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Changing Risk Groups for Malignant Mesothelioma

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Although malignant mesothelioma is a relatively rare tumor, its incidence is rising. Much of the increase is attributable to widespread exposure to asbestos in past decades in asbestos-related industries. In recent years, it has become increasingly clear that mesothelioma risk is no longer confined to workers in the asbestos industry. This article reports a variety of recently identified "risk groups" and highlights the need for increased surveillance of these groups to document the occurrence of asbestos-related malignancy and the institution of measures for disease prevention. *Cancer* **1992; 69:2704–2711.**

The incidence of mesothelioma, previously a relatively rare tumor, has experienced a well-recognized increase during the last 2 decades. Data from the National Cancer Institute's SEER (Surveillance Epidemiology and End Results) program of population-based registries show that the annual age-adjusted incidence for the years 1973 to 1978 *versus* 1979 to 1980 increased by almost 10% per year (in males).[1] Information from British Columbia indicates that for the year 1982, the incidence in that Canadian province was nearly six times higher than it was in period 1969 to 1975.[2] Clearly, mesothelioma is becoming an increasingly common clinical entity.

The etiologic link between asbestos and mesothelioma is well documented. The upsurge in incidence of this tumor closely parallels the widespread commercialization of asbestos, which is responsible for the majority of cases. Unfortunately, disease risk is no longer confined to workers in the asbestos industry. This article highlights recent trends in incidence by discussing some newly recognized risk groups. With increased understanding of changes in disease risk, more effective disease prevention strategies can be developed.

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Newly Recognized Occupational Risk Groups

Brake Mechanics

Friction products once constituted one of the major markets in the United States for asbestos, and it is estimated that approximately 900,000 workers in the Unites States are or at one time were employed as automobile mechanics and garage workers. It is uncertain what proportion of these workers regularly service brake linings and are, therefore, at risk for asbestos-related mesothelioma. In addition, it is also unclear what the health risks are to coworkers not directly involved in brake repair.

A major problem with epidemiologic studies of this work force is the difficulty in tracing a large, nonunionized group of workers. Estimation of disease risk has been impeded by lack of quantitative data on exposure levels among individuals with long-term exposure. However, several studies examining this occupational setting show the existence of a potentially serious health hazard.

In 1976, investigators at the Mount Sinai School of Medicine studied asbestos exposure among brake repair workers in New York city.[3] Both clinical examinations and fiber counts produced by various operations in brake maintenance workers were analyzed. Samples taken at a distance of 3 to 5 feet from brake drums during periods of blowing dust showed fiber concentrations of 6.6 to 29.4 fibers/ml, with a mean of 15.9 fibers/ml. In addition, ten samples of brake drum dust were analyzed by phase-contrast, optical microscopic examination and transmission electron microscopic examination to determine the percentage of short fibrils (*i.e.*, 250 to 500 angstroms × 750 to 3750 angstroms). Eighty-three percent of all chrysotile fibers were in this category, and almost 20% of the total mass of ten samples was chrysotile (determined by electron diffraction). "Throughout the examination by electron microscopy, attention was given to the morphology of the fibers. A majority of fibers showed little alteration in the typical chrysotile fiber."[3]

In an additional report from Mount Sinai, Rohl *et al.*[4] analyzed residual dust recovered from brake linings and made direct measurements of the free asbestos fiber content of "workroom air" in areas in which brake lining maintenance and brake shoe installation occurred. Airborne asbestos dust concentrations were similar to those cited by Lorimer *et al.*[3] (*i.e.*, mean airborne fiber concentrations during compressed air blowing of brake drums ranged from 2.6 fibers/ml at a distance of 10 to 20 feet to 16.0 fibers/ml at 3 to 5 feet). Samples of brake drum dust showed that the proportion of chrysotile in this material averaged 3% to 6% (as both free fiber and as particulates in pulverized binder).

Regarding the health effects resulting from the exposures described, Langer and McCaughey[5] published an analysis of a case of mesothelioma in a brake repair worker; the report included lung fiber studies, including electron microscopic examination. The subject was a 55-year-old man who had worked in the used car, tire, and car repair business since the age of 19 years. He reported routinely servicing automobiles, including the replacement of brake linings. No other source of asbestos exposure was found.

