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An Exposure Study of Bystanders and Workers During the Installation and Removal of Asbestos Gaskets and Packing

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From 1982 until 1991, a series of studies was performed to evaluate the airborne concentration of chrysotile asbestos associated with replacing gaskets and packing materials. These studies were conducted by the senior author in response to concerns raised by a report from the Navy in 1978 on asbestos exposures associated with gasket work. A series of studies was conducted because results of those who worked with gaskets within the Navy study did not address the background concentrations of asbestos in the work areas, which may have been significant due to the presence of asbestos insulation in the ships and shipyards. The intent of the studies performed from 1982 through 1991 was to re-create the Navy's work practices in a contaminant-free environment during an 8-hour workday (so the data could be compared with the OSHA permissible exposure limit [PEL]). Samples were collected to characterize personal and area airborne asbestos concentrations associated with the formation, removal, and storage of gaskets, as well as the scraping of flanges and the replacement of valve packing. The results indicate that the 8-hour time-weighted average (TWA) exposures of pipefitters and other tradesmen who performed these activities were below the current PEL and all previous PELs. Specifically, the highest average 8-hour TWA concentration measured for workers manipulating asbestos gaskets during this study was 0.030 f/cc (during gasket removal and flange face scraping onboard a naval ship). Likewise, the 8-hour TWA breathing zone concentrations of a worker removing and replacing asbestos valve packing did not exceed 0.016 f/cc. In most cases, the concentrations were not distinguishable from ambient levels of asbestos in the ships or the general environment. These results are not surprising given that asbestos fibers in gasket materials are encapsulated within a binder.

Keywords asbestos, gaskets, Navy, packing materials, shipyard

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Asbestos is a mineral that was commonly used in industrial operations in the United States for the greater part of the 20th century. Because of its high thermal stability and resistance to corrosion, it has appeared in more than 3000 manufactured goods, and at least 30 million tons of asbestos have been used in construction and manufacturing industries since the year 1900.(1) The widespread use of asbestos in the past has led to exposure of millions of Americans at concentrations that, at times, resulted in significant adverse health effects. Today, asbestos use is highly regulated and most industries have replaced asbestos materials with substitutes in an effort to protect workers and comply with federal regulations.

The concerns about the role of asbestos in the development of a pulmonary disease began in the United States in the 1930s and progressed slowly as more was learned about sources of exposure and the pathogenesis of asbestos-related diseases. Much of the historical research was focused on disabled workers with obvious work-related exposure to raw asbestos fibers used commercially. Few, if any, industrial hygiene controls were followed at that time, and asbestosis of varying degrees of severity was frequently observed among highly exposed workers. These workplace conditions continued until the 1960s, when the association between asbestos and certain types of cancers became clear and industrial hygiene practices in the workplace began to reduce occupational exposures.

Historically, asbestos insulation and asbestos gaskets and packing have been used on pipes and machinery in industries such as refineries, powerhouses, chemical plants, and naval ships and shipyards. Asbestos was considered a "magic mineral" because it was inexpensive and highly resistant to heat and corrosion. Alternative materials with comparable properties were not readily available and so asbestos was widely used in high heat operations internationally. Up until the late 1960s, the U.S. Navy used amosite and chrysotile asbestos insulation extensively on pipes and machinery onboard naval ships. The Navy published explicit specifications regarding the percentages of each fiber type (amosite or chrysotile) that were to be used in materials such as insulating felt, insulating blocks, insulating cement, sheet gaskets, and packing materials. Some of the asbestos-containing materials used included 85% amosite insulating blocks and 100% chrysotile insulating cements.(2,3) In the first author's experience, chrysotile was the only type of asbestos used in naval gaskets and packing; however, crocidolite gaskets have been historically used for highly acidic applications,[4] such as certain processes in pulp and paper plants and refineries.

The magnitude of asbestos use in a naval shipyard was extremely high. For example, a World War II-era destroyer is estimated to have contained at least 96,000 pounds of asbestos-containing insulation.[2,3,5−7] Based on data presented by Fleischer et al.,[8] naval shipyards are estimated to have used between 100,000 and 500,000 pounds of asbestos products per month for new ship construction during World War II. At least 90% of these asbestos materials were in amosite blankets or pads, loose amosite, magnesia block insulation, and asbestos cements. All of these materials were loose, easily crumbled, and handled directly by workers.

By comparison, gaskets and packing constituted a small fraction of the total weight of the various asbestos products onboard a naval vessel,[2,3,5,6,8] and the asbestos within these materials was encapsulated in a binder, making it unlikely for the material to release significant amounts of asbestos fibers.[9,10] In the National Emission Standards for Hazardous Air Pollutants (NESHAP) regulations, the Environmental Protection Agency (EPA) acknowledged the low potential for gaskets and packing to release significant amounts of fibers. The regulations state that even broken or damaged gaskets and packing would rarely, if ever, release significant levels of asbestos, even under the conditions in which a building is demolished.[10]

A major goal for industrial health and hygiene professionals in the 1960s was to improve worksite safety and reduce high level asbestos exposures that occurred during the manufacture and use of asbestos products containing raw and friable asbestos that were used in large volumes in construction and in shipyards. However, at that time, small-volume products and those that were encapsulated were not considered a health risk.[11,12] In the 1970s, researchers and institutions, including Selikoff[13] and the International Agency for Research on Cancer (IARC),[14] declared that packing and gasket materials did not pose any conceivable health hazard. There were some internal studies conducted during the 1970s to evaluate worker exposures associated with these products but most were inconclusive or had small sample populations. Additionally, these tests were likely obscured by the high background levels from highly friable products, such as asbestos insulation.[11,12,15,16] Without adequate characterization of background concentrations, it is virtually impossible to identify the source of exposure in worksite studies when multiple asbestos products are used in close proximity to each other.

During the 1960s and 1970s, the Navy pioneered changes in the use of asbestos by implementing dust control devices, enforcing the use of respirators, and replacing asbestos with alternative materials as they became available. As sources of free fibers were eliminated or contained, the Navy focused on evaluating low-level sources of exposures, such as gaskets. Other industries followed the Navy's lead in implementing industrial hygiene controls and eliminating the use of friable asbestos-containing products. By the 1980s, use of asbestos for new applications in the United States was uncommon. However, due to the latency of asbestos-related diseases, medical and scientific researchers continued to evaluate asbestos exposure and incidence of asbestos-related disease among workers.

