An updated evaluation of potential health hazards associated with exposures to asbestos-containing drywall accessory products

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Abstract

Following a previously published (2012) evaluation of the potential health hazards related to the use of asbestos-containing drywall accessory products, additional information regarding asbestos exposures during the use of accessory products, as well as studies of chrysotile asbestos risk as a function of exposure, have been published in the peer-reviewed literature. The purpose of this analysis is to update the original evaluation with this new information. It was previously estimated that a professional drywaller performing joint compound-associated tasks could have a lifetime cumulative chrysotile exposure of 12–26 f/cc-year. Using conservative assumptions regarding airborne asbestos levels during different drywalling tasks, task duration, and job tenure, we found that a range of 4.3–36.3 f/cc-year is a plausible estimate of a career drywaller's cumulative asbestos exposure from historical joint compound use. The estimated range for bystander exposures would be below (sometimes significantly below) this range depending on the frequency and duration of work near drywallers. Further, the estimated drywaller and bystander total fiber exposures were well below a recently published “no-observed adverse effect level, best estimate” for predominately chrysotile exposures of 89–168 f/cc-year for lung cancer and 208–415 f/cc-year for mesothelioma. We also determined that, even if the chrysotile or possibly talc ingredients in the drywall products had contained asbestiform tremolite, the cumulative tremolite exposures would have been well below a recently published tremolite no-effect level of 0.5–2.6 f/cc-year. Based on our calculations, typical drywall work using asbestos-containing drywall accessory products is not expected to increase the risk of asbestos-related lung cancer or mesothelioma. These conclusions are consistent with the lack of epidemiological evidence that drywall work resulted in an increased incidence of asbestos-related disease in the drywall trades.

Introduction

Joint compound (sometimes referred to as drywall mud, spackle, patching compound, or joint cement) is commonly a gypsum-based material that is used along with joint tape to seal joints between drywall boards, cover nail and screw holes, and provide a smooth wall surface. Dry joint compounds (which required mixing with water prior to use) were introduced in the mid-1940s, while wet or pre-mixed joint compounds were introduced in the mid-1950s (CPSC Citation1977b). Dry joint compound is still sold, although its use is typically reserved for smaller projects where only the required quantity is mixed. Until the late 1970s, chrysotile asbestos was added as a reinforcing agent to some joint compound products in the United States (Rhodes and Ingalls Citation1975b; Rhodes and Ingalls Citation1976). The unique properties of asbestos created a flocculated network of fibers – these fibers loosened when troweled, allowing the compound to move and feather, and reflocculated, or amassed together, once applied, holding the compound in place (CPSC Citation1977b). The chrysotile asbestos also helped control shrinkage and cracking as the joint compound dried, improved the temperature stability of the joint compound during outdoor storage (i.e. joint compound could still be used after freezing, unlike products that did not contain asbestos), and also improved the application properties, which allowed an applicator to evenly apply and feather the wet edge of the compound, creating a smoother texture upon which paint could be applied.

The asbestos content of drywall finishing products (e.g. joint compound, texture, and tape) historically ranged from approximately three to 15% chrysotile by weight. It has been suggested that, when joint compound products were first introduced, formulations contained 10–15% asbestos, and that the asbestos concentrations decreased with time (CPSC Citation1977b). Only the chrysotile form of asbestos was intentionally added as an ingredient in joint compound formulations; amphibole fibers (e.g. tremolite, amosite, crocidolite) were not used as ingredients in joint compounds (Phelka and Finley Citation2012). However, industrial talc was also used in some joint compound formulations, and some chrysotile asbestos and industrial talc deposits contained trace levels of tremolite asbestos (Fiume et al. Citation2015).

In the mid-1960s, it was reported that insulation workers had a high incidence of asbestos-related diseases (Selikoff et al. Citation1964, Citation1965). These studies by Selikoff were the first to demonstrate that use of an asbestos-containing insulation (predominately amosite) could pose a significant risk to insulators. Soon thereafter, researchers and industry representatives began to quantify the fiber exposures experienced by other workers, including individuals performing drywall finishing activities (Schmidt Citation1970; Dotti Citation1972; Brown Citation1973; Gypsum Association Citation1973; National Gypsum Company Citation1973a, Citation1973b; Rohl et al. Citation1975; Rhodes and Spencer Citation1977; Verma and Middleton Citation1980). The airborne fiber concentrations reported in these studies generally represented variable short-term, task-based, and peak measurements that were analyzed by phase contrast microscopy (PCM), utilizing a method which measures all fibers (including non-asbestos fibers) greater than five microns in length.

In 2012, Phelka and Finley published a state of the science evaluation of the potential exposures and health hazards associated with the use of asbestos-containing drywall accessory products (Phelka and Finley Citation2012). In that analysis, the authors summarized and interpreted the available data related to the asbestos content of joint compound as well as the related toxicology, exposure, and epidemiology literature. Based on 40-h time-weighted average (TWA) data reported in the Verma and Middleton (Citation1980) study of commercial drywallers, as well as the median job tenure of 5.7 years for drywall installers reported by Carey (Citation1988), Phelka and Finley (Citation2012) calculated a cumulative fiber exposure estimate of 12–26 f/cc-year for occupational drywallers performing the drywall finishing tasks of mixing, sanding, and cleanup, on a daily basis. The cumulative exposure estimate for a non-occupational user (e.g. a homeowner conducting a renovation) was 0.01 f/cc-year (Phelka and Finley Citation2012). Phelka and Finley (Citation2012) concluded that these estimated exposures were far below the chrysotile no-effect levels (NOAELs) for mesothelioma and lung cancer that had been published by Pierce et al. (Citation2008).

Since the publication of Phelka and Finley (Citation2012), additional data have been published regarding: airborne asbestos concentrations during the use of drywall accessory products, updated chrysotile NOAEL exposure values for mesothelioma and lung cancer, and case reports of mesothelioma in drywall workers. Additional historical documents regarding the use and composition of joint compound have also become available. Further, tremolite NOAEL exposure values for mesothelioma have been published. The purpose of this paper is to update the Phelka and Finley (Citation2012) analysis with this new information, as well as expand the scope to include additional drywall accessory products. Specifically, we evaluate drywall worker, bystander, home renovator, and take-home exposures for both chrysotile and tremolite asbestos. These exposures are compared to the recently published NOAEL values for both fiber types. We also describe the most current findings of asbestosis, lung cancer, and mesothelioma incidence in drywall workers, as well as the potential amphibole asbestos content of some joint compound products. Finally, we highlight areas of potential research as additional exposure or epidemiological literature becomes available.

Overview of drywall trades

Prior to the use of dry wallboard, interior walls in US homes were made by applying wet plaster to a slatted wooden lath frame (i.e. lath and plaster method). It took several days for the plaster to dry and set, making this construction method time consuming and costly. In the early 1900s, United States Gypsum Company (US Gypsum) developed a dry, gypsum-based, fireproof wallboard tile, marketed as Pyrobar. The formulation was reengineered into a layered gypsum and paper wallboard sold as Sackett board. By 1916, it was sold as a single plaster and paper layer under the names Adamant Panel Board and Sheetrock (USG Corp. Citation2019). Wallboard is now commonly referred to as sheetrock and drywall.

There are several distinct job titles for workers in the drywall industry. Drywall hangers or drywall installers typically cut wallboard to size, hung wallboard, and cut holes in the wallboard to accommodate outlets, fixtures, or vents. Drywall tapers or finishers (referred to as “drywallers” in this paper) applied drywall tape and applied and sanded joint compound.