Analysis of lung tissue showed the presence of chrysotile fibers (no amphibole was found) confirmed by electron diffraction techniques. Ten percent of the fibers found were longer than 10 microns. The authors point out that "Controversy over the potential of chrysotile to cause mesothelioma has continued despite evidence from asbestos textile fabricators, thought to have used only chrysotile, from workers making brake pads, from chrysotile miners and millers and from animal studies."[5] They also state, "The risk of malignant asbestos disease among these workers seems to be low but mortality data have yet to be thoroughly evaluated."[5]

The most recent report of mesothelioma in a brake mechanic reviews a pleural mesothelioma occurring in a 47-year-old male automobile mechanic whose only known exposure to asbestos was from clutch and brake repair work during an 11-year period.[6] From age 30 to 41 years, the man worked as a brake mechanic in five different automobile service stations and dealerships. During his employment, he primarily performed brake and clutch repairs, engine overhauls, and automotive transmission and electrical system repairs. He reported asbestos exposure from clutches, fly wheels, and brakes and said that he often used compressed air to "blow out brake drums," which he described as creating "dusty working conditions."

Another case of mesothelioma in a brake repair worker was recently published.[7] In this report, a 56-year-old male elevator mechanic was noted to have anisocoria on routine physical examination. Subsequently, right upper quadrant pain and chest discomfort developed. Medical evaluation with computed tomography showed a right paracervical mass that, on biopsy, was found to be pleural mesothelioma. The patient reported working as an elevator mechanic for 30 years. He reported asbestos exposure primarily from elevator brake linings that he routinely cut, fitted, and removed during elevator installation and maintenance.

Several recent studies from Scandinavia on this topic also deserve mention. Hansen,[8] from the Institute of Community Medicine in Denmark, completed a historical cohort study examining the mortality of car mechanics from ischemic heart disease and malignant neoplasms. The study cohort was identified using records of a nationwide census carried out in Denmark in November 1970. Comparison was made with another cohort of skilled male workers who were not exposed to asbestos or "petrochemical substances." Of 583 observed deaths, one case of pleural mesothelioma was found.

Likewise, Jarvholm and Brisman,[9] in a 1988 report used the Swedish Death Register and the census of 1960 to study the occurrence of asbestos-associated tumors in car mechanics. One hundred eighty-seven deaths attributable to cancer were observed, whereas 154 were expected. Thirty-nine were caused by lung cancer, whereas only 23 were expected. Again, one death from pleural mesothelioma was found. Analyses of mesothelioma mortality in the United States, which rely on death certificate data, have a major flaw (*i.e.*, misclassification of pleural tumors as deaths caused by lung cancer or other tumors of the thorax). Because the diagnosis of mesothelioma often can be difficult from a pathologic standpoint, death certificate studies may result in gross underestimation of incidence It is unclear how this problem may have influenced the results of the two reports detailed here.

It has been estimated that 20,000 deaths from asbestos-related cancer will occur during the next 40 years among automobile maintenance workers in the United States.[10] With the many difficulties faced by epidemiologists studying this work force, it is unclear how accurate this estimate will prove to be. Clearly, what is needed is better information on duration and intensity of exposure to respirable asbestos fibers in this occupational group. Additional study is needed to accurately determine the incidence of mesothelioma among members of this work force.

Railroad Workers

The 1960 report by Wagner *et al.*[11] of occupational mesothelioma risk included reports of several workers exposed to asbestos through employment in the railroad industry. Recently, Schenker *et al.*[12] published the results of a large scale study in this occupational group. In a case–control analysis, the authors examined mesothelioma deaths among current and retired US railroad employees. Of 15,059 deaths reported by the Railroad Retirement Board, death certificates were obtained for 87%, which identified 20 deaths caused by mesothelioma. Among workers who had worked in jobs with potential asbestos exposure, a significant odds ratio of 7.2 was found (based on a 10:1 matched analysis with railroad workers dying of nonmalignant nonaccident causes). Comparison of groups used in skilled trades (*e.g.*, locomotive repair) with regular exposure to asbestos, yielded a statistically significant odds ratio of 21.4. A nonsignificant odds ratio of 2.3 was found for workers in occupations with intermittent exposure.

