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Review Article

Government and Navy knowledge regarding health hazards of asbestos: A state of the science evaluation (1900 to 1970)

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Abstract

We evaluated dozens of published and unpublished documents describing the knowledge and awareness of both the scientific community and governmental entities, particularly the US Navy, regarding the health hazards associated with asbestos over time. We divided our analysis into specific blocks of time: 1900–1929, 1930–1959, and 1960–1970. By 1930, it was clear that high occupational exposure to asbestos caused a unique disease (asbestosis). Between about 1938 and 1965, a considerable amount of exposure and epidemiology data were collected by various scientific and government organizations. Between 1960 and 1970, mesothelioma was clearly linked to exposure to amphibole asbestos. Nonetheless, the Navy continued to require the use of asbestos-containing materials on ships, but also recommended that proper precautions be taken when handling asbestos. We concluded that the Navy was arguably one of the most knowledgeable organizations in the world regarding the health hazards of asbestos, and that it attempted to implement procedures that would minimize the opportunity for adverse effects on both servicemen and civilians. Finally, it is apparent from our research that through at least 1970, neither the military nor the private sector believed that the myriad of asbestos-containing products considered "encapsulated" (e.g. gaskets, brakes, Bakelite) posed a health hazard to those working with them.

Keywords:: Asbestos, asbestosis, mesothelioma, Navy

Introduction

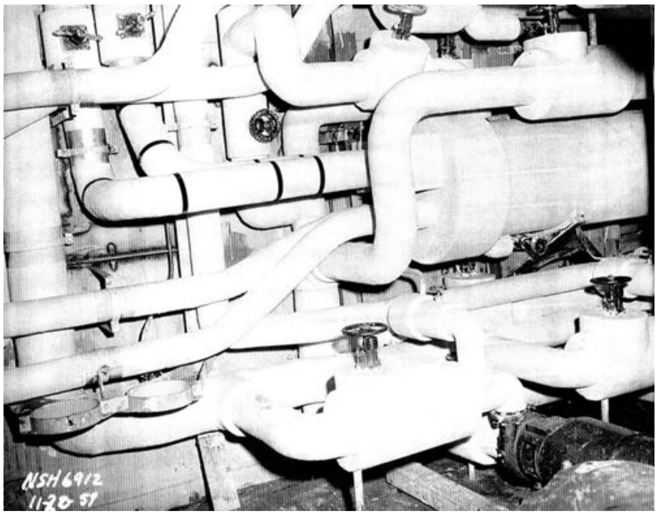
Because of its unique physical and chemical properties, asbestos has historically been used to prevent exposure to hot surfaces, contain and preserve heat or cold, fill certain molded materials (and building materials), as well as act as a flame retardant (Maines, 2005). In the United States, asbestos use began around the end of the 19th century, and its consumption increased substantially during World War II (WW II) due to its use in shipbuilding and repair (Balzer & Cooper, 1968; Balzer, 1968; National Institute for Occupational Safety and Health [NIOSH], 1972b).

Because of the immediate threat of fire and the great loss of life from fires in residential and public buildings and aboard ships during the late 19th and early and mid-20th centuries, asbestos was recommended or required by many municipalities and organizations, such

tion Association and the National Board of Fire Underwriters, as a means to prevent fire (Maines, 2005). Its

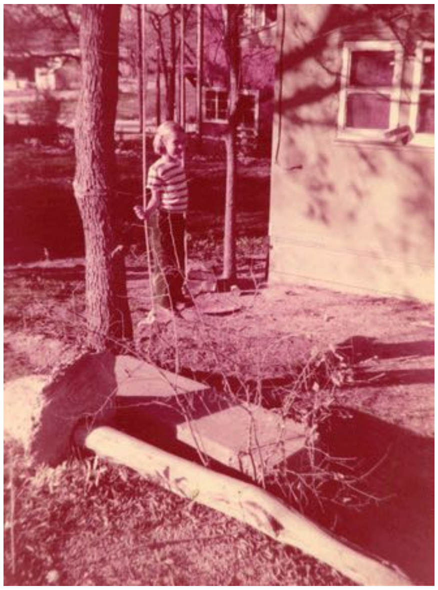
by the US military for much of the 20th century because of its predictable and effective qualities regarding use was explicitly required by the US military for much of the 20th century because of its predictable and effective qualities regarding temperature resistance or incombustibility (US Department of Defense, 1954, 1967; US Navy, 1941b, 1945). During WW II, for example, the military insisted on using asbestos in hundreds of applications in military settings, particularly aboard Navy ships (Rushworth, 2005). Suppliers to the government were expected to follow government specifications regarding the precise amount of asbestos to be used in materials such as insulation, gaskets, some filters, packing, plastic materials, and so on; these materials were to contain a certain percentage of asbestos to increase durability and/or to minimize flammability. According to a former Naval official, for example, WWII destroyers carried 24 to 30 long tons of thermal insulation per ship, and "*USS Iowa* class battleships carried nearly 465 long tons of thermal insulation" (Rushworth, 2005, p. 36). As shown in Figure 1, virtually every pipe and many of the ventilation ducts on the ship on which this photo was taken were covered with asbestos insulation.

Figure 1. Passage leading to a boiler room (1959). Photo source: Carl Mangold. Previously published in Hollins et al., 2009.



Following WW II, asbestos uses shifted to the building and construction industry, accounting for more than two-thirds of the total asbestos demand in the United States by the 1980s. For example, asbestos was used in prefabricated homes such as the one shown in Figure 2. Between 1920 and 1985, thousands of residential and industrial products and applications contained asbestos, including: (i) insulation or filler; (ii) blocks and pipe sections; (iii) gaskets and packing; (iv) cement sheets and paper; (v) textiles; (vi) blankets or felts; (vii) friction materials (e.g., brakes); (viii) consumer products like Bakelite, used for knobs on furnaces and other hot objects, radios, TVs, and other electrical applications; (ix) flooring; (x) pipe; (xi) home siding; (xii) joint compound; and (xiii) other heat-resistant materials, such as coatings, mastics, welding blankets, and gloves (Lindell, 1973).

Figure 2. Prefabricated home manufactured with asbestos-containing materials (1956). Photo courtesy of Rachel Maines.



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The health hazards associated with exposure to raw asbestos fibers did not begin to be recognized until the early 20th century. While a number of case reports were published between 1900 and 1930 suggesting that exposure to high concentrations of airborne asbestos dust might produce a lung disease other than that already known to be caused by high exposure to any dust (Auribault, 1906; Murray, 1907; Fahr, 1914; Pancoast & Pendergrass, 1925; Oliver, 1927; Simson, 1928; Seiler, 1928; Wood, 1929; Wood & Page, 1929; Stewart & Haddow, 1929), it was not until 1930 that studies clearly showed that occupational exposures to asbestos fibers in manufacturing settings could cause a unique disease (asbestosis), a potentially debilitating lung disease, at high airborne concentrations (Merewether & Price, 1930). Prior to that, the ability to identify asbestos as the cause of a unique lung disease was confounded by the prevalence of pneumonia, silicosis, and tuberculosis in the general population. A causal association between occupational exposure to asbestos and two types of cancer (lung cancer and mesothelioma) was established in the second half of the 20th century. Although there were ample case reports regarding the cancer hazard posed by asbestos, the elevated risk of lung cancer was first formally demonstrated by Doll in 1955 (Doll, 1955). Similarly, although there were numerous case reports regarding the possible mesothelioma hazard posed by amphiboles (and possibly chrysotile), it was not until 1960 and the work of Wagner et al. that crocidolite was shown to cause this disease, and, shortly thereafter, Selikoff et al (1964) confirmed that amosite could do the same (Wagner et al., 1960, Selikoff et al., 1964).

It is noteworthy that until the mid-1940s the toxicology and industrial hygiene fields were in their infancy. Prior to this time, very few animal toxicity studies were being conducted and, of those conducted, most were designed to identify whether any health effects occurred within 1 or 2 days of chemical exposure (acute toxicity testing). Long-term (chronic) animal toxicology studies that mimicked occupational exposures were generally not conducted until the 1950s or 1960s. The industrial hygiene field did not begin to mature until the late 1930s and early 1940s (Corn, 1992; Drinker, 1950). The American Conference of Governmental Industrial Hygienists (ACGIH), for example, was not formed until 1938, the American Industrial Hygiene Association (AIHA) was formed in 1939, and the Society of Toxicology was not formed until 1960. Not surprisingly, for the first five decades of the 1900s, there were no national guidelines or regulations to limit exposure to airborne contaminants in the workplace or outdoors (i.e. ambient air).

This article, then, presents a state-of-the-art analysis of the roles the scientific community and governmental entities assumed in terms of characterizing the health hazards associated with asbestos and the use of asbestos-containing products over time, with particular focus on the US Navy and its knowledge about asbestos exposure and associated health risks. This evaluation is divided into three time periods: 1900 to 1929, 1930 to 1959, and 1960 to 1970, based on what were perceived to be seminal events. The first era describes the beginning of awareness and eventual recognition of asbestos-related diseases in mining and manufacturing. The second era is defined by a significant increase in the use of asbestos throughout the world and, in particular, by the US government, and especially by the

Navy. During this period, the fields of toxicology, industrial hygiene, and occupational medicine took shape. The second era is also distinguished by the setting of the first occupational exposure limits, as well as the implementation of various control techniques for limiting exposure to asbestos in the workplace. The third era is marked by several key epidemiology studies that clearly characterized the health risks associated with performing insulation work both in buildings and on military vessels. During this period, there were significant efforts to reduce exposure by tightening exposure limits, using engineering controls, and educating workers. It was during this period that the ACGIH recommended a lower occupational exposure limit for asbestos, as it became more clear that previously established guidelines were not protective against all asbestos-related diseases.