Additionally, drywallers sometimes belonged to the Painters or Carpenters Union (Lipscomb and Dement Citation1998). Some general drywall workers, carpenters, or general contractors performed both hanging and finishing tasks.

Asbestos-containing materials and airborne asbestos levels associated with drywall and plaster trades

Below, we describe published and unpublished literature characterizing spackle, textured paint, texture compound, plaster, and joint compound construction materials. When possible, we have included airborne fiber levels measured during the use of each product and noted how these exposures compared to contemporaneous health-based guidelines for asbestos.

As noted previously, drywall accessory products contained asbestos between the mid-1940s and late-1970s. From 1946 to 1968, the American Conference of Governmental Industrial Hygienists (ACGIH) recommended limiting asbestos exposures to 5 million particles per cubic foot (mppcf), equivalent to approximately 30 f/cc as an 8-h time-weighted average (TWA). This guideline was proposed to be lowered to 2 mppcf, roughly equivalent to 12 f/cc, in 1968 (American Conference of Governmental Industrial Hygienists (ACGIH) Citation1968; American Conference of Governmental Industrial Hygienists (ACGIH) Citation2001; Greenberg Citation2003). Asbestos has been regulated in the U.S. at the federal level since the Occupational Safety and Health Administration's (OSHA) promulgation of an asbestos standard in May 1971; the preliminary Permissible Exposure Limit (PEL) was 12 f/cc as an 8-h TWA, and was set to minimize risk of asbestosis and "asbestos-induced forms of cancer" (OSHA Citation1994). An emergency temporary standard (ETS) was enacted in late 1971, which lowered the asbestos PEL to 5 f/cc as an 8-h TWA, with an allowable peak exposure level of 10 f/cc. The ETS was permanently adopted in 1972 and remained in place until 1976, when the standard was further lowered to 2 f/cc as an 8-h TWA (OSHA Citation1994).

Spackle products

The term "spackle" is often used interchangeably with "joint compound," particularly when referring to minor wall repair tasks like filling nail holes, etc. However, while some spackle products contained an unspecified quantity of talc, spackle products historically did not contain asbestos as an added ingredient (CPSC Citation1977b). There are no data in the available literature describing dust or fiber exposures during the mixing, application, or sanding of spackle products. Given that spackle did not contain asbestos as an added ingredient, any asbestos exposures during the use of this product are expected to be minimal and well below contemporaneous occupational exposure limits.

Textured paints

Textured paint is a pre-mixed product containing a paint component and an added texturing compound component, which is applied to surfaces by brush or roller. This product is allowed to dry in place and is not sanded. Prior to the late 1970s, asbestos was used as a constituent in some textured paints to provide strength, decay resistance, vermin resistance, stability, and durability (Anderson et al. Citation1982). Latex-based textured paints contained limestone, lesser amounts of mica, and 1–5% chrysotile asbestos (Anderson and Farino Citation1982; Anderson et al. Citation1982). A report on chrysotile asbestos substitute performance analysis prepared for the US Environmental Protection Agency (EPA) stated that “[s]mall amounts of asbestos (approximately 1%)” were historically used in textured paints (Krusell et al. Citation1982, p. 225). According to a guidance document issued in the United Kingdom in 1999, textured paints historically contained 3–5% chrysotile asbestos (MRC Institute for Environment and Health Citation1999). Chrysotile asbestos is classified or graded by fiber length. The shortest grades of chrysotile were used in coatings, paints, and sealants; it has been reported that over 95% of the asbestos used in these products was Group/Grade 7 chrysotile (Meylan et al. Citation1978).

Exposure data are not available for the hand application of textured paint. However, Paustenbach et al. (Citation2004) reported that no airborne asbestos fibers were detected in personal samples during the application of wet, encapsulated, asbestos-containing coatings, mastics, and adhesives. It is reasonable to expect that minimal asbestos exposure would similarly occur during the hand application of wet, encapsulated textured paint, and that any exposure experienced would be well below contemporaneous asbestos exposure limits.

Texture compound

In 1975, Rhodes and Ingalls collected airborne fiber samples during the field mixing and application of ceiling texture at two construction sites in order to compare airborne concentrations during the usage of Canadian and California-sourced chrysotile. The first test was “typical of the small, custom operator,” and the second test was “representative of large, ‘mass-production’ type procedures and equipment” (Rhodes and Ingalls Citation1975a). Personal (sprayer and wiper) samples were collected during mixing and spraying tasks during both tests, and were analyzed using PCM and transmission electron microscopy (TEM) methods. Sample collection durations were reportedly task-based and the exact durations were not specified. Airborne fiber concentrations ranged from 0.5 to 3.2 f/cc for dry mixing and from 0.2 to 1.6 f/cc for spraying (PCM). It is unclear whether the short-term sample concentrations were converted to 8-h TWA measurements. The authors noted that results based on TEM were “an order of magnitude lower than the optical counts,” suggesting that 90% of the fibers counted by PCM were not asbestos (Rhodes and Ingalls Citation1975a). Assuming that the task durations were all less than 8 h, these concentrations were all below the asbestos exposure limits in place at the time the study was performed (5 f/cc).

Between 1975 and 1977, Verma and Middleton (Citation1981) surveyed eight operations in Canada where texture compound was in use (Verma and Middleton, Citation1981). It was noted that texture products were “similar in composition to the taping joint compound,” and contained 3–6% chrysotile asbestos by weight (Verma and Middleton Citation1981). Airborne fiber concentrations were measured in 36 samples during ceiling and wall texture processes, specifically mixing, spraying, cutting angle and scraping, and sweeping and cleaning. Samples were analyzed in accordance with an unspecified NIOSH method for asbestos dust. Median task-specific airborne fiber concentrations and task durations were used to estimate that a typical residential texture worker’s 40-h work-week TWA was 4.2 f/cc. This concentration exceeded the contemporaneous 1976 OSHA PEL of 2 f/cc.

In 2005, the United Kingdom’s Health & Safety Laboratory examined airborne fiber concentrations during the removal of textured coating from 35 domestic sites (Revell Citation2005). Samples were collected during removal and cleaning activities. A subset of samples ($n = 28$) were treated to remove soluble calcium sulfate particles from filters prior to analysis by PCM and TEM. The pooled mean for the treated TEM PCME samples was 0.014 f/mL, with the calculated 4-h TWA and 10-min TWA being ∼0.005 f/mL and ∼0.06 f/mL, respectively. It was noted that chrysotile fibers were the only mineral type of asbestos detected in the analyzed TEM samples (Revell Citation2005). These concentrations are all well below contemporaneous asbestos exposure limits, as well as below the current OSHA PEL of 0.1 f/cc (OSHA Citation1994).

Plaster products

Plaster work is still performed in the US on building interiors and is also used to create decorative building exteriors. Wet plaster is applied by hand and trowel, or sprayed on. Raw asbestos fiber was sometimes added to spray mixtures to reduce hose clogging during application. Exterior plaster workers also use cement, stucco, or imitation stone. The plaster worker trade union classification is broad and also includes workers who handle cork, wood, and stone. Plaster workers familiar with trowel and sprayed application techniques also potentially handled chrysotile and amphibole asbestos materials through their work with fireproofing materials and insulation (Stern et al. Citation2001). We were unable to locate published or unpublished data regarding potential airborne asbestos exposures during plaster work, the fiber type of asbestos used in these products, or specific records of the exact time period during which these workers would have handled asbestos-containing plaster materials.

