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Evaluation of airborne asbestos exposure from routine handling of asbestos-containing wire gauze pads in the research laboratory

Ediberto Garcia[a], Daniel Newfang[a], Jayme P. Coyle[a], Charles L. Blake[b], John W. Spencer[c], Leonard G. Burrelli[c], Giffe T. Johnson[a], Raymond D. Harbison[a,*]

[a] *Center for Environmental and Occupational Risk Analysis and Management, Department of Environmental and Occupational Health, College of Public Health, University of South Florida, 13201 Bruce B. Downs Blvd., Tampa, FL, 33612, USA*
[b] *Bureau Veritas North America, Inc., 3380 Chastain Meadows Pkwy, Suite 300, Kennesaw, GA, 30144, USA*
[c] *Environmental Profiles, Inc., 8805 Columbia 100 Pkwy., Ste 100, Columbia, MD, 21045, USA*

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ABSTRACT

Three independently conducted asbestos exposure evaluations were conducted using wire gauze pads similar to standard practice in the laboratory setting. All testing occurred in a controlled atmosphere inside an enclosed chamber simulating a laboratory setting. Separate teams consisting of a laboratory technician, or technician and assistant simulated common tasks involving wire gauze pads, including heating and direct wire gauze manipulation. Area and personal air samples were collected and evaluated for asbestos consistent with the National Institute of Occupational Safety Health method 7400 and 7402, and the Asbestos Hazard Emergency Response Act (AHERA) method. Bulk gauze pad samples were analyzed by Polarized Light Microscopy and Transmission Electron Microscopy to determine asbestos content. Among air samples, chrysotile asbestos was the only fiber found in the first and third experiments, and tremolite asbestos for the second experiment. None of the air samples contained asbestos in concentrations above the current permissible regulatory levels promulgated by OSHA. These findings indicate that the level of asbestos exposure when working with wire gauze pads in the laboratory setting is much lower than levels associated with asbestosis or asbestos-related lung cancer and mesothelioma.

1. Introduction

Asbestos is a fibrous material used as a component in thousands of construction, industrial, and household products, including roofing and siding shingles, friction products in automobile parts, thermal systems insulation and electrical wiring, personal protective gear, and in certain laboratory equipment components. Since asbestos is classified as a known human carcinogen, its use in both commercial and industrial products has raised concerns of potential human health risks. During residency in the lungs, a significant immunological response occurs that facilitates clearance (Bernstein et al., 2005, 2008; Churg, 1994) may also cause lung injury. Asbestos-related pulmonary disease occurs in occupations associated with heavy exposure, e.g., insulators, shipyard workers, and textile workers. However, occupational exposure assessment of workers during routine use of certain asbestos-containing products, such as heavy construction equipment, automobile brakes, and plane parts, have not demonstrated exposure levels above the current regulatory Permissible Exposure Level (PEL) of 0.1 f/cc promulgated by OSHA and are not expected to result in asbestos-related disease (Blake et al., 2006, 2009; Boelter et al., 2007; Goodman et al., 2014). This assumption is in agreement with the lack of epidemiological evidence for enhanced asbestos-related disease among several occupational cohorts (Garabrant et al., 2016; Madl et al., 2009; Goodman et al., 2014).

Of the asbestos utilized commercially in the Unites States, approximately 98% was of the chrysotile asbestos type, while crocidolite composed 1.2% of the market with the remaining 0.8% split between amosite and anthophyllite; tremolite was used in low amounts (Virta, 2006). It is prudent to differentiate the *type* of asbestos in addition to asbestos *exposure* to characterize risk, as differing asbestos species have been associated with varying lung cancer potency profiles (Baur et al., 2012; Berman and Crump, 2008).