In 1978, the Department of the Navy, as a part of an ongoing industrial hygiene program, set about collecting airborne asbestos samples during the storage, handling, and processing of gaskets of all kinds in naval shipyards. The evaluation was an important undertaking because only a few such studies had been conducted. The Navy report[17] concluded that even the simplest of general housekeeping controls or work practices were sufficient to maintain occupational exposures to asbestos at acceptable levels. Although the Navy achieved its intended objective of characterizing the exposure to any and all fibers in the breathing zone of workers, it did not measure exposure levels specifically associated with handling of asbestos-containing gasket materials. Breathing zone air samples were collected in work areas during various gasket processing activities; however, the area was not cleaned prior to the commencement of the study. Furthermore, given that background samples were not collected prior to initiation of gasket work, it is questionable whether the data truly reflected asbestos exposures associated with gaskets. Although the concentrations reported for gasket handling were generally close to 0.1 f/cc, trace contamination from insulation or other sources could have easily contributed to these values.[17]

The intent of the study presented here was to measure personal and area airborne asbestos concentrations associated with handling of asbestos-containing gasket and packing materials by repeating many of the activities studied by the Navy, yet performing them in a contaminant-free environment. The measurements were collected between 1982 and 1991 by Carl Mangold, a certified industrial hygienist with 10 years experience working on asbestos control measures for the Navy at the Puget Sound Naval Shipyard. As a result of his shipyard experience, Mangold was familiar with techniques and activity frequency associated with gasket and packing replacement as well as the high potential for worksite asbestos contamination from other sources. Recent interest in asbestos exposures for workers handling nonfriable and encapsulated asbestos-containing materials prompted the authors to publish the data from this comprehensive series of studies.

METHODS

The objective of this series of studies was to evaluate potential asbestos exposures to workers and bystanders during the removal and installation of asbestos-containing gasket and packing materials. Personal and area airborne asbestos exposures were characterized over the course of an 8-hour workday as workers performed gasket and packing work. The activities studied included scribing of gasket materials, formation of asbestos sheet gaskets, opening of flanges and removal of gaskets, cleaning of flange faces using putty knives and wire brushes, and removal and installation of asbestos packing from valves.

In these studies, emphasis was placed on characterizing 8-hour TWA exposures so that the magnitude of exposure to the maximally exposed worker (e.g., a worker who replaces gaskets or packing in the field throughout the course of the day) could be determined. The time required to perform tasks associated with gasket and packing replacement makes it unlikely that a worker would perform more than eight replacements (of either gaskets or packing) per day. Based on professional experience, with the exception of a site-wide shut-down or overhaul, it is uncommon for a millwright or other craftsman to replace more than two gaskets or packings in a single day.

By simulating this work, it was possible to repeat the activities several times throughout the course of the day because all the tools, raw materials, and flanges were already set up at the workers' workbench. Thus, the measurements collected in these studies likely represent more severe conditions than those experienced by workers in the field. In practice, workers typically receive their assignments, go to storerooms and lockers to retrieve the appropriate materials and tools for the job, and change into their work clothes. Additionally, workers must travel to each location where the flange or valve work will be conducted, determine how the flanges or valves will be accessed, and then remove pipe insulation and bolts before any gasket replacement work is performed. The actual time spent forming a gasket or removing and installing packing or gaskets is a small portion of the overall workday.

Short-term excursion samples were not collected in this series of studies for two reasons. First, the short-term airborne concentrations presented in the 1978 Navy study were nearly uniformly below both the current and historical excursion limits.[17] Considering that the Navy study is likely an overestimation of genuine exposure, it seems unlikely that any short-term samples collected in a contaminant-free environment would be greater than those concentrations measured in the Navy study. Second, the exposures experienced by a worker repeating a task eight times over the course of an 8-hour sample made it unnecessary to collect short-term excursion samples. If the airborne asbestos concentration due to one repetition of the task was in excess of the excursion limit, then the 8-hour TWA concentration for eight repetitions of the task would likewise be in excess of the PEL. Therefore, it was determined that the best way to evaluate exposure to a worker whose responsibilities include frequent gasket and packing replacement would be to collect samples during several repetitions of the tasks over 8 hours.

Only phase contrast microscopy (PCM) analysis was conducted on the filter samples during the phases of this study performed prior to 1989. At the time, transmission electron microscopy (TEM) analysis was not a standard analytical method for airborne asbestos and, even today, TEM data are not directly comparable to the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL). Although it is a more powerful analytical method, due to the higher resolution for counting smaller fibers and differentiating fiber type, its use in worksite regulatory compliance is a supplement to PCM data by providing information regarding fiber type and size. PCM analysis is the most important method for comparing exposures to the OSHA 8-hour TWA PEL. The TEM analysis that was performed served to confirm the absence of asbestos and non-asbestos fiber contamination, as indicated by the PCM data. Bulk samples were collected only in the 1989 series of studies and were analyzed by polarized light microscopy (PLM). The rationale for assuming that the gaskets and packing contained asbestos is discussed in the Methods section for each study.

This series of testing is unique among the existing published studies on gasket and packing removal and replacement because it combines elements of both worksite and simulation studies. Like simulation studies, this series of studies emphasized the characterization and/or the elimination of sources of asbestos contamination, so that all of the measured airborne asbestos could be attributed to the work activity of interest. The limitation of simulation studies is that they may be performed by scientists unfamiliar with typical worker techniques or daily activities. Worksite studies overcome this by sampling workers as they perform their daily tasks; however, these types of studies are often subject to contamination from other activities or general contamination in the area. In this series of studies, the first author's previous employment history lent him considerable familiarity with the activities of interest, as well as the scientific methods for evaluating exposure and minimizing contamination.

These studies on gaskets and packing took place over several years. To clarify the differences between each study, the methods are discussed separately.

Test I: Disassembly and Assembly of Flanges Containing Three Types of Gaskets (No Flange Face Cleaning), Conducted in 1982

All simulation work was performed inside an enclosure measuring 3 × 3 × 3 meters (27 cubic meters) that was constructed of PVC plastic piping and 0.01 cm polyethylene plastic, including the floor. This type of enclosure was selected because it represents the smallest practical work space in which gasket work would normally have been conducted. No dilution or local exhaust ventilation was used. The work area was cleaned between each activity.

Standard medium-sized flanges (approximately 8 to 16 cm in diameter) were taken from a decommissioned naval ship and were cleaned thoroughly prior to the study to remove any surface contamination. The mechanic assembled and disassembled flanges containing gaskets intermittently over the course of an 8-hour day, similar to the typical work activity in the removal and installation of gasket materials. However, the flange faces were not cleaned in any way. One day was devoted to each of the three types of gaskets that were evaluated: spiralwound, braided, and encapsulated. The simulated work activities evaluated included the storage, handling, removal, and installation of asbestos-containing gaskets.