Background

Three forms of asbestos have been used commercially over the past 100 years. Chrysotile (a member of the serpentine mineral family) was the predominant form used through the 1930s, after which amosite (an amphibole) became the dominant fiber type because of its extensive use in the shipyard industry for the next 30–40 years (Balzer & Cooper, 1968). Crocidolite was not frequently used in products, but would sometimes be needed in some specialized gaskets, packing, pipe, commercial siding, and filters such as those used in gas masks (Maines, 2005).

The other forms of asbestos, specifically, anthophylite, tremolite, and so on, were never specifically isolated and used in commercial products. However, some of these forms were present in trace amounts in various products.

Around 1960, chrysotile again became the most used fiber type for a number of reasons, including its use in molded products and textiles, and its increased use in building materials. Starting in the 1970s, chrysotile was sometimes mixed with other forms of asbestos, such as crocidolite and amosite, to produce special products with certain characteristic; insulation was the most notable example (NIOSH, 1972a, 1972b). Because of its widespread use, asbestos presented numerous exposure opportunities for workers handling or using asbestos-containing materials in the manufacturing, construction, maritime, and other industries.

Regarding historical asbestos use in the Navy, beginning in the 1880s and continuing well into the 1950s, amosite and chrysotile fibers, and to a much lesser extent, crocidolite, were used extensively as insulating materials on naval ships because of their incombustibility, low thermal conductivity, light weight, and strength (Fleischer et al., 1946; Harries, 1968; Murphy et al., 1971; Rushworth, 2005; Hollins et al., 2009). After the US Navy approved the use of amosite asbestos in the mid to late 1930s, and then subsequently required it in many applications, it became the prominent fiber type used in molded insulation materials aboard naval vessels (Rushworth, 2005).

Methods

We conducted a comprehensive search of publicly available documents that directly or indirectly addressed the US government's knowledge of the hazards of asbestos dust. We attempted to find published and unpublished literature, conference proceedings, correspondence, manuals, and specifications. Several database search engines (e.g. PUBMED, Web of Science) were used to identify potentially relevant conference proceedings or publications in the peer-reviewed literature, using keywords such as "asbestos," "asbestosis," "dust," and "industrial medicine."

The bulk of key information was gathered from the holdings of industrial hygienists and toxicologists who practiced between 1930 and 1975. We consulted numerous libraries and collections including the Drinker collection at Harvard, and the personal collections of Leroy Balzer and Clark Cooper of University of California at Berkeley. In addition, we reviewed a large number of documents previously produced by various product manufacturers as part of asbestos litigation in the last decade. Previously, these documents were not readily available, as they were often kept in the personal files of individuals or of bankrupt corporations. Finally, we searched the Johns Mansville trust, a collection of 37,000,000 documents which contain information regarding asbestos; however, we did not identify additional government documents at the trust.

Our search focused on the period from 1900 to 1970, and on information written by government institutions and the military. Government documents such as the Federal Register and asbestos textbooks were also evaluated. More than 100 documents are cited in this paper, and at least 200 additional documents were reviewed, but not included.

Within each temporal period, we present a brief overview of important documents and findings, and then discuss specific documents in approximate chronological order. Subheadings are used to designate the beginning of a set of related documents, such as a chronological set of quarterly reports published by the US Navy, or a series of related memorandums.

Results

Period I (1900–1929)

In general, the focus of many occupational health studies conducted prior to 1930 was on the dusty trades, such as coal mining and stone masonry (Hunter, 1955, 1964). Early researchers were also attracted to disease categories associated with a few of the organic solvents, particularly benzene (Hamilton, 1929, 1934). Scientists had long recognized that long-term exposure to highly dusty environments could lead to lung diseases, generally called pneumoconiosis or "dusty lung disease" (Pancoast & Pendergrass, 1925). During this time period, asbestos was initially considered to be similar to the more common nuisance dusts, such as silica and coal dust, that could cause pneumoconioisis (e.g. dusty lung disease).

The first documented case of lung disease associated with asbestos exposure was observed in 1899 and reported in 1907; the case involved diffuse pulmonary fibrosis and the presence of asbestos spicules in the subject's lungs (Murray, 1907; Castleman, 2005). Testifying before an inquiry at the British Government Commission on Occupational Disability, Murray (1907) connected the workplace exposure of airborne asbestos to the scarring he observed in the worker's lungs (Kilburn, 1992). Around the same time, case reports were published in France and Germany, and factory inspectors in the United Kingdom and the United States reported on possible dangers associated with asbestos dust observed during surveys of manufacturing environments (Auribault, 1906; Collis, 1911; Fahr, 1914; Hoffman, 1918).

More than 10 years later, Cooke (1924) published a description of pulmonary fibrosis in a woman who had worked for 20 years in an asbestos textile factory. Shortly thereafter, the term "asbestosis" was used to describe the asbestos spicules observed in the lungs of case report subjects, and the term "pulmonary asbestosis" was used to describe the pneumoconiosis condition observed (Cooke, 1927; McDonald, 1927; Oliver, 1927). By the late 1920s, additional case reports were published in the literature, all of which contributed to a growing awareness that inhaling asbestos dust might be a potential cause of disease (Pancoast & Pendergrass, 1925; Seiler, 1928; Simson, 1928; Cooke, 1929; Stewart & Haddow, 1929; Wood, 1929; Wood & Page, 1929). However, these early case reports provided little, if any, information regarding the specific activities of workers, the concentration of airborne particles, or details about the disease in these workers. Often, these reports were also complicated by the presence of tuberculosis (TB), making it unclear whether the lung dysfunction was primarily caused by asbestos or by TB, or whether one disease had to precede the other (Pancoast & Pendergrass, 1925). In addition, these workers had also often been exposed to other dusts during their careers, were smokers, or may have had pneumonia, all factors making it more difficult to clearly single out asbestos exposure as the primary cause of subject's respiratory disease.

Most studies during this period did not identify the type of asbestos or quantify the concentration of airborne fibers to which workers were exposed. Fulton et al. (1935) indicated that "chrysotile, a mineral of the serpentine group, comprises the bulk (about 95%) of the asbestos of commerce" in the United States during the 1930s (Fulton et al., 1935, p. 4). Brake linings for automobiles in North America and Europe are known to have contained only chrysotile fibers (with occasional trace concentrations of tremolite at or below the limit of detection—about 6 ppm), although amphibole fibers were reportedly used in some railroad engine brake linings in the United Kingdom during this time period (Newhouse et al., 1982). Amphibole fibers, sometimes in combination with chrysotile fibers, were also used during this period in insulation and other products, such as asbestos cement pipe (Fleischer et al., 1946; Finkelstein, 1983).

Thus, there are a number of case reports indicating that an awareness of the adverse health effects of high levels of exposure to airborne asbestos existed prior to 1930. Although it is clear, then, that asbestos was being used in the United States between 1900 and

1929, no documents from the Navy or other US government agencies were identified that addressed the US government's knowledge of the hazards of asbestos dust for this time period (Maines, 2005; Bartrip, 2006).

Period II (1930–1959)

During the period from 1930 through 1959, researchers identified a health risk associated with working with particular types of asbestos in certain occupations and at certain levels of exposure. These studies primarily involved workers in mines or in very dusty factory conditions where raw asbestos was used who were exposed to high airborne asbestos concentrations (significantly greater than 5 mppcf or 30 f/cc; Merewether, 1930; Dreessen et al., 1938).

In 1935, the textbook *Industrial Medicine* noted the relationship between asbestos and asbestosis (Clark & Drinker, 1935). This book identified chrysotile as an important variety of asbestos, and stated that "sufficient exposure to dust of asbestos in any stage of its processing may cause asbestosis" (Clark & Drinker, 1935, pp. 115–116). A similar physicians' reference text, published in Canada in 1949, cautioned that exposure to asbestos dust "occurs in the crushing, carding, spinning and weaving of the material, and in the manufacture of brake linings and asbestos insulating products" (National Health and Welfare, 1949, p. 109). These texts made no mention of potential exposures or hazards to end-users of asbestos-containing products (such as brakes, gaskets, molding compounds, floor tiles, and so on).

In industrial hygiene reference books published during this time period, asbestos was linked to asbestosis, but not to cancer. For example, the 1948 edition of *Industrial Hygiene and Toxicology*, the most cited and respected text of its time in both professions, notes that "most observers feel that the incidence of asbestosis in American asbestos workers is quite low," and asbestosis is reported to appear "milder than silicosis;" there is no mention of asbestos-related malignancy (Patty, 1948, p. 511). A second major reference text from the same year notes only that asbestos causes "fatal lung changes which…show an entirely different picture from silicosis" (Teleky, 1948, p. 207).

In addition to the scientific literature and reference texts, a number of important government and military memorandums and publications were written, and conferences were held during this period. Memorandums among Naval personnel discussed the Navy's use, and even stockpiling of, amosite through WW II, as well as the importance of proper ventilation for controlling asbestos dust exposures (Jenkins, 1939; Brown, 1941; Knowlson, 1942). Tens of thousands of bags of asbestos were being delivered to the United States, inspected, sorted, and stored for future use in war-related products. Beginning in about 1930, numerous publications discussed the need to use preventative measures, such as using respirators or wetting methods to reduce the magnitude of exposure to asbestos among pipefitters and other craftsmen. For example, throughout the 1950s and 1960s, various Naval memorandums and manuals continued to stress the importance of using ventilation or respirators when working with asbestos-containing insulation (US Navy, 1943; Drinker, 1944b; Wheelock, 1944). The Navy, in particular, because of the massive effort to build new ships for WW II, and then during the decommissioning process following the war, had to purchase and install millions of tons of asbestos insulation; such as the stacks of asbestos supplies shown in figure 3. During this time, the Navy developed numerous guidelines and medical programs in an attempt to protect government employees and contractors from disease (US Navy, 1939, 1943; Shilling, 1955; Rushworth, 2005).