As previously indicated, asbestos-containing materials were found in diverse settings, in the public or private sector, including the chemistry, biology, and physics laboratory. In labs of training institutions, asbestos airborne contaminants could have been inhaled by not

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* Corresponding author.
E-mail addresses: edg@mail.usf.edu (E. Garcia), dnewfang@health.usf.edu (D. Newfang), jcoyle3@health.usf.edu (J.P. Coyle), charlie.blake@us.bureauveritas.com (C.L. Blake), jspencer@episervices.com (J.W. Spencer), lburrelli@episervices.com (L.G. Burrelli), gtjohnso@mail.usf.edu (G.T. Johnson), rharbiso@health.usf.edu (R.D. Harbison).

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only research personnel, but also by students and instructors. Expectedly, there have been concerns over health risks from laboratory equipment-originated asbestos exposure (Nagel, 1988), but there has been minimal asbestos exposure research of laboratory personnel to either refute or warrant heightened perception of disease risk beyond conjecture. An earlier assessment in a chemistry laboratory using asbestos-containing wire gauze pads did not show detectable levels of asbestos (Yager, 1981), though the experimental set-up and exposure conditions were not stated with enough detail to ascertain its external validity.

In this study, we evaluated three different scenarios of exposure to asbestos-containing wire gauze pads commonly found in laboratory settings in the past. In the first scenario we simulated a "worst-case" exposure with sub-standard, though safe ventilation, on newly purchased wire gauze pads under routine use. The second scenario was expected to be more consistent with standard lab ventilation conditions (2 + air changes per hour), and examined the exposure potential to length of time of wire gauze pad heating. Finally, the third scenario examined whether use of well-worn pads under standard environmental conditions resulted in measurable asbestos exposure.

2. Material and methods

2.1. Scenario facilities

2.1.1. Scenario 1

The evaluation for scenario 1 was conducted in an isolation chamber (test space) of about 4000 ft^3, with a contiguous 360 ft^3 staging room that provided two layers of protection to the outside analytical team from potential asbestos exposure. At the isolation chamber/staging room and the staging room/outside environment interfaces, makeshift doors were constructed from overlapping 6 mil polyethylene sheets. Prior to testing, the test space was thoroughly cleaned and sampled to establish baseline asbestos contamination. The space was equipped with negative pressure HEPA exhaust ventilation operated at one air exchange per hour, well below the ASHRAE minimum standard of 6 exchanges per hour for academic laboratories (ASHRAE, 2011). These conditions provide a worst-case exposure scenario that would overestimate real-world asbestos exposure observed in routine lab work. The exchange rate was sufficient to prevent noxious CO gas buildup, thus making the environment sufficiently safe for the workers. Bulk samples were completed before and after the assessment study at the experimental site. They were submitted for laboratory determination for the presence and quantity of asbestos and matrix components.

2.1.2. Scenario 2

The evaluations undertaken for scenario 2 were conducted inside a closed room of approximately 1000 cubic feet (29.8 cubic meters). The room and adjoining space was served by a ducted, forced air, heating ventilating and air conditioning system. Testing of this room using tracer gas methodology ASTM E − 741-11 demonstrated a ventilation rate of two + air changes per hour. The room was accessible via a standard personnel door and testing activities could be observed through an available viewing window. Prior to actual testing the room was thoroughly cleaned followed by collection of pretest area background air samples. Bulk samples were completed before and after the assessment study, and were submitted for laboratory determination for the presence and quantity of asbestos and matrix components.

2.1.3. Scenario 3

The simulation for scenario 3 was performed within a custom-made glove box with an internal area of 63 ft^3. The glove box frame was constructed of PVC, and flame-retardant polyethylene sheeting was affixed to the frame to create the enclosure. Air ventilation was achieved using a HEPA vacuum calibrated to provide 10 air exchanges per hour – fresh air was introduced through a one ft^2 opening in the polyethylene sheeting. The air was drawn into the chamber from the space directly outside of the glove box occupied by the analytical team, and was shown to be free of airborne asbestos (background measurements) during the execution of testing. Air fiber sampling cassettes were introduced from the ceiling while affixed to a clean rigid straight-edge, and lowered to 18 inches directly above the simulation activity (PBZ simulation sampling). Bulk samples of the wire gauze squares were completed before and after the assessment study. They were submitted for laboratory determination for the presence and quantity of asbestos and matrix components.