The mechanic remained in the plastic enclosure for two 4-hour work periods separated by a one-half hour break. At the beginning of each of the two work periods, the mechanic was fitted with two open-faced 37 mm, 0.8 μm mixed cellulose ester (MCE) filter cassettes positioned in the breathing zone on the left and right lapel, for a total of four samples per day. Each breathing zone sample was collected for 4 hours at 2 L/min. Additionally, two area samples were collected per 4-hour period, each one on an opposite side of the sealed enclosure. All samples were analyzed by PCM analysis using the P&CAM 239 Method, the precursor to National Institute for Occupational Safety and Health (NIOSH) Method 7400. Bulk samples were not collected from the gaskets removed in this study. Based on the ship's naval provenance and the appearance of the gaskets, the first author was confident that most, if not all, of the gaskets contained asbestos.

Test II: Various Gasket Work, Conducted in 1982

Simulated work in this phase of testing was conducted in industrial work areas where asbestos-containing materials were routinely processed, rather than in an enclosed, contaminant-free workspace. Flanges were taken from an out-of-service naval ship and the exterior surfaces were cleaned thoroughly prior to the study. The work area was not cleaned or decontaminated prior to the study, but samples were collected for 8 hours each for 3 to 5 days before any gasket work was performed to evaluate background airborne asbestos in the work area.

Personal air samples were collected for 8 hours at 2 L/min on open-faced 37 mm, 0.8 μm MCE filter cassettes placed in the breathing zone of workers conducting the gasket activities of interest. Gasket formation activities included the use of ball peen hammers, hand-operated mechanical punches, machine punches, machine shears, machine nibblers, and the use of hand shaping tools such as knives, scissors, and scribes. Other activities evaluated included gasket installation on a clean surface, gasket removal with hand scraping of the flange surface, and hand scraping of the flange surface only (no gasket removal). The workers wore clean work clothes or plastic-impregnated coveralls during each day of the test period.

The activities were performed by workers at a typical rate over the course of the day, which ranged from intermittent to continuous. The intent of this test was to compare the 8-hour TWA airborne concentration during gasket work to the average background airborne asbestos. All samples were analyzed by PCM analysis using the P&CAM 239 method. Bulk analysis was not performed. The first author had knowledge that the gaskets being formed at this industrial site contained asbestos and, as with the previous study, his belief that the flanges contained asbestos gaskets was based on his knowledge of the flanges' source.

Test III: Disassembly of Ship Flanges and Gasket Removal, Including Flange Face Cleaning, at Two Different Worksites, Conducted in 1983

The purpose of this study was to evaluate the concentration of airborne asbestos while removing gaskets and cleaning flange faces within an actual ship. The study took place in two phases: one onboard the USS Gypsy (ARSD-1) and the other using valves taken from a former naval ship, the Offshore I. Both ships were World War II vintage transport vessels and were ideal for this experiment because they contained flanges that had probably never been opened during the life of the ship (meaning they had been in place for nearly 40 years). Many of the flange bolts had to be cut with an oxygen-acetylene torch because they had been frozen by age and corrosion.

In the first phase of the study onboard the USS Gypsy, an auxiliary ship, 20 asbestos gaskets were removed from flanges on the ship and the flange faces were scraped with a putty knife. The gaskets were removed from four flanges over the course of each 8-hour workday for 5 consecutive days. Each day, four samples were collected for 8 hours at 2 L/min on open-faced 37 mm, 0.8 μm MCE filter cassettes placed on the right and left lapel of the workers removing the gaskets. The workers wore clean clothing each day to minimize the effects of contaminated clothing. Although the ship's insulation had been removed long before the study took place, background samples were collected onboard the ship and away from the work area to verify that the background concentrations of asbestos were negligible.

In the second phase of this study, 30 pipe flanges were removed from the first and second deck of the Offshore I (an LST, tank landing ship) using an oxygen-acetylene torch. The flanges, still intact and unopened, were moved to a remote asbestos-free site and cleaned prior to the study. At the study site, each flange was placed on a clean piece of polyethylene plastic and disassembled. Once the flange was opened, the gasket was removed and the flange surfaces were scraped with a putty knife in the manner typical of shipboard procedure.

During this second phase of testing, six flanges were disassembled during each 8-hour work day over a 5-day period. Two breathing zone air samples were collected for 8 hours at 2 L/min on open-faced 37 mm, 0.8 μm MCE filter cassettes placed on the right and left lapel of the worker. Duplicate environmental air samples were also collected prior to the testing to confirm the absence of ambient asbestos contamination. All samples were analyzed by PCM using the NIOSH P&CAM 239 method. Bulk analysis was not performed on the gaskets removed during this test. However, the gaskets used in the following test (Test IV) were also taken from flanges on the USS Gypsy and were analyzed by PLM. The results of the bulk sample analysis are presented in the Test IV section.

Test IV: Gasket Formation, Removal, and Flange Face Cleaning, Conducted in 1989

The primary purpose of this set of studies was to evaluate bystander exposure to asbestos due to gasket removal and replacement activities, although worker breathing zone samples were also collected. Air samples were collected during gasket formation, gasket removal, and the cleaning of flanges from valves and piping taken from the USS Gypsy (ARSD-1). This study was similar to the previous study performed in 1983, yet it characterized additional gasket formation and removal activities and included an evaluation of bystander exposures. Some of the gaskets collected during this study were taken from flanges that contained bolts that were frozen in place with corrosion and showed no indication of being opened since the vessel was built. Prior to the study, all of the residual asbestos insulation on the outside of the piping was removed to prevent contamination when the gaskets were removed from the flanges. The study took place in a new metal building to ensure that accumulation of dust or previous asbestos insulation contamination was not present. Electron microscopy samples showed that the amount of ambient asbestos in the facility was 0.002 fibers/cc or less for all sizes of fibers.

A clean work bench was placed in the center of a clean enclosure measuring $6 \times 6 \times 3$ meters high (Figure 1). There was no ventilation in the enclosure and there were no air exchanges as the study took place. The gaskets were processed on the bench according to the descriptions given by some workers. All of the work was performed by the first author or by a professional mechanic. Plastic-impregnated protective clothing (Tyvec) was worn by the operator to minimize contamination and prevent confounding personal air measurements with dust resuspended from worker clothing. The tests were conducted over an 8-hour workday so that the data could be compared to the federal occupational standard for asbestos. One personal sample was collected in the breathing zone of the operator at 2 L/min. Eight area sample stations were set up with four stations being within 1.5 m of the work station and four within 3 m at approximately 10 L/min. Both personal and area samples were collected on open-faced 25 mm, 0.8 μm MCE filter cassettes. The area samples were analyzed by both TEM and PCM using NIOSH methods 7400 and 7402. The personal samples were analyzed by PCM using NIOSH method 7400. Samples of the removed and installed gaskets were analyzed by PLM.

