ChemRisk®

COPY

December 28, 2010

Dolores Nunez Studier
Ford Motor Company
One American Road
Suite 410-A2
Dearborn, MI 48126

Re: Ford Billing Rates - Proposal from ChemRisk for 2011

Dear Dolores:

When we met in July in your office in Detroit, and again when I met with Craig and others in September, I asked if we could revisit our billing arrangements. You indicated in July and Craig indicated in the September meeting that we should set up a time to meet before the end of the year to address this matter.

Alas, we began to try to get on your calendar beginning in mid-November and have been told that you were not available until mid-January. This was unfortunate as I had hoped to begin the rate change effective Jan. 1, 2011, which would be plausible if we can reach agreement before we send our January invoices (usually issued by us around Feb. 12). Hopefully, Pam Chapman or I will have secured a time on your calendar this week.

As you are well aware, ChemRisk has had a long standing relationship with Ford. I have expressed to you on numerous occasions that we are hugely appreciative of your support. Based on what you have indicated to me, you have been generally pleased with our performance on behalf of Ford. Over the past 8 or more years, Brent Finley and I have worked closely with Darrell, John and others to understand and further the science of asbestos while providing sound technical expertise both in and out of the courtroom.

<u>Our Problem</u>

As you are aware, our history goes back to 2002 when I was originally approached by Darrell. As we discussed in July and then later in September with Craig, we are currently working under the 2004 billing rate structure for Ford. While the auto industry was in financial turmoil, it made sense for us to accommodate the needs of each firm to control costs.

As I went over with Craig, in some detail, the internal problems generated for our firm have been difficult, but some nuances have now moved to the near ridiculous. I know Jill is aware of some of the issues.

Not only are our billing rates nearly 7 years "out of date", our approved Ford rates are not consistent with current job titles for our employees. For example, in 2004, Meg McKinley had a Senior Associate Health Scientist title and a $145 hourly bill rate. As of January 1st, she is a Senior Health Scientist with an hourly bill rate of $220, yet she is "locked" at the 2004, $145 bill rate on all Ford cases. She, like many other early to mid career scientists have seen a 50% pay raise during that time period so, our profit margin on her work for you is virtually zero. This is true for many staff who have been working on your projects.

For those persons who do work on Ford cases and who are locked into the 2004 rates, our multiple (base salary and bonus vs. their hourly Ford billing rate) does not equal 2.1. The U.S. government contracts "start" at multiples of 2.8 because they assume it is not possible to stay in business below this level in the professional services industry.

Personally, I am wildly happy with the fantastic turn around in Ford's profitability, its stock price, and the quality of its products. It is a tribute to American ingenuity and discipline. The recent article in the Economist must make everyone at Ford very happy. I am asking that since we have done our share in helping you control costs for the past 7 years that you can help us out. In spite of what outside counsel has been telling us for the past 4 years, that is, "every expert's rates have been frozen," that is not the case. In fact, nearly all of your smaller shop or individual providers have enjoyed annual pay increases if they asked for them. I recognize that our total invoices far exceed theirs but for good reason.

Beyond the obvious problems of a 7 year freeze, there are other vagaries of your billing system that simply appear to be illogical and have nothing to do with controlling costs. For example, a number of our full time BS, MS and PhD consultants are "locked in" at the rates we billed them as summer interns. For example, we have a couple employees who bill you at $75/hr (a rate from when they were still in school) and every other client at $130/hr.

And there are other bureaucratic problems which is making it difficult for us to serve you. Specifically, we are unable to get many new timekeepers approved. This significantly hampers our ability to handle the current case load, and it is impacting our ability to accept last minute "emergency" requests from local counsel. These requests have become more frequent and I assume this, too, is to control costs. Craig agreed that we should not be having this problem, but it has been the case for more than 12 months.

At my request, our accounting department did a rough estimate comparing our Ford revenue loss using outdated and inaccurate rates. We can document that in 2009, we had a $600,000 "shortfall" based on using 2004 versus 2009 rates. In 2010, the shortfall was approximately $525,000 (based on using 2004 versus 2010 rates). This was in large measure because we had to assign our most junior staff to many of your cases in order to be financially viable.

Historically, as you know, beyond the "old rate" shortfalls, the time to payment has been the worst of our more than 200 clients. Although the transition to the Collaborati e-billing system has significantly improved payments, prior to this transition, we payed the bank about $100,000 annually in interest to cover the difference between when we had to pay our employees vs. when we received payment from Ford.

<u>Some case studies regarding most persons who are assigned to Ford projects</u>

To illustrate some of the problems we are having with your account, I have selected a few consultants as examples. These persons are key members of the team who know the science of asbestos and brake wear debris, who therefore operate with considerable efficiency, who can serve well your talented (and not inexpensive) outside counsel, and for those reasons, who like them to perform the majority of the Ford work.

As you will see, the salary increases alone (not to mention the increasing overhead and health care benefit costs) are creating billing structures that are no longer profitable for us.

- Name: Pam Chapman, MPH
  Current Friction bill rate: $180.00 per/hr
  Current Friction title: Managing Health Scientist

  Actual 2011 bill rate: $255.00 per/hr
  Actual 2011 title: Managing Health Scientist

  Difference in bill rates $75.00 per/hr or a 42% discount / loss
  Consultant's percentage increase in salary (only) since 2004 of 49%.
  Consultant's percent increase in total compensation since 2004 was 70%.

- Name: Brent Finley, PhD
  Current Friction bill rate: $375.00 per/hr
  Current Friction title: Managing Principal

  Actual 2011 bill rate: $475.00 per/hr
  Actual 2011 title: Principal Health Scientist and VP

  Difference in bill rates $100.00 per/hr or a 27% discount / loss
  Consultant's percentage increase in salary (only) since 2004 of 100%.
  Consultant's percent increase in total compensation since 2004 was 200%.

  <u>Note</u>: This is currently what it takes to retain a super senior and well respected consultant within a firm like Exponent or ChemRisk since they could easily work out of their house and make more money if we were not able to compensate aggressively when they become relatively famous testifying witnesses. I am certain Brent is "far less" expensive to Ford working within our firm than if he

were to be an independent consultant like a Pat Hessel, Roy Balzer, Mort Corn, or David Garabrant.

- Name: Meg McKinley, MPH
  Current Friction bill rate: $145.00 per/hr
  Current Friction title: Associate Health Scientist

  Actual 2011 bill rate: $220.00 per/hr
  Actual 2011 title: Senior Health Scientist

  Difference in bill rates $75.00 per/hr or a 52% discount / loss
  Consultant's percentage increase in salary (only) since 2005 of 35%.
  Consultant's percent increase in total compensation since 2005 was 50%.

- Name: Dennis Paustenbach, PhD, DABT, CIH
  Current Friction bill rate: $425.00 per/hr
  Current Friction title: Chief Principal

  Actual 2011 bill rate: $575.00 per/hr
  Actual 2011 title: President and Founder

  Difference in bill rates $150.00 per/hr or a 35% discount / loss

- Name: Amanda Phelka, PhD
  Current Friction bill rate: $155.00 per/hr
  Current Friction title: Senior Health Scientist

  Actual 2011 bill rate: $220.00 per/hr
  Actual 2011 title: Senior Health Scientist

  Difference in bill rates $65.00 per/hr or a 42% discount / loss
  Consultant's percentage increase in salary (only) since 2004 of 27%.
  Consultant's percent increase in total compensation since 2005 was 45%.

- Name: Sam Serrano, BS
  Current Friction bill rate $75.00 per/hr (Intern rate from 3 years ago)
  Current Friction title: Research Associate II

  Actual 2011 bill rate: $110.00 per/hr
  Actual 2011 title: Assistant Health Scientist I

  Difference in bill rates $35.00 per/hr or a 47% discount / loss
  Consultant's percentage increase in salary (only) since 2009 of 17%.

Another way for you to understand our problem

Another way to understand our predicament is to evaluate this issue on a "per case basis". To estimate a per case "average loss" (what you might call a discount), we selected 10 cases from 2010.

		Actual Billings for cases at FRIC current rates	**Billings would have been if we were on 2010 rates**	**ChemRisk loss**	**% change**
FRIC	929	40,784.56	53,059.00	-12,274.44	-23%
FRIC	923	12,229.50	15,746.50	-3,517.00	-22%
FRIC	914	14,715.50	19,277.00	-4,561.50	-24%
FRIC	911	16,906.50	21,847.00	-4,940.50	-23%
FRIC	904	11,055.00	14,593.00	-3,538.00	-24%
FRIC	888	11,154.75	14,626.75	-3,472.00	-24%
FRIC	878	16,022.50	21,116.25	-5,093.75	-24%
FRIC	873	35,485.50	46,592.00	-11,106.50	-24%
FRIC	872	13,171.25	16,887.50	-3,716.25	-22%
FRIC	871	27,534.25	36,475.50	-8,941.25	-25%
				Average	-24%

My proposal

Dolores, currently, you are among our largest clients. And, Ford has certainly been a loyal supporter. The Big 3 were the foundation of the firm during our formative years, and for this reason, I have tried to go the extra mile to try to satisfy your needs.

Because of the nature of our industry, we have not had to discount our other work for other clients (other than, arguably, the government) for several years. Beyond that, it is never even requested because of the pressure to retain scientists who know asbestos and toxic tort litigation. As you are aware, for many of your toxicology or medical consultants, they have more work than they can do, and I know that some of them have chosen not to always be available to you in light of the billing difficulties they believe that they have experienced.

I would hope you agree that it is an appropriate time to set up a different compensation arrangement with us for 2011.

Along those lines, and because your calendar has been too crowded for us to have a "face to face" discussion and resolution, for 2011, I am proposing that we adopt one of the two following approaches:

1) Implement 2011 rates at current titles and increase PO approval amounts.

    1. Currently, 2a approval is case dependent but averages approximately $14,500. We recommend increasing this to $18,125.

    2. Similarly, 2b (deposition) is approximately $4,500. We recommend a comparable (25%) increase to $5,625.

    3. Finally, Trial approval averages $50k per case. We will need this increased to $62k.

2) Go to 2011 rates and back to a flat fee arrangement of $24k per case to cover both phases 2a and 2b. Trial approvals will be for $62k.

Brent and I, as well as the entire ChemRisk friction team, hope that we can reach agreement in early January on our billing arrangements for 2011. I have asked that Pam Chapman be available to meet with you as soon as a date can be identified. I am led to believe that this can occur before Jan. 15th. She is the closest person to the financials for your projects.

<u>Closing Thoughts</u>

I believe you can assure your management that you have been "the good steward" of Ford resources over the past 8 years in your dealings with our firm. To be specific, during this time period, when we were generally not "discounting" any of our invoices, Ford received approximately $4,000,000 in professional courtesies (which includes write-offs, discounts on rates, and the interest on monies borrowed while waiting for payment). I think you would agree that for a firm of our size, this is a remarkable loss in income.

Let me close with another issue which the two of us have not discussed previously, and I am not sure that outside counsel has brought this to your attention. Over the past 5 years, I have personally spent (in hard or soft dollars) a little more than $3M in profits (which would have been distributed to me or the staff) in asbestos related research which resulted in publications which have been enormously illuminating to the courts and juries. I did this because I believe that the courts deserve to have all the scientific information that can be brought to the table when reaching conclusions. In my view, these papers have changed the scientific playing field in the courtroom. You know this better than anyone as you have seen the number of plaintiff verdicts decrease and the cost of settlement go down over time.

As I am constantly reminded by the 1-14 person shops who work for Ford as experts (including Exponent, Veritox, and a host of industrial hygienists), all of them base the background of their testimony on our published papers. We know this because of the dog fight we just went through on the Bankhead case. The Kazan firm successfully argued that even if Paustenbach and Ford were no longer in the case, everyone else was relying our published work so they were entitled to the basis for our conclusions.

I will bring to your attention (attached) our recent paper on bystander exposure to asbestos. From what I can determine, it has been used in perhaps 30 "friction" cases over the past 90 days since it was published. This was a ChemRisk funded paper which required no less than $300,000 in effort.

I wish you the best this holiday season and look forward to seeing you in the month of January.