Joint compound

Phelka and Finley (Citation2012) performed a review and analysis of scientific studies assessing fiber type and dimension, toxicological and epidemiological endpoints, and airborne fiber concentrations associated with the use of joint compound. Below, we summarize and evaluate studies that were not originally addressed in this evaluation, as well as studies that have been published since the initial analysis.

Characterization of joint compound dust

In 2012, Berman et al. characterized the fiber dimension distributions of dusts generated from recreated dry joint compounds using commercial chrysotile fiber (JM 7RF3); these results were compared to dust generated from use of a historically manufactured dry joint compound, as well as dust generated from chrysotile fibers alone (JM 7RF3). The authors examined the effects of the sanding process on the characteristics of generated dust and found no significant differences in fiber size distributions and mean fraction of matrix-associated fibers and bundles between un-sanded vs. sanded dusts for dry joint compound products (Berman et al. Citation2012). This finding indicates that joint compound dust properties are primarily dictated by the bulk material rather than mechanical processes, with sanding primarily disaggregating the hardened matrix rather than altering fiber size.

Tremolite in joint compound

As discussed in Phelka and Finley (Citation2012), some historical joint compounds contained 0.5-10% industrial talc by weight, while many joint compounds contained no talc. Some industrial talc mines, as well as some chrysotile mines, have been reported to contain the amphibole, tremolite (Fiume et al. Citation2015). Hence, it is reasonable to expect that tremolite mineral could be present in joint compounds that contain chrysotile and/or industrial talc, and indeed some of the earlier analyses of drywall accessory products did report the presence of tremolite mineral. Specifically, Fischbein et al. (Citation1979) reported that four of 15 industrial taping and spackling compounds contained tremolite structures at concentrations ranging from 1 to 2% (Sterling Ready Mix, Sterling All-Purpose) to 8–12% (S-C-L Taping Compound) (Fischbein et al. Citation1979). Rohl et al. (Citation1975) reported that one of the 15 consumer products under evaluation (Metro spackling putty) contained 4–6% tremolite structures (Rohl Citation1975). However, neither of these studies determined whether the tremolite mineral was in the asbestiform habit. This is a critical distinction because only asbestiform tremolite is a regulated form of asbestos and non-asbestiform amphiboles (including tremolite) do not pose a risk of asbestos-related disease (Gamble and Gibbs Citation2008).

Analyses conducted since the late 1990s have consistently reported either no evidence of amphibole (non-detect) or trace levels of tremolite structures or fibers in joint compound products (Hatfield and Longo Citation1997; Longo et al. Citation2000; Hatfield et al. Citation2003; MAS Citation2003; Brorby et al. Citation2008; EMSL Analytical Inc. Citation2010). For example, bulk analyses of a Bestwall (Georgia-Pacific) joint cement performed by Materials Analytical Services, Inc. (MAS) found no evidence of any amphibole asbestos (Longo et al. Citation2000). This same group of researchers evaluated a joint cement manufactured by UGL in 1971 and reported 0.003% tremolite fibers (using Addison

Davies method) (MAS Citation2003). In additional analyses by this laboratory, there was no evidence of amphibole asbestos in a Kaiser Gypsum finishing compound (Hatfield and Longo Citation1997) and only a single possible “tremolite/actinolite” structure in a Kaiser Gypsum joint compound (Hatfield et al. Citation2003). Brorby et al. (Citation2008) utilized TEM to examine samples of a reformulated Georgia-Pacific joint cement originally manufactured in 1967 and concluded that all of the observed structures were chrysotile (Brorby et al. Citation2008). EMSL analyzed 1960s/1970s vintage joint cement from residential wall and ceiling samples and identified only chrysotile structures in both samples (EMSL Analytical Inc. Citation2010).

Airborne fiber concentrations during product use

Predictive models

Recent research has shown that contemporary studies using asbestos-free joint compound can be used to better understand historical asbestos exposures to asbestos-containing joint compound. Specifically, a derived empirical factor can be applied to respirable dust measurements collected during contemporary drywall studies to accurately estimate airborne fiber concentrations had an asbestos-containing joint compound been used instead. The application of this empirical factor has the potential to greatly expand our understanding of historical asbestos exposures during drywall work, which was previously limited by the availability of historical documents. Sheehan et al. (Citation2011) recreated a 1960s-era chrysotile-containing joint compound and measured airborne fiber concentrations during the sanding and sweeping of this product in a chamber simulation (analyzed by PCM). They performed the same simulation using an asbestos-free joint compound. They used their results to derive a median conversion factor of 0.044 f/cm^3 per mg/m^3 respirable dust for sanding tasks and 0.025 f/cm^3 per mg/m^3 respirable dust for sweeping tasks (Sheehan et al. Citation2011).

Jones et al. (Citation2011) and Brorby et al. (Citation2012) developed mathematical models to estimate respirable dust exposures from sanding modern, asbestos-free joint compound products (Jones et al. Citation2011; Brorby et al. Citation2012). Jones et al. measured personal and area respirable dust concentrations during the sanding of joint compound in an isolation chamber. They developed and validated a model used to predict TWA concentrations of respirable and total dust during sanding tasks. Brorby et al. used published dust levels measured during the handling of modern day asbestos-free joint compound to estimate fiber concentrations during handling of historical asbestos-containing joint compound. The authors concluded that the fiber concentrations estimated with the new model were not significantly different from fiber concentrations measured during the historical use of asbestos-containing joint compound, for both enclosed and non-enclosed environments (Brorby et al. Citation2012).

Boelter et al. (Citation2015) calculated cumulative asbestos exposures for the sanding tasks performed by drywallers based on previously published survey data, direct field observations from contemporary construction worksites, and a semi-empirical mathematical model (Boelter et al. Citation2015). At each worksite, the investigator recorded the dimensions of the floor and wall area, and task-specific durations (drywall installation, tape and joint compound application, sanding, and other activities), and calculated the sanding speed for the drywaller. During the observations, workers were classified as a drywall specialist, generalist, bystander tradesperson, or “do-it-yourselfer.” Task-based respirable dust measurements, collected during the Jones et al. study, were used to calculate 8-h TWA concentrations of respirable dust (mg/m^3) for sanding tasks. The empirical factor derived by Sheehan et al. (0.044 f/cm^3 per mg/m^3 respirable dust) was applied to convert the respirable dust measurement to the equivalent 8-h TWA concentration of respirable fibers (as measured by PCM). Further, Brorby et al. analyzed a subset of joint compound respirable dust samples by NIOSH Method 7402 and determined that “virtually all of the fibers were chrysotile fibers (all other fibers were non-asbestos minerals; data not shown)” (Brorby et al. Citation2012). Likely based on this finding, Boelter et al. used these studies to report chrysotile-specific exposures based on Jones et al.’s respirable dust measurements. It should be noted, however, that it does not seem that a chrysotile fiber-specific respirable dust conversion factor has been established, and Brorby et al. did not report the percentage of non-asbestos fibers detected. Boelter et al. concluded that the mean annual exposure to chrysotile fibers for the sanding tasks performed by a drywall specialist was 0.088 f/cm^3. The authors calculated that a specialist who used asbestos-containing joint compound over a 40-year career would have a cumulative chrysotile exposure of approximately 3.5 f/cm^3-year from their sanding work. The authors noted that their estimate was “an order of magnitude lower” than the value of 12–26 f/cc-year presented earlier in Phelka and Finley (Citation2012). They attributed this difference to Verma and Middleton’s assumption that a drywaller would spend 25–30% of their week performing sanding tasks, which was far greater than the value of 1–11% determined by Boelter et al. (Citation2015). It is unclear why their observations differed. It is important to note that, in addition to addressing asbestos exposure during sanding work, the Phelka and Finley (Citation2012) cumulative exposure estimate also accounted for potential exposures during mixing, application, and clean-up tasks. Further, the Phelka and Finley (Citation2012) estimate relied on PCM data, while Boelter et al. (Citation2015) reported chrysotile-specific data.