Gasket Formation Using Hand-Held Tools

Asbestos exposures associated with gasket formation using hand-held tools were evaluated over the course of 4 days. Hand-held tools used for gasket formation included a scribe, ball peen hammer, circular cutter, hollow punch, and hand shears. The new gaskets were made from Garlock gasket material (style #900/7735, Garlock Sealing Technologies, Inc., Palmyra, N.Y.), containing about 70% chrysotile asbestos. This type of gasket material was typical of the types used from the 1940s to 1970s. Activities were repeated intermittently, similar to the rate of a worker preparing gaskets throughout the day.

The following gasket forming activities were studied, each on a separate day:

- Scribing of gasket material: Two gasket stock pieces were marked with the scribe each hour for 8 hours, for a total of 16 gaskets over the course of the 8-hour day.

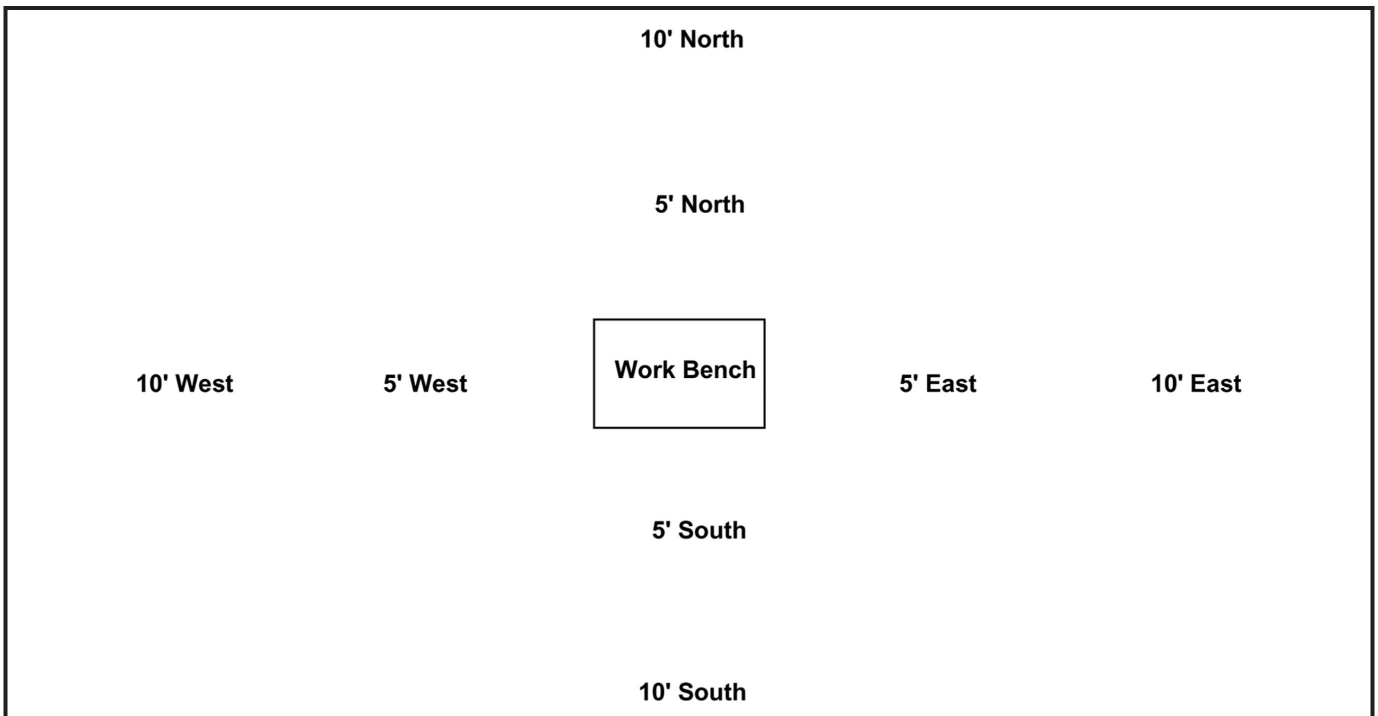

FIGURE 1. Location of area sampling stations in Tests IV and V

- Gasket cutting with a circular cutter: One gasket was cut each hour for 8 hours, for a total of eight gaskets.
- Gasket cutting with a ball peen hammer: Both the shape of the gasket and the bolt holes were cut using the ball peen hammer. One gasket was formed each hour for 8 hours, for a total of eight gaskets.
- Gasket cutting with hand shears and a hollow punch: One gasket was formed each hour for 8 hours, for a total of eight gaskets.

Removal of Asbestos Gaskets

One day was spent evaluating asbestos exposures during the removal of asbestos gaskets. Eight flanges were opened over an 8-hour sampling period to determine the 8-hour TWA associated with the removal of gaskets from flanges. Although the gaskets were pried from the flange using a putty knife, the flange faces were not cleaned. All of the removed gaskets were similar and determined to contain chrysotile asbestos.

Flange Face Cleaning

Three days were dedicated to evaluating asbestos exposures during flange face cleaning. In this evaluation, a hand scraper, hand wire brush, and power wire brush were used to remove any residual material left on the flange face after the gasket had been removed. The work with each tool was performed on a separate day and repeated at least eight times over the 8-hour day. All of the gaskets taken from these valves were verified to contain chrysotile asbestos and therefore the gasket residual also contained chrysotile asbestos.

When cleaning the flange face with the hand wire brush, it was necessary for the worker to also use a scraper to clean the surface. The power wire brushing involved the use of an electric drill with a circular wire brush attachment.

Test V: Removal and Replacement of Valve Packing, Conducted in 1991

The air sampling during the removal and replacement of valve packing was conducted using two dozen medium sized steam valves obtained from a municipal steam plant. The exterior surfaces of the valves were cleaned to remove any residual asbestos-containing materials adhering to the valves without disturbing the packing nuts and asbestos-containing packing material in any way.

A clean workbench was placed in the center of a clean enclosure measuring 6 × 6 × 3 m high (Figure 1). There was no ventilation in the enclosure and there were no air exchanges as the study took place. The valves were placed beside the workbench so that one valve after another could be processed by removing the old and installing the new packing material. The first author and an assistant, both wearing breathing zone sampling cassettes, worked on eight valves over the course of approximately 4.5 hours. The personal samples were collected at 2 L/min and the area samples at 10 L/min on 25 mm, 0.8 μm MCE filter cassettes. Plastic-impregnated protective clothing (Tyvec) was worn by the operators to control for the potential release of non-asbestos fibers from street clothing, and dust from shoes. Eight area sample stations were set up; four were 1.5 m away from the work station and four were 3 m away. Area samples were analyzed by both PCM and TEM using NIOSH methods 7400 and 7402 respectively. The personal samples were analyzed by PCM using NIOSH method 7400. Bulk analysis data from the packing used in this test are not available.