Figure 3. The U.S.S. Detroit, a fast combat support ship, with asbestos cloth supplies stacked dockside. Photo source: Carl Mangold. Previously published in Hollins et al., 2009.

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Specific documents from this period

The first report from this era that presented new evidence for asbestos-related disease was published in 1930. Dr. E. R. A. Merewether, Medical Inspector of Factories, and C. W. Price, Engineering Inspector, were commissioned by the government of the United Kingdom to prepare a report on the risk of disease among asbestos workers, which was published by His Majesty's Stationery Office in London. That same year, a similar report was published by Dr. Merewether in the United States in the *Journal of Industrial Hygiene* (Merewether, 1930; Merewether & Price, 1930). Merewether and Price's report was the first epidemiological study that clearly showed that exposure to asbestos dust could cause asbestosis. They reported that the findings of this study "establish the facts that the inhalation of asbestos dust over a period of years results in the development of a serious type of fibrosis of the lungs, that the development of the disease varies in direct proportion to the length of the exposure to dust"(Merewether & Price, 1930, p. 4).

In their study, Merewether and Price examined data collected from 363 asbestos workers during 1928 and 1929 in the United Kingdom (Merewether & Price, 1930). The study population was divided into groups representing the following manufacturing processes: (i) crushing, opening, disintegrating, and mixing; (ii) carding; (iii) spinning, twisting, doubling, and plaiting; (iv) insulating mattress making; (v) weaving and associated processes; and (vi) miscellaneous processes and unclassified workers. They concluded that "it seems clear that fibrosis of the lungs is a definite occupational risk amongst asbestos workers as a class" and "it appears that the risk falls most heavily on those longest employed and on those engaged in the more dusty processes" (Merewether & Price, 1930, p. 13). They added, "It is of interest to consider why it is that this disease [asbestos fibrosis] has only recently attracted notice and become a problem in the industry, although asbestos was known to, and worked by the ancients" (Merewether & Price, 1930, p. 17).

Even after the papers by Merewether and Price, the idea that asbestos dust caused a unique disease was hardly universally known or accepted. A lack of certainty existed as to whether asbestos caused a disease markedly different than silicosis, or whether it could occur in a worker who had not also had either pneumonia or tuberculosis (two fairly prevalent lung diseases at that time).

For example, seven years after the Merewether and Price publications, Senior Surgeon R. R. Sayers, Chief of the Division of Industrial Hygiene in the US Public Health Service, discussed harmful industrial dusts in the transactions issued for the Twenty-sixth National Safety Congress. In his discussion of fibrosis-producing dusts (including asbestos), Dr. Sayers stated that "so far as it is known, no inorganic substances other than silicon derivatives cause more than a very moderate degree of fibrosis of the lung" (Sayers, 1937, p. 89). He added that a study of anthracite miners indicated that "asbestos dust seems to be unique among silicates in the prevalence and severity of the disease it causes" (Sayers, 1937, p. 89). Dr. Sayers also discussed dust control measures and their importance (Sayers, 1937). He published a similar article in *National Safety News* in 1938 (Sayers, 1938).

In the late 1930s, the Assistant US Surgeon General and his colleagues (Dreessen et al., 1938) were the first researchers to quantify exposure to asbestos and relate it to specific health effects. Their study was commissioned and conducted by the US Public Health Service; Dr. Dreessen was an employee of the US Department of Public Health. The study was published as a Public Health Bulletin in August, 1938, and was prepared under the direction of the US Surgeon General. The study population consisted of 541 asbestos textile factory employees in North Carolina. The authors reported that "the only cases of asbestosis, three in number, found below 5 million particles per cubic foot were diagnosed as doubtful; well-established cases occurred at higher concentrations. It appears from these data that if asbestos dust concentrations in the air breathed are kept below this limit new cases of asbestosis would not appear" (Dreessen et al., 1938, p. ix). The authors concluded that "5 million particles per cubic foot may be regarded tentatively as the threshold value for asbestos-dust exposure until better data are available" (Dreessen et al., 1938, p. 91).

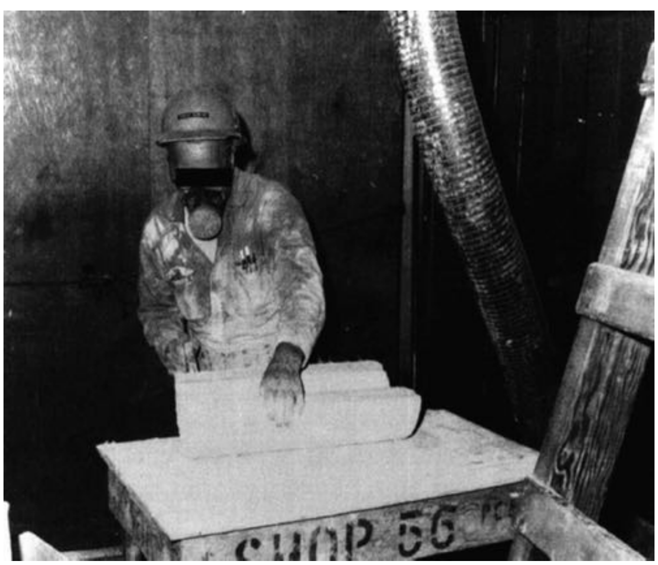
US Navy

The US Navy was at the forefront of asbestos use and control. By 1939, the Navy was recommending that exposure controls be used during asbestos handling. A memorandum from H. E. Jenkins, a Medical Officer for the US Navy, to the manager of Boston Naval Yard addressed the health hazards of insulating material. He reported that the pipe covering shop was currently "thoroughly wetting down asbestos-containing insulating material," but recommended that "personnel wear a respirator and protective gloves" as an additional precaution (Jenkins, 1939, p. 1). He also recommended that "'amosite' be kept sufficiently moist at all times to prevent dust" when working aboard ship where respirators were impractical (Jenkins, 1939, p. 1).

In 1941, Ernest Brown, a captain in the Navy Medical Corps, discussed the Navy's industrial hygiene program in a military publication. He wrote: "One of the most important concerns of the Medical Department of the United States Navy today is industrial hygiene, especially in navy yard practice" (Brown, 1941, p. 3). Regarding asbestos exposure, Brown acknowledged that "there is a potential occupation disease hazard due to inhalation of asbestos dust among workers engaged in the manufacture of asbestos insulating covers for flanges, valves, and high temperature steam turbines" (Brown, 1941, p. 12).

Brown (1941) wrote that he "recently conducted a medical survey of the workers of the pipe-insulating shop of the New York Navy Yard, inclusive of roentgen studies. The maximum working period of exposure was seventeen years. No cases of asbestosis were found. Similar findings have been reported from two other yards, but the study should be extended to all men in this trade" (Brown, 1941, p. 12). He suggested control measures, including moistening the asbestos material, using localized exhaust ventilation, and wearing a respirator during the dustiest aspect of the process. As an example, Figure 4 shows a worker using a respirator and local exhaust ventilation.

Figure 4. Local exhaust ventilation in the work area of an insulator sawing pipe insulation. Photo source: Carl Mangold. Previously published in Hollins et al., 2009.



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A 1941 memorandum from Commander Charles S. Stephenson, head of the Division of Preventative Medicine within the Navy's Bureau of Medicine and Surgery, to Admiral McIntyre, Surgeon General of the US Navy, regarding various health hazards reported that with

regard to asbestos exposure and asbestosis, "we are having a considerable amount of work done in asbestos and from my observations, I am certain that we are not protecting the men as we should. This is a matter of official report from several of our Navy

Yards" (Stephenson, 1941, p. 2).

Also in 1941, the US Navy Department Bureau of Medicine and Surgery published a booklet entitled *Statistics of Diseases and Injuries in the United States Navy for the Calendar Year 1939* (US Navy, 1941a). This report discussed many kinds of hazards to Navy workers, including asbestosis, the development of which was noted to depend on "the concentration of the dust, the size of the dust particles, and the length of exposure" (US Navy, 1941a, p. 24). The report also recommended methods for preventing asbestos dust exposure, such as local exhaust ventilation for insulators in the fabrication shop.

Required use of asbestos by the Navy in WWII

Although the Navy recognized asbestos as a genuine occupational hazard, it remained very much in use, since the current belief was that it could be handled safely with proper training and instruction. Indeed, during WW II, asbestos use was controlled by the government for the war effort, and was designated as a critical raw material. For example, on January 21, 1942, the Director of Priorities, Office of Production Management, issued a Conservation Order curtailing the use of certain types of asbestos by those outside the military. Specifically, chrysotile asbestos and various grades of amosite asbestos were prohibited for civilian use and other applications, "except where… necessary to fill Defense Orders" (Knowlson, 1942, p. 2). The purpose of the conservation order was "to promote the defense of the United States, to conserve the supply and direct the distribution" of asbestos (Knowlson, 1942, p. 2). The worker in Figure 5, a photograph taken in 1942, is manufacturing asbestos coils for the war effort.

Figure 5. Worker winding an asbestos insulated low-volt coil (1942). Photographer: Alfred T. Palmer. Library of Congress Prints & Photographs Division.

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In a report to the Operations Vice Chairman of the War Production board, the Cork, Asbestos, and Fibrous Glass Division Requirements Committee for the War Production Board stated that "the types of asbestos required for the war effort are three, chrysotile, amosite and blue" (Meloy, 1944, p. 1). Table 5 of the Meloy report shows that in 1944, no asbestos was to be designated for civilian uses (i.e. packing, gaskets, friction, or aircraft). The report added that "the asbestos section maintains supervision of all gaskets, packing, and oil seals, and all friction materials" (Meloy, 1944, p. 21).