Although this study is important in that it reports the existence of a mesothelioma risk among a previously unexamined occupational group, these data must be viewed as representing an underestimate of the occurrence of this disease. This is because of the reliance on death certificate data, which in the case of mesothelioma, often results in misclassification.

Additional support for a high risk of mesothelioma among railroad employees is provided by Mancuso.[13] This study explored the occurrence of mesothelioma deaths among machinists in the railroad and other industries. Among a cohort of 197 machinists employed at the same railroad before 1935 and observed until 1982, causes of death were identified for 132. Of 29 deaths attributable to cancer, 9 were caused by mesothelioma. The author comments that based on other data available in the literature "because of the small size of the cohort, it is remarkable to have detected such a large number of mesotheliomas."[13]

In addition, in 1987, Huncharek and Muscat[14] reviewed a series of autopsy-confirmed cases of pleural mesothelioma with documented occupational exposure to asbestos. Of 37 cases reviewed, 4 subjects had been railroad employees. In two instances, specific job titles were unavailable; the other two had been a brake repair worker and a machinist. These data provide additional support for the existence of a mesothelioma hazard in this occupational setting, particularly in light of the death being documented pathologically, rather than relying on death certificate information.

Construction Trades

Use of asbestos-containing materials (ACM) is particularly widespread in building construction, including commercial and noncommercial structures. The US Environmental Protection Agency (EPA) estimates that approximately 733,000 buildings in the United States contain ACM.[15] Of particular concern is that thousands of these structures are public and private school buildings. Obviously, with such widespread use of ACM in a multitude of capacities in buildings across the country, employees in the various construction trades constitute another mesothelioma risk group.

Estimates suggest that as many as 7,500,000 construction workers have been exposed to elevated levels of respirable asbestos in the past.[16] These exposures are the result of such activities as installation of metal duct work, ventilation systems, and manual removal of asbestos fireproofing.[17] "Bystander exposure" also is thought to play a role because sheet metal workers often work in asbestos-contaminated areas secondary to other related construction work (*e.g.*, boiler removal).

Zoloth and Michaels[18] analyzed 385 deaths that occurred between January 1976 and April 1983 among members of a sheet metal workers union in the New York metropolitan area. A proportional mortality analysis showed elevated proportional mortality ratios (PMR) for lung, colon, and rectal cancer and an increased incidence of mesothelioma. In 1987, this study was extended to include deaths occurring before October 1986, resulting in the increase of the study population by 331 subjects. Statistically significant elevated PMRs were observed for all malignant neoplasms (PMR = 148) and for cancers of the stomach (PMR = 259), liver (PMR = 260), and lung (PMR = 186). Six deaths attributable to mesothelioma were documented on death certificates. The authors conclude that "the 1.8% of the deaths in this study attributable to mesothelioma (6 of 331) demonstrates that this disease continues to be an important cause of mortality in this population."[18]

Recent data from Sweden[19,20] using the Swedish Cancer-Environment Registry also documents increased mesothelioma risk among workers in the construction industry. Malker *et al.*[19,20] examined cancer incidence data from that National Swedish Cancer Registry for 1961 and 1979. Thirty-five confirmed cases of peritoneal mesothelioma were found, 13 cases among employees in the construction industry (three of the employees were insulators). In addition, textile workers, painters, and pulp and paper industry workers showed a nonsignificant elevated risk of peritoneal mesothelioma.

Also suggesting the existence of a mesothelioma risk in this occupational group is a recent report of pleural mesothelioma in an electrician who did not work in a shipyard.[21] This patient worked as an electrician from 1959 until retirement in 1974. He reported working in buildings in which acoustic insulation was being sprayed. In 1971, he became employed as a maintenance electrician at an airport and reported being in contact with old asbestos insulation and fireproofing material. He stated that insulators and other coworkers often would remove asbestos insulation in his presence.

Although electricians who do not work in shipyards are known to have an increased risk of lung cancer, the risk of mesothelioma in these workers has received little attention. Increased surveillance of this occupational group may be justified.[22]

Indoor Asbestos Exposure

Knowledge of the health risks associated with asbestos exposure in the work place has led to concerns that environmental (*i.e.*, nonoccupational) exposure could represent a serious health hazard. These concerns are particularly acute with regard to exposure to ACM in buildings.