The valves were disassembled and the old packing was removed. New packing with similar asbestos content to that used during the 1950s (Garlock styles 127 and 733 containing about 70% chrysotile asbestos) was measured, cut, and installed in the valve. This process continued for more than 4 hours and, since it is unlikely that a worker would replace packing for any more than eight valves per day, it was assumed that the asbestos concentrations measured during the sampling period were representative of the upper range of concentrations a worker would experience over an 8-hour workday. Based on professional experience, unless the circumstances were unusual, it is more common for a millwright to replace packing on only two to three valves in a single day.

RESULTS

Tables I–V present the data from the studies described above, including sample averages and standard deviations. For samples below the detection limit, one-half the limit of detection was used for the calculations.

Test I: Disassembly and Assembly of Flanges Containing Three Types of Gaskets (No Flange Face Cleaning) (1982)

As shown in Table I, the assembly and disassembly of flanges, without any flange face cleaning, produced asbestos fiber concentrations that were at or below the lower limits of detection. Average breathing zone 8-hour TWAs ranged from 0.004 to 0.005 f/cc for the different types of gaskets, with standard deviations less than or equal to 0.001 f/cc. Average area samples were at or below the limit of detection of 0.004 f/cc.

Test II: Various Gasket Work (1982)

This phase of the study involved gasket removal and formation in an environment that was neither enclosed nor asbestos-free, thereby characterizing both the background and the combined background and activity-related airborne asbestos concentrations associated with the worksite. Many of the activities or areas sampled, as reported in Table II, were similar to those sampled by the Navy in their 1978 report.[17] The area samples taken before the work activities commenced had average concentrations ranging from 0.02 to 0.11 f/cc, with standard deviations as high as 0.07 f/cc. The average 8-hour TWA exposures (including background sources of asbestos)

TABLE I. Airborne Concentrations of Asbestos for Workers During Disassembly and Assembly of Flanges

	Asbestos Concentrations by PCM (f/cc)^{A,B,C}							
	Breathing Zone				Area			
Gasket Type	1st 4-hour TWA^D	2nd 4-hour TWA^D	8-hour TWA	Std. Dev.^{E}	1st 4-hour TWA^D	2nd 4-hour TWA^D	8-hour TWA	Std. Dev.^{E}
Spiral wound metal encased	0.005	0.003	0.004	0.001	0.002	0.002	0.002	0.000
Braided	0.005	0.006	0.005	0.001	0.003	0.004	0.004	0.001
Encapsulated sheet	0.005	0.005	0.005	0.000	0.003	0.004	0.004	0.001

Note: Flanges, which were disassembled and assembled over an 8-hour workday (no flange face cleaning) contained three types of gaskets. Sampling was conducted in 1982.
[A] The limit of detection was 0.004 f/cc.
[B] PCM analysis counted all fibers >5 μm in length with at least a 3:1 aspect ratio.
[C] For nondetectable samples, average and standard deviation were based on 1/2 the limit of detection.
[D] Two samples were collected in each 4-hour sampling period for each gasket type.
[E] Value represents standard deviation of all four samples collected.

ranged from 0.02 to 0.14 f/cc, with standard deviations as high as 0.05 f/cc.

Statistical comparisons between asbestos measurements for background and specific work tasks demonstrate the difficulty in quantitating low-level asbestos exposures associated with a particular source when background environmental contamination is present. The data collected during each gasket activity were tested for distribution fit using the D'Agostino Test and were found to have a lognormal distribution at a 95% confidence level.[18] The two-sample Student's t test of the log-transformed data showed no difference at a 95% confidence level between background concentrations and activity concentrations, in which five samples were collected for each activity. The two-sample Student's t test of the pooled activity data showed no statistically significant difference between background and activity measurements ($p = 0.073$).

Test III: Disassembly of Ship Flanges and Gasket Removal, Including Flange Face Cleaning, at Two Different Worksites (1983)

The 1983 study involved the collection of airborne asbestos samples while disassembling flanges at two worksites: on a ship and in a building. The data from the removal of gaskets from flanges both onboard a ship and in a building are presented in Table III. In both settings, the background concentrations of asbestos were minimal, 0.004 and 0.003 f/cc, respectively, both with a standard deviation of 0.001 f/cc. The average of the 20 personal breathing zone samples taken onboard the USS Gypsy was 0.030 f/cc (standard deviation of 0.021 f/cc). The average of the 10 breathing zone samples collected at the onshore site was 0.023 f/cc (standard deviation of 0.013 f/cc). These data were tested for distribution fit using the D'Agostino Test and were found to have a lognormal distribution at a 95%

TABLE II. Airborne Concentrations of Asbestos for Workers During the Performance of Various Gasket Activities

	8-Hour Asbestos Concentration by PCM (f/cc)^A					
	Breathing Zone			Background		
Site	n^B	8-hour TWA	Std. Dev.	n^B	8-hour TWA	Std. Dev.
Storage of gasket material^C	0	NA	NA	5	0.02	0.01
Hand-punching	5	0.06	0.01	5	0.04	0.03
Hand operated mechanical punch	5	0.02	0.02	5	0.02	0.00
Machine punch	5	0.11	0.04	5	0.09	0.07
Hand shaping table (knives, scissors, scribes)	5	0.04	0.02	5	0.03	0.03
Machine shearing	5	0.09	0.04	5	0.07	0.03
Nibbler machine	5	0.14	0.05	5	0.11	0.05
Flange opened no scraping (gasket installation)	3	0.03	0.02	3	0.03	0.00
Flange opened, scraping with knife	3	0.03	0.01	3	0.02	0.01

Note: Sampling was conducted in 1982 and involved characterization of work activities over an 8-hour workday, limit of detection unknown. NA – not applicable.
[A] PCM analysis counted all fibers >5 μm in length with at least a 3:1 aspect ratio.
[B] Each sample was collected for 8 hours.
[C] No work activities were conducted in the gasket storage area.

TABLE III. Airborne Asbestos Concentrations for Workers During Disassembly of Ship Flanges and Gasket Removal

Source of Valves	Study Site	Valves per Day[C]	8-Hour Asbestos Concentration by PCM (f/cc)[A,B]							
			Breathing Zone				Background			
			n[D]	Average	Min.–Max.	Std. Dev.	n[D]	Average	Min.–Max.	Std. Dev.
USS Gypsy[E]	Onboard ship	4[D]	20	0.030	0.01–0.08	0.021	5	0.004	0.002–0.005	0.001
Offshore I[F]	Building (on land)	6[E]	10	0.023	0.01–0.05	0.013	9	0.003	0.002–0.004	0.001

Note: Sampling was conducted in 1983 and involved flange face cleaning at two different worksites over an 8-hour workday. Limit of detection unknown.
[A]PCM analysis counted all fibers >5 μm in length with at least a 3:1 aspect ratio.
[B]It is assumed that all fibers detected were asbestos.
[C]Study took place over the course of 5 days.
[D]Total number of samples collected over the 5 days.
[E]Four lapel and one background samples were collected for 8 hours each day; four valves were processed per day for a total of 20 valves.
[F]Two lapel and two background samples were collected for 8 hours each day; however, one of the background samples was lost. Six valves were processed per day for a total of 30 valves.

confidence level.(18) The two-sample Student's t test of the log-transformed data showed no statistical difference ($p = 0.58$) between the mean asbestos concentrations measured in the two settings.