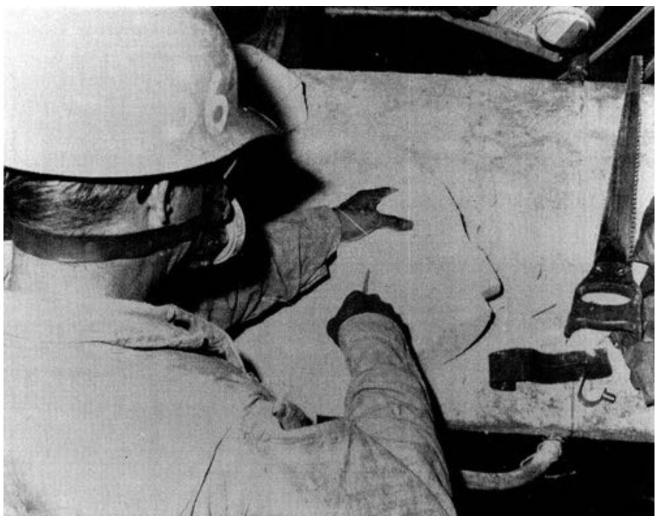
The Chief of Naval Material sent a memorandum in 1952 to the Chairman of the Munitions Heard, regarding the "proposed…discontinuance of the stockpiling of amosite asbestos in view of the availability of fibrous glass as an alternate material for the manufacture of thermal insulating felt" (US Navy, 1952, p. 1). However, the Chief reported that "a careful study of this problem indicates that the Department of the Navy will continue to require substantial quantities of amosite and accordingly cannot recommend the discontinuance of stockpiling of asbestos at this time" (US Navy, 1952, p. 1).

Shipyards/Drinker studies and memos

As a result of the Navy's extensive use of asbestos-containing materials, consisting almost entirely of insulation products, it was aware that shipyard workers were also known to be at relatively high risk of disease from asbestos. In 1942, Dr. Philip Drinker, Chief Health Consultant to the US Maritime Commission, as well as a professor and engineer at Harvard University, submitted a report detailing an industrial health survey performed at Bath Iron Works to the US Maritime Commission. In this report, Dr. Drinker made general recommendations, such as "periodic examinations of all workers engaged in occupations potentially hazardous to themselves or others should be conducted" (Drinker et al., 1942, p. 1).

Regarding workers in the pipe covering shop at Bath, Drinker reported that "the work involves the making of asbestos covers for the pipes on board the ships… cutting and pounding of asbestos matting… [and] cutting of hard wedge-shaped pieces of asbestos by… band saw" (Drinker et al., 1942, p. 12). He stated that "all of these processes result in the spreading of asbestos and fibers throughout the shop," and "the conditions in this shop present a very real asbestos hazard and immediate steps should be taken to segregate the most [dusty] processes into a well ventilated area" (Drinker et al., 1942, p. 12). Figure 6 illustrates the process of shaping insulation material in a shipyard.

Figure 6. Insulator shaping a piece of insulation at Puget Sound Naval Shipyard. Photo source: Carl Mangold. Previously published in Hollins et al., 2009.



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In early 1943, the Navy Department and Maritime Commission jointly issued "Minimum Requirements for Safety and Industrial Health in Contract Shipyards." This report set standards for industrial health and safety, and urged that "any standards of higher level be continued and that where substandard conditions of health and safety exist, they immediately be brought to required standard or better" (US Navy, 1943, p. 1).

Overall, the Navy was concerned about its need to use asbestos, and seemed to work diligently to educate and protect as many workers as feasible given the pressures it faced. For example, asbestos (such as in pipe coverings) was listed in a table titled "Jobs Requiring Respiratory Protective Equipment," which was a table listing examples of jobs during which asbestos dust could be breathed, included handling, sawing, cutting, molding, and welding rod salvage. Regarding asbestosis, the report noted that jobs involving asbestos dust could be performed safely with "segregation of dusty work" and special ventilation or wearing special respirators (US Navy, 1943, p. 9). "Periodic medical examination" was also recommended (US Navy, 1943, p. 9).

Two years after his report on the industrial health survey of Bath Iron Works, Dr. Drinker sent a memorandum to Captain Ingram and others at the Navy Bureau of Ships. In his memo, Dr. Drinker presented union workers' concerns regarding amosite pipe insulation on Navy vessels. He noted that dust counts where men were working, measured by the US Public Health Service, were "very much higher than anyone would recommend" (Drinker, 1944a, p. 1). He recommended an increased use of control measures, including wearing

respirators, applying amosite materials wet, and properly ventilating. In response to Dr. Drinker's letter, C. D. Wheelock of the US Maritime Commission supplied the following information: "(a) Amosite with water repellant is used as an insulating material on all pipe lines carrying fresh and salt water. It is the primary material used and no satisfactory substitute is available. (b) It cannot be satisfactorily applied when moistened. (c) It is suggested that when Amosite is being installed in restricted spaces that the workmen use either airline respirators or filter respirators" (Wheelock, 1944, p. 2).

A 1944 letter to the US Navy Supervisor of Shipbuilding noted that "recently, the Bureau of Medicine and Surgery conducted shipboard 'dust counts' during the application of 'Water Repellant Amosite Felt' insulation. The Bureau is informed that the 'dust counts' showed a concentration well above the accepted maximum of 8 million particles of dust, one micron and less in size, per cubic foot" (US Navy, 1944, p. 1). The letter went on to state that work involving all types of water repellant amosite showed high dust concentrations, and that "the Bureau considers that such high dust concentration constitutes a dangerous hazard to personnel" (US Navy, 1944, p. 1). The Bureau thus authorized a substitute for low-temperature pipes that required thermal insulation, which involved layering untreated felted amosite, paper, fibrous glass cloth, and white fire retardant paint (US Navy, 1944, p. 2).

In 1945, Dr. Drinker sent a memorandum to Captain Thomas J. Carter of the Bureau of Medicine and Surgery describing a report by Drs. Fleischer and Dreessen on asbestosis cases at Bath Iron Works, including dust counts and dust analyses conducted at Harvard (Drinker, 1945b). According to Drinker, "this evidence is enough to indicate a fairly serious dust risk at Bath and to make it very probable that the same sort of thing will be found in other plants and yards where the same type of pipe covering materials are used" (Drinker, 1945b, p. 12).

Later that same year, Dr. Drinker sent a memorandum to Admiral Mills of the Bureau of Ships, with carbon copies to Captain Burton at the Bureau of Medicine and Surgery and a Mr. Tracy at the Maritime Commission. Attached to this letter was a report titled "Health Survey of Pipe Covering Operations in Constructing Naval Vessels" (Drinker, 1945a, p. 1). Drinker reported that, based on data, pipe covering operations "as found in our Navy yards is most unlikely to cause ill health" (Drinker, 1945a, p. 1). He also requested authorization to publish the study in a medical journal, and recommended that a copy of his conclusions be sent to the insurance divisions of the Bureau of Ships and the Maritime Commission, as both were "concerned with possible damage suits from workers in shipyards" (Drinker, 1945a, p. 1).

In 1946, Comdr. Fleischer, US Navy Reserves Assistant Chief Health Consultant, Lieut. Viles and Lieut. Gade, US Navy Reserves Health Consultants, along with Drinker, published their report, previously mentioned in the 1945 letter from Dr. Drinker to Admiral Mills, in the *Journal of Industrial Hygiene and Toxicology* (Fleisher, 1946). The authors performed a large epidemiology study involving pipe coverers in shipyards. They described pipe covering tasks as (i) laying out and cutting, (ii) band saw cutting, (iii) sewing and preparation of boots and jackets, (iv) cement mixing, (v) molding, (vi) grinding, and (vii) installation on board ship. Few cases of asbestosis were observed in more than 1000 shipyard pipe fitters exposed to amosite asbestos in pipe-covering material. Examples of the manner in which these workers cut and handled asbestos insulation, such as shown in Figure 7, have been described and presented in photos elsewhere (Hollins et al., 2009).

Figure 7. Workers in the PSNS sewing room. Photo source: Carl Mangold. Previously published in Hollins et al., 2009.

Display full size

When reporting their medical findings, the authors stated that "since only three workers out of the 1074 X-rayed had asbestosis, and each of the three had been a pipe coverer for more than 20 years, it would appear that asbestos pipe covering of naval vessels is a relatively safe occupation" (Fleischer et al., 1946, p. 14–15). Based on their observations, researchers concluded that covering pipe with asbestos insulation, while known to be a dusty task, was not a dangerous trade, especially if some precautions or controls were implemented (Fleischer et al., 1946). However, their conclusion that insulators were not at risk for asbestosis was later shown to be erroneous (Marr, 1964), since they had failed to wait long enough to see all the adverse effects of such activities (unbeknownst to them, the latency for all asbestos diseases can exceed 40 years).

In the same year, 5 years after the ACGIH established a committee to investigate, recommend, and review exposure limits for chemical substances, the organization adopted the first set of exposure limits, which, at that time, were known as Maximum Allowable Concentrations (ACGIH, 1946). The ACGIH guidelines were intended to represent "as accurately as possible that concentration at which a worker exposed for a sufficient period of time will just escape physiological or organic injury and occupational disease" (ACGIH, 1946, p. 54). The initial limit for asbestos dust was set at 5 mppcf, equal to the existing limit for mineral dust, in 1946. The history of setting occupational exposure limits and, in particular, the ACGIH TLVs, is presented elsewhere (Paustenbach et al., 2011).

Cook noted, in the original documentation of these limits, that "the intent in presenting these maximum allowable concentrations is to provide a handy yardstick to be used as guidance for the routine industrial control of these health hazards—not that compliance with the figures listed would guarantee protection against ill health on the part of exposed workers" (Cook, 1945, p. 936). He repeated this intention in an updated version of the limits (Cook, 1987).