Of all indoor pollutants, asbestos represents a particularly difficult problem from a health risk assessment and risk management perspective. This is largely because of its widespread use as fireproofing in buildings, for acoustic control, and as pipe and boiler insulation. Surveys by the US EPA estimate that friable ACM is present in approximately 733,000 public and commercial buildings in the United States,[23] representing 20% of 3.6 million buildings examined. Five percent (192,000) of buildings were found to have sprayed or troweled asbestos surfacing material, representing a total of 1.2 billion square feet. In addition, 563,000 buildings contain asbestos in the form of thermal insulation. The EPA also conducted a national telephone survey of US schools and found that approximately 35,000 contain friable ACM, representing 35% of all school facilities. Unfortunately, little information is available in the published literature evaluating ambient levels of airborne asbestos fibers in buildings. In addition, data that assess exposure risks given a building's function, type of ACM present, and condition of these materials are not available.

Few studies exist that document airborne concentration of asbestos fibers in buildings. However, some useful information is available, such as that from a 1987 EPA report of 43 asbestos-containing federal buildings.[23] Air sampling was done at sites containing the most seriously damaged ACM within each building. Samples were subsequently analyzed using transmission electron microscopic examination. In addition, data were obtained from 35 buildings in the United Kingdom and Canada.

The EPA report indicates that "Prevalent airborne asbestos levels . . . ranged from 0.0 to 0.2 fibers per cubic centimeter (cc), with an arithmetic mean of 0.006 f/cc."[23] In a related transmission electron microscopy (TEM) measurement of airborne fibers in US, Canadian, and British school buildings, fiber levels ranged from 0.0 to 0.1 f/cc, with an arithmetic mean of 0.03 f/cc.[24] The EPA qualified these findings by stating, "These data . . . provide an indication of prevalent levels which may be found in schools and in nonschool buildings. However, they are insufficient to support generalizations about the total population of buildings or the relative airborne concentrations in schools as contrasted with public and commercial buildings."[21]

In addition, the EPA presents the caveat that maintenance and cleaning activities in such structures can result in elevated airborne asbestos levels, a fact not reflected in air sampling data.

Data such as that discussed have led some to suggest that asbestos exposure in buildings poses an extremely low cancer risk. Unfortunately, a major limitation of using short-term air sampling as a basis for risk assessment is that it does not necessarily reflect long-term airborne fiber levels. Sampling generally takes place under "nonroutine" conditions (*i.e.*, under circumstances of curtailed activity). Thus, the data do not reflect contamination levels that may occur with routine building use.

For instance, in a review of several hundred cases of pleural mesothelioma conducted by the author in 1986 to 1987,[14] two cases of pleural mesothelioma in school teachers were found. Both of the teachers were exposed to friable ceiling and pipe insulation during the course of many years. Analysis by an independent laboratory of the insulation material in both environments showed the presence of predominantly chrysotile asbestos with, in one case, small amounts of amosite.

A study from the United Kingdom reports pleural mesothelioma in a female office worker; the disease resulted from exposure to amosite in the building of the patient's employment. The ceiling of this building was sprayed with amosite insulating material approximately 1 inch thick covered by a layer of paint. This material was in disrepair for some time, causing dust release into the indoor environment. Analysis of the ceiling material showed 70% amosite asbestos. This patient died of mesothelioma 9 months after it was diagnosed. The cause of death was confirmed at autopsy.[25]

In addition to building occupants, another group that must be evaluated for possible health risks is maintenance and repair workers. Oliver *et al.*[26] reported finding radiographic abnormalities and impaired pulmonary function associated with asbestos exposure among school custodians. Little information concerning these groups is available, although it is easy to envision how periodic, intense exposure could occur among such workers. Short-term air sampling cannot evaluate this type of potential hazard. Projections of expected disease incidence among building occupants and building maintenance personnel may grossly underestimate such occurrences.