2.2. Experimental simulations and personnel

2.2.1. Scenario 1

Scenario simulations were performed on a single bench with four laboratory set-ups, each consisting of a tripod mount, a Bunsen burner and individual propane supply, an Erlenmeyer flask with 200 mL water and a boiling chip, and a wire-gauze pad. Five unused asbestos-containing wire gauze pads (The Perfect Parts Co., Baltimore, Maryland) were purchased for testing measuring 4″ x 4" and the asbestos-containing 3.5 diameter pad. These pads have been typically used in labs in the past to evenly distribute and transfer heat from a heating source to glassware. Only wire pads with intact shipping containers were used for air sample testing; one wire gauze pad was opened prior to testing and thus only underwent bulk content sampling. Personnel present during the evaluation included the technician performing the work, the lab assistant (sampler/recorder), a videographer, and a Certified Industrial Hygienist who ensured adherence to the preapproved protocols. The laboratory technician followed the pre-approved protocol to simulate a laboratory activity consisting of six consecutive cycles, each cycle consisting of a single 20–25 min burn period, 3–5 min cool-down (Trivet), and a 2 min manual manipulation, e.g., bending/flexing pad. Summarized activity times are tabulated in Table 1. All personnel potentially exposed to asbestos within the isolation chamber wore protective clothing (Tyvek suits) and splash goggles throughout the duration of testing.

2.2.2. Scenario 2

The simulation consisted of subjecting two wire gauze pads to a repeat-burn regimen cycle. The wire gauze pads were placed upon separate ring stands, and position directly above Bunsen burners. Erlenmeyer flasks with approximately 200 mL of water were set onto the gauze pads and makeup water was added as boiling depleted water levels. During testing, both wire gauze pads were simultaneously heated in succession for 2 h followed by 2–3 min of cooling; 1 h followed by 2–3 min of cooling; 30-min followed by 2–3 min of cooling; and 30 min followed by 2–3 min of cooling. The wire gauze pads were not manipulated manually during testing in order to isolate the effect of repeated heating and cooling on ambient asbestos concentration. A laboratory technician who wore safety glasses performed this simulation.

2.2.3. Scenario 3

The test simulations were performed in a glove-box enclosure

Table 1
Scenario 1 simulation protocol summary.

Pad Number	2	3	4	5	Average
Total Burn Time*	179*	176	170	178	176
Total Trivet Time*	28	24	28	19	25
Total Manipulation Time*	11	11	11	11	11

Pad numbers correspond with the schematic in Table 2 (Results).
*All values are expressed in minutes.

Table 2
Bulk sample results.

Scenario	Pad	Time/location of sample	Asbestos % type	Other fibers present	Particulate present
1	1	Before Study	80% chrysotile	5% mineral wool	15% Ca Carbonate
	2	Before Study	80% chrysotile	10% mineral wool	10% Ca Carbonate
		After Study/Center	75% chrysotile	None detected	Binder/filler
		After Study/Middle	75% chrysotile	None detected	Binder/filler
		After Study/Edge	85% chrysotile	None detected	Binder/filler
	3	Before Study	80% chrysotile	5% mineral wool	15% Ca Carbonate
		After Study/Center	75% chrysotile	None detected	Binder/filler
		After Study/Middle	75% chrysotile	None detected	Binder/filler
		After Study/Edge	80% chrysotile	None detected	Binder/filler
	4	Before Study	85% chrysotile	5% mineral wool	10% Ca Carbonate
		After Study/Center	75% chrysotile	None detected	Binder/filler
		After Study/Middle	75% chrysotile	None detected	Binder/filler
		After Study/Edge	80% chrysotile	None detected	Binder/filler
	5	Before Study	80% chrysotile	10% mineral wool	10% Ca Carbonate
		After Study/Center	75% chrysotile	None detected	Binder/filler
		After Study/Middle	75% chrysotile	None detected	Binder/filler
		After Study/Edge	75% chrysotile	None detected	Binder/filler
2	6	Before Study	5% tremolite	None	Binder filler
		After Study/Center	2% tremolite	2% Talc	Calsite
		After Study/Edge	2% tremolite	2% Talc	Calsite
	7	Before Study	5% tremolite	None	Binder filler
		After Study/Center	2% tremolite	2% Talc	Calsite
		After Study/Edge	2% tremolite	2% Talc	Calsite
3	8	Before Study	15% chrysotile	None detected	Non-fibrous Other