Test IV: Gasket Formation, Removal and Flange Face Cleaning (1989)

Several of the methods used by workers in the field to remove and replace gaskets are listed in Table IV. During gasket formation activities using circular cutters, hand shears, ball peen hammers, or scribes, the average breathing zone concentrations were at or below the limit of detection of 0.005 f/cc by PCM analysis. The area samples during the same gasket formation activities were less than or equal to 0.006 f/cc by PCM analysis and less than or equal to 0.003 f/cc by TEM analysis. All of the standard deviations of the area samples were less than or equal to 0.002 f/cc. Similarly, gasket removal and flange scraping with a putty knife created breathing zone and area asbestos concentrations less than 0.005 f/cc by both TEM and PCM analysis.

Hand and power wire brushing created higher and more varied data. The breathing zone 8-hour TWA airborne concentrations were 0.007 f/cc for hand wire brushing and 0.009 f/cc for power wire brushing (PCM analysis). The average area 8-hour TWAs for gasket removal involving hand wire brushing and power wire brushing samples were 0.024 and 0.028 f/cc by TEM analysis, while the PCM analysis of the same samples yielded average concentrations of 0.003 and 0.001 f/cc, respectively. The standard deviations of the PCM data for both types of wire brushing samples were less than or equal to 0.001 f/cc, yet the standard deviations of the TEM data was 0.012 f/cc for hand wire brushing and 0.007 f/cc for power wire brushing.

Bulk sampling indicated that the removed gaskets contained 60–80% chrysotile asbestos and the installed gaskets contained 70–80% chrysotile asbestos, with no other asbestos fiber types identified.

Test V: Removal and Replacement of Valve Packing (1991)

Table V shows area and worker airborne asbestos concentrations during the removal and replacement of valve packing. The eight area samples had an average of 0.008 f/cc by TEM analysis and an average of 0.004 f/cc by PCM analysis. The standard deviations of the two datasets were 0.003 and 0.001 f/cc, respectively. By PCM analysis, the operator breathing zone concentration was below the detection limit of 0.011 f/cc and the bystander breathing zone concentration was below the detection limit of 0.009 f/cc. Since a single sample was collected each for the worker and the bystander during the packing activities (as compared to several samples collected during gasket activities), both samples were submitted for a blind recount. The recount yielded operator and assistant breathing zone concentrations of 0.016 and 0.009 f/cc, respectively, indicating that there was little variability in the counting method.

DISCUSSION

This series of studies evaluated worker and bystander exposures during various types of gasket and packing work, including installation, removal, cleanup, and gasket formation. Overall, the data indicate that the 8-hour TWA exposures to workers performing these activities throughout the 8-hour workday were well below the current OSHA 8-hour TWA exposure limit of 0.1 f/cc and all previous OSHA exposure limits. Gasket removal without flange face cleaning yielded the lowest airborne asbestos concentrations, with most measurements falling below the limit of detection of 0.004 f/cc by PCM analysis (Table I). The highest concentrations, excluding those reported in Table II, were measured during the disassembly of flanges onboard a ship (with flange face cleaning), with 8-hour TWAs of 0.03 f/cc by PCM analysis (Table III). The breathing zone concentrations reported in Table II were not significantly different from the background

TABLE IV. Airborne Concentrations of Asbestos for Workers and Bystanders During Gasket Formation, Removal, and Flange Face

Activity	No. of Activities Performed	Asbestos Content of Gaskets (%)[F]	8-Hour Asbestos Concentration by PCM (f/cc)[A,B,C]						8-Hour Asbestos Concentration by TEM (f/cc)[B,C,D,E]			
					Area/Bystander				Area/Bystander			
			Breathing Zone[G]	Background[G]	n	Average[H]	Min.–Max.	Std. Dev.[H]	n	Average[H]	Min.–Max.	Std. Dev.[H]
Circular cutter	16	70–80	<0.005	<0.002	8	0.003	0.002–0.006	0.001	8	0.002	<0.002–0.005	0.001
Hand shears	8	70–80	<0.005	<0.002	8	0.004	<0.003–0.006	0.001	8	0.002	<0.002–0.005	0.002
Ball peen hammer	8	70–80	0.005	<0.002	8	0.006	0.004–0.007	0.001	8	0.003	<0.002–0.007	0.002
Scribe	8	70–80	<0.005	<0.002	8	0.003	0.002–0.004	0.001	8	0.001	<0.002	0.000
Gasket removal	8	60–80	<0.005	<0.002	8	0.002	<0.001–0.003	0.001	8	0.001	<0.002–0.002	0.000
Putty knife	8	60–80	<0.005	<0.002	8	0.001	<0.001–0.002	0.000	7	0.001	<0.002–0.002	0.000
Hand wire brush	8	60–80	0.007	<0.002	8	0.003	0.002–0.005	0.001	8	0.024	0.012–0.042	0.012
Power wire brush	8	60–80	0.009	<0.002	8	0.001	<0.001	0.000	8	0.028	0.021–0.042	0.007

Notes: Sampling was conducted in 1989 and involved characterization of work activities over an 8-hour workday. There was no ventilation in the room. Each task was studied for 1 day (one personal and eight area samples per task).

[A] PCM analysis counted all fibers >5 μm in length with at least a 3:1 aspect ratio.

[B] Samples below the limit of detection are reported as less than (<) the quantification limit.

[C] All samples were collected for 8 hours.

[D] TEM analysis counted all chrysotile asbestos fibers >5 μm in length with at least a 3:1 aspect ratio; other asbestiform fibers were not identified.

[E] These values represent the asbestos concentration measured by TEM, not the corrected PCM concentrations.

[F] Bulk samples analyzed using PLM; only chrysotile fibers were detected.

[G] n = 1.

[H] For nondetectable samples, average and standard deviation were based on 1/2 the limit of detection.