Other Risk Groups

As mentioned, mesothelioma risk was once thought to be limited to asbestos-industry workers. During the last 2 decades, it has become increasingly clear that this risk is quite diverse. A recent study by Muscat and Wynder[27] highlights this point. In a hospital-based case–control study, an attempt was made to determine the role cigarette smoking plays in the etiology of malignant mesothelioma and to quantify the risk of asbestos exposure in this malignancy. One hundred five male and 19 female patients with histologically confirmed malignant mesothelioma and 265 age-matched control subjects without tobacco-related conditions were included in the study. Table 1 shows the occupations of 68 male patients with mesothelioma and 1 female patient with mesothelioma with probable or likely asbestos exposure. As shown, 38 patients were employed as construction/maintenance workers, including such occupations as carpenter, painter, electrician, welder, and sheet metal worker.

Table 1. Occupations of 68 Men With Mesothelioma And 1 Woman With Probable or Likely Asbestos Exposure

Occupation	No. of yr of asbestos exposure
Shipyard workers (n = 18)	
Worker	3, 2, 3, 1, 3, 1, 1, 2, 3, 1, 2, 1
Electrical engineer	20
Maintenance/construction	39, 16
Mechanic	2
Welder	2
Metal/shipyard worker	23
Construction/maintenance workers (n = 38)	
Carpenter	20, 25, 36
Carpenter/construction worker	14
Construction worker	38, 3
Construction manager	60, 38, 47, 35
Electrician	36, 33, 1, 54, 38
Electrical engineering technician	2
Gasket winder	30
Insulator	32, 26, 38
Maintenance supervisor/metal worker	40
Painter	13, 31
Plumber/pipe layer	24, 44, 11, 2, 2
Plumber/pipe layer/sheet metal worker	33
Sheet metal worker	41, 30
Other metal worker	3, 31
Welder	13, 15
Other construction worker	19, 5
Other construction/painter	40

Data are summaries of patients in Muscat J, Wynder EL. Cigarette smoking, asbestos exposure and malignant mesothelioma. *Cancer Res* 1991; 51:2263–2267. Used with permission.

Table 2 lists patients with mesothelioma from the same study who were not employed in asbestos-related industries. Of particular interest were the cases of mesothelioma in a potter, who reported using a kiln with asbestos insulation, and a teacher, whose exposure was from friable asbestos insulation in a classroom during a 2-year period. Both females listed in Table 2 had histories of domestic asbestos exposure.

Table 3 lists the occupations of 24 male and 16 female patients with mesothelioma and without known or self-reported asbestos exposure. It is unclear how many of these individuals were exposed to respirable fibers because exposure in nonasbestos industry settings often goes unnoticed. For this reason, it is unknown what proportion of all mesothelioma cases are nonasbestos induced.

In the discussion section of their article, Muscat and Wynder[27] comment on a report by Zielhuis *et al.*,[28] who reported a female patient with mesothelioma; the woman had worked as an ironer in a laundry where deteriorating asbestos cloths were used that contaminated the surrounding environment. Another patient was found to have worked for 5 years as a stagehand. This patient reported often being covered with painted asbestos flakes that originated from stage scenery, which had been covered with asbestos as a fire retardant.

The medical literature is filled with reports of other patients with mesothelioma attributable to unusual asbestos exposure. For instance, Otte *et al.*[29] reported three family members who died of mesothelioma secondary to exposure from an asbestos cement product manufactured by family members in their home. The family manufactured a material called "Rollfix," which was used to fix screws in drilled holes. Amosite, gypsum, and sand were the major components of the product; the material was produced in the basement of the family home for 17 years. As the author reports, "The basement had no ventilation and cleaning was undertaken by the mother. No protective equipment was used . . . and no special work clothes were used. . . . After production stopped, the family stayed in the same residence and no attempts were made to remove asbestos from the house."[28] The father, mother, and son all died of malignant mesothelioma; they were three of the six family members involved in the manufacturing process.