Following the shipyard studies, in 1947 the Navy published an issue of *The Safety Review*, its internal publication for providing health and safety information directly to workers, in which it warned: "Exposure to asbestos dust is a health hazard which cannot be overlooked in maintaining an effective occupational-hygiene program" (US Navy, 1947b, p. 13). In this report from the Portsmouth Naval Shipyard on asbestos covering activities, the review recommended "(1) That the asbestos covering process be confined to as small a section of the shop as possible, (2) That proper ventilation be secured, (3) That appropriate respirators be worn by the workers, [and] (4) That instruction be given workers in the use of respirators" (US Navy, 1947b, p. 13).

According to the Walsh-Healey Contracts Act published in 1952 by the US Department of Labor, the ACGIH recommended exposure limit of 5 mppcf was adopted as the guide for allowable concentrations of airborne fibers in certain industries. The Walsh-Healey Act declared that entities contracting with the federal government would have to ensure that their employees were not being exposed above this guideline while working on government contracts (US Department of Labor, 1952).

In addition to asbestosis, lung cancer emerged during this era as another disease that might be caused by asbestos. Although individual cases of lung cancer were reported as early as 1935, Richard Doll of the Medical Research Council in London published the first epidemiological study linking asbestos exposure and lung cancer, which showed that an increased risk of lung cancer could exist at some cumulative dose of asbestos (Doll, 1955; Lynch & Smith, 1935). Doll reviewed necroscopy records of 105 workers employed at an asbestos works, and classified those who had died from lung cancer as “asbestosis present” or “asbestosis absent;” he also followed an additional 113 workers with at least 20 years of asbestos dust exposure, 39 of whom died during the study period. He concluded that “lung cancer was a specific hazard of certain asbestos workers and that the average risk among men employed for 20 or more years has been of the order of 10 times that experienced by the general population” (Doll, 1955, p. 86).

Navy specs/manuals

A 1945 Navy manual describes the different applications and types of thermal insulation and lagging. Different asbestos-containing materials were recommended for different applications based on equipment and temperature conditions (US Navy, 1945). The US Navy revised the 1945 Bureau of Ships Manual, Chapter 39, in 1947. As in the previous edition, the manual described applications for, and types of, thermal insulation and lagging. Different asbestos-containing materials were required for different applications based on equipment and temperature conditions (US Navy, 1947a).

Navy Civilian Personnel Instruction 88 was issued in 1955 regarding the industrial health program for Navy civilian workers. This instruction stipulated that working with pipe covering was a hazardous occupation because of asbestos exposure, and so required these workers to have annual asbestosis screening chest X-rays. The instructions noted that “examination intervals indicated are approximate and will vary depending on the degree of exposure as determined by the Industrial Medical Officer” (US Navy, 1955b, p. 13).

Also in 1955, a memorandum from the Chief of the Navy’s Bureau of Medicine and Surgery was sent to all ships and stations indicating that the Navy should “establish as a basic reference the threshold limit values of toxic materials,” adopted by the ACGIH, in order “to provide guidance toward the reduction of potential health hazards encountered in the industrial environment for both military and naval civilian personnel” (US Navy, 1955a, p. 11). As noted previously, the TLV for asbestos was listed as 5 mppcf (about 30 f/cc).

Two years later, select personnel from all Navy shipyards, as well as the Navy’s Bureau of Ships in Washington, DC, gathered in May, 1957 at the Pipe and Copper Shop Master Mechanics’ Conference at Boston Naval Shipyard (US Navy, 1957). Mr. O. W. Meeker of Long Beach Naval Shipyard, a speaker at the conference, urged using respirators when working with amosite. In addition, he described new insulation materials, stating: “These new materials also offer a means of combating one of the most insidious of occupational diseases, asbestosis, by replacing amosite as an insulating material to a considerable extent” (US Navy, 1957, p. 6 of 7). He also noted asbestos’s role in causing silicosis, as “asbestos, when handled dry, produces vast amounts of silica dust” (US Navy, 1957, p. 6 of 7). Mr. L.W. Ferris of New York Naval Shipyard contributed to the discussion, stating “we should not have people handle [asbestos] without[t] protection” (US Navy, 1957, in “A Discussion of Mr. O.W. Meeker’s Talk Follows”).

Following the conference, in 1958, the Navy issued a safety handbook that discussed many health and safety issues, including accidents and exposures to chemicals and dust such as asbestos (US Navy, 1958). The handbook instructed workers that “asbestos dust is injurious if inhaled. Wear an approved dust respirator for protection against this hazard” (US Navy, 1958, p. 12). This safety handbook also warned, “when handling amosite, fiber glass, or unibestos sections tight-fitting leather gloves must be worn to prevent injury to hands” (US Navy, 1958, p. 8).

Period III (1960–1971)

During the period from 1960 to 1971, more became known about the airborne concentration of asbestos that might cause diseases, and the kinds of diseases such concentrations might cause, as well as the difference in potency between the various asbestos forms. Wagner et al. (1960) reported a significant finding when they discovered an association between exposure to crocidolite asbestos and mesothelioma, a very rare and fatal lung disease. A few years later, Dr. Irving Selikoff, a researcher at Mt. Sinai Hospital in New York City, presented a cohort mortality study of 632 workers who installed asbestos-containing insulation materials, significantly raising awareness of the hazard. Shortly thereafter, the serious hazards associated with asbestos insulation work began to be widely accepted by the scientific community, as well as by governmental agencies (Selikoff et al., 1964).

A 1964 industrial hygiene text, however, focused solely on exposures to asbestos factory workers, and did not mention insulation workers. Hunter and colleagues described factories in Germany and England in which heavy incidences of asbestosis or other lung diseases had been observed; the book lists “spinner, weaver, disintegrator, mixer, mattress maker, card cleaner, storekeeper, slab maker, presser and machinist” as the occupations in order of frequency of asbestosis diagnosis in asbestos workers in London (Hunter, 1964).

In 1964, the same year the ACGIH reaffirmed the TLV for asbestos as 5 mppcf (about 30 f/cc), a call for a lower TLV began at the “Biological Effects of Asbestos” conference organized by I. J. Selikoff and J. Churg. In 1968, the ACGIH recommended lowering the asbestos TLV to 12 fibers per milliliter or f/cc. Throughout this period, the Navy continued to require the use of asbestos-containing materials and, at the same time, recommended procedures for worker protection, such as wearing respirators and wetting-down products.

Specific documents from this period

Signaling the start of a new era in terms of understanding of the health hazards of asbestos dust, J. C. Wagner, a pathologist at the Pneumoconiosis Research Units in Johannesburg, South Africa, and Llandough, Wales, and his colleagues, in 1960 published a study in the *British Journal of Industrial Medicine*; it was the first publication to identify the causal relationship between asbestos exposure (specifically crocidolite) and the risk of mesothelioma (Wagner et al., 1960; Cotes, 2000). The authors reported on 33 cases of mesothelioma identified in three South African groups: (i) crocidolite asbestos miners, (ii) residents with no apparent occupational exposure to asbestos, but who lived in the vicinity of the crocidolite mine, and (iii) workers who were exposed in other asbestos-related industries.

The authors noted that there were two reasons for suggesting that asbestos might be implicated in mesothelioma development: “first, asbestos was found in the lungs of the first [mesothelioma] case (Case 1), and secondly, 10 of the cases come from a hospital to which suspected cases of tuberculosis were referred from a large asbestos mining area” (Wagner et al., 1960, p. 260). Thus, this case series study is credited with linking crocidolite exposure with mesothelioma, and highlighting the potential for asbestos-related disease among individuals with relatively low exposure levels.

Quarterly occupational health hazard reports issued by the US government

As they had done in the 1930s and 1940s, the armed forces (and the Navy in particular) continued to study the adverse effects of asbestos and to share that information within the government. For example, a series of Quarterly Occupational Health Hazards Reports was issued by the Bureau of Medicine and Surgery in the late 1950s through the 1960s, with the objective of serving as a “ready reference to current problems” and aiding “the Medical Department personnel in the recognition of potentially hazardous materials and processes” (US Navy, 1961b, p. 1). These quarterly publications compiled reports from Navy and private shipyards around the country, highlighting health hazards ranging from chemical exposures to noise, heat, and radiation. Not every release reported on exposure to asbestos (US Navy, 1960).

Earlier reports referenced a study undertaken to determine the extent of asbestos exposure to pipe coverers and insulators working aboard ships (US Navy, 1961a). Results of this study indicated that “dust counts usually exceeded[ed] safe concentration[s]” during work involving cutting and installing insulation block and removing old insulation, and recommended using respirators and wetting techniques during this type of work (US Navy, 1961b, p. 88). In addition to respirator use and wetting techniques, later reports recommended that ventilation be provided during layout and cutting activities, tasks found to be the dustiest operations. Another related report issued by the Navy also emphasized the importance of regular chest x-rays for pipecoverers, and indicated that “one former employee [was] receiving compensation for asbestosis” (US Navy, 1961c, p. 32). Visual examples of the work conditions that Navy personnel and contractors had during this time period have been presented by Mangold et al. (1968) and Hollins et al. (2009). For example, in Figure 8, a worker wears a respirator while cleaning asbestos dust.

Figure 8. Worker cleaning work area with a vacuum, while wearing a respirator. Photo source: Carl Mangold. Previously published in Hollins et al., 2009.