Reported airborne asbestos concentrations have likely been over-estimated

It has been suggested that air sampling results prepared by NIOSH Method P&CAM 239 during the 1970s may overstate chrysotile exposures for drywallers. Brorby et al. compared this method to the current NIOSH Method 7400 and concluded that carbonate-based joint compound reacted with historical preparation (clearing and mounting) chemicals, releasing an average of 1.7 times more fibers than would otherwise be bound in a matrix and not available for inhalation, and, therefore, artificially inflated the fiber count over what was airborne when the exposure occurred (Brorby et al. Citation2011). Similarly, Sheehan et al. (Citation2011) concluded that due to differences in the total and respirable dust conversion factors and destruction of the matrix of large particles during impaction on the cassette filter, following PCM analysis, historical cassette sampling during tasks with asbestos-containing joint compound resulted in a fiber count per unit air volume that is five times greater than if respirable dust were collected by cyclone during the same task (Sheehan et al. Citation2011). When evaluating historical exposures, it is, therefore, important to use caution when making direct comparisons between studies if the sampling instrumentation differs.

In addition, it appears that many joint compound structures counted as "fibers" with optical PCM methods were not asbestos fibers. For example, Rhodes and Ingalls collected personal and area samples during commercial construction in a residential home in the late 1970s. Asbestos-free, dry mix topping compound was applied and "steady, heavy" pole sanding was performed for four hours. Samples were analyzed using an unspecified NIOSH optical phase contrast method. Average airborne fiber concentrations were reported as 0.2 f/cc (range: 0.1–0.4 f/cc) for six personal samples and 0.2 f/cc (range: 0.0–0.4 f/cc) for three area samples (CPSC Citation1977c). In addition, Equitable Environmental Health and OSHA compliance inspectors collected personal and area samples during residential construction. In one section, non-asbestos taping compound and asbestos-containing finishing compound were applied and sanded "heav[il]y" for 30 min by a worker who utilized a pole sander and stilts. Samples were analyzed using the same method used by Rhodes and Ingalls. Airborne fiber concentrations were reported as 0.2 f/cc for one personal sample and 0.1 f/cc for two area samples. In the same building, samples were collected in an area where only asbestos-free joint compound was applied and subsequently pole sanded for 30 min. The airborne fiber concentration for the one personal and one area sample was reported as 0.1 f/cc (CPSC Citation1977c). This is consistent with the fact that the PCM method does not distinguish between asbestos fibers versus non-asbestos structures that have the dimensions of a fiber.

Bystander exposures

Donovan et al. (Citation2011) reviewed airborne asbestos concentrations at known distances from a source in various occupational environments and developed a metric for estimating bystander exposures. Included in their analysis were 14 personal samples collected during drywall finishing work (Rohl et al. Citation1975; Fischbein et al. Citation1979; Verma and Middleton Citation1980). Eight of these samples were collected 8–20 feet from the source worker and six samples were collected in an adjacent room at a distance of 15–35 feet from the source worker. The decrease in exposure at increasing distance from the source differed by task performed. Pole and hand sanding at a distance of eight feet resulted in an exposure that was 50–80% of the source worker. Airborne fiber concentrations during dry mixing was 5% of the source at a distance of 10–20 feet, and 10% of the source at a distance of 16–35 feet (Donovan et al. Citation2011).

Another consideration in estimating bystander exposures is the likelihood of other trades being present during joint compound use. Most residential and commercial construction projects follow some form of construction sequencing or the sequencing of specific activities that limit other trades being present while drywall installation and finishing take place. For example, wall studs and electrical and plumbing rough-ins are typically completed by carpenters, electricians, and plumbers, respectively, before drywall can be installed and finished using joint compound. The use of pole sanders, scaffolding, and drywall stilts further limits the likelihood that other trades would be in the area during drywall finishing and the use of joint compound.

Take-home exposures

Take-home, or para-occupational, exposures can potentially occur when a worker is exposed to a compound during the workday, wears or brings their work clothing home with them, and then this clothing is laundered by a family member. While take-home exposures to asbestos as a result of drywall work have not been evaluated in the published literature, take-home exposures to chrysotile asbestos have been evaluated generally. Sahmel et al. (Citation2014, Citation2016) published two exposure assessment studies evaluating take-home exposures associated with the handling of clothing contaminated with chrysotile asbestos. In the 2014 study, three target airborne chrysotile concentration ranges (low, medium, and high) were used during a total of six loading events on clothed mannequins to establish levels representative of a variety of workplace exposure scenarios (Sahmel et al. Citation2014). The average TEM concentrations for each loading event ranged from 0.01 to 3.30 f/cc, as measured by NIOSH Method 7402. Following the loading events, six matched 30-min clothes-handling and shake-out events were conducted, each including 15 min of active handling (15-min means; 0.014–0.097 f/cc) and 15 additional minutes of no handling (30-min means; 0.006–0.063 f/cc) (Sahmel et al. Citation2014). Sahmel et al. (Citation2014) showed that take-home airborne concentrations associated with the handling and shake-out of clothing contaminated with chrysotile from a low level occupational setting would be extremely low. Sahmel et al. (Citation2016)'s follow-up study was designed to investigate a much more intense occupational exposure scenario than the 2014 study, and reported an average PCME airborne concentration for the two loading events of 11.4 f/cc (Sahmel et al. Citation2016). The average 15 min PCME concentration during active clothes handling and shake-out was 2.9 f/cc. The results of both studies confirmed that weekly TWA exposures from laundering activities would be a small fraction (approximately 1% or less) compared to worker exposures (Sahmel et al. Citation2014, Citation2016).

Product reformulation

Several joint compound manufacturers began experimenting with asbestos-free joint compound formulas in the early to mid-1970s. Reformulation efforts were driven by public attention on asbestos and forthcoming government regulations (CPSC Citation1977b).

A significant challenge to formulation of asbestos-free joint compounds was finding a substitute ingredient or mixture of substitutes that provided the same flocculating properties as asbestos (CPSC Citation1977b). Initial substitute materials included atapolgite, calcium carbonate, mica, and other fiber-like materials (Rhodes and Ingalls Citation1975b; CPSC Citation1977b). These raw replacement materials were reportedly more expensive than asbestos ingredients (CPSC Citation1977b). Additional cellulosic thickeners were also added to improve the viscosity. However, the new formulations were difficult to stabilize, resulting in a product that was workable when manufactured at the plant but too thick or too fluid at the jobsite, particularly in regions where materials were stored outdoors and could potentially freeze (Rhodes and Ingalls Citation1975b). These products were initially heavy to use and difficult to re-work by trowel (CPSC Citation1977b). Further, while asbestos typically was free of silica, it was challenging to source cost-effective clay substitute materials with low silica content (Rhodes and Ingalls Citation1975b).

