou A, Koumpaniou C, Stachouli C, et al. 1996. Malignant pleural mesothelioma from nonoccupational asbestos in Metsovo (north-west Greece): slow end of an epidemic? *Eur. Respir. J.* 9:1206–10
52. Segura O, Burdorf A, Looman C. 2003. Update of predictions of mortality from pleural mesothelioma in the Netherlands. *Occup. Environ. Med.* 60:50–55
53. Selikoff IJ, Churg J, Hammond EC. 1964. Asbestos exposure and neoplasia. *JAMA* 188:22–26
54. Selikoff IJ, Lee DHK, eds. 1978. *Asbestos and Disease.* New York: Academic. 559 pp.
55. Stayner LT, Dankovic DA, Lemen RA. 1996. Occupational exposure to chrysotile asbestos and cancer risk: a review of the amphibole hypothesis. *Am. J. Public Health* 86(2):179–86
56. Straif K. 2009. A review of human carcinogens—part C: metals, arsenic, dusts, and fibres. *Lancet Oncol.* 10:453–54
57. Sullivan P. 2007. Vermiculite, respiratory disease, and asbestos exposure in Libby, Montana: update of a cohort mortality study. *Environ. Health Perspect.* 115:579–85
58. Takahashi K, Huuskonen M, Tossavainen A, Higashi T, Okubo T, Rantanen J. 1999. Ecological relationship between mesothelioma incidence/mortality and asbestos consumption in ten Western countries and Japan. *J. Occup. Health* 41:8–11
59. Takahashi K, Karjalainen A. 2003. A cross-country comparative overview of the asbestos situation in ten Asian countries. *Int. J. Occup. Environ. Health* 9(3):244–48
60. Tossavainen A. 1997. Asbestos, asbestosis, and cancer: the Helsinki criteria for diagnosis and attribution. *Scand. J. Work Environ. Health* 23:311–16
61. Tossavainen A. 2004. Global use of asbestos and the incidence of mesothelioma. *Int. J. Occup. Environ. Health* 10:22–25
62. US Geol. Surv. (USGS) 2012. *Mineral Commodity Summaries 2012.* Reston, VA: USGS. 198 pp. **http://minerals.usgs.gov/minerals/pubs/mcs/2012/mcs2012.pdf**
63. Virta RL. 2006. *Worldwide Asbestos Supply and Consumption Trends from 1900 Through 2003*. Circ. 1298. Reston, VA: US Dep. Inter., USGS. 80 pp. **http://pubs.usgs.gov/circ/2006/1298/c1298.pdf**
64. Wagner JC, Sleggs CA, Marchand P. 1960. Diffuse pleural mesothelioma and asbestos exposure in the North Western Cape Province. *Br. J. Ind. Med.* 17:260–71
65. Wang X, Lin S, Yano E, Qiu H, Yu IT, et al. 2012. Mortality in a Chinese chrysotile miner cohort. *Int. Arch. Occup. Environ. Health* 85:405–12
66. Wang XR, Yu IT, Qiu H, Wang MZ, Lan YJ, et al. 2012. Cancer mortality among Chinese chrysotile asbestos textile workers. *Lung Cancer* 75(2):151–55
67. World Bank Group (WBG). 2009. *Good Practice Note: Asbestos: Occupational and Community Health Issues*. Washington, DC: WBG. **http://www.bwint.org/pdfs/WB-AsbestosGuidanceNote.pdf**
68. World Health Organ. (WHO). 2010. *Asbestos: elimination of asbestos-related diseases*. Fact sheet N°343, July. **http://www.who.int/mediacentre/factsheets/fs343/en/index.html**
69. Yano E, Wang ZM, Wang XR, Wang MZ, Lan YJ. 2001. Cancer mortality among workers exposed to amphibole-free chrysotile asbestos. *Am. J. Epidemiol.* 154(6):538–43