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In 1964, another Occupational Health Hazard report provided data from the Boston Naval Shipyard (BNSY) on “random dust sampling aboard ship during the stripping of amosite from two boilers,” collected in part to “reemphasize the essential need for respiratory protection among pipe shop personnel” (Brown, 1964, p. 57). Breathing zone dust counts ranged from 24 to 67 mppcf. It was reported that although the two pipecoverers performing the work were wearing respirators, “workmen of other trades and members of the ship’s crew in the vicinity were generally unprotected” (Brown, 1964, p. 57). This report was among the first to express concern for coworkers who were not performing the asbestos exposure related task, a situation that, over time, has become known as “by-stander exposure” (Donovan et al., 2011).

In 1962, a US Navy publication described measures that could be taken to avoid asbestosis (Robbins & Marr, 1962). They reported that, by 1937, “manufacturing problems were solved, and the [asbestos] was used productively aboard naval vessels,” and that “asbestos was used extensively” during the war years (Robbins & Marr, 1962, p. 10). The authors asserted that “By far, the greatest potential exposure to asbestos fibers occurs during rip-out of old insulation for ship overhaul or reconversions” (Robbins & Marr, 1962, p. 10).

Based on reports published at this time, scientists believed “that asbestosis is caused by breathing relatively long fibers (10–25 microns) and that the fine asbestos dust is relatively inert” (Robbins & Marr, 1962, p. 10). Control measures described for the insulation shop involved keeping a cloth damp as it was drawn onto the table, and making sure that it “remains damp throughout the process of filling, sewing, and stalling pins in the [insulation] pads. Additional exhaust ventilation has been installed in the shop and is not operated constantly during working hours” (Robbins & Marr, 1962, p. 10). Work conducted much later demonstrated that it was, indeed, the longer fibers that were the primary cause of disease, especially with chrysotile (Eastern Research Group (ERG), 2003, Stanton, 1973, Stanton et al., 1977, 1981, Agency for Toxic Substances and Disease Registry (ATSDR), 2002, Berman & Crump, 2003, 2008).

Control measures on ships for pipe coverers were also recommended by Robbins and Marr: “the workers best protection is to avoid careless creation of dusty conditions, use damp materials when possible and wear respiratory protection constantly” (Robbins & Marr, 1962, p. 10).

Soon after the 1962 Robbins and Marr paper, William Marr of the Medical Department at Long Beach Naval Shipyard, published a study of insulation workers at the insulation shop at that shipyard in Industrial Hygiene Journal, the industrial hygiene profession’s premier journal (Marr, 1964). He noted that for insulation shop workers, “exposures occur during the fabrication and installation of asbestos insulations and during removal of insulation for repairs or overhaul of ships” (Marr, 1964, p. 264). Researchers measured asbestos exposure concentrations ranging from trace amounts to 8.0 mppcf during work with materials such as 100% amosite asbestos blankets and 85% Magnesia and 15% amosite asbestos blocks and pipe sections.

Marr explained that “asbestos exposure during ship overhaul and repair varies extensively giving an entirely different problem from exposure in mining and manufacturing operations,” which generally have more constant exposure levels (Marr, 1964, p. 268). The study identified several workers on disability and one death due to asbestosis. Marr concluded that “employees in this trade should wear respirators when exposed to dry insulation material containing asbestos” (Marr, 1964, p. 268).

The US Department of Health, Education, and Welfare published a reference text in 1964 on recognizing occupational diseases, edited by W. M. Gafefer of the Division of Occupational Health (Gafafer, 1964). This book was the first official government publication issued on the broad concerns about the health effects associated with exposure to chemicals that became a standard reference used by most practicing hygienists. The guide recognized asbestosis as an occupational disease, and described how “prolonged inhalation of asbestos fibers between 20 and 50 microns long may result in the production of a typical pulmonary fibrosis which may be accompanied by severe respiratory disability” (Gafafer, 1964, p. 51). Interestingly, the guide cited the Doll epidemiology study on lung cancer that had been issued 6 years earlier, and noted that there was some skepticism about the validity of Doll’s conclusions. Specifically, the guide stated: “conflicting opinions and differences in reports make it difficult to confirm or deny conclusively a causal relationship between asbestosis and cancer of the lung or extrapulmonary tissue. However, there is increasing evidence to suggest that such a relationship exists” (Gafafer, 1964, p. 52). This text continued to be one of the primary references used by industrial hygienists in the 1960s and 1970s until the next edition was released in 1974.

The Selikoff story

Also in 1964, Dr. Irving Selikoff and his colleagues reported on a cohort mortality study of 632 workers who installed asbestos-containing insulation materials (Selikoff et al., 1964); their report was published in the *Journal of the American Medical Association*.

Specifically, Selikoff et al. reported that “far more deaths from cancer of the lung and pleura occurred among the asbestos workers than would have occurred had their death rates from these diseases been the same for all U.S. white males” (Selikoff et al., 1964, p. 144). For example, 45 of the 632 workers died of lung or pleural cancer, which “was 6.8 times as high among these asbestos workers as in the general U.S. white male population” (Selikoff et al., 1964, p. 144). Of the pleural tumors identified, three were mesotheliomas, which “is an exceedingly high incidence for such a rare tumor” (Selikoff et al., 1964, 142). The majority of participants in the Selikoff et al. study had worked in the same industry for more than 20 years. The authors noted that the data reported in this study “would not necessarily apply to asbestos exposure in other industries, such as the factory production of asbestos products, the asbestos textile industry, etc. where conditions might be quite different” (Selikoff et al., 1964, p. 145).

That same year, the Conference on the Biological Effects of Asbestos called attention to the rising rate of lung cancer among asbestos workers (Schall, 1965; Whipple & van Reyen, 1965; Corn, 1986; Nowinski, 1987). I. J. Selikoff and J. Churg cochaired the conference, which was supported by a grant from the National Institutes of Health and attended by over 400 scientists from academia, industry, government, and unions. Over 50 presentations were given, on topics ranging from the geology of asbestos to exposure studies, to toxicology and epidemiology of asbestos and asbestos-related diseases. In one of the final presentations of the conference, J. C. Wagner noted that regarding the “sequelae of exposure to asbestos dust,” including inhalation, deposition, and retention, “all these subjects have been discussed and a number of the controversial aspects clarified. Certain points of disagreement remain and there are many important facets yet unsolved” (Whipple & van Reyen, 1965, p. 691).

Following this conference, E. L. Schall of the New Jersey State Department of Health published a paper in the *Annals of the New York Academy of Sciences* calling for a lower exposure limit (Schall, 1965). Schall noted that “the present threshold limit relates to the prevention of asbestosis” and also that “it is not commonly appreciated that the five mppcf indicates a total count, including background dust which may vary greatly” (Schall, 1965, p. 316, 318). He concluded, “therefore, [five mppcf] cannot be presumed to represent a safe limit of asbestos in all applications” (Schall, 1965, p. 320).

Around the same time as this conference, the Navy published two key documents discussing hazards of asbestos and dust. The Hazardous Materials chapter of a 1965 safety manual titled “Safety Precautions for Shore Activities” states that while asbestosis is as disabling as silicosis, “the handling of asbestos products in the Navy are not so well controlled, if the prevalence of cases of asbestosis is any indication” (US Navy, 1965, pp. 20–22). The book notes that “exposure to asbestos dust is usually encountered in the installation, repair, and removal of insulating pipe covering used principally aboard ship[s]” (US Navy, 1965, pp. 20–22). The book’s suggested precautions include permanent general ventilation, exhaust hoods over dust making machine tools, using respirators, and using industrial vacuum cleaners instead of dry sweeping.

In 1968, Selikoff et al. reported a synergistic effect between smoking and asbestos exposures (Selikoff et al., 1968). This paper, which was published in the *Journal of the American Medical Association*, reported on 370 insulation workers. Of the 87 workers who were not cigarette smokers, none died of bronchogenic carcinoma, while 24 of the 283 cigarette smokers died of bronchogenic carcinoma. Compared to the calculated rate of bronchogenic carcinoma among smokers, these data suggested that “asbestos workers who smoke have about 92 times the risk of dying of bronchogenic carcinoma as men who neither work with asbestos nor smoke cigarettes” (Selikoff et al., 1968, p. 106). The authors concluded that “there is an extraordinary risk of developing and dying from lung cancer for asbestos workers who smoke cigarettes regularly” (Selikoff et al., 1968, p. 111). Later studies have questioned the degree of additivity or synergy in Selikoff’s report, due, in large part, to the lack of complete data on cigarette use by the participants, but, nonetheless, the observation was quite alarming at the time.

Also in 1968, Murray C. Brown, Medical Director of the USPHS and Chief of the Occupational Health Program, sent a memorandum regarding Dr. Selikoff’s recent work to Vice-Admiral R. B. Brown of the Bureau of Medicine and Surgery. M. C. Brown stated that Dr. Selikoff “has recently completed a study of non-insulation shipyard workers’ exposure to asbestos,” and “reports he has some very interesting data and has requested that we arrange an informal meeting with your Department and the U.S. Department of Labor to discuss his findings” (Brown, 1968, p. 1).

On December 4, 1968, Thomas O’Toole, a staff writer for the *Washington Post*, published an article in that newspaper entitled “U.S. Warned of Asbestos Peril.” O’Toole reported that “the Government has been told that the Nation’s 350,000 shipyard workers face a serious occupational hazard from the asbestos in their place of work,” and went on to describe findings at Mt. Sinai Hospital. He specifically mentioned that autopsies performed at Mr. Sinai “have shown that most men who worked in shipyards had ‘excessive’ asbestos fibers in their lungs.” Dr. Selikoff was quoted throughout the one-page article (O’Toole, 1968).

That same day, a letter, signed T. Kenney, was sent from SHIPS 072C referencing the *Washington Post* article. The SHIPS letter reported that Dr. Selikoff had met with BUMED, the Department of Labor, and the USPHS at BUMED on August 8, 1968, “at which time the results of the autopsies mentioned in [the *Washington Post* article] were presented by him” (US Navy, 1968a, p. 1). Kenney reported that BUMED was actively working with the USPHS and the Harvard School of Public Health to “obtain more definitive scientific information on the subject,” but that no action regarding more rigorous controls for shipyards had been suggested.