(3'x3'x7′) consisting of a single desk, a ring stand, a Bunsen burner and gas source, a wire gauze, an Erlenmeyer flask, and sampling equipment. The wire gauze pad was of a well-worn condition and obtained from the University of South Florida campus. The analytical team consisted of a technician, an assistant, and a Certified Industrial Hygienist. The technician performed a 30 min simulation of heating a water-filled 200 mL Erlenmeyer flask atop the wire gauze pad using a Bunsen burner (15 min), followed by a brief cooling period (2–3 min), and finally manual manipulation, e.g., flexing/bending for 2 min. The entire protocol was performed within the isolation chamber via glove manipulation; thus, no personnel were exposed directly to asbestos during the simulation. This simulation aimed to examine whether well-worn wire gauze pads shed asbestos fibers in a restricted environment and in a short exposure interval. Minor variances in procedure among the 3 scenarios result from the unique testing environment of these novel asbestos containing products. All sampling was conducted within the range of acceptable volumes and flow rates of CFR §1910.1001 – Detailed Procedures for Asbestos Sampling and Analysis, and sampling was conducted at a rates intended to protect the sampling cassette from overload.

2.3. *Bulk sampling*

For all three scenarios, wire gauze pad bulk samples were taken prior to testing and analyzed for matrix contents by polarized light microscopy (PLM) in accordance with EPA Method 600-R-93-116. Additional post-simulation samples were taken from gauze pads heated in tests one and two. The fifth wire gauze pad excluded from simulation in scenario 1 (Designated Pad 1) was included in bulk sampling. Results include fiber type and fiber as a percent of total matrix fibers; other non-fibrous matrix components are reported where appropriate. Results are stratified based on scenario number and tabulated below (Table 2).

2.3.1. *Scenario 1*

To determine the asbestos contents of the gauze pads, a single ¼ mm diameter sample was taken from of each pad using a scalpel. The wire gauze pads were promptly resealed using adhesive tape until simulation testing, and the bulk sample sealed for transportation to the analytical site. After simulation, each wire gauze pad was resealed and submitted for post-test PLM analysis where three additional ¼ mm^2 bulk samples were taken from the circumferential edge, center, and mid-point between center and edge (denoted middle).

2.3.2. *Scenario 2*

Wire gauze pad bulk sampling was performed similar to scenario 1. Again, a single sample from the pad edge was taken for PLM analysis prior to simulation. After simulation, bulk samples were taken from pad centers and outer edges analyzed by PLM and TEM.

2.3.3. *Scenario 3*

As the wire gauze pads were well-worn, only a single 1 mm^2 edge bulk sample was taken from the single wire gauze pad prior to testing. The bulk sample was removed using a scalpel, and sealed in a separate self-sealing plastic bag and sent for PLM analysis.

2.4. *Air sampling*

For safety during scenario 1, carbon monoxide measurements were taken using the digital Kidde Nighthawk 900-0076 detector (Mebane, N.C.). In the event of detector failure or potential technical issues, a secondary monitor (Draeger colorimetric tubes) for carbon monoxide was included. During the second scenario the CO build-up was not expected to attain unsafe levels given the moderate ventilation rate, thus no CO measurements were taken. Since the contents of the third test chamber were isolated from research personnel and under adequate ventilation, CO measurements were deemed not necessary.