Asbestos substitutes were eventually found for many joint compound systems starting in the early 1970s, and asbestos-free joint compounds were widely available from multiple manufacturers by 1977 (CPSC Citation1977b). Specifically, US Gypsum offered asbestos-free joint compounds starting “a few years prior” to 1977 and Bondex first sold asbestos-free formulations in August 1976 and discontinued the manufacture of their asbestos-containing lines in April 1977 (CPSC Citation1977b). It was suggested at the time that professional customers chose to purchase asbestos-containing products even as asbestos-free products were brought to market since the asbestos-containing products were easier to use. It was also noted that inventories of asbestos-containing joint compounds were depleted and replaced with asbestos-free products within 30–90 days of initial production (CPSC Citation1977c). Some of these new products were labeled on their packaging as asbestos-free (CPSC Citation1977b).

Career drywaller cumulative chrysotile exposure calculation

Joint compound

We utilized exposure and task duration values reported in Verma and Middleton (Citation1980) and Boelter et al. (Citation2015), and job tenure data from Carey (Citation1988) and Maguire (1993) to estimate upper and lower bound cumulative asbestos exposures for career drywallers (Verma and Middleton Citation1980; Carey Citation1988; Maguire Citation1993; Boelter et al. Citation2015). The lower bound estimate is intended to apply to drywallers who performed wallboard cutting and hanging tasks and joint compound work, while the upper bound estimate applies to workers who only performed joint compound finishing work.

Airborne asbestos concentration

Verma and Middleton (Citation1980) provide the most representative measurements of historical airborne fiber concentrations during drywall activities (Verma and Middleton Citation1980). In January 1978, they performed "a realistic and comprehensive assessment of typical exposure" experienced by drywallers during the construction of a multi-story hotel in Edmonton, Canada. Samples were collected during mixing, application, sanding, and sweeping tasks. Separate sampling was performed during the mixing of dry and pre-mixed products, and during pole sanding and hand sanding tasks. Samples were analyzed by an unspecified "NIOSH reference Membrane filter method," which we have assumed was an optical microscopy method equivalent to PCM analysis.

and summarize the lower and upper bound airborne fiber values for the mixing, application, and cleaning tasks as reported in Verma and Middleton. We included pre-mix mixing and pole sanding in the lower bound scenario and dry mixing and hand sanding in the upper bound scenario. We also relied on Verma and Middleton to represent the upper bound airborne fiber measurement of 11.5 f/cc for sanding, but instead relied on the recent work of Boelter et al. as a likely realistic sanding value for our lower estimate scenario. As noted earlier, Boelter et al. specifically estimated airborne asbestos levels during sanding tasks using recently published predictive models. Boelter et al. reported a mean 8-h TWA of 0.28 chrysotile f/cc for drywallers performing sanding work, based on a median sanding event duration of 90 min. To determine a maximum potential exposure concentration, we conservatively assumed that drywallers were exposed to 0 f/cc during the remaining 390 min, resulting in a 90-min sanding task-based value of 1.5 f/cc.

Table 1. Lower bound task duration and exposure concentration parameters used in cumulative exposure calculation.

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Table 2. Upper bound task duration and exposure concentration parameters used in cumulative exposure calculation.

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Task duration

Verma and Middleton (Citation1980) reported task durations (hours per 40-h work week) for mixing, application, sanding, and clean-up based on observations they made at worksites between 1975 and 1977. They noted that mixing took 5–10 min per batch to complete and that 1–3 batches were needed per day. Application was likely performed a maximum of three times per 40-h work week. Therefore, as a lower bound, mixing could take 15 min (0.25 h) to complete per 40-h work week (5 min/batch × 1 batch/day × 3 days/week = 15 min/week). As an upper bound, Verma and Middleton also suggest that a typical drywall worker would spend two hours per week mixing; however, it is unclear whether this refers to the use of pre-mixed or dry joint compound products. It was further reported by Verma and Middleton that application, sanding, and clean-up took 27 h, 10 h, and 1 h to complete per 40-h week, respectively.

Boelter et al. estimated task durations for joint compound application and sanding based on observations at four sites where work was conducted in 2008 and 2009. On average, 28% of the time was spent applying tape and joint compound, while 6.8% of time was spent on sanding tasks (Boelter et al. Citation2015). Assuming a 40-h work week, this equates to 11.2 h for joint compound application tasks and 2.7 h for sanding tasks. As can be seen in and , the upper bound exposure estimate assumes joint compound use throughout a 40 h work week, while the lower bound estimate assumes joint compound work for 15.15 h per week (the remaining 24.85 h being spent on drywall cutting and hanging, per Boelter et al.).

Tenure

Phelka and Finley (Citation2012) used a median job tenure of 5.7 years, as reported by Carey (Citation1988), to estimate cumulative chrysotile exposures for career “drywall installers” (Carey Citation1988). According to a more recent 1993 report by Maguire using the Current Population Survey data from the Bureau of Labor Statistics, the median occupation tenure of a “drywall installer” in 1991 was 8.1 years (Maguire Citation1993). The reason for this discrepancy is unclear. We used the Carey and Maguire job tenure values to estimate the lower and upper bound cumulative exposures, respectively.

Cumulative asbestos exposure from joint compound work

Based on the inputs reported in and , the 40-h TWA concentration for a drywaller is estimated to range from 0.76 to 4.48 f/cc. Based on the median job tenures reported by Carey and Maguire, the lower-bound estimate for cumulative asbestos exposure was 4.3 f/cc-year and the upper-bound estimate was 36.3 f/cc-year. Using the same assumptions as Phelka and Finley (Citation2012) regarding non-occupational drywall work (3 days every 10 years, over a 60 year time period), this equates to a non-occupational cumulative exposure of 0.04–0.22 f/cc-year. A bystander who spent 10% of their time in each five-foot incremental distance from the source, up to a 50-foot total distance (in accordance with Donovan et al. Citation2011), could have a cumulative exposure of 0.55–4.68 f/cc-year (12.9% of the source exposure). A family member who laundered the drywaller’s clothing could have a cumulative exposure of 0.043–0.36 f/cc-year (1% of the source exposure) or less.

Texture compound

As noted previously, Verma and Middleton (Citation1981) conducted air monitoring at eight operations where texture compound was in use and estimated that a typical residential texture worker’s 40-h TWA was 4.2 f/cc (Verma and Middleton Citation1981). The job median tenure estimates reported by Carey and Maguire were used to estimate the expected cumulative fiber exposure for a texture worker. The lower-bound estimate was 23.9 f/cc-year and the upper-bound estimate was 34.0 f/cc-year ().

Table 3. Cumulative exposure estimate range for texture work.

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NOAELs for chrysotile asbestos

Studies conducted by Pierce et al. (2008) and (2016) evaluated the exposure–response relationships for lung cancer and mesothelioma in predominately chrysotile-exposed cohorts for the purpose of identifying NOAELs, or chrysotile exposure levels at which no statistically significant increased incidences of lung cancer or mesothelioma are observed. Pierce et al. (Citation2008) concluded that “low occupational exposures to chrysotile…are unlikely to cause mesothelioma” (Pierce et al. Citation2008). Similarly, Pierce et al. (Citation2016) found that “In a majority of the studies, there was no increased risk of lung cancer and/or mesothelioma at any cumulative exposure, including chrysotile exposures in the hundreds to thousands of f/cc-years” (Pierce et al. Citation2016).