Sincerely,

Dennis Paustenbach, PhD, DABT
President and CEO

CC: C. Halseth
J. Plensdorf
J. Henderson
M. Garavaglia
D. Grams
P. Lankford
P. Chapman
P. Barnette

Enclosures: Donovan et al. 2010
2004 ChemRisk Rate Sheet
2010 ChemRisk Rate Sheet
2011 ChemRisk Rate Sheet

Critical Reviews in Toxicology, 2010, 1–23, Early Online

informa
healthcare

REVIEW ARTICLE

Evaluation of bystander exposures to asbestos in occupational settings: A review of the literature and application of a simple eddy diffusion model

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Abstract

This article presents a review of the publicly available information as it relates to airborne asbestos concentrations at varying distances from a source in an occupational environment. Personal and area samples collected 5–75 feet from the primary worker from workplace surveys conducted in the 1970s and area samples collected 5–50 feet from the primary worker during more recent simulation studies were identified, compiled, and analyzed. As expected, airborne asbestos concentrations generally decreased with distance from the worker who performed a given task. Based on this review, however, the authors found that no systematic research to quantitatively relate fiber concentration with distance from the source (including consideration of fiber length, dilution ventilation, and initial momentum of the particle) has been conducted to date. A simple mathematical model was therefore used, and the results were considered, along with available published data comparing exposure data for both workers and persons/areas near workers. From this analysis, the authors offer guidance for estimating airborne asbestos concentrations at distance from a source. Based on the available data and our modeling results, the authors propose the following approach as a rule of thumb: for persons 1–5 feet from the source, airborne asbestos concentrations can be roughly approximated at 50% of the source concentration; 35% at >5–10 feet, 10% for >10–30 feet, and less than 1% at distances greater than 30 feet. This approach should be helpful for bracketing the range of likely exposures to bystanders being evaluated in asbestos-related dose-reconstruction analyses.

Keywords: *Asbestos; bystander exposure; exposure assessment; indirect exposure; industrial hygiene; near field*

Contents

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Introduction

Because of its unique physical and chemical properties, asbestos has historically been used as a hot surface exposure preventive, as a filler for certain molded materials (and building materials), and as a flame retardant (Maines, 2005). In the United States, asbestos began to be used around the end of the 19th century, and its overall consumption increased substantially during World War II due to its use in shipbuilding and repair (Balzer and Cooper, 1968; NIOSH, 1972). In later years, it was used mostly in the building and construction industry, which accounted for more than two-thirds of the total asbestos demand in the United States by the, 1980s (US EPA, 1988). Thousands of commercial and industrial products and applications have contained asbestos, including (1) insulation or filler, (2) blocks and pipe sections, (3) gaskets and packing, (4) cement sheets and paper, (5) textiles, (6) blankets or felts, (7) friction materials, and (8) other heat-resistant materials, such as phenolic resins, floor tiles, ceiling tiles, coatings, mastics, cloth, and gloves (Lindell, 1973).

Historically, three types of asbestos have been used most frequently. Chrysotile (a member of the serpentine mineral family) was predominantly used through the 1930s, although during World War II, amosite (an amphibole) was used extensively in the US shipyard industry (Bowles and Stoddard, 1933; Bowles and Barsigian, 1951; Balzer and Cooper, 1968; Virta, 2005). Around the mid-1950s or early 1960s, chrysotile fiber comprised the vast majority of asbestos used in the United States for a number of reasons, including the introduction of molded products in the marketplace and increased use in various building materials, including sealants (mastics, asphalt coatings, etc.). Starting in the 1970s, chrysotile was sometimes mixed with other forms of asbestos (such as crocidolite and amosite) for use in insulation and a very small fraction of gaskets (NIOSH, 1972; Mangold et al., 2006). Because of its widespread use, asbestos presented numerous exposure opportunities for workers producing, handling, or using asbestos-containing materials in the manufacturing, construction, maritime, and other industries (Maines, 2005).

Knowledge regarding the health hazards posed by asbestos evolved considerably throughout the 20th century (Paustenbach, 2004). In 1930, Merewether and Price conducted the first epidemiology study in an asbestos textile plant, after which they concluded that a clear risk existed for developing a unique lung disease from inhaling asbestos dust (i.e., asbestosis). They also noted that exposure duration and amount of dust inhaled were key factors for predicting disease (Merewether and Price, 1930). With few exceptions, the workers evaluated in the studies conducted throughout the 1930s performed activities in manufacturing settings (i.e., among the dustiest environments). At the time, the scientific and industrial hygiene communities believed that asbestos exposure could be significantly lessened by using engineering or administrative controls to reach acceptable airborne concentrations. By the mid-1940s, focus expanded to include individuals who used, rather than produced, asbestos-containing materials. Some of the major studies of this era were conducted in the shipbuilding industry, where asbestos was heavily used in pipe covering and insulation (Fleischer et al., 1946). Because of the confined spaces and lack of ventilation inside the ships, as well as the large volume of asbestos-containing materials used, exposures in this industry could be quite substantial (Marr, 1964).

By, 1955, it was clear that sufficient exposure to asbestos could increase the risk of lung cancer (Doll, 1955). In 1960, Wagner et al. reported a causal link between mesothelioma and crocidolite exposure (Wagner et al., 1960). Recognition of the hazards of insulation work in the shipyard industry eventually broadened to include other trades in which insulation use was also commonplace, such as construction. In the 1960s, for example, Dr. Irving Selikoff and his colleagues conducted a large scale study of over 1000 union insulators in the New York-New Jersey area (Selikoff et al., 1965a). They reported an increased risk of both lung cancer and mesothelioma in this cohort, which included active workers as well as deceased or retired individuals, many of whom had over 20 years of asbestos exposure (Selikoff et al., 1964, Selikoff et al., 1965b).

As more was learned about the hazards of asbestos, by the late 1960s, concern about the hazards regarding the exposure of "bystanders" began to grow. Historically, this term has been used to describe persons who are in the immediate vicinity of a worker handling asbestos-containing products. The duration and extent of bystander exposures can vary considerably (usually due to the magnitude of the exposure of the primary worker and the bystander's distance from that person). There have been some anecdotal reports of possible hazard to bystanders in the scientific literature; however, much of the historical concern and exposure estimates revolve around less than five studies (which were not intended to quantify concentration at a distance from the source). Although it was not until 1979 that the term "bystander" was used in the peer-reviewed literature (Lilis et al., 1979), similar terms have been used over the years, such as "indirect exposure" or "nearby workers." In 1964, for example, Selikoff et al. first noted that "asbestos exposure in industry will not be limited to the particular craft that utilizes the material. The floating fibers do not respect job classification. Thus, for example, insulation workers undoubtedly share their exposure with their workmates in other trades; intimate contact with asbestos is possible for electricians, plumbers, sheet-metal workers, and foremen..." (Selikoff et al., 1964, p. 146). Initially, the concern for bystanders focused more frequently on persons who were near workers who handled relatively large quantities of raw fibers (e.g., asbestos mining or manufacturing). Later, concern was expressed regarding craftsmen who might be working in the vicinity of insulators (especially during initial construction or tear-down). Examples of typical work settings in which asbestos was used in the early years are provided in Figures 1 and 2, indicating how some activities had the potential to generate very dusty environments in the immediate area near the work task.

In the late 1960s, several studies in British shipyards reported that significant airborne concentrations (up to 200 f/cc) could occur during the application of sprayed-on crocidolite asbestos insulation (Harries, 1968, 1971a, 1971b). These findings were not surprising, given the method of application and lack of engineering controls. These airborne concentrations were higher than what had been reported for non-shipyard settings or for shipyards in the United States, which also differed with respect to the asbestos fiber type present in the insulation and the method of application (Mangold et al., 1970). The Harries studies alerted the industrial hygiene community that although the primary worker, such as the spray insulator, might be protected because he used a supplied-air respirator, those within 100 feet of the sprayer usually did not wear respiratory protection and thus may not be as protected. Indeed, the shipyard industry was among the first in which increased awareness existed regarding the potential for exposure to asbestos of workers in close proximity to insulation work (specific precautions for "neighbourhood workers," defined as workers not directly in contact with asbestos, but employed near or with asbestos workers, were actually described in Harries, 1971b). The potential for high exposure (i.e., airborne asbestos concentrations well over 100 f/cc during some activities) in this industry was primarily due to the quantity of insulation used, confined work areas, inability to have high-quality local exhaust ventilation, and the use of amphibole asbestos during shipbuilding and repair. In the shipyard studies, bystander exposures were discussed generally, rather than quantitatively, and they lacked a complete description regarding the concentrations with respect to distances from a source (i.e., an insulator). In his 1971 testimony before Congress, Selikoff noted that "asbestos diseases were found not only in men directly working with the material, but [in] other people in the same industries as, for example, not only the insulation worker in a shipyard, but the electrician in the shipyard, the steamfitter, the shipfitter, the plumber, et cetera, because they were in the same atmosphere, on the same ship with the men actually using the material" (Selikoff, 1971, pp. 28–29).

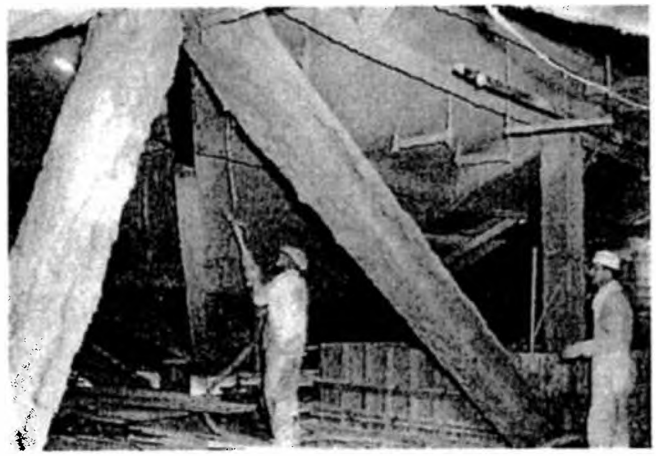

Figure 1. Application of spray insulation.

Figure 2. Asbestos carding plant. From Hunter, 1955 (p. 876).

Reitze et al. (1966) conducted one of the first studies outside of the shipbuilding industry to evaluate the exposure of workers who sprayed asbestos insulation, and they also evaluated the exposure of bystanders (Reitze et al., 1972). They were the first to provide quantitative information regarding airborne concentrations measured at a distance from the spraying activity. They noted that they were interested in evaluating exposures among the workmen who actively applied the insulation materials, as well as other workers who were on the site during or shortly after the application (Reitze et al., 1972). In the years that followed, additional studies of craftspersons other than insulators were conducted (Ferris et al., 1971; HM Factory Inspectorate, 1973; NIOSH, 1975; Rohl et al., 1975; Bell, 1976; Liukonen et al., 1978; Fischbein et al., 1979; Verma and Middleton, 1980; McMillan, 1983; Baker et al., 1985; Sprince et al., 1985; Zoloth and Michaels, 1985; Drucker et al., 1987; Verma et al., 2003). The potential for bystander exposure to insulation work was recognized among these crafts, but it was also acknowledged that these workers often handled asbestos-containing materials in the course of their own duties. A comprehensive review published by Williams et al. (2007) summarized the available asbestos air monitoring data for these craftspersons. Although the majority of the available air samples were collected during insulation work, the data were inadequate for estimating bystander exposures among the other craftspersons. It was noted by the authors that "the available data and our professional experience indicate that bystander exposures to most airborne particles were usually no greater than one-tenth the concentration measured in the primary worker's breathing zone" (Williams et al., 2007, p. 372).

Over the last 10 years, there have been an increased number of court cases involving bystanders or passers-by that have been termed "premises cases." The potential for exposure to bystanders in proximity to work involving asbestos has not been well characterized to date. Much of the available data were collected 30 or more years ago, and were not intended to quantitatively characterize bystander exposure, yet this information is often extrapolated to more recent exposures, which are, in general, considerably lower (Paustenbach, 2004). The purpose of this analysis, then, is to review the published literature to characterize the evolution of knowledge regarding bystander exposure to asbestos. Nearly 100 published studies describing persons working with or in the vicinity of asbestos were evaluated and ranked based on whether they contained sampling results and information regarding distance from the source. The scientific literature was also reviewed to determine whether any mathematical models specific to fibers could be used to estimate airborne concentrations at various distances from a source. Relevant published data were assembled and coupled with results from a simple mathematical model to derive some general guidelines for estimating ranges of airborne concentrations for bystanders within 50 feet of a hypothetical source.