Another report was published by Driscoll *et al.*[30] in 1988. These investigators reported five patients with malignant mesothelioma in a Native American pueblo of 2000 persons. In such a small population, far fewer cases were expected to occur during a 17-month period

Table 2. Nonasbestos-Related Occupations of 14 Men With Mesothelioma and 2 Women With Mesothelioma With Reported Asbestos Exposure

Occupation	No. of patients	No. of yr of asbestos exposure
Men		
Police officer	2	2,* 10
Teacher	1	2†
Potter	1	12‡
Navy ensign	1	1§
Environmental consultant	1	
Navy machinist	1	6
Navy service engineer	1	40
Stationary engineer	1	36
Machinist	1	31
Insurance salesperson	1	2
Navy seaman	1	3
Plant manager	1	2
Supervisor (oil company)	1	26
Women		
Bank teller	1	10*
Executive director	1	5*

* Reported domestic exposure to asbestos

† Reported friable asbestos crumbling from classroom ceiling for 2 years and worked in an asbetsos plant for 2 months

‡ Used a kiln with asbestos insulation

§ Reported asbetos exposure on a Navy ship

Data are summaries of patients in Muscat J, Wynder EL. Cigarette smoking, asbestos exposure and malignant mesothelioma. *Cancer Res* 1991, 51:2263–2267. Used with permission.

(April 1984 to September 1985). Additional investigation showed that asbestos was routinely used by Native American craftsman in the production of silver jewelry (*i.e.*, "Asbestos was used to insulate worktables against the intense heat of brazing torches and molten metal"). Silver slag periodically built up on these boards, which were cleaned by clapping the boards together or rubbing the working surfaces together. This procedure liberated respirable asbestos fibers.

In addition, this population also experienced asbestos exposure through the use of asbestos as a whitening agent for buckskin leggings and moccasins that are used in ceremonial dances. These leather items are scrubbed with cakes of asbestos, which often is derived from pipe insulation.

Talcott *et al.*[31] studied a cohort of cigarette filter workers (all males) involved in manufacturing asbestos-containing filters from 1951 to 1957. The primary type of asbestos used was crocidolite. Of the 33 men in the cohort, 28 had died as of December 31, 1988, *versus* the 8.3 expected deaths. The authors state that the threefold increase in mortality was almost entirely attributable to asbestos-associated diseases (*i.e.*, lung cancer, malignant mesothelioma, and asbestosis). Five of the 28 deaths were attributable to mesothelioma.

Chrysotile and Mesothelioma

Any discussion of asbestos-related mesothelioma risk must consider the controversy regarding what role the asbestos fiber type plays in the etiology of mesothelioma. This is particularly true because the chrysotile variety of asbestos accounts for about 95% of the world's production of asbestos.

Early work by Stanton *et al.*[32] demonstrated that fiber dimensions are an important determinant of biologic response and carcinogenic potential. Recent modifications of those findings have led some, such as Moss-

Table 3. Occupations of 24 Men and 16 Women With Mesothelioma With no Asbestos-Related Jobs or Self-Reported Exposures

Men
Accountant
Air traffic controller (Air Force)
Bus driver/salesman/ironworker
Carpet installer
Delivery driver/tire recapper
Director of merchandise
Health officer
Insurance sales (n = 2)
Inspector (steel mill)
Jewelry manufacturer
Lumber business manager
News editor
Musician/telephone coin collector
Office administrator
Owner of boat business/boat engine repair/farmer/rabbi/teacher
Real estate sales
Retail
Stationary engineer
Stock clerk/bus driver
Truck driver/bakery owner
Truck terminal manager
Vice president (fuel company)
Women
Housewife/secretary/machine operator*
Artist
Bookkeeper
Data entry operator
Housewife (n = 3)
Housewife/farm worker
Housewife/nurse
Housewife/secretary
Salesperson (n = 2)
Secretary
Secretary/driver
Showroom manager
Teacher/real estate agent

Data are summaries of patients in Muscat J, Wynder EL. Cigarette smoking, asbestos exposure and malignant mesothelioma. *Cancer Res* 1991, 51:2263–2267

* Husband is an auto mechanic.

man *et al.*,[33] to advocate the "amphibole hypothesis." Mossman *et al.* suggest that chrysotile is of doubtful carcinogenicity, whereas the amphiboles are much more potent carcinogens and are therefore responsible for most asbestos-related mesotheliomas. Unfortunately, numerous factors complicate analyses of the pathogenic potential of different fiber types. These factors include the scarcity for study of occupational cohorts exposed to a single fiber type during considerable time periods. Most past exposures have been to mixtures of fibers. In addition, accurate exposure data often are lacking or of questionable quality.