In the Phelka and Finley (Citation2012) review, estimated lifetime cumulative chrysotile exposures for drywalling activities were compared to the chrysotile NOAELs reported by Pierce et al. (Citation2008). These NOAELs have since been revised to include updated published risk estimates for two of the previously included cohorts, as well as studies of three additional chrysotile-exposed cohorts. The authors concluded that their “best estimate” NOAELs ranged from 89 to 168 f/cc-years for lung cancer and 208 to 415 f/cc-years for mesothelioma (Pierce et al. Citation2016). Even the upper-bound calculated cumulative exposure estimates for joint compound and texture work were several-fold below the estimated NOAELs for chrysotile exposure and lung cancer or mesothelioma. We conclude it is, therefore, unlikely that a drywaller would be at an increased risk of developing lung cancer or mesothelioma due to chrysotile under the described exposure scenarios.

Career drywaller cumulative tremolite exposure calculation

We estimated a drywaller's potential lifetime cumulative exposure to tremolite, which has been detected in some chrysotile and talc deposits, by multiplying the percentage of tremolite in joint compound by the upper bound TWA exposure for a drywaller. Joint compounds only would have contained chrysotile asbestos prior to 1978. It is important to emphasize that, while the tremolite mineral has been identified in some joint compounds, asbestiform tremolite has not.

Chrysotile

Some historical joint compound products contained 3–15% chrysotile. As noted in Phelka and Finley (Citation2012), a maximum concentration of 1% tremolite has been reported in some raw and processed chrysotile. With a formula of 3–15% chrysotile that contained 1% tremolite, the joint compound would contain a maximum of 0.03–0.15% tremolite (3–15% chrysotile × 1% tremolite).

Talc

As previously noted, some historical joint compound products contained 0.5–10% talc. Additionally, some talcs contained approximately 1–5% tremolite (Pfizer Citation1977a, Citation1977b). Under a worst case scenario with 10% industrial talc that was composed of 5% tremolite, joint compound would contain a maximum of 0.5% tremolite (10% talc × 5% tremolite).

Total tremolite

The concentration of tremolite present in joint compound could, therefore, be 0.53–0.65% (0.03–0.15% tremolite from chrysotile + 0.5% tremolite from talc). If this batch of joint compound also contained 3–15% chrysotile (upper bound of what has been historically reported), the total fraction of asbestos in the product would range from 3.53% (3% chrysotile + 0.03% tremolite from chrysotile + 0.5% tremolite from talc) to 15.65% (15% chrysotile + 0.15% tremolite from chrysotile + 0.5% tremolite from talc).

Therefore, the fraction of total asbestos mineral in joint compound that was specifically from tremolite would range from 0.042 (0.65% tremolite/15.65% total asbestos) to 0.15 (0.53% tremolite/3.53% total asbestos). If we applied this tremolite-specific fraction to the upper bound 40 h-TWA exposure of 4.48 f/cc, with a median drywaller tenure of 8.1 years, as discussed above, the resulting cumulative exposure to tremolite for drywallers would range from 1.5 f/cc-year (0.042 × 4.48 f/cc × 8.1 years) to 5.45 f/cc-year (0.15 × 4.48 f/cc × 8.1 years). Regarding talc, the presence of asbestiform tremolite has not been reported in analyses with a limit of detection of 0.1% by weight. It is, therefore, reasonable to conclude that the asbestiform tremolite content of joint compound is closer to 0.015–0.054 f/cc-year, if any asbestiform tremolite is present at all. This assumes that the fraction of total asbestos mineral from asbestiform tremolite could range from 0.00042 to 0.0015.

NOAELs for asbestiform tremolite

Finley et al. (Citation2012) reported that the NOAEL for mesothelioma is between 0.5 and 2.6 f/cc-year for asbestiform tremolite (Finley et al. Citation2012). In addition, Garabrant and Pastula (Citation2018) proposed a relative mesotheliogenic potency in the ratio of 1:23 for chrysotile and Libby Amphibole mineral (Garabrant and Pastula Citation2018). Libby Amphibole is an ore found near Libby, Montana, that historically contained winchite, richterite, and 6% tremolite (Meeker et al. Citation2003). Applying these factors to the chrysotile mesothelioma NOAEL range of 208–415 f/cc-year reported in Pierce et al. (Citation2016) results in an estimated tremolite mesothelioma NOAEL range of 0.5–1.1 f/cc-year [(208 f/cc)/23 × 6% to (415 f/cc)/23 × 6%]. This range is consistent with the range reported in Finley et al. (Citation2012). Therefore, even under a worst case scenario where it was assumed that the chrysotile and talc used in joint compound did contain asbestiform tremolite, the resulting cumulative exposure from the use of this joint compound (0.015–0.054 f/cc-year) would be well below the tremolite NOAEL, and given any reasonable exposure scenario, too low to increase the risk of mesothelioma among drywallers.

Early health concerns, case reports, and epidemiology

Early research on drywallers was published in popular news articles, drawing attention to the potential for asbestos exposure from drywall work. The New York Times reported in 1973 that Dr Selikoff had recently discovered asbestos in the lung of a drywall taper and planned to survey members of a painters' union (Sherrill Citation1973). OSHA reported in a June 1974 news brief that chrysotile asbestos exposures during joint compound sanding could be “as much as” 13.7 f/cc, and that Dr Selikoff had detected fibrosis through X-ray in nine of 17 union workers (OSHA (Occupational Safety and Health Administration) Citation1974). No further follow-up was reported.

As reported below, several recent studies have described cohorts potentially exposed to asbestos-containing joint compound, in addition to other sources of asbestos.

Stern et al. (Citation2001) performed a mortality study of unionized construction plasterers and cement masons using union records. The authors concluded that plasterers were at an increased risk of developing asbestosis (PMR 1657; $p < 0.01$). In contrast with drywallers, approximately 10% of plasterers’ duties involved insulation work, including the preparation, installation, and repair of interior and exterior insulation systems and the fireproofing of steel beams and columns (Stern et al. Citation2001). Therefore, this trade is not an appropriate surrogate for drywallers when evaluating potential asbestos exposure and asbestosis risk.

Olsen et al. (Citation2011) reported an increased risk of mesothelioma following exposure to asbestos during home renovation in Western Australia using data collected through the Western Australia Mesothelioma Register. The authors concluded that the incidence of malignant mesothelioma among those involved in home maintenance and renovation increased over the study period (1960–2008), with a concurrent rise in the proportion of mesotheliomas attributable to such residential exposure (versus occupational exposure) (Olsen et al. Citation2011). The authors noted that the reported increase in age-adjusted incidence rates among home renovators from 1995 to 2008 may be attributable to changes in diagnostic techniques used for data collection in the registry (WACR (Western Australian Cancer Registry) Citation2005). Joint compound and other drywall accessory products (e.g. textured paint, etc.) were not mentioned in this paper. Instead, the authors make specific references to activities with cement-containing products, such as sanding asbestos cement walls, replacing tiles that contained asbestos cement, and using asbestos cement sheeting to put up fences or sheds, extend laundries, and enclose verandas. As noted by the authors, the cement products used in construction often contained crocidolite asbestos that was sourced from nearby mines (Olsen et al. Citation2011). Given the common usage of crocidolite asbestos-containing products in Australian residential construction (Leigh et al. Citation1997), if the increase in mesothelioma among home renovators is truly asbestos-related, it is likely due to work with crocidolite-containing cement construction products. As discussed in detail in the Phelka and Finley (Citation2012) paper, potency varies widely by fiber type, with crocidolite being the most potent commercial amphibole fiber (Hodgson and Darnton Citation2000; Berman and Crump Citation2008). There is no evidence to suggest that crocidolite was ever present in joint compound products.