Methods

Literature review

A comprehensive search of publicly available documents that directly or indirectly addressed bystander exposure to asbestos was conducted. The search included studies covering industrial and shipyard settings, but excluded studies that presented data collected during asbestos abatement work. Several database search engines (e.g., TOXNET, PubMed) were used to identify potentially relevant conference proceedings or publications in the peer-reviewed literature. Government documents, such as National Institute for Occupational Safety and Health (NIOSH) Human Health Evaluation (HHE) reports, and industrial hygiene textbooks were also considered. Although there are studies in the published literature relating to asbestos exposure to building occupants during routine maintenance activities (often considered a type of bystander exposure), these were also excluded from this review, as they rarely included precise measurements of distance from the source, and such work is often similar to abatement work. Nearly a dozen search terms were used in an attempt to capture the various ways that bystander exposure has historically been described, including: "bystander," "indirect," "secondary," "onlooker," "diffuse," "non-occupational," "viewer," "witness," "spectator," "eyewitness," as well as "tradesmen exposure" and "personal-versus-area sampling."

The approximately 100 articles identified in the initial search were ranked based on the following criteria: (1) specific reference to bystanders (or equivalent term), (2) availability of quantitative data, and (3) availability of information regarding the distance from the primary exposure source or time elapsed after work involving asbestos was completed by the primary worker. Because many earlier studies relied on area samples to characterize "nearby" exposures, no effort was made to restrict the search based on sample type (i.e., personal or area sampling) or the analytical method used (i.e., phase-contrast microscopy [PCM] or transmission electron microscopy [TEM]). Similarly, there were no inclusion criteria for sample duration.

Air monitoring data from studies that included samples considered representative of "bystanders," as well as those providing information regarding the distance from the primary source or time elapsed following the primary worker activity, were compiled and summarized. These studies could be broadly categorized as either (1) workplace surveys or (2) simulation studies. The workplace surveys were conducted in several different industries during the 1970s, and included area samples collected anywhere from 5 to 75 feet from the worker. Data collected during simulation studies, which typically contained more detailed quantitative asbestos exposure data for both the primary worker and bystanders, were also considered. In the context of this review and analysis, a "simulation study" is defined as a controlled exposure study in which a worker performs a series of tasks and air samples are collected simultaneously to measure airborne asbestos concentrations. Many of the simulation studies included area samples that were collected at a known distance and location relative to the primary worker in order to characterize exposures for a hypothetical bystander. In total, 12 simulation studies were identified as relevant.

To facilitate data analysis, the available air sampling results from the studies that presented individual sampling results were assembled into Excel spreadsheets (one per study). When possible, PCM measurements were adjusted for asbestos fiber content according to the method outlined in NIOSH Method 7402, in which the PCM fiber concentration is multiplied by the ratio of asbestos fibers to total fibers observed in the TEM analysis. In cases where the PCM result was below the analytical sensitivity limit, but asbestos fibers were detected in the corresponding TEM measurement, a value of one-half the PCM analytical sensitivity limit was multiplied by the ratio of asbestos fibers to total fibers observed by TEM. If the PCM measurement was above the analytical sensitivity limit, but asbestos fibers were not detected by TEM, a value of "0" was used for the PCM-adjusted concentration in any calculations.

Each study was evaluated in detail to identify possible bystander samples and link them to the corresponding worker sample(s). A variable for the distance from the primary worker was assigned to each bystander sample. In most cases, the distance from the worker was reported in the original study, and that value was included in our analysis. There were several cases, though, in which the authors of the original study reported that the work occurred in an adjacent area, but did not provide specific distance measurements. In these instances, the distances between the bystander and the worker were estimated based on professional judgment. If the distance from the worker was reported as a range by the authors, the midpoint of that range was used in this analysis.

After each bystander sample was linked with the appropriate primary worker sample and a variable for distance from the source was added, the ratio between the airborne asbestos concentration for each bystander sample and the corresponding worker sample was calculated. This step also served to "normalize" the bystander samples to allow for comparison across different studies (or activities within a single study). The analysis was limited to worker-bystander pairs in which there were detectable concentrations of asbestos in the worker sample. It should also be noted that in several of the studies (Paustenbach et al., 2006; Jiang et al., 2008; Madl et al., 2008), samples were collected separately on the left and right lapels of the worker and/or in time series (two successive 15-minute samples) and averaged to arrive at a single value for analysis. In instances in which one or more of the individual samples were below analytical sensitivity limits, the samples reported as "non-detect" were included in the calculation of an average value using a value of one-half of the limit of detection (LOD).

As part of a preliminary data analysis, the percent reduction in mean airborne asbestos concentrations at varying distances from the source was calculated for the various tasks that were evaluated in each study. If individual sampling results were available, a Student's t test was used to determine whether there was a significant difference in the airborne asbestos concentrations of the bystander and worker samples. Variance between sample sets was assessed using Excel's "FTEST" function; based on these results, the Student's t test was performed assuming unequal variance.

The data from the individual studies were also pooled into a single data set for further analysis. An x-y scatter plot was generated in order to evaluate whether there was a relationship between the ratio of bystander to worker airborne asbestos concentrations and distance. Box plots were generated in order to determine whether there appeared to be a relationship with distance when all the available data were pooled. Secondary box plots and x-y scatter plots were also generated using a bystander:worker ratio cutoff of 1 (i.e., for any bystander:worker ratios greater than 1, a value of 1 was used) in an attempt to reduce some of the variability that was due to the high number of ratios based on bystander samples with <LOD results; this phenomenon occurred almost exclusively in the simulation studies. Samples were grouped by distance from the source/ worker into the following categories: 1-5, >5-10, >10-30, and greater than 30 feet (Figure 3). It was assumed that the "source" comprised a distance of 0-1 foot. Distances greater than 50 feet away were considered too great to be significantly influenced by the single point source where the primary worker was engaged. Often, at distances greater than 50 feet, background concentrations of asbestos, room ventilation, and other nearby activities would have more impact than the source itself. The mean bystander:worker ratios were calculated for each category of distance.

Mathematical modeling of airborne asbestos concentration with distance

As will be discussed in greater detail, there was considerable variability in the available published data. Based on the preliminary analyses, there was a general decrease in airborne asbestos concentrations at increasing distances from the source, but there were many inconsistencies in the data, and no clear trends for bystander exposures were seen. An additional literature review was therefore conducted to identify any mathematical models that could be used to predict concentrations of airborne fibers in the workplace. Initially, the focus of this additional review was on those studies that compared modeled estimates to measured fiber concentrations. As noted previously, however, a fairly limited number of studies were found that reported fiber concentrations over time or at specific distances from a source.

Because of the inherent variability associated with comparing bystander to worker air concentrations from simulation studies and workplace surveys, an indoor air eddy diffusion

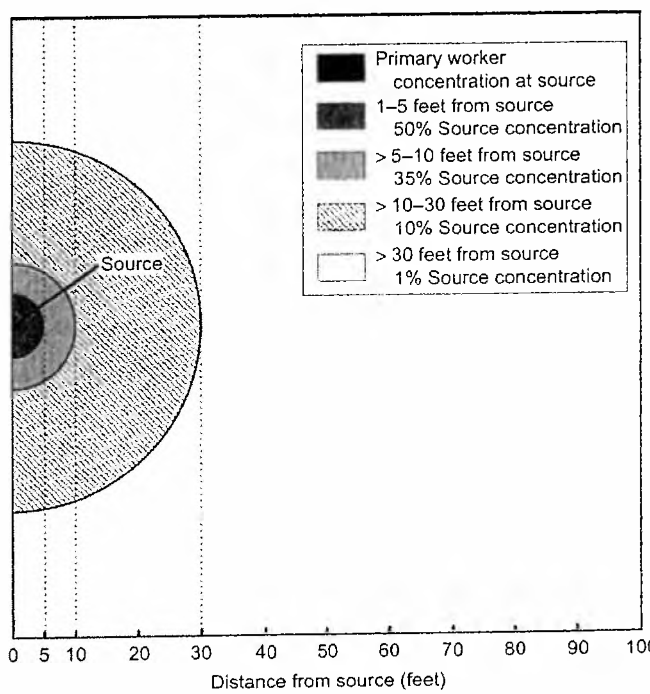

Figure 3. Proposed guidelines for estimating airborne asbestos concentration at various distances from a point source.

analytical model for particulate emissions was applied for a simplified scenario to provide a point of comparison to the bystander:worker ratios derived from the published data. Although a more complicated model, such as the Markov Chain Model (Nicas, 2001), could have been used, the level of input data required for such models is more suited to evaluate specific emission scenarios (i.e., a particular emission activity in a specific location), rather than the generic assumptions used in this analysis. Because of the variability in activities, source characteristics, and types of indoor locations associated with the simulation study and workplace survey data to which the model results were to be compared, the eddy diffusion models (which require a lower level of source and location input data) were considered more suitable for this application.

Specifically, the indoor air eddy diffusion models developed by Drivas et al. (1996) and Keil (2000) for particulate emissions were used to estimate the airborne concentrations over time for a one time, point source release of particles (in this case, fibers). These models are based on the same equations, except that the Drivas et al. (1996) model also accounts for surface deposition and reflection off of room walls. As such, the Drivas et al. (1996) model was considered to be more representative of a typical work environment, but bystander:worker ratios were also generated based on the Keil (2000) model, which does not consider removal from these transport and loss mechanisms, to provide upper bound concentrations.

A scenario of a "source" performing maintenance work near the middle of a wall in a 100 × 100 × 20-foot room was evaluated. This scenario was meant to represent typical emissions that might be caused by a worker working with asbestos containing materials (e.g., insulation). The emission source was assumed to emit 9,290,000 Occupation Safety and Health Administration (OSHA) fibers (greater than 5 μm in length with an aspect ratio of at least 3:1) over a 15-minute period of worker activity. This assumption essentially ignores the mass build-up during the activity, and treats it as an instantaneous release at the end of the 15 minutes, equivalent to a peak worker air concentration of 5 f/cc, at a height of 6 feet. Air concentrations were estimated every 15 minutes after the emissions occurred for the worker (0–1 foot), and for bystanders who were 1–75 feet in a straight line distance from the source. All air concentration estimates were for a breathing zone height of 6 feet. For both the worker and bystanders, a 15-minute time-weighted average asbestos air concentration and the ratio of the worker and bystander air concentrations were calculated. Because the sampling duration for the simulation study and workplace survey data varied, a 15-minute time-weighted average fiber concentration was estimated in order to provide a value that would be representative of a short-term air sample that may have been collected immediately after the exposure activity in a manner similar to a simulation study.

The proposed scenario is based on a single release of fibers into the air. As described in detail in Keil (2000), the equation that can be used when there is an instantaneous or "puff" release of a pollutant is:

$$C_{r,t} = \frac{M}{8(\pi Dt)^{1.5}} e^{\frac{r^2}{4Dt}} \qquad (1)$$

where M is the number of fibers instantly released; C is the concentration (fibers/m^3); D is eddy diffusion coefficient (m^2/s); t is time from start of generation (s); r is the radial distance from source (m).

To account for additional transport and loss mechanisms such as surface deposition and reflection off room walls, the following equations from Drivas et al. (1996) were used:

$$C(x,y,z,t) = \frac{Q_{x_0 y_0 z_0} e^{-\left(n + \frac{W_D A}{V}\right)t}}{(4\pi Dt)^{\frac{3}{2}}} R_x R_y R_z \qquad (2)$$

where $c(x,y,z,t)$ is the indoor concentration (fibers/m^3) at position x,y,z at time t in the room and $Q_{x_0y_0z_0}$ is the total amount of fibers released at the source position $(x_0y_0z_0)$.

The R_x, R_y, and R_z terms in Equation 2, which specify the wall reflection terms, are defined as follows for a rectangular room:

$$Rx = \sum_{i=-\infty}^{\infty} \left[e - \frac{(x+2iL-x_0)^2}{4Dt} + e - \frac{(x+2iL-x_0)^2}{4Dt} \right] \qquad (3)$$

$$Ry = \sum_{i=-\infty}^{\infty} \left[e - \frac{(y+2iW-y_0)^2}{4Dt} + e - \frac{(y+2iW-y_0)^2}{4Dt} \right] \qquad (4)$$

$$Rz = \sum_{i=-\infty}^{\infty} \left[e - \frac{(z+2iH-z_0)^2}{4Dt} + e - \frac{(z+2iH-z_0)^2}{4Dt} \right] \qquad (5)$$

where L is the room length (m), W is the room width (m), and H is the room height (m).