TABLE V. Concentration of Asbestos for Workers and Bystanders During the Removal and Replacement of Valve Packing

Activity	Background Concentration by TEM^{C,E}	Asbestos Concentration by PCM (f/cc)^{A,B}						Asbestos Concentration by TEM (f/cc)^{C,D}			
		Breathing Zone		Area				Area			
		Worker^{E}	Bystander^{E}	n	Average	Min.–Max.	Std. Dev.	n	Average	Min.–Max.	Std. Dev.
Packing removal and installation	0.002	<0.011	<0.009	8	0.004	0.002–0.006	0.001	8	0.008	0.002–0.012	0.003

Notes: Sampling was conducted in 1991 and involved characterization of area concentrations over an 8-hour workday. Personal samples were collected from a worker and a bystander for more than 4 hours. There was no ventilation in the room. To evaluate analytical variability, the worker and bystander samples were recounted. The results were 0.016 f/cc (worker) and 0.009 f/cc (bystander).
^{A}PCM analysis counted all fibers >5 μm in length with at least a 3:1 aspect ratio.
^{B}Samples below the limit of detection are reported as less than (<) the quantification limit.
^{C}TEM analysis counted all chrysotile asbestos fibers >5 μm in length with at least a 3:1 aspect ratio.
^{D}These values represent the asbestos concentration measured by TEM, not the corrected PCM concentrations.
^{E}n = 1.

concentrations. Even though some of the breathing zone samples were in excess of the current OSHA PEL of 0.1 f/cc, the corresponding background concentrations were also close to 0.1 f/cc

In the studies in which both TEM and PCM analysis were conducted, the concentrations reported by PCM analysis were often greater than those reported by TEM analysis. In the case of hand wire brushing, power wire brushing, and packing replacement, this was not the case. TEM analysis, unlike PCM, counts only asbestos fibers, so it would seem that TEM analysis should yield lower counts than PCM data. However, TEM provides better resolution than PCM and may count two fibers when PCM would count one.

One shortcoming in the studies reported here is the lack of bulk sampling data for many of the gaskets and packing that were removed and installed. Several of the airborne asbestos concentrations were close to background concentrations, making it especially desirable to verify that all of the materials handled contained asbestos. However, in conducting these studies, there are several reasons that the first author was confident that the materials contained asbestos. First, his former shipyard employment gave him considerable knowledge about the prevalence of asbestos in the gaskets and packing used onboard naval ships. Second, his background in characterizing shipyard sources of asbestos exposure gave him the ability to visibly distinguish asbestos-containing materials from non-asbestos materials. Third, based on his interactions with various industries as a consultant, he was aware of which industries historically used asbestos packing and gaskets.

The study conducted by the Navy in 1978 and those conducted by the first author of this article were the first to evaluate potential asbestos exposures associated with handling asbestos-containing gasket and packing materials. It was not until 1991 that the first study on this issue was published in the peer-review literature.[19] Since then a number of studies have evaluated exposures associated with removal and installation of asbestos-containing gaskets and packing materials.[19–27] Direct comparison of the results from other studies to those described in this paper is difficult given that the tasks evaluated, sampling and analytical methods, and overall study design are quite different. For example, some studies conducted short-term sampling,[19,23–26] while others collected samples over the course of an 8-hour workday.[19–22,27] In addition, different tasks involved with removal and installation of gaskets and packing were characterized by different studies and not all investigators collected background samples, particularly during worksite studies, to assess the contribution of environmental contamination to airborne asbestos measurements.

With a few exceptions, the results from the series of tests described in this article are generally consistent with other gasket and packing studies conducted to date.[17,19–21,27] The exceptions include the studies conducted by Fowler et al.[26] and Longo et al.[23] In the Fowler study, asbestos exposures in excess of regulatory standards were reported for tasks involving bandsawing stock asbestos sheet gaskets. This type of activity was not commonly performed, and therefore was not an area of interest in the series of studies described in the paper. Longo and colleagues reported asbestos concentrations in excess of regulatory levels during the removal of gaskets using scrapers, hand wire brushes, and power wire brushes. This data contrasts the data reported in this study, as well as by other authors, including the Navy, Cheng and McDermott, Spencer, and Boelter et al.[17,19–21,23,27] It is not clear why the data reported in the Longo study are several times higher than the values reported in the other studies; however, it has been noted that the sample filters were overloaded and that the work area was not decontaminated before each task (e.g., power wire brushing).[28] Due to differences in sampling times and vague study descriptions, it is unclear whether the short-term packing studies by Milette[24] and McKinnery[25] are consistent with the 8-hour TWA concentrations measured in this study.

Work site studies that do not report background airborne concentrations, such as those conducted by the Navy[17] in 1978 and Cheng and McDermott[19] in 1991, could easily overestimate the airborne asbestos exposures associated with handling of asbestos-containing gasket and packing materials. Nonetheless, it can be concluded from the overall weight of the results from the studies conducted to date that workers directly handling asbestos packing and gasket materials, or working in an area where such products are being used, up until the early 1980s (when the use of non-asbestos materials became widespread) were not likely to have been exposed to asbestos levels in excess of the contemporaneous PELs.

In many industrial settings, particularly prior to the 1980s, the contribution of airborne asbestos from other sources, such as insulation, would have substantially overwhelmed any potential release from asbestos-containing gaskets and packing materials. As discussed earlier, gaskets and packing constitute a small fraction of the asbestos-containing materials used on a ship. Historical exposure studies have shown that exposure during handling of insulation materials can be extremely high. Airborne asbestos measurements collected at British Naval shipyards have shown average concentrations of 226 f/cc (range 23–493 f/cc) during removal of sprayed crocidolite asbestos, 152 f/cc (range 7–896 f/cc) during removal of pipe lagging, and 9 f/cc (range 0.1–55 f/cc) during application of pipe lagging.[8] Similarly, relatively high exposures were documented among insulation workers in U.S. naval shipyards. Nicholson and colleagues[29] reported average airborne asbestos concentrations of 4.6 f/cc during mixing and applying cement insulation, 11.5 f/cc during cutting and applying block insulation, and 67 f/cc while spraying asbestos fiber insulation. Intermittent peak exposures from rip out of asbestos insulations in machinery spaces (boiler, engine and control rooms) of ships could measure in the hundreds of fibers/cc as measured in the 1960s. An 8-hour TWA of 0.03 f/cc during the disassembly of flanges onboard a ship (with flange face cleaning), the highest average concentration measured in this study, is negligible compared to potential exposures associated with direct handling of insulation material or working in an area in which insulation work is being conducted.

The data from the samples collected during all activities associated with asbestos gasket and packing work indicate that the asbestos fibers released during these activities are considerably lower than the current 8-hour TWA permissible exposure limit of 0.1 f/cc, let alone all previous standards. Both the worker and bystander 8-hour exposures were extremely low, often below the limit of detection. The TEM data were supportive of PCM measurements, which is to be expected when sources of background contamination of asbestos is eliminated. The data from this study represent the actual airborne asbestos exposure encountered by a worker or bystander as gasket and packing replacement are performed. These data indicate that asbestos exposure to workers conducting removal and installation of asbestos-containing gasket and packing materials is below historical and current occupational exposure limits for asbestos and suggest that the health risks associated with these activities are negligible.