Dahlgren and Peckham (Citation2012) described three cases of mesothelioma in which “[t]he only known asbestos exposure was to joint compound” (Dahlgren and Peckham Citation2012). As described in the paper, these cases were litigated by plaintiff lawyers who hired Dahlgren and Peckham (Citation2012) and provided them with case information; it is unclear whether this information was in the form of plaintiff testimony, interrogatories, medical records, plaintiff interviews, or some other source. In the absence of a full description of the occupational and non-occupational histories of these cases, it is difficult to determine whether and to what degree other asbestos exposures may have occurred and as the authors noted, other asbestos exposures “cannot be excluded for any of the cases.”

In 1984, in collaboration with the National Center for Health Statistics, the National Cancer Institute, the US Census, and state health departments, NIOSH developed the National Occupational Mortality Surveillance (NOMS) database, which reports the results of surveyed associations of cause-specific mortality and occupation and/or industry among the 30 states that participate in the program (Robinson et al. Citation1995; NIOSH Citation2018a, Citation2018b). The NOMS database initially included data for 9,964,280 US workers who died between 1985 and 1998. Deaths attributable to mesothelioma and/or asbestosis were documented among plumbers, pipefitters, steam fitters, electricians, and carpenters. Recently, mortality information for approximately 5 million additional workers whose death occurred in one of 24 US states in 1999, 2003–2004, or 2007–2013 were added to the NOMS database (NIOSH Citation2018b). Occupational PMRs are not estimated in the NOMS database until at least five deaths are reported; it was not until 2016 that greater than five deaths attributable to mesothelioma were reported among “drywall installers”.

As of 2019, NOMS reported 16 mesothelioma deaths among “drywall installers,” with a statistically significantly elevated PMR of 415 (95% CI: 237–674). Additionally, 364 trachea, bronchus, and lung cancer deaths were recorded among “drywall installers,” with a statistically significantly elevated PMR of 128 (95% CI: 115–142).

Because NOMS is a mortality database that relies on death certificate information for occupation status, little or no information is available regarding the decedent’s prior occupational history. Death certificates typically report most recent occupation (i.e. the one the decedent held last) or usual occupation (also likely to reflect recent jobs) and not jobs held 30–60 years prior. Further, it is not possible to determine the tasks that the specific worker performed or the exact products that they worked with. As stated in the NOMS database itself, the PMRs “should be interpreted with caution” and “[a] statistically significantly elevated PMR cannot be interpreted directly as indicating a causal relationship between the industry or occupation and the cause of death” (NIOSH Citation2018b).

It is worth noting that many occupations with no known asbestos exposures also have statistically significant elevated mesothelioma PMRs reported in the NOMS database (e.g. “top executives,” “management, business, finance, professional,” “architects,” “detectives, criminal investigators, police and sheriff’s patrol officers,” and others). In addition, the ICD code associated with “mesothelioma” (i.e. ICD-10-CM Diagnosis Code C45) utilized by the NOMS database captures both cases of benign (non-cancerous) and malignant (cancerous) tumors affecting the peritoneum, pleura, and pericardium; therefore it is not possible to determine how many of the 16 reported deaths from mesothelioma among “drywall installers” were due to malignant pleural mesothelioma. In contrast, when evaluating pleural malignancies, fewer than five cases have been reported among “drywall installers”. We suggest that at least some of the “drywall installer” mesotheliomas (as well as the mesotheliomas for the aforementioned occupations with no known asbestos exposures but highly elevated PMRs) were due to prior high risk occupations (e.g. insulation installation). It is also important to consider that mesothelioma occurs spontaneously (in the absence of asbestos exposure or any other known risk factor) at a consistent rate in the general population and the incidence rate increases exponentially with age (Glynn et al. Citation2017; Teta et al. Citation2008). Given the fact that a specific number of asbestosis deaths were not reported for “drywall installers” (<5 deaths are suppressed in the NOMS database), we believe that at least some of the “drywall installer” mesotheliomas in this database may not have been asbestos-related. Further, the lack of adjustment for smoking history introduces bias to the reported PMRs for “trachea, bronchus, and lung cancer” due to confounding.

Discussion

Between the mid-1940s and 1977, chrysotile asbestos was often added to joint compound products at levels ranging from 3 to 15%. The use of chrysotile as a joint compound ingredient was banned in 1977 by the Consumer Product Safety Commission (CPSC) (CPSC Citation1977a). The precautionary ban was not based on any epidemiological findings of increased risk for drywallers (no such studies existed at the time), but was instead based on a hypothetical analysis using heavy amphibole exposures that suggested a significant health risk was associated with the use of asbestos-containing joint compound. In contrast, as noted previously, joint compound did not contain amphibole asbestos ingredients.

To date, there are still no published epidemiology studies of asbestos-related risks among drywaller cohorts. We, therefore, employed a standard health risk assessment methodology to quantify the potential asbestos-related risks associated with use of historical joint compound products. We relied on current and historical information (none of which was available at the time of the CPSC assessment) regarding airborne asbestos exposures associated with joint compound use pre-1977. We estimated that a career drywaller's cumulative chrysotile exposure from work with joint compound could range from 4.3 to 36.3 f/cc-year. The lower end of this estimate applies best to a drywaller who performed a variety of tasks, including cutting and hanging wallboard. The upper end applies best to a drywall finisher who performed predominantly sanding work. This range is consistent with the 12–16 f/cc-year exposure range previously estimated by Phelka and Finley, and is far below the chrysotile NOAEL values for mesothelioma and lung cancer (208–415 f/cc-year and 89–168 f/cc-year, respectively) recently published by Pierce et al. The change in cumulative exposure for our updated estimate is driven by the use of sanding exposure and task duration data reported by Boelter et al. While Boelter et al.'s findings rely on a modeled distribution of potential exposures that includes inferences made based on observations of non-asbestos joint compound, the underlying data were based on surveys and direct field observations.

Our updated estimate suggests that, even under extreme usage scenarios, work with joint compound would not increase a worker's risk of developing lung cancer or mesothelioma. Joint compound sold in the US potentially contained asbestos between the mid-1940s and 1978. It is, therefore, possible that someone used asbestos-containing joint compound for a maximum of approximately 33 years. Under the exposure conditions described above, and assuming 33 years of usage, the maximum potential cumulative asbestos exposure from this work could be 24.9–147.8 f/cc-year. As noted previously, this is likely an overestimate because the Verma and Middleton (Citation1980) exposure data include all fibers and were not asbestos-specific findings. These exposures are below or within the exposures at which no lung cancer or mesothelioma have been observed (Pierce et al. Citation2016). These conclusions are similar for individuals who performed exclusively texture work or a combination of texture and drywall finishing tasks.

Estimated tremolite exposures, which could occur as a result of trace levels in chrysotile or talc (or both), were also far below the published asbestiform tremolite NOAEL values for mesothelioma (0.5–2.6 f/cc-year). We conclude that the evidence indicates that potential exposure to asbestiform tremolite as a result of occupational use of joint compound did not increase the risk of developing mesothelioma or lung cancer. By extension, potential asbestos exposures associated with bystander trades (e.g. painters and electricians) and non-occupational exposures to joint compound (e.g. home renovators) would have been below the NOAEL as well.