A 1968 Memorandum from the Department of the Navy, signed by Mr. W. R. Riblett, provided information on the health hazards of asbestos and referenced the December 4 *Washington Post* article and SHIPS memorandum (US Navy, 1968b). It emphasized that the greatest health risks occur during “rip-out…especially on ships built during and shortly after World War II” (US Navy, 1968b, p. 2). Packing and gaskets containing asbestos were not considered to be a significant health hazard because the products were not friable when cut.

A list of asbestos containing packing and gasket materials (“Enclosure (2)”) was referenced in the 1968 memorandum, regarding which Riblett wrote that “all of the asbestos in these items is fabricated as cloth, rope, or compressed sheet with binders, so that the items are not friable when they are cut. Thus these items do not cause dust in shipboard applications. In addition, in many instances, they are received already incorporated in the finished assembly, such as a valve, and do not require fabrication by the shipyard. For these reasons, packing and gaskets containing asbestos are not considered to be a significant health hazard” (US Navy, 1968b, p. 1).

Riblett also wrote that “contact was made with the Industrial Hygienists of Mare Island and Puget Sound Naval Shipyards to discuss this problem” of asbestos exposure; Ribleit reported that “it was quite obvious from these discussions that the shipyards have for many years been aware of the hazards of asbestos and have initiated appropriate safety precautions” (US Navy, 1968b, p. 2). The report outlined precautions, including “controlled ventilation, use of respirators, and wetting down of the material,” and “During ‘rip-out’ operations, respirators are worn and ventilation is controlled as far as possible” (US Navy, 1968b, p. 2).

An attachment, “Enclosure (1),” to the December 9 Riblett memorandum was titled the BUMED Analysis of Hazard and stated: “The U.S. Navy is well aware of the hazards of asbestos to its employees engaged in ship construction and ship repair at naval shipyards. Hazard control measures implemented by the shipyard medical departments and safety divisions are in accordance with accepted standards of industrial hygiene practices in the U.S.” (US Navy, 1968b, p. 3). In addition, the analysis noted that “upon the development of further scientifically founded recommendations for the control of this hazard, NAVSHIPS in cooperation with BUMED will take the necessary steps to implement them at the naval shipyards and other naval activities" (US Navy, 1968b, p. 3).

A separate attachment, "Enclosure (4)," to the December memorandum, entitled "Use of Asbestos for Piping and Machinery Insulation," added that "naval shipyards have been aware of the hazards associated with the use of asbestos for many years and have to a great degree eliminated its use. This is especially true with regard to asbestos felt materials which are considered the worst offenders with regard to propagation of air borne dust particles of the magnitude which can reach the lungs and cause asbestosis or mesothelioma" (US Navy, 1968b, p. 5). The attachment also noted that "rewettable asbestos cloth" was recently approved for Navy use, since "all asbestos fibers are bonded together by the adhesive and dust release is negligible" (US Navy, 1968b, p. 5).

Contemporaneous industrial hygiene findings and recommendations

In 1968, following the publication of the Selikoff report, C. R. Mangold, a Certified Industrial Hygienist, and colleagues in the Industrial Hygiene Division of Puget Sound Naval Shipyard presented their findings of increased lung abnormalities in naval insulators (Mangold et al., 1968). The report, which summarized two and a half years of research on nearly 7000 shipyard employees, was filed with the Industrial Hygiene Division of the Puget Sound Naval Shipyard.

Among pipefitters and insulators, 21.2% were diagnosed with lung abnormalities. There was one case of asbestosis, and no cases of lung cancer. According to Mangold, "exposure patterns and the high incidence of lung abnormalities suggest that the current threshold limit value of 5 mg/m^3 for asbestos may be too high" (Mangold et al., 1968, p. 6).

In a complementary study published the same year, J. LeRoy Balzer and Dr. Clark Cooper provided a detailed description of the work environment of insulating workers, and also proposed that the established threshold limit required reexamination. The authors looked at union insulation workers in the San Francisco Local (no. 16). They presented dust concentrations for various tasks, and found "three distinct areas—prefabrication, tearing out, and mixing—where the [contemporary] TLV is exceeded" (Balzer & Cooper, 1968, p. 226). Overall, though, they found that the "breathing-zone dust levels found in the dustiest operations observed were not as high as the incidence of pneumoconiosis may have led [them] to expect," and that calculated time-weighted averages for most activities and situations would not likely exceed the TLV (Balzer & Cooper, 1968, p. 227).

In early 1968, Dr. Clark Cooper of the University of California, Berkeley School of Public Health, wrote to the chairman of the ACGIH's Threshold Limits Committee, Dr. Herbert Stokinger, regarding the asbestos threshold limit values (Cooper, 1968). By that time, Dr. Cooper had committed at least 30 years of his life to studying the adverse effects of dusts (and asbestos in particular) in Bay Area shipyard workers. Dr. Cooper acknowledged Balzer's article suggesting that asbestosis occurred in some insulating workers who may have been exposed to time-weighted average asbestos dust levels below 5 mppcf (Balzer & Cooper, 1968). He listed a number of reasons for using caution in revising the asbestos limit:

> (1) Several effects, from pneumoconiosis to lung cancer to pleural and peritoneal tumors, must be controlled; (2) there are many uncertainties as to the relative importance of chrysotile, amosite, crocidolite, tremolite and anthophyllite, particularly in regard to tumors; (3) the best approach to setting limits for carcinogens is still not agreed upon; (4) in midget impinger samples, the proportion of the dust counted that represents asbestos in hazardous form in unknown, and probably varies from situation to situation; and (5) the role of co-factors, including cigarette smoking, is uncertain." (Cooper, 1968, p. 1)

Overall, Dr. Cooper recommended keeping the TLV of five mppcf, but regarded this number as a ceiling limit, instead of as an 8-hour TWA average (Cooper, 1968).

In 1968, the ACGIH recommended lowering the asbestos TLV to 12 fibers per milliliter or f/cc (ACGIH, 2001).

In February, 1969, Dr. Clark Cooper met with Captain Norbert Rosenwinkel, Chief of the Occupational Health Division, Bureau of Medicine and Surgery, and Captain Rosenwinkel's assistant, Lt. Commander Samuel H. Barboo. Cooper documented their meeting, which addressed asbestos hazards, in an abstract and a letter to the Captain, both dated February 21, 1969 (Cooper,

1969a, 1969b). According to Dr. Cooper, he had been asked to give a lecture on industrial hygiene to the Bremerton union, and sought a better understanding of Navy programs and directives in industrial hygiene before doing so. Based on his discussion with sought a better understanding of Navy programs and directives in industrial hygiene before doing so. Based on his discussion with Rosenwinkel and Barboo, he noted that the Navy had no national program for industrial hygiene and that “each Navy yard apparently develops its own program on the basis of rather general admonitions” (Cooper, 1969a, p. 1). Further, he reported that “the statement on asbestos which has been generally distributed dates back 20 or more years at which time it was thought that dust control to prevent asbestosis had the problem pretty well licked” (Cooper, 1969a, p. 1). He suggested that “the Navy has to consider the safety of insulating workers, of other workers in the shipyards, and the disposal of their wastes into the nearby communities” (Cooper, 1969a, p. 1). In his letter to Rosenwinkel, Dr. Cooper called for “prompt reconsideration of dust control measures” (Cooper, 1969b, p. 1).

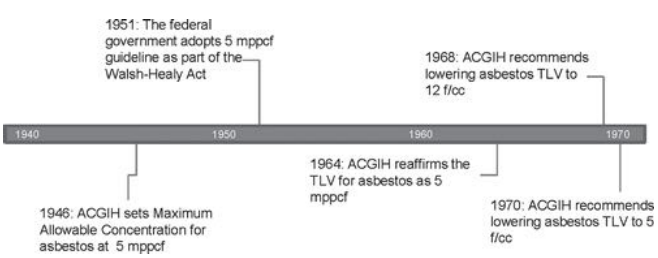
Shortly after that meeting, in May, 1969, Edward Cherowbrier of the Naval Ship Engineering Center published a paper on preventing asbestos inhalation in an internal Navy publication, *NavShips Tech News* (Cherowbrier, 1969). This document describes duties with the greatest potential for asbestos exposure, including “fabrication, installation, repair, and particularly ‘rip-out’ or removal” of asbestos-containing insulation (Cherowbrier, 1969, p. 10). Such tasks were associated with the “greatest health hazards” (Cherowbrier, 1969, p. 10). Cherowbrier also described precautions that should be taken to limit asbestos exposure for each duty. The report concluded that “dust should be kept to a minimum,” that “when exposed to dust, approved respirators should be worn,” and that “good housekeeping procedures should be maintained at all times” (Cherowbrier, 1969, p. 11).

Towards the end of the period of interest, a letter from the Officer in Charge, Naval Ship Engineering Center, Philadelphia Division, to the Commander of the Naval Ship Engineering Center in September, 1969 discussed a survey of asbestos hazards, and concluded that “the use of high-asbestos-containing thermal insulating materials should be curtailed due to hazards to the health of insulation workers” (Murdock, 1969, p. 9) The survey was conducted “in an attempt to improve the insulation program of the Navy,” and involved letter inquiries sent to Naval and private shipyards (Murdock, 1969, p. 3). Survey findings included the following: “Shipboard practices on the handling of asbestos-containing materials occasionally showed failure to isolate working areas, improper ventilation, dusting due to emptying cement bags, failure to wet down insulation preliminary to ripout and disposal in polyethylene bags, and failure to wear coveralls and properly equipped and approved respirators” (Murdock, 1969, p. 5).