To account for differences in the particle geometry between the standard spherical particle and the cylindrical asbestos fiber, a fiber settling velocity was calculated using the method presented by Spengler et al. (2001). To estimate a settling velocity that would be characteristic of the range of possible shapes associated with OSHA fibers, settling velocities were calculated for different combinations of particle density (2.4 or 2.6 g/cm^3), fiber diameter (0.2, 0.3, or 0.4 μm), and fiber length (5 or 10 μm). The calculated settling velocities for the 12 different combinations of particle characteristics ranged from 0.0011 to 0.005 m/s, and the average settling velocity of 0.0028 m/s was used in the Drivas et al. (1996) model to be characteristic of OSHA fibers. Because the effective eddy diffusion rate and ventilation rate are correlated with each other, the reported midpoint of the effective diffusion rate of 0.45 m^2/min and room ventilation rate of five air changes/hour for a 180 × 120 × 20-foot room were used. These values were based on effective diffusion rates that were measured and reported from several other studies (summarized and presented in Keil, 2000). The fixed input values used in the model are presented in Table 1.

Generation of a "rule of thumb" to estimate bystander exposure at specific distances from a source

In addition to presenting the results from the analysis of the published literature and modeling results, an exercise was also conducted to see how the results from each type of available bystander data (simulation study results, workplace survey results, and the modeling results for a simplistic work scenario) aligned at specific distances from the source. The purpose of this exercise was to develop a rough "rule of thumb" for several bystander distance categories. The specific distance categories were driven in large part by the distances for which data were available in the published studies. For example, many of the simulation studies collected samples at a distance of 5 feet to characterize bystander exposures, so there are a large number of samples at 5 feet, but only a handful that were collected at shorter distances ranging from 1 to 4 feet. As such, it was difficult to provide meaningful comparisons at, say, 2 feet from the source, given that there may have been only one or two samples at this distance.

The initial distance categories of 1–5, >5–10, >10–30, and greater than 30 feet were developed based on the frequency distribution of bystander:worker ratios that were generated for the pooled data set where all the samples that could not be analyzed (i.e., worker samples with airborne asbestos concentrations reported as below the LOD) had been excluded. For each of these categories, the bystander:worker ratios were averaged for any distances that were within the range (i.e., ratios reported at 6, 9, and 10 feet would have been averaged together to generate a single ratio for >5–10 feet category). Initially, this averaging was done separately for each type of bystander data. The modeling results based on Drivas et al. (1996) were used as the starting point because this model was considered to be more representative of an occupational setting; the average values from the other types of data were then evaluated, and, if necessary, used to adjust the proposed rule of thumb for each distance group. The factors by which the concentration reductions predicted by this model were adjusted differed within each distance category based on the similarity of results across the other types of data. In all cases, the adjustments of the initial estimates were based on professional judgment. The limitations of this approach and the uncertainties in the underlying data are discussed later in more detail.

Results

Based on the literature review, nearly 100 potentially relevant studies were identified. Only, 19 studies were identified in the published literature, however, that met our inclusion criteria (see Table 3). All air samples reported in the various studies measured OSHA fibers, defined as being greater than 5 μm in length with an aspect ratio of at least 3:1. The studies are described more specifically by activity below.

Workplace surveys (1970s)

Seven of the 19 studies included in this analysis were workplace surveys conducted in the 1970s (Reitze et al., 1972; Rohl et al., 1975, 1976; Barnes, 1976; Lorimer et al., 1976; Fischbein et al., 1979; Verma and Middleton, 1980). The available sampling data from these surveys are presented in Table 2. The first study to specifically measure airborne asbestos concentrations at fixed distances from the source was published by Reitze et al. in 1972, and examined workers who applied spray-on asbestos insulation. During this process, a worker holds a hose from which asbestos insulation

Table 1. Parameters used in the Drivas et al., (1996) and Keil (2000) air dispersion models to predict airborne fiber concentrations at various distances from the point source.

Parameter	Value	Units	Notes
Number of fibers emitted from source, $Q_{x_0y_0z_0}$	9.29E+06	fibers	Source located at (0 ft, 0 ft, 6 ft); 5 f/cc in breathing zone
Length of emission, Temit	900	s	
Fresh air ventilation, a	0.0014	1/s	5 air changes per hour
Fiber length, Fl	5, 10	μm	Range of fiber lengths assumed for asbestos fibers
Fiber diameter, Fd	0.2, 0.3, 0.4	μm	Range of fiber diameters assumed for asbestos fibers
Particle density, p	2.4, 2.6	g/cm^3	Range of particle densities for synthetic vitreous fibers from Spengler et al. (2001)
Deposition rate, wd	2.77E-03	m/s	Deposition rate for particle density of 2.4–2.6 g/cc; diameter of 0.2–0.4 μm; length of 5–10 μm
Length of the room, L	30.5	m	100 ft × 100 ft × 20 ft room
Width of the room, W	30.5	m	100 ft × 100 ft × 20 ft room
Height of the room, H	6.10	m	100 ft × 100 ft × 20 ft room
Surface area for deposition, A	929	m^2	Area of room floor (100 ft × 100 ft)
Room volume, V	5663	m^3	Volume of 100 ft × 100 ft × 20 ft room
Effective indoor diffusion coefficient, D	0.0075	m^2/s	0.45 m^2/min for 180 × 120 × 20 ft room
Ratio of surface area and volume, A/V	0.164		
X coordinate for source, X_0	0	m	
Y coordinate for source, Y_0	0	m	
Z coordinate for source, Z_0	1.8	m	Source located at breathing height of 6 ft

Table 2. Airborne Concentrations of Asbestos Fibers (Greater than in Length) Measured at Various Distances from a Worker Performing a Task (1972-1980).

Activity	Number of samples	Sample type	Sample time (minutes)	Point source sample concentration (f/cc)*	Bystander sample concentration (f/cc)*	Distance from point source (feet)**	Reference
Spray insulation studies							
Application of sprayed insulation	NR	Area	NR	80	5	20	Barnes, 1976
Application of sprayed insulation[a]	1	Area	NR	52 (24–85)	71	10	Reitze et al., 1972
	1	Area	NR	61(32–100)	70	10	
	1	Area	NR	96.75 (94.5–99)	17	15	
	1	Area	NR	35.2 (20–49)	66	20	
	1	Area	NR		37.6	20	
	1	Area	NR		10	35	
	1	Area	NR		46	75	
	1	Area	NR		1.12	30 min lapse	
	1	Area	NR		1.55	30 min lapse	
	1	Area	NR		1.01	30 min lapse	
	1	Area	NR		4.22	30 min lapse	
	1	Area	NR		0.55	60 min lapse	
	1	Area	NR		0.51	60 min lapse	
	1	Area	NR		0.28	60 min lapse	
	1	Area	NR		0.76	60 min lapse	
	1	Area	NR		0.26	60 min lapse	
Studies of consumer spackling, patching, and taping compounds							
Pole sanding	3	Personal	1 h	10 (1.2–19.3)	8.6 (3.5-19.8)	8	Rohl et al., 1975; Fischbein et al., 1979; Verma et al., 1980
	2	Personal	1 h		4.8 (0.7-8.8)[b]	25	
Hand sanding	2	Personal	1 h	5.3 (1.3-16.9)	2.3 (2.1-2.5)	8	
	2	Personal	1 h		4.3 (1.5-7.1)[b]	15	
Dry mixing	3	Personal	1 h	47.2 (35.4–59)	5.8 (0.5-13.1)	10 to 20	
	2	Personal	1 h		2.6 (2.1-3.1)[b]	16 to 35	
Automotive and heavy truck studies							
Blowing dust from brake drums (using compressed air)	3	Personal	3 to 8	16 (6.6–29.8)	3.3 (2.0-4.2)	5 to 10	Rohl et al., 1976; Lorimer et al.
	2	Personal	3 to 8		2.6 (0.4-4.8)	10 to 20	
	1	Area	NR		0.3	10	
	1	Area	NR		0.8	20	
	1	Area	NR		0.2	12 (5 min lapse)	
	1	Area	NR		0.1	50 (5 min lapse)	
	1	Area	NR		0.1	65 (7 min lapse)	
	1	Area	NR		0.1	75 (14 min lapse)	
Grinding used linings (heavy truck brake service)	1	Area	NR	3.75 (1.7–7.0)	1.2	10	
	1	Area	NR		1.7	10	
	1	Area	NR		1	25	
	1	Area	NR		0.6	25	
	1	Area	NR		0.2	60	
Beveling new brake linings (heavy truck brake service)	1	Area	NR	37.3 (23.7–72.0)	0.6	8	
	1	Area	NR		0.5	12	
	1	Area	NR		0.3	12	
	1	Area	NR		0.3	30	

NR = Not reported.
*Mean concentration presented if multiple sample results available. Reported ranges are in parentheses.
**Time lapse from activity of primary worker (source) also considered a type of bystander sample.
[a]The authors did not indicate how samples collected at varying distances from spray operations correlated with the four reported worker samples. It was also noted that ventilation conditions varied throughout the study.
[b]Samples collected in adjacent room.

Table 3. Continued.

Study	Distance from the source	Sample type	Sample title
Paustenbach et al., 2006	Samples collected 2–4 ft from removal of automobile exhaust systems containing asbestos gaskets	Area	Bystander
Jiang et al., 2008	Samples collected on either side of worker, 5ft from handling, unpacking and repacking of clutch discs, cleanup and clothes handling	Area	Bystander
	Samples collected 50 ft from handling, unpacking and repacking of clutch discs, cleanup and clothes handling	Area	Remote area
Madl et al., 2008	Samples collected on four sides of worker, 5 ft from packing and unpacking brake shoe and pad boxes	Area	Bystander
	Samples collected 25–30 ft from packing and unpacking brake shoe and pad boxes	Area	Remote area
Paustenbach et al., 2004	Samples collected 6 ft from application of mastics, coatings and adhesives	Area	Area
	Samples collected 6 ft from spill clean up of mastics, coatings and adhesives	Area	Area
	Samples collected 6 ft from removal of mastics, coatings and adhesives	Area	Area
	Samples collected 6 ft from sweep clean up of mastics, coatings and adhesives	Area	Area
Mowat et al., 2005	Samples collected on four sides, 6ft from band sawing of phenolic molding material	Area	Area
	Samples collected on four sides, 6ft from belt sanding of phenolic molding material	Area	Area
	Samples collected on four sides, 6ft from press drilling phenolic molding material	Area	Area
	Samples collected on four sides, 6ft from sweep cleanup during sawing, sanding and drilling	Area	Area
Cohen and Van Orden, 2008	Samples collected on four sides, 5–10 ft from the removal of automotive clutches	Area	Area
Fowler, 2000	Samples collected 2–3 ft from bandsawing sheet gasket material	Area	Area
Longo et al., 2002	Samples collected on four sides, approximately 7 ft from scraping and hand wire brushing large flange assemblies	Area	Bystander
	Samples collected on four sides, approximately 7 ft from power wire brusing of large flange assembly	Area	Bystander
Liukonen and Weir, 2005	Samples collected 10 ft from disassembly of a diesel engine	Area	Area
	Samples collected 3 ft[a] from disassembly of a diesel engine	Personal	Observer

[a]Distance from point source is estimated.

is shot out of the nozzle and projected over distances of 30 feet or greater. Area samples were collected at 10–75 feet from the spray nozzle during application, as well as at 30 and 60 minutes after spray operations had ceased. As expected, airborne fiber concentrations decreased with time at 30 and 60 minutes after spraying stopped. The samples collected at increasing distances during spray applications, however, did not follow an obvious pattern with regards to distance, which was noted by the authors to be "because of changes in on-site ventilation." In addition to the Reitze et al. (1972) study, a 1976 survey of asbestos spray operations in Sydney, Australia, also reported an airborne fiber concentration of 5 f/cc at floor level, 20 feet below the spray point during the application process, which was approximately 6% that of the spray operator (Barnes, 1976). Because spray insulation is such an unusual circumstance and the samples were collected "below" the operator (literally on the floor below scaffolding where a worker was applying the spray insulation), these data are not very informative.

Indirect exposure to asbestos was also studied among workers using several types of construction materials, including spackling, patching, and taping compounds. A total of 14 personal samples were collected at varying distances during mixing of the materials (prior to application) and during sanding (either by hand or using a pole) after application. Of these samples, eight were collected between 8 and 20 feet from the primary activity, and the remaining six were collected in an adjacent room at distances ranging from 15 to 35 feet from the worker. These data are presented in three different publications (Rohl et al., 1975; Fischbein et al., 1979; Verma and Middleton, 1980). Measured airborne concentrations were slightly lower as distance from the worker increased, although the magnitude of this difference varied across the tasks that were studied. For the pole and hand sanding bystander samples, which were collected 8 feet away from the sander, this difference ranged from 50% to 80% of the concentrations at the worker. For the dry mixing samples, the airborne concentrations ranged from approximately 5% to 10% (at 10–20 feet and 16–35 feet in an adjacent room, respectively) of that of the worker.