The chrysotile NOAEL benchmarks

It is important to note that the chrysotile mesothelioma and lung cancer NOAELs used in this analysis to benchmark the estimated drywaller chrysotile exposures are based largely on dose-response information obtained from cohorts exposed to relatively long fiber chrysotile. Specifically, of the asbestos cohorts considered in the Pierce et al. (Citation2016) NOAEL analysis, increased risk of disease was not observed in any of the six cohorts of cement or friction product manufacturing workers at any exposure level, yet each of the five studies of textile workers reported an increased risk at one or more exposure level. This is likely because friction and cement workers were exposed to much shorter chrysotile fibers. Cement and friction manufacturing industries primarily used medium- and short-length chrysotile fibers, respectively (cements: grades 4–7, friction products: grade 7) as a filler or binding material (Cossette and Delvaux Citation1979; Mann Citation1983), while the textile industries required the use of much longer fibers (grades 1–3) that could be spun and woven into products, such as insulating blankets (Mann Citation1983; Pigg Citation1994). To the best of our knowledge, there is no evidence indicating that historical users of short fiber chrysotile products are at increased risk of developing mesothelioma or lung cancer (Pierce et al. Citation2016). This observation is consistent with conclusions reached by two separate expert panels that evaluated disease risk as a function of asbestos fiber length: both panels concluded that fibers shorter than 10–20 μm were unlikely to pose a significant risk of cancer (Berman and Crump Citation2003; ERG Citation2003). Grade 7 chrysotile was the most common form of chrysotile used in joint compound formulations and the majority of the fiber lengths in this grade was less than 5 μm (Brorby et al. Citation2008). Rohl et al. reported that fiber lengths in 25 different drywall accessory products did not exceed 8 μm and that most fibers were less than 5 μm long (Rohl et al. Citation1975). Hence, use of the Pierce et al. (Citation2016) NOAEL values to benchmark drywaller exposures to short fiber chrysotile is a highly conservative comparison.

Anthophyllite

The amphibole anthophyllite was reportedly measured in one study of drywall accessory products (Rohl et al. Citation1975); the anthophyllite mineral was presumably present as a trace contaminant of industrial talc. It is unclear whether this analysis actually identified asbestiform anthophyllite because the methods used did not permit distinction between asbestiform and non-asbestiform structures. To our knowledge, there are no published mesothelioma or lung cancer NOAEL values for asbestiform anthophyllite. However, numerous animal studies involving intrapleural injections of various asbestos fiber types have found that anthophyllite exhibited a lower potency for inducing mesothelioma than other amphiboles, and, in some studies, lower than even chrysotile (Wagner et al. Citation1973;

Smith and Hubert Citation1974; Wagner et al. Citation1974; Wagner Citation1976; Pylev Citation1980). Hence, even if trace levels of asbestiform anthophyllite amphibole were truly present in some joint compound products, it is unlikely that these fibers pose a risk of asbestos-related disease.

Summary of epidemiology

Over the past 40 years (since the CPSC asbestos ban), only a few case reports of mesothelioma in drywallers have appeared in the published scientific literature, and as the authors noted, even these cases cannot necessarily be ascribed to joint compound use (Dahlgren and Peckham Citation2012). These findings are consistent with the aforementioned conclusions regarding fiber length and the fiber-specific comparisons of estimated exposures vs. NOAELs. Similarly, the 16 cases of mesothelioma reported in the NOMS database could have been a result of misclassification or prior occupational exposures to amphibole asbestos or not asbestos-related, due to the paucity of background information on each case. As discussed in the Phelka and Finley (Citation2012) paper, given that over a total of one million individuals were employed as drywallers between the mid-1940s and the late 1970s, it seems reasonable to expect that, if a significant increase in asbestos-related diseases in this occupation had truly occurred, it would have been observed. At the very least, it is clear that the alarming magnitude of disease risk predicted by the CPSC and others was overstated. For example, the CPSC predicted that several hundred thousand drywall accessory product-related respiratory cancer deaths would occur between 1980 and 2010 (due to pre-1977 exposures), while Fischbein et al. (Citation1979) suggested that asbestosis incidence in drywall workers would be similar to that observed in insulators (Bayard Citation1977; Fischbein et al. Citation1979). Neither of these predictions is supported by the available epidemiologic evidence, and this may be because these products were made of chrysotile and, as estimated in this paper, any cumulative exposure associated with this work would be relatively low.

Uncertainties

While the Phelka and Finley (Citation2012) analysis relied solely on a mean job tenure of 5.7 years from a 1987 survey, in the current paper, we also utilized a mean job tenure of 8.1 years from a 1991 survey. We were unable to determine why the mean tenure job durations differ by almost three years. It is also unclear why drywallers had such short careers, although it is suspected that this is because the work was physically taxing. Further, the job tenure data are from surveys conducted post-1977, well after asbestos was no longer added to joint compound. This may introduce some degree of uncertainty into our exposure estimates.

As is common with any historical asbestos exposure reconstruction, much of the airborne fiber concentration data was reported using methods (e.g. PCM) that are not specific to asbestos. These methods are known to over-represent the true asbestos fiber concentrations, particularly for joint compound. For example, given Rhodes' findings of detectable f/cc measurements when working with asbestos-free joint compound, it is a near certainty that some of the fibers counted by Verma and Middleton were not chrysotile asbestos fibers. In our analysis, we assumed that all reported fiber measurements were asbestos fibers, which would tend to bias our exposure estimates to higher values.

There are still no cohort or case–control epidemiology studies that can be evaluated to definitively determine whether drywall work with asbestos-containing joint compound is associated with an increased risk of asbestos-related disease. The elevated mesothelioma PMR for drywallers in the NOMS database is not sufficient evidence to conclude a causal relationship. In short, the lack of a series of epidemiology studies is a source of uncertainty. We believe that the risk assessment methodology used in this analysis (development of occupational exposure estimates that are benchmarked against fiber-specific NOAELs) represents the optimal use of the existing data.

Conclusions

Using conservative assumptions regarding airborne asbestos levels during different drywalling tasks, task duration, and job tenure, we found that a range of 4.3–36.3 f/cc-year is a plausible estimate of a career drywaller's cumulative chrysotile exposure from historical joint compound use. These estimated exposures were well below a recently published chrysotile NOAEL of 89–168 f/cc-year for lung cancer and 208–415 f/cc-year for mesothelioma. We also determined that, if the chrysotile or talc ingredients in the drywall products had contained asbestiform tremolite, the cumulative tremolite exposures would have been well below a recently published tremolite NOAEL of 0.5–2.6 f/cc-year. As only total fiber (PCM) air data are available for the mixing, application, and clean-up tasks commonly associated with joint compound use, we would expect that actual asbestos fiber exposures would be lower than the values presented in this analysis. We did not find an elevated epidemiological risk for drywallers, likely due to the fact that this trade had low exposures to chrysotile asbestos.

Declaration of interest

All of the authors are employed by Cardno ChemRisk, a consulting firm that provides scientific advice to the government, corporations, law firms, and various scientific/professional organizations. Cardno ChemRisk has been engaged by numerous companies involved in asbestos litigation, and three of the authors (N. J., B. F., and S. G.) have served as experts in asbestos litigation. However, the time invested by the authors to prepare this analysis was provided by their employer, and no external funding was received for this study. Furthermore, the work product, including the conclusions drawn, is exclusively those of the authors, and has not been influenced by anyone other than the authors. Aside from the authors, no one, including clients of Cardno ChemRisk, has reviewed, commented on, or revised this paper prior to its submission.

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