2.4.1. Scenario 1

Five background area samples were collected from inside of the isolation chamber and three from the outside of the chamber where research personnel could have been exposed. Active background air sampling was conducted using 25 mm OD conductive 0.45 μm pore mixed cellulose ester (MCE) particulate filter cassettes affixed to sampling pumps (Dawson; San Diego, CA) calibrated to draw 10 L per minute. The minimum sampling volume was 1200 L. Baseline samples were assessed for asbestos according to NIOSH Method 7400 (PCM) and Asbestos Hazard Emergency Response Act (AHERA) analytical method as prescribed in 40 CFR Part 76 (TEM).

During testing, six intra-chamber area samples were collected throughout the chamber perimeter. Active sampling was performed using high-volume Dawson air-sampling pumps affixed with a 25 mm OD conductive 0.8 μm pore MCE filter at a rate of 6–9.5 L per minute; cassettes were suspended at a height of 5'. Two area samples were included outside of the chamber to sample for background asbestos levels. MCE filters were assessed according to the NIOSH methods 7400 (PCM) and 7402 (TEM) to determine total fiber and asbestos fiber concentration.

Personal breathing zone (PBZ) was sampled using Mine Safety Appliance (MSA; Cranberry Township, PA) Escort Electronic Laminar Flow personal air-sampling pumps fitted with 25 mm OD conductive 0.8 μm pore MCE particulate filter cassettes. PBZ samples were collected at a rate of 2.5–2.9 L per minute. The technician and assistant were each fitted with three pumps in order to collect a single 30-min task-based sample (During wire gauze package opening and test manipulations) and two long-term duration samples: one four and the other 6 h. While the assistant remained primarily stationary, the technician was relatively mobile throughout the entire simulation.

2.4.2. Scenario 2

Prior to actual testing, five background area air samples were collected from inside the test room. Five additional area air samples were also collected outside the test room. Sample collection was done in a manner similar to that for Scenario 1. Analysis of background samples was done using TEM following AHERA methodology.

Over the conduct of testing, the technician wore two separate PBZ air samples during each of the four separate burn tests. Additional 30-min excursion level, PBZ samples were also taken during the one and 2 h burn tests. PBZ samples were collected on 0.8 μm pore sized, 25 mm OD, mixed cellulose ester membrane filters which were housed in electrically conductive plastic cassettes. Air was drawn through the filters at measured flowrates ranging from 2.16 to 2.22 L per minute, using MSA Flo-Lite® battery powered air pumps.

Air sampling flow rates were measured and recorded before the initial start and after completion of all burn tests. Airflow measurements were performed using a primary standard, airflow calibrator, (Bios International Model DC-1).

Three separate area air samples were taken from inside the test room during each burn session. Sample locations included the test bench in addition to the northeast and southeast corners of the test room. Sample cassettes were suspended with inlet parts facing downwards and at breathing zone heights (5-ft above floor). Gast model (1531-1075-0288x) line operated vacuum pumps were used to draw air through 0.8 μm pore sized filters at fixed flow rates ranging from 6 to 9.5 LPM.

2.4.3. Scenario 3

The air sampling method simulated a PBZ exposure in a confined space with 10 air exchanges per hour. Two 25 mm OD conductive 0.8 μm pore MCE cassettes, one each for PCM and TEM, were affixed to a clean metal straight-edge and lowered 18 inches above the wire gauze pad simulation space. The air-sampling rate for both cassettes was performed using Gast air pumps calibrated to 15 L/minute, and collected a minimum total sampling volume of 460 L per cassette.