Brake repair maintenance workers in New York City were also monitored during a variety of tasks, including blowing out dust from drum brakes, renewing used brake linings by grinding, and beveling new linings (Lorimer et al., 1976; Rohl et al., 1976). Personal samples collected 5–10 feet away from the primary activity (3–8 minutes) were 20% the value for the worker performing brake blowouts (16 f/cc). The average concentration for samples collected 10–20 feet from the primary worker was approximately 15% the value reported for the worker. Area samples collected between 10 and 75 feet from the worker were significantly lower (0.1–0.8 f/cc); however, sample duration was not reported, and four of the six samples were collected between 5 and 14 minutes after the worker completed the blowouts, making direct comparison difficult. During grinding of used brake linings, airborne concentrations in area samples were approximately 33% to 20% to 5% that of the worker during grinding of used brake linings at distances of 10, 25, and 60 feet, respectively. During beveling of new linings, samples collected at distances of 8, 12, and 30 feet had airborne asbestos concentrations that were approximately 2%, 1.3%, and 0.8% that of the worker, respectively.

Simulation studies (2000s)

Twelve of the 19 studies that met the criteria of this review were simulation studies conducted in the 2000s. The majority of the available data were collected to characterize exposures associated with using products in which the asbestos fibers were encapsulated (that is, the asbestos was often embedded in a polymer or tar-like substance). As such, the airborne concentrations of OSHA fibers were orders of magnitude lower than what was reported in the workplace surveys of the, 1970s. A summary of the concentrations measured for workers and bystanders in the simulation studies is presented in Table 4.

Raw data were available for approximately half of the simulation studies, whereas average values were presented in the others. In many cases, the reported results had been converted to 8-hour time-weighted average (TWA) values for purposes of comparison to occupational exposure limits. In some of these studies, "bystander" or remote samples (usually area samples) were collected at more than one distance from the worker, and the authors conducted statistical analyses to determine whether concentrations were significantly different at greater distances. Wherever possible, these results are presented.

Removal and manipulation of gaskets

A number of simulation studies have evaluated the removal, manipulation, and installation of asbestos-containing gaskets. Three of these studies assessed airborne asbestos concentrations associated with changing gaskets on flanges or valves. The work was performed in enclosed, ventilated chambers in two of the studies (Fowler, 2000; Longo et al., 2002), but not in the third (Mangold et al., 2006). The results reported by Mangold et al. (2006) were collected over nearly a 10-year period, and were intended to characterize a maximally exposed worker (i.e., one who handles gaskets and packing all day). Personal and area samples were taken over an 8-hour workday as workers performed various tasks with packing and gasket materials. Because all PCM results (worker and bystander alike) were less than 0.01 f/cc and did not differ significantly from background, this study was of limited use.

The two studies that collected short-term samples (<30 minutes) in ventilated enclosures reported higher airborne asbestos concentrations than what was found by Mangold et al. (2006). Specifically, Longo et al. (2002) collected personal and area samples (15–30 minutes) during scraping and hand-wire brushing of four large flange gaskets and during power-wire brushing of a large flange assembly. Area samples were located in four equidistant quadrants at a distance of 2.1 m (approximately 7 feet) from the work bench during the activities. Because an average value was not reported for the area samples, it was not possible to directly compare worker and "bystander" values for this activity; however, the minimum and maximum values reported for the area samples were approximately 25% to 33% of those reported for the worker. Bystander area samples collected during power-wire brushing were approximately 50% of what was reported among the corresponding worker samples. Similar ratios were observed among personal and area samples collected during a simulation study involving band sawing of asbestos sheet gasket materials (Fowler, 2000). It should be mentioned that there were several analytical and study design issues with the Fowler (2000) and Longo et al. (2002) studies, which are discussed in more detail in Madl et al. (2008). The ratios of concentrations between the bystander and worker samples, however, were fairly consistent with values reported in other simulation studies.

Other gasket studies included in this analysis involved installing and/or removing gaskets in automobiles. In 2006, Paustenbach et al. published their findings regarding personal and bystander exposures to asbestos during the removal of automobile exhaust systems containing asbestos gaskets. In this study, a considerable portion of the available samples were below analytical sensitivity limits. In total, for workers, 17/23 (74%) of PCM results and 18/29 (62%) of TEM results were below analytical limits and were reported as undetectable, whereas 29/38 (76%) of bystander PCM results and 35/41 (85%) of bystander TEM results were below analytical limits. The lack of detectable asbestos concentrations in the bystander samples was also noted in the Blake et al. study, in which area samples were collected from nine locations at distances ranging from less than 1 foot to 50 feet from the test area (Blake et al., 2006). Of the 43 area samples, asbestos fibers were only detected in 8. Further, the average concentrations represent a combination of activities, and it was not possible to quantitatively characterize the degree to which airborne concentrations decreased with increasing distance from the worker. The authors noted, however, that the highest reported sample result occurred in one of the corners of the shop, and not in the immediate work area (Blake et al., 2006). All but two of the samples collected in a gasket

Table 4. Samples collected to characterize bystander exposures to asbestos fibers (greater than 5μm in length) during simulation studies (2000-2008).

Activity	Number of samples	Sample type	Sample time (minutes)	Point source sample concentration (f/cc)*	Bystander sample concentration (f/cc)*	Distance from source (ft.)	Reference
Automobile studies (gaskets)							
Removal of automobile exhaust systems containing asbestos gaskets in four single and two double exhaust engines	6	Area	30-50	0.018 (0.002-0.04)	0.008 (0.0008-0.015)	2-4	Paustenbach et al., 2006[d]
Automobile studies (clutches)							
Handling, unpacking, and repacking boxes of automobile clutch discs	40	Area	30	0.044 (0.000-0.366)	0.0025 (0.000-0.019)	5	Jiang et al., 2008
Stacking clutch boxes	2	Area	30	0.2125 (0.180-0.245)	0.010 (0.003-0.016)	5	
Cleanup	6	Area	30	0.002 (0.000-0.006)	0.000 (0.000-0.000)	5	
Clothes handling	2	Area	30	0.0015 (0.000-0.005)	0.000 (0.000-0.000)	5	
Handling, unpacking, and repacking boxes of automobile clutch discs	20	Area	30	0.044 (0.000-0.366)	0.000 (0.000-0.003)	50	
Stacking clutch boxes	1	Area	30	0.2125 (0.180-0.245)	0.000 (0.000-0.000)	50	
Cleanup	3	Area	30	0.002 (0.000-0.006)	0.000 (0.000-0.000)	50	
Clothes handling	1	Area	30	0.0015 (0.000-0.005)	0.000 (0.000-0.000)	50	
Removal of automotive clutches	58	Area	26-161	0.047 (0.015-0.13)	0.013 (<0.002-0.03)	5-10	Cohen and Van Orden, 2008
Automobile studies (brakes)							
Filing of brake shoes	4	Area	Associated worker samples ranged from 30 to 107 min; sample duration not reported for individual area samples	0.0356	0.0128	<10	Blake et al., 2003
	2	Area			0.0097	>10	
Hand sanding brake shoes	4	Area		0.0684	0.0097	<10	
	1	Area			0.0091	10	
	2	Area			0.0092	>10	
Arc grinding I	4	Area		0.4358	0.0266	<10	
	1	Area			0.0828	10	
	2	Area			0.0389	>10	
Arc grinding II	4	Area		0.1734	0.0186	<10	
	1	Area			0.0372	10	
	2	Area			0.0154	>10	
Cleaning	4	Area		0.0000	0.0000	<10	
	1	Area			0.0000	10	
	2	Area			0.0000	>10	
Packing and unpacking brake pads	26	Area	30	0.2974 (0.008-1.190)	0.0166 (0.001-0.076)	5	Madl et al., 2008[d]
Packing and unpacking brake shoes	16	Area	30	0.0646 (0.021-0.193)	0.065 (0.002-0.038)	5	
Cleanup after packing and unpacking activities	2	Area	30	0.004 (0.002-0.006)	0.002 (0.001-0.004)	5	
Clothes handling after packing and unpacking activities	1	Area	30	0.011 (0.007-0.015)	0.010	5	

Table 4. continued on next page

Table 4. Continued.

Activity	Number of samples	Sample type	Sample time (minutes)	Point source sample concentration (f/cc)*	Bystander sample concentration (f/cc)*	Distance from source (ft.)	Reference
Packing and unpacking brake pads	13	Area	NR	0.2974 (0.008–1.190)	0.0082 (0.003–0.017)	25–30	
Packing and unpacking brake shoes	5	Area	NR	0.0646 (0.021–0.193)	0.001 (0.001–0.002)	25–30	
Cleanup after packing and unpacking activities	3	Area	NR	0.004 (0.002–0.006)	0.003 (0.001–0.006)	25–30	
Clothes handling after packing and unpacking activities	1	Area	NR	0.011 (0.007–0.015)	0.002	25–30	
Gasket Studies							
Disassembly and assembly of flanges	12	Area	4 h[a]	0.004–0.005	0.003 (0.002–0.004)	(opposite end of 3x3x3 m enclosure)	Mangold et al., 2006[b]
Cutting gaskets using circular cutter	8	Area	8 h	<0.005	0.003 (0.002–0.006)	5.0–10.0	
Cutting gaskets using hand shears	8	Area	8 h	<0.005	0.004 (<0.003–0.006)	5.0–10.0	
Cutting gaskets using ball peen hammer	8	Area	8 h	0.005	0.006 (0.004–0.007)	5.0–10.0	
Shaping gaskets using scribe	8	Area	8 h	<0.005	0.003 (0.002–0.004)	5.0–10.0	
Gasket removal	8	Area	8 h	<0.005	0.002 (<0.001–0.002)	5.0–10.0	
Flange face cleaning using putty knife	0	Area	8 h	<0.005	0.001 (<0.001–0.002)	5.0–10.0	
Flange face cleaning using hand wire brush	8	Area	8 h	0.007	0.003 (0.002–0.005)	5.0–10.0	
Flange face cleaning using power wire brush	8	Area	8 h	0.009	0.001 (<0.001)	5.0–10.0	
Packing removal and installation	1	Personal	4.5	<0.011	<0.009	NR[+]	
Packing removal and installation	8	Area	4.5	<0.011	0.004 (0.002–0.006	5.0–10.0	
Band sawing sheet gasket material	1	Area	25	2.2–3.1	0.75–0.96	~2–3 (60–90cm)	Fowler, 2000[b]
	1	Area	6	3.1–4.9	1.8–2.3	~2–3 (60–90cm)	
Scraping and hand wire brushing large flange assemblies	24	Area	15–30	9.3–24.0	2.1–8.4	~7 (2.1 m)	Longo et al., 2002[b]
Power wire brusing of large flange assembly	16	Area	15–30	14.9–31	7.6–15.7	~7 (2.1 m)	
Gasket removal	1	Area	148[a]	0.0035	0.0017	9	Blake et al., 2006[d]
	1	Area	151[a]	0.0035	0.0013	15	
	1	Area	148[a]	0.0035	0.0011	18	
	1	Area	151[a]	0.0035	0.0026	19	
	1	Area	148[a]	0.0035	0.0017	30	
	1	Area	151[a]	0.0035	0.0007	2[c]	
	1	Area	120[a]	0.0004	0.0009	19	
Day 1: Disassembly of a medium duty diesel engine — Removal of gaskets	2	Area	29–60	<0.028–<0.046	<0.021–<0.022	10	Liukonen and Weir, 2005[b]

Table 4. continued on next page

Table 4. Continued.