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REFERENCES

1. **Karnell-Corn, J., and J. Starr:** Historical perspectives on asbestos: Policies and protective measures in World War II shipbulding. *Am. J. Ind. Med. 11*:359–373 (1987).
2. **United States Navy:** *Military Standards, Thermal Insulation Requirements*. Bureau of Ships Technical Manuals, Mil-Std-769E, 1974, 1975.
3. **United States Navy:** Chapter 39-Thermal Insulation, Bureau of Ships Technical Manuals. 1945, 1947, 1967, 1972.
4. **Kelleher, D., and W. Bartlett:** Asbestos packing and gaskets. Technical Association of the Pulp and Paper Industry (TAPPI) Engineering Conference. Quezon City, Philippines, 1983.
5. **United States Navy:** Bureau of Ships, Series of Plans. DD-3902, circa 1942–1943.
6. **United States Navy:** Bureau of Ships, Basic Set of Hull Machinery & Electrical Plans. DD-3902, 1943.
7. **Plisko, M.:** *Asbestos Materials Summary for Fletcher-Class Destroyer.* Baltimore: Environmental Profiles, Inc., 2002. pp. 1–4.
8. **Fleischer, W.E., F.J. Viles, R.L. Gade, and P. Drinker:** A health survey of pipe covering operations in constructing naval vessels. *J. Ind. Hyg. Toxicol. 28*:9–16 (1946).
9. **Occupational Safety and Health Administration:** Title 29–Labor, Chapter XVII, Part 1910–Occupational Safety and Health Standards, Standard for Exposure to Asbestos Dust. 37FR 11318-11322, 1972.
10. "National Emission Standards for Hazardous Air Pollutants; Asbestos NESHAP Revision." *Code of Federal Regulations Title 40,* Part 61. 1990. Volume 55, No. 24.
11. **Mangold, C.A., R.R. Beckett, and D.J. Bessmer:** *Asbestos Exposure and Control—Puget Sound Naval Shipyard*. 13ND NAVYSHIPYDBREM P6260.1, (11–70). Washington, D.C.: Department of the Navy, 1970.
12. **Mangold, C.A., R.R. Beckett, and D.J. Bessmer:** *Asbestos Exposure and Pulmonary X-ray Changes to Pipe Coverers and Insulators at Puget Sound Naval Shipyard*. Presented at the American Industrial Hygiene Association Meeting at Richland, Washington, 1968.
13. **Selikoff, I., and D. Lee:** Table 20-1. In *Asbestos and Disease*, D. Lee, E. Hewson, and D. Okun (eds.). p. 466. New York: Academic Press, 1978.
14. **Lindell, K.:** Biological effects of asbestos. In *Biological Effects of Asbestos: Proceedings of a Working Conference held at the International Agency for Research on Cancer*, P. Bogovski, J. C. Gilson, V. Timbrell, and J. C. Wagner, (eds.). Lyon, France: International Agency for Research on Cancer (IARC), 1973. pp. 323–328.
15. **Balzer, J.L., and W.C. Cooper:** The work environment of insulating workers. *Am. Ind. Hyg. Assoc. J. 29*:222–227 (1968).
16. **Murphy, R.L., Jr., B.G. Ferris, Jr., W.A. Burgess, J. Worcester, and E.A. Gaensler:** Effects of low concentrations of asbestos. Clinical, environmental, radiologic and epidemiologic observations in shipyard pipe coverers and controls. *N. Engl. J. Med. 285*:1271–1278 (1971).
17. **Liukonen, L.R., K.R. Still, and R.R. Beckett:** *Asbestos Exposure from Gasket Operations*. Bremerton, Wash.: Naval Regional Medical Center, Occupational & Environmental Health Service, 1978.
18. **D'Agostino, R.B., Belanger A., and R.B. D'Agostino Jr.:** A suggestion for using powerful and informative tests of normality. *Am. Statistician 44*(4):316321 (1990).

19. **Cheng, R.T., and H.J. McDermott:** Exposure to asbestos from asbestos gaskets. *Appl. Occup. Environ. Hyg. 6*:588–591 (1991).
20. **Spencer, J.W.:** *Exposure assessment: An Evaluation of the Actual Contribution of Airborne Asbestos Fibers from the Removal and Installation of Gaskets and Packing Material*. Project No. 8489. Baltimore: Environmental Profiles, Inc., 1998.
21. **Spencer, J.W.:** *Exposure Assessment: An Evaluation of the Actual Contribution of Airborne Asbestos Fibers from the Fabrication of Gaskets*. Project No. 8500. Baltimore: Environmental Profiles, Inc., 1998.
22. **Spence, S.K., and P.S. Rocchi:** Exposure to asbestos fibers during gasket removal. *Ann. Occup. Hyg. 40*:583–588 (1996).
23. **Longo, W.E., W.B. Egeland, R.L. Hatfield, and L.R. Newton:** Fiber release during the removal of asbestos-containing gaskets: A work practice simulation. *Appl. Occup. Environ. Hyg. 17*:55–62 (2002).
24. **Millette, J.R., and M.D. Mount:** A study determining asbestos fiber release during the removal of valve packing. *Appl. Occup. Environ. Hyg. 8*:790–793 (1993).
25. **McKinnery, W.N., and R.W. Moore:** Evaluation of airborne asbestos fiber levels during removal and installation of valve gaskets and packing. *Am. Ind. Hyg. Assoc. J. 53*:531–532 (1992).
26. **Fowler, D.P.:** Exposures to asbestos arising from bandsawing gasket material. *Appl. Occup. Environ. Hyg. 15*:404–408 (2000).
27. **Boelter, F.W., G.N. Crawford, and D.M. Podraza:** Airborne fiber exposure assessment of dry asbestos-containing gaskets and packings found in intact industrial and maritime fittings. *Am. Ind. Hyg. Assoc. J. 63*:732–740 (2002).
28. **Boelter, F., G. Crawford, and D.M. Podraza:** Airborne fiber exposure assessment of dry asbestos-containing gaskets and packings found in intact industrial and maritime fittings. Authors' reply. *Am. Ind. Hyg. Assoc. J. 64*:595 (2003).
29. **Nicholson, W.J., D.A. Holaday, and H. Heimann:** Direct and indirect occupational exposure to insulation dusts in United States shipyards. In *Safety and Health in Shipbuilding and Ship Repairing.* Geneva: International Labor Office (ILO), 1972. pp. 37–47.