2.5. Sample handling and analysis

Both PZB and area air samples were analyzed in accordance with NIOSH Method 7400 by PCM, and Method 7402 by TEM. Analysis of pretest background samples followed the AHERA analytical method as prescribed in 40 CFR Part 76 (TEM). If the air sample results were above the analytical limit of detection for PCM, the samples were then analyzed by TEM. Since PCM can only detect fibers in general without being able to discriminate between asbestos and non-asbestos fibers, TEM analysis is essential. Electron microscopy has robust count reproducibility for fibers larger than 0.5 μm in length. Only identity-confirmed asbestos fibers of ≥0.25 μm diameter and a ≥5.0 μm length with an aspect ratio ≥3:1 were classified as asbestos for quantitation purposes.

All analytical laboratories responsible for PLM, PCM, and TEM studies in this investigation were certified by federally-recognized accreditation organizations. EMSL Analytical, Inc. (Beltsville, MD) is accredited by NIST for TEM analysis and by the American Industrial Hygiene Association (AIHA) for PCM. Bureau Veritas North America, Inc. (Kennesaw, GA) is accredited by AIHA for PCM and by NIST for PLM and TEM.

2.6. Data analysis

Data from all tests are stratified based on scenario number, sampling location, and measurement type, i.e., area or PBZ sample. Where appropriate, descriptive statistics are presented as the arithmetic mean of independent trials with associated standard deviation. Otherwise, values for independent trials are reported.

3. Results

3.1. Bulk sampling

3.1.1. Scenario 1

Pre-test bulk samples from all five wire gauze pads were submitted for PLM evaluation. However, as previously mentioned, only four underwent simulation testing and subsequent post-test bulk sampling – the results are presented in Table 2. All wire gauze pads contained 75–85% chrysotile-type asbestos fibers prior to testing, and decreasing slightly after testing. Following exposure to heat, the chrysotile asbestos fibers remained homogenously distributed throughout the entire gauze pad. In addition to chrysotile, each sample contained 10–15% calcium carbonate and 5–10% mineral wool.

3.1.2. Scenario 2

Bulk sampling with PLM analysis revealed a substantially different asbestos fiber profile than those pads utilized in scenario 1. All wire gauze pads contained 5% tremolite asbestos, while no other fiber types were identified (Table 2). After testing, analysis using TEM indicated both wire gauze pads contained 2% tremolite asbestos, which was homogenously distributed throughout the pad. Talc was identified in low amounts (2%) in addition to tremolite. Calcite was also identified as a constituent of the plaster pad mass.

3.1.3. Scenario 3

Only a single wire gauze pad was included for bulk analysis prior to simulation testing. Similarly to scenario 1, only chrysotile asbestos was found, albeit at a substantially lower concentration of 15%. No other fibers were detected, and the particulate matrix was reported generally as “non-fibrous other”.

Bulk sampling PLM analysis revealed that not all wire gauze pads contained the same type of asbestos, e.g., chrysotile or tremolite, and that there is substantial heterogeneity in asbestos amount. Since the age of each wire gauze pad was different: five unused, one well-worn, and two unknown, the temporal fate of asbestos in the wire gauze pads remains unknown, i.e., if repeated use results in reduction of asbestos fibers. Nonetheless, all wire gauze pads in this investigation were confirmed to contain asbestos.

3.2. *Air sampling*

3.2.1. *Scenario 1*

Background samples analyzed by PCM prior to wire gauze pad simulation showed that fibers were present within the isolation chamber 0.004 f/cc ± 0.001 f/cc, though no fibers were identified by TEM. Similarly, no asbestos fibers were found in the ambient air outside of the isolation chamber, denoting the environment in which the test was conducted was asbestos-free.

Six (6)-hour area sampling within the isolation chamber during testing showed an average concentration of 0.0076 f/cc by PCM (Range: 0.0069–0.0085). Among all six PCM-accompanying intra-chamber area TEM samples, three cassettes were positive for chrysotile. Bulk sampling of the wire gauze pads tested concurred the presence of chrysotile asbestos, suggesting that the source of the asbestos fibers likely arose from the gauze pads. The minimum and maximum TEM-adjusted PCM asbestos fiber concentration estimates were < 0.0009 f/cc and 0.0017 f/cc, respectively. Four-hour area samples were not positive for asbestos.