Activity	Number of samples	Sample type	Sample time (minutes)	Point source sample concentration (f/cc)*	Bystander sample concentration (f/cc)*	Distance from source (ft.)	Reference
Day 2: Disassembly of a medium duty diesel engine — Removal of gaskets and cleaning of gasket surfaces	6	Area	11-64	<0.021-<0.12	<0.02-<0.118	10	
	1	Personal	11[e]	<0.021-<0.12	<0.113	2-5	
Day 3: Disassembly of a medium duty diesel engine — Cleaning of gasket and other surfaces	2	Area	38-192	0.012-<0.023	<0.007-<0.034	10	
	2	Personal	38-192	0.012-<0.023	<0.008-<0.035	2-5	
Mastic studies							
Application of Lagtone 31-95 coating	12	Area	NR	ND	0.0092 (ND-0.15)	6	Paustenbach et al., 2004[b]
Application of Sealfas 41-96	8	Area	NR	ND	0.0092 (ND-0.012)	6	
Application of C.I Mastic 60-25	12	Area	NR	ND	0.0055 (ND-0.0063)	6	
Application of fibrous adhesive 81-27	4	Area	NR	ND	0.01 (ND-0.011)	6	
Spill clean up of Lagtone 31-95	36	Area	NR	0.068	0.014 (ND-0.031)	6	
Spill clean up of Sealfas 41-96	36	Area	NR	ND	0.01 (ND-0.012)	6	
Spill clean up of C.I. Mastic 60-25	36	Area	NR	ND	0.01 (ND-0.018)	6	
Spill clean up of Fibrous adhesive 81-27	36	Area	NR	ND	0.012 (ND-0.018)	6	
Sanding of Lagtone 31-95	12	Area	NR	ND	0.015 (ND-0.021)	6	
Sanding of Sealfas 41-96	12	Area	NR	ND	0.011 (ND-0.014)	6	
C.I. Mastic 60-25	4	Area	NR	ND	0.011 (ND-0.011)	6	
Removal of Lagtone 31-95	12	Area	NR	ND	0.013 (ND-0.018)	6	
Removal of Sealfas 41-96	12	Area	NR	ND	0.012 (ND-0.018)	6	
Sweep cleaning of Lagtone 31-95	12	Area	NR	0.080	0.041 (max of 0.062)	6	
Sweep cleaning of Sealfas 41-96	12	Area	NR	ND	0.011 (ND-0.014)	6	
Phenolic Molding Stuides							
Band sawing of phenolic molding material	12	Area	30	0.11 (<0.04-0.21)	0.07 (<0.03-0.32)	6	Mowat et al., 2005
Belt sanding of phenolic molding material	16	Area	30	0.03 (<0.03-0.05)	0.04 (<0.02-0.08)	6	
Press drilling phenolic molding material	16	Area	30	<0.01 (<0.01)	0.01 (<0.003-0.02)	6	
Sweep cleanup during sawing, sanding and drilling	36	Area	30	0.02 (<0.01-0.08)	0.01 (<0.003-0.03)	6	

*Mean concentration presented if multiple sample results available. Reported ranges are in parentheses. Results presented as PCM-adjusted for asbestos content, unless otherwise noted.
[a]Sample results reported as 8-hr TWAs.
[b]Sample results reported as PCM results, not PCM adjusted.
[c]Distance from point source is estimated.
[d]Samples were reported only when asbestos fibers were detected.
[e]A personal sample was taken only during one portion of the day. It was then compared to a primary source sample from that time period only.
ND= Not detected.
NR= Not reported.
NR*= The sample was reported as a bystander sample on an assitant working close by, but not at a specified distance.

study conducted by Liukonen and Weir in 2005 were less than the analytical limit of detection (Liukonen and Weir, 2005). This study did not provide any useful data for this analysis.

Work with friction products (clutches and brakes)

In 2008, two studies were published that characterized airborne asbestos concentrations associated with handling clutches. The first of these, by Cohen and Van Orden (Cohen and Van Orden, 2008), assessed bystander exposures using area samples taken in four different directions 5–10 feet from where the mechanic disassembled and removed manual clutches from a variety of vehicle types. Although this study did not present area sample results separately by distance (5 versus 10 feet from the mechanic), the authors noted that the area samples "were significantly lower than those obtained from the mechanic" (p value not provided). The average concentration reported for the bystander (area) samples was approximately 30% the average concentration reported for the worker.

The second clutch study (Jiang et al., 2008) evaluated airborne asbestos concentrations associated with handling of clutch parts (stacking, unpacking/repacking of boxes containing clutches), as well as cleanup and clothing handling. Worker samples were collected as two sets: two 15-minute consecutive samples ($n=4$, left and right lapels) and one 60-minute sample ($n=2$, left and right lapels). During each sampling event, 30-minute bystander samples were collected at two locations 5 feet from the main activity, as well as at a remote location (50 feet). For purposes of this analysis, the two 15-minute consecutive samples were averaged and compared to the 30-minute bystander area samples. The authors noted that airborne concentrations for the workers were considerably higher in the first of the two consecutive samples; however, because the corresponding bystander samples were 30 minutes, it was not possible to directly compare the worker and bystander concentrations for the shorter sample duration. Bystander samples were 4–10% that of the primary worker during these activities. Just over half (27/50) of the bystander (5 feet) samples were non-detects, whereas nearly all (24/25) of the remote background (50 feet) samples were reported as such. This study also reported that airborne asbestos concentrations differed significantly between (1) workers and bystanders 5 feet away ($p<.005$), (2) workers and bystanders 50 feet away ($p<.005$), and (3) bystanders 5 feet away and bystanders 50 feet away ($p<.05$).

In a similar study involving brakes, Madl et al. (2008) measured airborne asbestos concentrations during the unpacking and repacking of brake pads and shoes. Again, two consecutive 15-minute worker samples, as well as one 30-minute worker sample (collected concurrently with the two 15-minute samples), were obtained. Four area samples were collected at breathing zone height at distances of 1.5 m (5 feet) and between 7.6 and 9.1 m (25–30 feet) from the worker; these were 30-minute samples that corresponded to the two consecutive 15-minute samples. Like the Jiang et al. (2008) study, bystander asbestos concentrations were approximately 4–10% that of the primary worker; this difference was statistically significant ($p<.05$), as was a comparison between the worker and remote (25–30 feet) samples.

The second brake study (Blake et al., 2003) presented data collected during six complete (four-wheel) brake changes involving sanding, arc grinding, and cleaning operations; one cleaning test was also performed. Although individual sampling results were not available for the area samples that were representative of bystanders, the authors reported that there was not a statistically significant difference between the samples in close proximity to the work and those collected at the opposite ends of the shop. Individual results were available for area samples collected approximately 3 m (10 feet) from the primary worker (three samples were referred to as "bench" by the authors, and presumably represented an adjacent workbench). Area samples during the various activities were approximately, 20–25% the values reported for the primary worker.

Occupational use of coatings, mastics and adhesives, and phenolic molding compound

Two simulation studies involving the application, removal, manipulation, and cleanup of several materials that contained encapsulated asbestos were considered in this review. The first of these, published in 2004 by Paustenbach et al., evaluated airborne asbestos concentrations during a variety of tasks involving asbestos-containing coatings, mastics, and adhesives. This study was of limited use in this analysis, primarily because only 6 of 452 samples had detectable levels of asbestos fibers (Paustenbach et al., 2004).

In 2005, Mowat et al. measured airborne asbestos exposures during band sawing, belt sanding, drill press operating, and phenolic molding material (Bakelite) cleanup. For each activity (performed in four 30-minute replicates), four area samples were collected simultaneously at breathing zone height at a distance of approximately 1.8 m (6 feet) from the center of the work surface. Of the bystander (area) samples, just over half (57%) were below the analytical sensitivity limit. A similar proportion of non-detects (60%) was noted among the corresponding worker samples (Mowat et al., 2005). Average asbestos concentrations during the various activities were similar for the bystander (area) and worker (personal) samples, regardless of whether the samples reported as less than the limit of detection were analyzed using a value of one-half the limit of detection or the full limit of detection.

Ratio of bystander:worker asbestos concentrations

In addition to comparisons of bystander to worker airborne asbestos concentrations within the individual studies, the results were compiled into a single data set. As noted previously, worker-bystander pairs in which the worker sample had a result below the LOD were excluded from further analysis. No discernable trends were evident when bystander:worker ratios were plotted independently against distance from the primary worker (Figures 4 and 5). Similarly, the box plots by distance groups (1–5, >5–10, >10–30, and >30 feet) did not follow a linear pattern (Figure 6).

Within each distance group, the average bystander:worker ratios were as follows: 1–5 feet, 0.08 (range = 0–1, σ = 0.17); >5–10 feet, 0.61 (range = 0.01–1, σ = 0.33); >10–30 feet, 0.11 (range = 0–1, σ = 0.05); and >30 feet, 0.10 (range = 0–1, σ = 0.09). It should be noted that the bystander:worker ratios at the >5–10 feet distance group were much higher than the other three groups. Nearly all of these samples were from the Mowat et al. (2005) study, which had a significant number of samples less than the LOD.

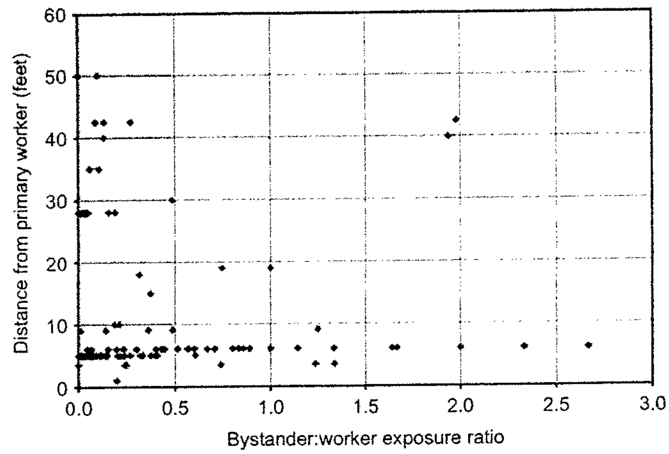

Figure 4. X-Y scatter plot for published data. bystander:worker ratios of airbone asbestos concentrations at distance from a source

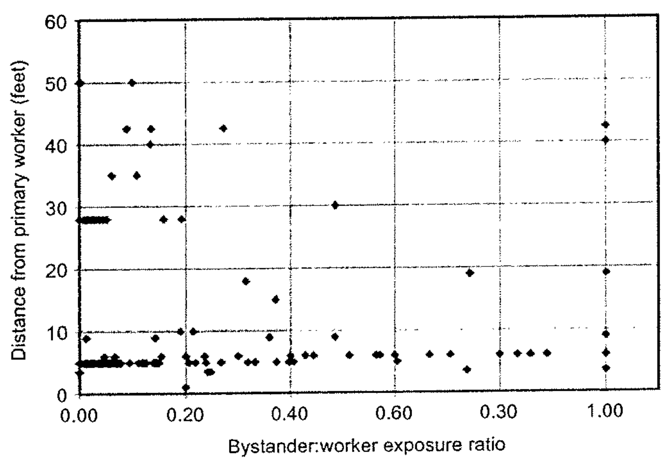

Figure 5. X-Y scatter plot for bystander:worker ratios of airborne asbestos concentrations with all ratios >1 replaced by 1.

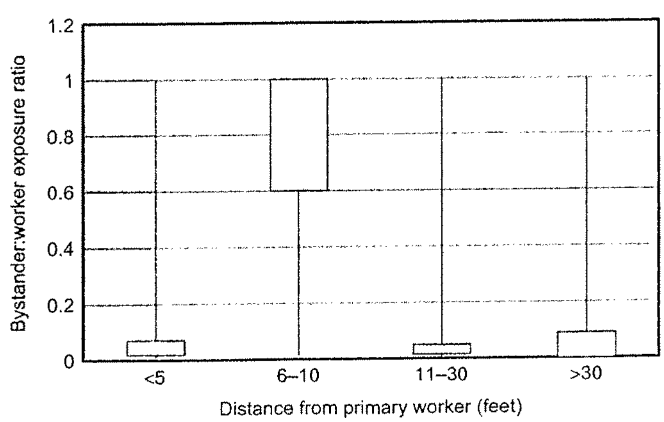

Figure 6. Box plot by distance groupings for bystander:worker ratios of airborne asbestos concentrations with all ratios >1 replaced by 1.

Summary of available literature relevant to mathematical modeling of airborne asbestos concentration with distance

Because the available published data could not provide resolution on the relationship between airborne asbestos concentrations with distance from a source, an additional literature review was conducted to determine whether mathematical models could be used. Although there are no commonly applied models that directly address asbestos fiber concentrations in air, there are several that have been developed in an attempt to understand the characteristics of airborne particles, including their movement in air and the rate and distance at which they are likely to settle out of air (Timbrell, 1965). Some of the basic assumptions set forth in general particle movement models include the idea that fluid or air is incompressible, that there are no walls or other particles nearby, that motion is constant, that the particle is a rigid sphere (or spherical equivalent), and that the fluid velocity of air at the particle's surface is zero (Hinds, 1999).