In addition, “several responses from insulation manufacturers have indicated that new materials are being developed for the replacement of asbestos for thermal insulation” (Murdock, 1969, p. 7). The letter concluded that “Naval and private shipyards as well as insulation suppliers are well aware of the serious hazards attending the use of asbestos. Nevertheless, considerable asbestos-containing insulation material currently is being used in Naval applications and stringent handling precautions are not being enforced in all instances” (Murdock, 1969, p. 9).

In 1970, ACGIH recommended lowering the TLV to 5 f/cc for fibers greater than 5um and recommended a 15 min ceiling limit of 10 f/cc (ACGIH, 2001). Subsequently, in 1971, OSHA established regulations that promulgated PELs for asbestos, as well as over 400 other chemicals and substances used in the United States. OSHA published its first permissible exposure limit (PEL) for asbestos of 12 f/cc as an eight-hour time weighted average in 1971. This limit was based on the proposed ACGIH TLV (Occupational Safety and Health Administration, 1971). Figure 9 shows the progression of asbestos exposure limits and recommendations through 1970.

Figure 9. Timeline of asbestos exposure limits and recommendations, 1946–1970.



Display full size

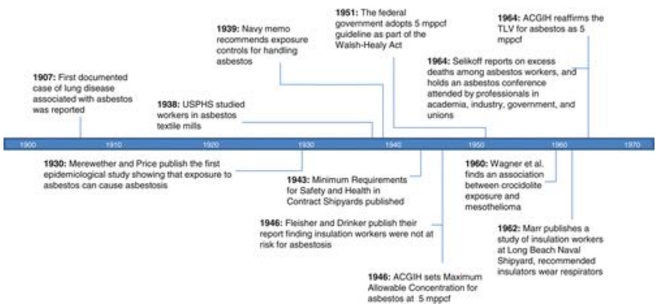
In 1970, Congress passed the OSHAct, which created the regulatory body that would adopt numerous industry and consensus standards as legal requirements for all firms and certain aspects of various state and local governments. At this point, the field of occupational health entered a new phase in which thousands of rules were written and enforced. The wealth of industrial hygiene, toxicology and epidemiology information on chemicals that had been gathered by government, military, university, research bodies and industry thus became more widely available, bringing the occupational health field into the modern era.

Discussion

Many scientists and historians have discussed the state-of-knowledge relating to the recognition of asbestos hazards during the 20th century. However, that body of literature leaves some degree of uncertainty about the overall scientific community's understanding of the asbestos hazard and the swiftness with which various governmental and other groups responded to the hazard that this family of different fibers posed to those who worked with them.

We evaluated more than 300 documents in an attempt to understand when various scientific and regulatory groups became concerned about the occupational hazards posed by chrysotile, amosite, crocidolite, anthophylite, tremolite, and other asbestos forms. Our research has indicated that because of the economic importance of asbestos, and its perceived vital role in the war effort, the regulated community and the military held a broad belief that overly restrictive work standards should not be applied to this material. Indeed, consistent with the setting of occupational limits for virtually all chemicals from about 1940 to 1995, the industrial hygiene community pushed to identify an occupational exposure limit for asbestos that was health protective, but not unduly burdensome on the regulated community (including the US Navy and its contractors). Figure 10 shows a timeline of key events and documents that significantly contributed to the understanding of asbestos and disease.

Figure 10. Timeline of key events and documents regarding asbestos and disease, 1900–1970.



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The information we gathered indicates that the US government had a significant interest in understanding the hazards posed by all asbestos forms as far back as the late 1920s, as was apparent from its various research efforts in the 1930s and 1940s. This interest was stimulated, in part, because of the economic significance of asbestos, as well as its capacity to reduce the truly significant and tragic effects of fires that had haunted much of the population for the prior 200 years (Maines, 2005). The concern about fire hazards was nowhere greater than on board ships, on which not only are there ample quantities of combustibles, but there is also little chance of survival if the fire should get out of hand. This fact was well recognized by the US Navy when it specified various building materials for ships used in WW II, and the Korean and Vietnam wars. Indeed, as described here, the Navy was among the leaders in terms of initiating work practices that attempted to reduce exposure to various asbestos forms, as it wanted to ensure that asbestos could continue to be used on various ships (which it was, for nearly five decades).

Although it is debatable whether the Navy or the private sector that supplied it with materials was more knowledgeable with respect to the hazards posed by asbestos, it is clear that the US government generally was the first to understand its hazards, since it sponsored a large fraction of asbestos toxicology and/or epidemiology studies. This view is based on understanding the funding source for the early research at Saranac Lake laboratories, the many industrial hygiene studies conducted by the Navy, and the exceptionally well formulated occupational medical programs initiated by the Navy in the early 1940s (Forman, 1988). Interestingly, according to Dr. Samuel Forman, an expert in occupational health and a former medical doctor within the US Navy, the Navy occupational health practitioners did not depend upon information or advice from equipment manufacturers related to the health effects of asbestos dust (Forman, 2009). He stressed that when the Navy specified using a particular type of asbestos in a product, the supplier had no choice but to supply it in the manner specified; enforcement provisions were in place for those who failed to comply.

but to supply it in the manner specified; enforcement provisions were in place for those who failed to comply.

The Navy and other government organizations continued to require using asbestos in hundreds of materials far into the 1970s, and later because of concern that other materials may not perform as well, and because of their belief that nearly any material could be handled safely if proper precautions were taken. This view was not limited to asbestos, but also included beryllium, all sources of radiation, cadmium, cobalt, nickel, plutonium, radium, and numerous other substances known for their high toxicity. The results of industrial hygiene studies conducted over several decades by not only the military, but by also by numerous researchers interested in asbestos, gave the military considerable confidence regarding its belief that education and controls could minimize or eliminate the vast majority of the risks.

It was apparent to the military and other institutions that used any asbestos forms, for example, that as occupational exposure limits grew smaller, studies needed to be conducted to quantitatively understand any hazard. The studies by Fleischer et al. (1946) were intended to alert the Navy about the hazards to those involved in ship building and decommissioning; they concluded (albeit erroneously) that if exposures were maintained below 5 mmpcf, the hazard was negligible. With each passing decade, though, other studies were conducted of not only those working with insulation (which had been clearly acknowledged as a serious hazard), but also of gaskets and packing, materials that often were required to contain asbestos (Mangold et al., 1968, Mangold, 1983).

Over the course of 20–30 years, from about 1970 to 2000, a number of additional studies of worker exposure to so-called “encapsulated materials” were conducted, and these, too, gave the military and others a fair degree of confidence that if handled in a reasonably prudent manner, asbestos containing materials would not pose a significant increased health hazard. Specifically, studies were conducted on floor tiles (Lange, 2006, Lange et al., 2008), gaskets and packing (Cheng & Mcdermott, 1991, Madl et al., 2007), and brakes (Hickish & Knight, 1970, Paustenbach et al., 2004a). After about 1995, in an attempt to answer questions about exposures that likely occurred in the past, but reflected exposures that no longer occurred in the United States, a number of simulation studies or dose-reconstruction studies were conducted to help inform those conducting epidemiology studies or the courts. These studies evaluated glues and mastics (Mowat et al., 2007, Paustenbach et al., 2004b), phenolic molding compounds (Mowat et al., 2005), and other materials in which asbestos was used as a filler. Nearly all these studies were conducted after about 1975, addressed the possible hazards posed by products that were made primarily of encapsulated asbestos, and yielded results that were anticipated by Selikoff and others in the early 1970s when they noted that “it is fortunate that the greatest part of [the U.S.’s asbestos use] has been in products in which the asbestos is ‘locked in’—that is bound with cement or plastics or other binder so that there is no release, certainly no significant release, of asbestos fiber in either working areas or general air” (Selikoff, 1970, p. 23).

In her 1974 edition of *Industrial Toxicology*, Alice Hamilton illustrated the uncertainty remaining in the scientific community regarding the mechanism by which asbestos caused its effects when she wrote: “Another important problem far from settled is whether asbestos fibers acting as mechanical irritants deep in the lung are alone responsible for disease” (Hamilton & Hardy, 1974, p. 421). She goes on to say that “several key facts are missing and great research effort is currently directed to their solution” (Hamilton & Hardy, 1974, p. 422).

Not surprisingly, it was the US military that encouraged the private sector to develop materials other than asbestos that would be equally effective as a fire retardant, but that would pose a lesser human health hazard. Over time, fiberglass and a few other materials were sometimes found to be an adequate substitute as an insulating material and as filler for polymeric materials. The military was aware that for many uses, however, there was no substitute equal to asbestos; nevertheless, ultimately the Navy concluded that it was virtually impossible to insure that everyone who handled these products would do so safely. Thus, by about 1990, the US government and most US manufacturing firms specified that no asbestos be present in virtually all the goods they sold or used (Maines, 2005).

In conclusion, the aim of this review was to provide a well-documented timeline of the knowledge of the hazards of asbestos within the scientific community and governmental organizations, especially the Navy. Based on the published and unpublished studies, reports, and memorandums that we collected, we concluded that the Navy was at the forefront of asbestos research, and was aware of the degree of exposure of its contractors working with insulation. We also found that precautionary recommendations, which included using respirators or local ventilation, were specific to friable types of asbestos-containing products such as insulation, and that these

measures were not suggested for users of encapsulated materials, such as gaskets, floor tiles, mastics, sealers, and materials made of phenolic molding compounds. Many scientists inside and outside the government published on the correlation between asbestos and disease between 1930 and 1970, and it is clear from the record that the Navy attempted to control exposures to concentrations that it considered acceptable. It began looking into substitute materials in the early 1970s, and appears to have eliminated most uses by about 1985.

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Declaration of interest

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Supplemental material

Supplementary Material

Download PDF (511 KB)

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