Two contiguous 30-min personal breathing zone sampling excursion samples were obtained from each, the technician and assistant, during the first two burns and pad manipulations. These samples were expected to represent the peak exposure window for comparison against the OSHA 1.0 f/cc excursion limit. Summary statistics for both excursion limit PCM and TEM analyses are presented in Table 3. Since no excursion limit PCM sample exceeded the fiber detection limit (0.032 f/cc), TEM analyses were not performed.

Long-term PBZ samples from the technician and assistant were taken in addition to excursion samples. The sampling window for the 4-h air sample began immediately prior to wire gauze pad opening and initialization of the protocol. The longer, 6-h PBZ measurement was initiated simultaneously with the 4-h PBZ sampling, and included an additional 2 h after the 4-h PBZ measurement ceased; the results of the four- and 6-h PBZ measurements are shown in Table 3. The PCM analysis for the shorter 4-h sampling during testing showed a higher total fiber concentration compared to the 6-h measurements. No asbestos fibers were identified in the NIOSH 7402, TEM analysis, effectively demonstrating that the exposure to asbestos was well below current occupational health standards and guidelines. Extrapolating both the four- and six-hour TEM-adjusted PCM measurements to an 8-h TWA likewise did not exceed the OSHA 8-h TWA PEL of 0.1 asbestos f/cc.

Table 3
Scenario 1 PBZ samples.

Sample	Technician			Assistant		
	PCM (f/cc)	TEM (Ratio)	8-Hour TWA (f/cc)[a]	PCM (f/cc)	TEM (Ratio)	8-Hour TWA (f/cc)[a]
30-Minute	< 0.029	N/A[b]	–	< 0.032	N/A[b]	–
30-Minute	< 0.029	N/A[b]	–	< 0.032	N/A[b]	–
4-Hour	0.018	0	BDL[c]	0.013	0	BDL[c]
6-Hour	0.012	0	BDL[c]	0.005	0	BDL[c]

[a] 8-Hour TWA are extrapolated from the TEM-adjusted PCM asbestos concentration estimates from the four- and 6-h PBZ measurements. No TEM sample contained asbestos fibers, thus the TEM-adjusted 8-Hour TWA are denoted simply as below the limit of detection.

[b] N/A = Not Assessed. No fibers were detected by PCM.

[c] Below Detection Limit.

Table 4
Scenario 2 area sampling.

Sample	Location	PCM (f/cc)	TEM (Ratio)	Asbestos adjusted PCM (f/cc)
120 Minutes	Bench	0.042	0.55	0.023
	NE Corner	0.029	0	BDL[b]
	SE Corner	0.050	0	BDL
60 Minutes	Bench	< 0.014	N/A[a]	N/A
	NE Corner	< 0.016	N/A	N/A
	SE Corner	0.028	0	BDL
30 Minutes	Bench	< 0.030	N/A	N/A
	NE Corner	< 0.032	N/A	N/A
	SE Corner	0.056	0	BDL
30 Minutes	Bench	< 0.034	N/A	N/A
	NE Corner	< 0.032	N/A	N/A
	SE Corner	< 0.032	N/A	N/A

[a] N/A = Not assessed.

[b] BDL = Below Detection Limit.

3.2.2. *Scenario 2*

Analysis of background area air samples did not detect any asbestos fibers. Of the 12 area air samples collected during wire gauze burn tests, five contained detectable fibers via PCM analysis. The analytical results are presented in Table 4. The southeast corner area air samples detected fibers during the 120 min, 60 min and one of the two 30 min burn tests. Detectable fibers were also found during the 120 min burn test in the northeast corner and at the bench. The five area air samples showing detectable fibers were submitted for TEM analysis and asbestos was only found in the bench sample for the 120 min burn. (55% of total fibers were positively identified as asbestiform), yielding a TEM-adjusted PCM estimation of 0.023 f/cc. The 120 min burn test occurred first in the series of four tests and the bench area air sample was closest to the supply package from which the gauze pads were removed prior to the 120 min test.