Other authors have also explored the effects of forces outside of settling velocity on the removal of particulates from air. Reist indicated that in more turbulent airflows, such as what would be expected in a typical workplace, particles may be removed from the air by mechanisms other than settling, including impaction on other bodies, centrifugation, agglomeration, Brownian motion, and diffusion (Reist, 1975). According to Drinker and Hatch (1954), diffusion is the primary method by which micron-sized particles are removed from the air. It is also important to note that dynamic projection of small particles (i.e., adding kinetic energy of velocity) does not appear to significantly change the distance that they travel. For example, a 10-μm round unit density particle with an initial velocity of 5000 cm/s will be significantly affected by the viscous forces of air, and, despite its initial velocity, will travel only approximately 4 cm before stopping. Likewise, a 1-μm round unit density particle will travel only approximately 0.4 mm after being projected at the same initial velocity. As Drinker and Hatch note, this finding is important to the study of dust dispersion in industry because it indicates that the extension or reach of microscopic particles in the work environment is not dependent on the kinetic energy of the particles or the energy with which they are released into the environment. Rather, the small size of these particles causes them to be affected by the viscous forces of air, and significantly reduces the distance that they are able to travel.

In situations where a clear generation source of a contaminant exists in an enclosed space, a multizone model approach has been used to characterize the differences in contaminant concentration in different areas of the space with increasing distance from the source. In the transient two-zone model, a localized box or space that contains and surrounds the generation source of a contaminant is typically defined as the "near field," whereas the rest of the room or work space is defined as the "far field." The near field is most commonly defined as a sphere or hemisphere with a radius of approximately arm's length, or 0.78 m (2.5 feet). This definition is consistent with the conventional industrial hygiene definition of the breathing zone, as well as other published studies that have used the transient two-zone model (Keil, 2000; Nicas et al., 2006; Keil et al., 2009). The two zone model has been used to predict chemical or particulate exposure for a diverse range of published exposure scenarios (Keil and Murphy, 2006; Vernez et al., 2006; Armstrong and Haas, 2007; Gaffney et al., 2008). A model with three or more zones can also be used to further differentiate the space if needed (US EPA, 1997), but the improvement in precision is often not worth the effort, since differences between the second and third zones may be small (Sahmel et al., 2009).

Particle models can be adapted to characterize airborne fibers. Because asbestos fibers are not spheres, a correction factor such as the dynamic shape factor (defined as the ratio of the actual resistance force of the nonspherical particle to the resistance force of a sphere having the same volume and velocity, referred to as the aerodynamic diameter) can be applied (Reist, 1975; Hinds, 1999). The asbestos fiber characteristic of a very consistent diameter along the length of a fiber has led some researchers to attempt to estimate air concentrations and movement of fibers using a cylinder shape for aerodynamic purposes (Bragg et al., 1974; Assuncao and Corn, 1975).

Beginning in the 1970s, the scientific community began to look at modeling asbestos exposures (Bragg et al., 1974; Sawyer and Spooner, 1978; Committee on Indoor Pollutants Board on Toxicology and Environmental Health Hazards, 1981). For example, the National Research Council's Committee on Indoor Pollutants reported that fiber settling velocity depends far more heavily on fiber diameter than on fiber length, and estimated that in still air in a room with a height of 3 m, a fiber with dimensions 5 μm long by 1 μm in diameter would remain airborne for approximately 4 hours. The committee further estimated that a fiber of the same length with a 0.1 μm diameter would remain airborne for closer to 20 hours. In 1978, the US Environmental Protection Agency (EPA) also evaluated the speed with which asbestos fibers may settle out of air (US EPA, 1978). They estimated that settling velocity was more strongly dependent on fiber diameter than on length, and determined that settling velocities for fibers that were 5, 2, and 1 μm in length with a 5:1 aspect ratio would require 4, 20, and 80 hours, respectively, to settle out of still air from a height of 9 feet. They further estimated that air turbulence would prolong the settling and cause reentrainment of fallen fibers. According to these reports, OSHA fibers (i.e., those equal to or longer than 5 μm) tend to have shorter settling times than shorter fibers, and the fiber aspect ratio has an important influence on the concentration vs. settling time relationship. There was no discussion in these reports of the relationship of concentration decrease with distance versus particle or fiber length.

Despite these calculated estimates of the time required for asbestos fibers to settle out of air, both laboratory and field studies have shown that asbestos fibers appear to remain airborne for shorter time periods than would be expected based on such modeling. In a study conducted by Moorcraft and Duggan in which airborne asbestos concentrations were measured in a room with no mechanical ventilation after vigorous dust disturbance, for example, the authors found that the asbestos fibers settled out of air more quickly than was expected based on their settling velocity calculations (Moorcroft and Duggan, 1964). Specifically, the duration for which the disturbed fibers remained airborne was less than 1 hour. It was postulated that additional fiber removal mechanisms other than gravitational settling were at work in the study space, including interception and impaction on surfaces, or possible electrification of the fibers and subsequent removal from the air by electrical forces. The authors indicated that less than 25% of the fibers counted had a diameter of greater than 1 μm, and almost all fibers had aspect ratios of greater than 10 to 1. Similarly, limited measurements by Corn et al. (1966) found that few particles above 5 μm in size remained suspended in air, despite calculations that showed that room air currents could theoretically keep particles up to 90 μm in size airborne. The authors hypothesized that this finding could be due to one or more of three factors: (1) effects of the slow-moving air boundary layer that adjoins the surfaces of objects and slows the speed of particles traveling close to these surfaces (therefore reducing the ability of particles to be pulled back into room air currents once they enter this air boundary layer); (2) the likelihood of air currents to deposit particles as frequently as they remove them from surfaces; or (3) the inertia of particles in motion resulting in rapid deposition by impaction on surfaces.

To evaluate the potential for reentrainment of dust once it has settled out of air, Corn and Stein (1966) also evaluated the forces by which particles adhere to surfaces, including mechanical, electrical, and air drag forces. Based on calculations using experimental data for the adherence of particles less than 80 μm in size, they estimated that particles in this size range were unlikely to encounter mechanical, electrical, or velocity forces alone in the typical occupational environment that were sufficient to break the adhesive forces of particles on surfaces. They concluded that active disruption of particles from human activity would be required to cause reentrainment.

In summary, based on our literature review, there were no widely used mathematical models that could be applied to estimate airborne fiber concentrations at varying distances from a source. Much of the work that has been conducted thus far has involved applying a correction factor to particle models to account for differences in fiber characteristics. The available information about particle or fiber behavior in air indicates that multiple forces, such as settling velocity, interception and impaction on surfaces, and possible electrification of the fibers may all play a role in removing fibers from the air, which is consistent with the assumptions set forth by Drivas et al. (1996). As noted previously, we considered the bystander estimates generated using this model to be based on a more accurate representation of workplace conditions, whereas the the Keil (2000) model was used to provide an upper bound concentration if reflection and deposition did not occur. Our review of the available particle and fiber literature appears to support this approach.

Results of mathematical modeling developed to estimate airborne asbestos concentration with distance

The bystander:worker ratios generated by the eddy diffusion models with and without deposition and reflection are presented in Table 5. Under the Drivas et al. (1996) model that includes reflection and deposition, the predicted bystander concentrations relative to the airborne concentration at the source, were 37% at 3 feet, 2% at 10 feet, and 0.3% at 15 feet. The ratio increased significantly at a distance of 20 feet (0.03%), and all calculated ratios at 25 feet or greater were less than 0.0001%.

Using the Keil (2000) model without reflection and deposition, the decrease in predicted airborne asbestos concentrations with distance from the source was less dramatic. As noted previously, the purpose of this model is to provide an "upper bound" on the expected concentration relationships between a bystander and worker. Under this second set of conditions, this model assumes that the only mechanism by which particles are removed from the air is dilution by room ventilation, an assumption that would tend to over predict the actual field concentration of the fibers. Under these conditions, the predicted bystander concentrations, relative to the airborne concentration at the source were 83% at 3 feet, 38% at 10 feet, 14% at 15 feet, 7% at 20 feet, and 0.8% at 30 feet. For distances greater than 50 feet, the ratios were less than 0.0001%; in other words, there is virtually no impact of the asbestos emitted from a point source, for OSHA fibers, at distances greater than 50 feet. This finding is entirely consistent with what has been predicted by both the theories described above and most field studies.

Proposed "rule of thumb" to estimate bystander exposure at specific distances from a source

In this analysis, the calculated or modeled bystander:worker ratios differed at specific distances from the source. However, based on our understanding of the individual studies, we felt that it would still be a worthwhile exercise to consider the data together for purposes of developing a rough "rule of thumb" for evaluating bystander exposure with distance from a source. As described previously, the results based on the Drivas et al. (1996) model were considered a starting point, and any adjustments to the modeled values were based on professional judgment. A summary of the values used to derive the rule of thumb is provided in Table 6.

For persons between 1 and 5 feet from the worker, it is expected that the airborne asbestos concentrations would be approximately 50% of that measured at the source. This estimate is based primarily on the Drivas et al. (1996) modeling results, and is conservative in comparison to the average bystander:worker ratio reported for the various simulation studies for which data were available (8.2%). However, because there were no workplace survey data (which had higher initial airborne asbestos concentrations) in this

Table 5. Model predicted relationship between the airborne concentration of asbestos fibers (greater than 5μm in length) and the concentration at various distances (concentrations are based on 15 minutes of possible emissions at the source).

	Model with Reflection and Deposition (Based on Drivas et al, 1996)		Model without Reflection and Deposition (Based on Keil, 2000)	
Distance from source (ft)	15 min time averaged concentration (f/cc)	Ratio of bystander:worker airborne asbestos concentration	15 min time averaged concentration (f/cc)	Ratio of bystander:worker airborne asbestos concentration
0	0.43	1.0000	0.028	1.0000
1	0.38	0.8840	0.028	0.9814
2	0.27	0.6229	0.026	0.9298
3	0.16	0.3748	0.024	0.8555
4	0.094	0.2182	0.022	0.7710
5	0.060	0.1383	0.019	0.6864
6	0.041	0.0959	0.017	0.6077
7	0.029	0.0684	0.015	0.5367
8	0.021	0.0481	0.013	0.4730
9	0.014	0.0332	0.012	0.4152
10	0.0097	0.0224	0.010	0.3623
11	0.0065	0.0150	0.0088	0.3139
12	0.0043	0.0100	0.0076	0.2699
13	0.0029	0.0067	0.0065	0.2304
14	0.0019	0.0044	0.0055	0.1953
15	0.0013	0.0029	0.0046	0.1645
16	0.00082	0.0019	0.0039	0.1379
17	0.00054	0.0012	0.0032	0.1150
18	0.00034	0.0008	0.0027	0.0956
19	0.00022	0.0005	0.0022	0.0791
20	0.00014	0.0003	0.0018	0.0653
25	<0.0001	<0.00001	0.00067	0.0237
30	<0.0001	<0.00001	0.00022	0.0077
35	<0.0001	<0.00001	<0.0001	0.0022
40	<0.0001	<0.00001	<0.0001	0.0006
45	<0.0001	<0.00001	<0.0001	0.0001
50	<0.0001	<0.00001	<0.0001	0.0000
55	<0.0001	<0.00001	<0.0001	<0.00001
60	<0.0001	<0.00001	<0.0001	<0.00001
65	<0.0001	<0.00001	<0.0001	<0.00001
70	<0.0001	<0.00001	<0.0001	<0.00001
75	<0.0001	<0.00001	<0.0001	<0.00001

Table 6. Summary of data used to derive "rule of thumb" for bounding bystander exposure estimates.

	Model with reflection and deposition (based on Drivas et al. 1996)		Model without reflection and deposition (based on Keil 2000)		Combined data set based on published simulation studies and workplace surveys		
Distance from source	*N*	Mean bystander: worker ratio	*N*	Mean bystander: worker ratio	*N*	Mean bystander: worker ratio	*SD*
1-5 ft	6	0.54	6	0.87	121	0.08	0.20
>5-10 ft	5	0.07	5	0.48	51	0.61	0.60
>10-30 ft	12	0.004	12	0.14	30	0.11	0.23
>30 ft	8	<0.00001	8	0.00	34	0.10	0.47

*For modeling results, *N* is the number of distances for which bystander concentrations were estimated. See Table 5 for data that were used in this calculation.

distance category, we did not feel that we could justify lowering the proposed reduction. Thus, because the Drivas et al. (1996) estimate of 50% was close to the midpoint of the upper bound average of 87% based on Keil (2000) and the average reported for the published data (8.2%), we chose to keep this number as the proposed value for this distance category.