Nicholson[34] points out that wide variations of risk exist among different industrial settings and even within a single industry, suggesting that fiber type is not the parameter responsible for these differences. Although errors in exposure estimates may partially account for such discrepancies, it is likely that the altering of the asbestos fibers by industrial processing is responsible. For instance, processing chrysotile may change fiber dimensions from the majority being long, curly fibers to narrow, straighter ones that are known to be more carcinogenic. Thus, fiber type becomes a far less important parameter in estimating risk than actual fiber dimensions.

Also supporting the belief in chrysotile's carcinogenicity are data of the unit risk for mesothelioma. The unit risk data for mesothelioma closely parallel those found for lung cancer, suggesting that the same factors that affect unit risk for lung cancer also influence mesothelioma risk. As Nicholson points out, "the risk of mesothelioma per fiber exposure in three studies where it can be estimated directly from exposure and incidence data, is identical to that for exposure to 98% chrysotile plus 2% crocidolite, 60% chrysotile plus 40% amosite and 100% amosite respectively. Moreover, in most other studies where the mesothelioma risk cannot be estimated directly, the ratio of the number of mesothelioma to excess lung cancers is the same for exposures to predominantly chrysotile, to 100% amosite and to mixtures of chrysotile, amosite and crocidolite. . . . The ratio for 100% crocidolite is about twice as great."[34]

Animal studies provide additional evidence that all types of asbestos can induce mesothelioma. Inhalation studies reveal that chrysotile is a potent carcinogen. Implantation of fibers into the pleural cavity of laboratory animals shows that the carcinogenicity of mineral fibers is directly related to their dimensions and not their chemical composition.[35,36]

The debate over the carcinogenic potential of chrysotile also is complicated by the insistence of some investigators that lung fiber studies of exposed workers demonstrates that the amphiboles are responsible for the majority of lung cancers and mesotheliomas. This is based on the finding that chrysotile often is present in much smaller quantities in lung tissue than is amphiboles. Unfortunately, because little is known about the biologic properties of asbestos fibers in the human lung, it is difficult to interpret these data. It has been found that chrysotile is preferentially cleared from the lung within the first few weeks of exposure in contrast with amphiboles, although the ultimate fate of the fibers is unknown (*i.e.*, chrysotile may be preferentially cleared to the pleura).[37]

In summary, available data support the idea that all fiber types are capable of inducing malignancy. Although crocidolite may be more potent than chrysotile, it is not unique in its tumorigenic ability. With the widespread use of chrysotile in a multitude of products and applications, it would seem unwise to ignore the potential health risks of chrysotile.

Conclusion

Few commercial products have been as extensively studied as asbestos, and few commodities have generated as much legal, public health, and public policy interest as this "miracle mineral." The use of asbestos fibers dates to ancient times, but the health concerns related to its use are a recent phenomenon.

In 1960, Wagner *et al.*[11] provided the first clear evidence of a relationship between asbestos exposure (in this case crocidolite) and mesothelioma. Since then, hundreds of studies have documented the epidemiologic, biologic, and clinical characteristics of this disease. Initially, mesothelioma risk was confined primarily to miners, millers, and workers in asbestos-manufacturing industries. Subsequently, occupational groups using asbestos products (*e.g.*, insulators, pipe fitters, and shipyard workers) demonstrated a relatively high incidence of this tumor. Today, it is clear that the populations at risk for having this malignancy continue to expand. As pointed out in this article, occupational risk is no longer confined to asbestos-industry workers. Likewise, nonoccupational hazard exists, such as household and building-occupant exposures.

Many questions regarding the biologic behavior of mineral fibers remain unanswered (*e.g.*, how does asbestos cause cancer; how are fibers transported in the human respiratory tract, and what role does fiber type play in pathogenesis). With the widespread use of asbestos worldwide, particularly now in the Third World, the epidemic of mesothelioma may continue well into the 21st century.[38] It is hoped that, with a greater appreciation of the scope of asbestos exposure occurring outside of the industrial setting, more effective strategies for disease prevention can be developed.

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