At distances of >5-10 feet, the results based on Drivas et al. (1996) decrease from 9.6% at 6 feet to 2.2% at 10 feet (average value is 6%), whereas the corresponding values based on the Keil (2000) model range from 60.8% at 6 feet to 36.2% at 10 feet (average value is 47.9%). The average bystander:worker ratio based on the published data is 61%. It should be noted, however, that of the 51 samples from the published data set that comprise this group, 44 are from the Mowat et al. (2005) study, which had a very high proportion of samples below the LOD. Because the samples in this particular study were collected in groups of two or four and averaged together, it was often the case that one to three of those individual sample results were less than the LOD, but included in our analysis because at least one of the other samples used to calculate the average value had a detectible result. The airborne asbestos concentrations measured in this study were extremely low in both the worker and bystander samples, so the higher bystander:worker ratio calculated in this analysis for the Mowat et al. (2005) study should be interpreted with caution. The remaining seven samples were also from simulation studies with lower asbestos concentrations; the average bystander:worker ratio among these samples was 37.9%. For this distance group, a value of 35% was selected for the rule of thumb.

Between >10 and 30 feet, the Drivas et al. (1996) model predicted reductions from 1.5% at 11 feet to 0.001% at 30 feet (average reduction was 0.4%), whereas the corresponding Keil (2000) values were 31.39% at 11 feet and 0.77% at 30 feet (average reduction was 14%). There are relatively few simulation study results for this distance range; notably, nearly all available data correspond to very low airborne asbestos concentrations (<0.01 f/cc) at the source. For the workplace surveys, the worker to bystander ratios vary considerably by source/activity, from 81% during hand sanding of patching compounds at 15 feet to 5% during a brake blowout at 20 feet. It should be noted that the data generated during sanding of patching and spackling compounds (described previously) reflect fairly similar airborne asbestos concentrations between the source and nearly all distances for which air samples were collected. The average reduction based on the published studies at >10–30 feet was 12%. For this distance group, a value of 10% was selected for the rule of thumb.

Lastly, a factor of 1% was selected for distances of 30 feet or greater. At 30 feet, estimates from both models are below 0.1%. The average value for the published data was higher at 9.1%, but, again, the data were dominated by simulation study results with very low airborne asbestos concentrations. The simulation studies considered in this review included "remote area" samples at 50 feet, and the reported concentrations among these samples were less than 1% of those measured for the worker. Although it is possible that smaller fibers (those less than 5 μm) could "drift" longer distances, there are numerous factors that indicate that such drifting is unusual, and even when it does occur, the actual concentration (by mass) is very small.

Discussion

Based on this review, two primary sets of data for characterizing bystander exposure to asbestos were identified. The first included short-term peak (task-based) samples collected during workplace surveys conducted in the 1970s involving activities in which airborne concentrations could be appreciable (particularly during spray-on asbestos operations). The second set was comprised of simulation study results. Unlike the field studies, the simulation studies were designed to obtain a general understanding of bystander exposure, and, just as importantly, benefited from very low limits of detection and data with very good quality control. Airborne asbestos concentrations in the workplace surveys were orders of magnitude higher than what was observed in the simulation studies involving asbestos-containing, encapsulated products. Despite the obvious differences in the data sets, airborne asbestos concentrations in bystander samples were, as expected, nearly always lower than the corresponding worker samples. The magnitude of this difference varied considerably among the field studies, which hampered our ability to make meaningful comparisons.

Nonetheless, the topic of particle physics and particle dynamics has enjoyed a considerable amount of study over the past 40 years, and it would be erroneous to suggest that, at least for general estimation purposes, the airborne concentration in the typical workplace cannot be predicted if there is some knowledge of the particle size distribution (aerodynamic mean diameter) and the magnitude of the point source. To that end, a simple mathematical model was incorporated into this analysis to characterize the relationship between breathing zone concentration at a source and distance; as expected, the predicted airborne asbestos concentrations decreased with distance from the source. It should be noted, however, that this model is relatively simplistic, in that it is based on a single worker in a single room with typical room ventilation (dilution ventilation). We did perform one exercise where net advective airflow was included in the models (data not shown), but the impact varied widely depending on where the ventilation source was placed relative to the bystander (i.e., directly upwind or along an axis perpendicular to the bystander, creating a crosswind) (Keil et al., 2009). It was determined that for purposes of this assessment, a simpler model as preferable. As such, the models used in this analysis are not be able to account for situations in which there may be local exhaust ventilation, open windows, large body cooling fans, or high dilution ventilation (such as in some hot workplaces, for example ship boiler rooms or steel mills).

Based on the available published literature and the modeling results, we have proposed general guidelines for estimating bystander exposures to airborne asbestos if the airborne concentration for the worker is known, and if the distance from the source is less than 50 feet. We also propose that, going forward (for future published papers), there be agreement that the term "bystander" shall describe persons working 3 to 10 feet from the primary worker, as it is more likely that these individuals may be working on their own tasks, handing the primary worker tools, or simply standing guard (as seen with welding or clean-up duty), and not directly assisting the primary worker. This distance is generally consistent with what has been considered in the simulation studies to be representative of bystander exposure (5–10 feet), and, in fact, the term "bystander" has often been used to characterize samples at these distances in a large fraction of published studies. For distances less than 3 feet, we propose that the term "coworker" or "assistant" be used. Because a coworker may be in very close proximity to the primary worker, it is possible that this person may actually be assisting the worker in performing the task at hand. For persons working at distances 11–30 feet from the primary worker, we suggest the term "remote bystander."

There are several sources of uncertainty in this analysis, most of which stem from the variability of exposure scenarios and asbestos products that were evaluated in the individual studies and issues in the various data sets used to arrive at a single factor for each distance group. First, there were few workplace studies in the published literature that provide air sampling data at known distances from a source. The 1970s studies included in this analysis span a wide variety of workplace conditions, and are not directly comparable. All of these studies were conducted more than 30 years ago, and none were intended to answer the questions raised in this paper. Shortcomings of these early studies were that insufficient samples were collected, and that fiber length or diameter analyses were not rigorously evaluated. Had these shortcomings been addressed, the differences in the ability of very small fibers (shorter than 5 μm), OSHA fibers (longer than 5 μm and often less than 40 μm), and very long fibers (those greater than 40 μm) to travel specific distances could have been better characterized. Analytical procedures and quality control were less rigorous at that time, although this is probably not a large source of uncertainty, given the magnitude of the airborne concentrations. Later studies included craftspersons who were likely bystanders to insulation work, but often also personally handled asbestos in the course of their own work, making it nearly impossible to make inferences about the point source to distance relationship.

Second, the more recent simulation studies included in this analysis were conducted during activities resulting in airborne asbestos concentrations that were orders of magnitude lower than the 1970s workplace studies. In some cases, half or more of the samples (worker and bystander alike) were below analytical detection limits, limiting their utility to aid in this assessment. In our analysis, we excluded worker-bystander pairs in which the worker sample (or pair of samples, such as left and right lapels) was below the LOD. We did, however, include bystander samples that were less than the LOD by using a value of one-half the LOD in the calculation of the bystander:worker ratio. This inclusion could have served to underestimate the reduction in airborne asbestos concentration with distance because a value was used when, in fact, the asbestos fibers may have already settled out of the air. The basic comparisons (i.e., percent reduction) of mean airborne asbestos concentrations among workers and bystanders may have also been impacted by the preponderance of samples below the LOD, as most of the mean values reported in the simulation studies included some results that were less than the LOD. Had there been higher concentrations at the point source, or had it been possible to have a lower limit of detection for samples taken at specific distances from the source, more could have been learned from these studies. Madl et al. (2008) reported a statistically significant difference between worker and bystander (5 feet) airborne asbestos concentrations, as well as between the samples for the bystander at 5 feet and the bystander at 50 feet. It is possible that this difference was observed most clearly in this study because a larger number of samples were collected, thus allowing for genuine differences in concentration to be measured.

Lastly, as we have indicated, there is moderate uncertainty regarding the precision of our estimated rule of thumb, but it should be acknowledged that the universe of potential values for estimating the airborne concentration of OSHA fibers, at a distance, is limited because of particle physics, as well as the matter of mass balance. For example, it is known that the vast majority of the larger particles or fibers deposit fairly close to the source, only a lesser amount is left and available for transport to much longer distances. With respect to uncertainty regarding the relationship between airborne asbestos concentrations and distance from a source, we considered offering up a range for each distance, but, given the vagaries of air movement and deposition (and agglomeration) that can occur in the workplace environment, additional precision is probably not necessary. For example, even when the left and right lapels of a worker doing a particular task are sampled, it is not uncommon for the values to be different by a factor of 2 at low concentrations (e.g., 1 versus 2 ppm).

The purpose of the rule of thumb is to help the exposure or risk assessor develop an understanding of the likely reductions that will occur in asbestos concentrations based on increasing distances from the source, as well as fiber-specific properties including diameter and length. Thus, given that there is currently no guidance offered for estimating historical exposures of workers in the typical "open industrial environment," we believe that providing this analysis of both field data and current dispersion models will be helpful to those involved in estimating asbestos concentrations in workplaces for which no quantitative exposure data exist, such as in historical exposure reconstruction efforts. If, for example, one were interested in determining whether respiratory protection would be needed for potential bystanders in an active workplace, use of the proposed rule of thumb would be too uncertain given that there is the option of collecting quantitative exposure data such as air samples that are specific to the workplace of interest.

This review of the literature indicates that much more research is needed to quantitatively understand the relationship between the airborne concentrations at the source versus the concentrations at a distance, especially for fibers between 5 and 20 μm and those greater than 20 μm (i.e., those of biological significance). We suggest that future studies incorporate air sample collection at numerous fixed distances from a source (north, south, east, west), along with consideration of fiber length and aspect ratio. Ultimately, such studies will help fine tune existing mathematical models for particulates. Such studies would also greatly advance the development of new models that more accurately characterize the movement of asbestos fibers in the air. Given the increased interest in conducting dose-reconstruction studies in an attempt to provide dose components in epidemiology studies, this work, then, appears to be worthwhile.

Declaration of interest

A small portion of the research associated with this work was originally done in preparation for litigation and was supported by a number of companies that have been, and are, involved in asbestos-related litigation. The authors were not compensated for most of the work of compiling the information for this article, or for preparing it. One of the authors (D.J.P.) has served as an expert in asbestos-related litigation.

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Chem*Risk*

2004 Rate Sheet

Title		Hourly Rate Health Scientist	Epidemiologist
Chief Principal	$	425	425
Managing Principal	$	375	385
Supervising Principal	$	300	310
Principal	$	250	260
Senior Managing	$	225	235
Managing	$	195	205
Supervising	$	180	190
Senior	$	170	180
Scientist/Epidemiologist	$	155	165
Senior Associate	$	145	155
Associate	$	115	125
Research Associate, II	$	105	105
Research Associate, I	$	75	85
Administrative	$	60	60
Other Direct Costs			
Direct Project Costs*	$	8/hour	8/hour
Subcontractor Markup		20%	20%
Expense Markup		20%	20%

*Direct project costs include PC, copy jobs <100 pages, telephone and fax.

Note: Oustanding balances over 45 days are subject to 18% APR.

Chem*Risk*

2010 Rate Sheet

Title		Hourly Rate
Chief Principal	$	575
Managing Principal	$	450
Supervising Principal	$	390
Senior Principal	$	360
Consulting Physician	$	350
Principal	$	310
Senior Managing	$	300
Managing	$	245
Supervising	$	225
Senior	$	210
Scientist/Epidemiologist	$	190
Senior Associate I - II	$	160 - 175
Associate I - II	$	125 - 145
Assistant I - II	$	100 - 120
Research Associate I - II	$	85 - 115
Administrative	$	70

Other Direct Costs		
Direct Project Costs*	$	8/hour
Subcontractor Markup		20%
Expense Markup		20%

*Direct project costs include PC, copy jobs <100 pages, telephone and fax.

Note: Outstanding balances over 45 days are subject to 18% APR.

Chem*Risk*, LLC

2011 Rate Sheet

Title		Hourly Rate
Chief Principal	$	575
Managing Principal	$	475
Managing Principal IH	$	425
Consulting Physician	$	425
Senior Principal	$	375
Principal	$	350
Senior Managing	$	310
Managing	$	255
Supervising	$	235
Senior (Industrial Hygienist)	$	220/230
Scientist/Epidemiologist	$	200
Senior Associate I - II	$	165-180
Associate I - II	$	130-150
Assistant I - II	$	110-130
Research Associate I - II	$	90-120
Administrative	$	70

Other Direct Costs		
Direct Project Expense*	$	8/hour
Subcontractor Markup		20%
Expense Markup		20%

*Expenses associated with the allocation of internal administrative costs such as telephone, fax, copy jobs less than 100 pages, postage, administrative support, etc. that are too small to track and allocate individually.

Note: Outstanding balances over 45 days are subject to 9% APR.