PBZ measurements from scenario 2 testing corroborated the general temporal fiber generation pattern observed in area sampling. After 120 min, no fibers were detected by PCM in the personal breathing zone of the technician. (Table 5). For the initial 2 h, both personal samples registered airborne fibers via PCM, but TEM analyses were negative for the presence of asbestos. Even the 30-min excursion PCM sample initiated 200 min after the beginning of the overall testing series remained below the detection limit of 0.027 f/cc. However, the 30-min excursion PCM sample beginning at 75 min demonstrated the highest

Table 5
Scenario 2 PBZ samples.

Sample	Technician		
	PCM	TEM	8-Hour TWA
	(f/cc)	(Ratio)	(f/cc)*
120-Minute	0.033	0	BDL[c]
	0.048	0	BDL
30-Minute$_{75}$ (excursion)	0.054	0	
60-Minute	< 0.014	N/A[b]	- -
30-Minute$_{200}$ (excursion)	< 0.027	N/A[b]	- -
30-Minute	< 0.028- < 0.030	N/A[b]	- -
30-Minute	< 0.029- < 0.030	N/A[b]	- -

[a] 8-Hour TWA are values extrapolated TEM-adjusted asbestos concentration from the 2-h PBZ measurements. No TEM samples contained asbestos fibers, thus the TEM-adjusted 8-Hour TWA are denoted simply as below the limit of detection.

[b] N/A = Not Assessed. No fibers were identified by PCM.

[c] Below Detection Limit.

total fiber concentration (0.054 f/cc) of all scenario 2 PBZ measures. Nonetheless, no asbestos fibers were identified by TEM.

3.2.3. Scenario 3

Airborne PCM and TEM fiber analysis from the single wire gauze pad in scenario 3 revealed that an insignificant amount of total fibers were released, and remained below the detection limit of 0.006 f/cc via PCM; a result corroborated by TEM analysis for which no fibers (Asbestiform or otherwise) were identified. Under the conditions examined in scenario 3, a short-term, 30-min wire gauze pad manipulation would not immediately present a risk of asbestos exposure. Indeed, comparing these results against those of scenario 1 affirmed these results. For example, the highest TEM-adjusted PCM asbestos concentration was 0.0017 asbestos f/cc, well below the detection limit of scenario 3. Furthermore, the asbestos content of the pads utilized in scenario one contained approximately 5–6 times more chrysotile (75–85%) than the well-worn pads used in scenario 3 (15% chrysotile). Nonetheless, the asbestos exposure characterized in scenario 3 was well below the established OSHA excursion limit of 1.0 asbestos fiber/cc. Extrapolations to an 8-h TWA were not appropriate for this scenario.

4. Discussion

The equipment used and the actual procedures employed were representative of standard activities likely common in a scientific laboratory setting involving wire gauze pads. Overall, we found that laboratory personnel and bystanders are exposed to levels of asbestos far below the OSHA PEL (0.1 f/cc) during the routine use of new asbestos-containing wire gauze pads. Further, no discernible pattern of exposure was discovered regarding proximity to asbestos source, e.g., PBZ versus area samples (Tables 3 and 4). Comparison of well-worn and new asbestos-containing wire gauze pads for short-term exposure similarly did not produce ambient asbestos fiber concentrations above the 30-min OSHA regulatory excursion limit of 1.0 f/cc.

All wire gauze pads tested contained chrysotile asbestos, except for those pads used in scenario 2 (Table 2). In the first simulation, newly purchased pads were composed primarily of chrysotile (75–85%), while the scenario 3 well-worn pad contained substantially less asbestos (15%). In spite of high pad chrysotile content found in scenario 1, the maximum detectable ambient air sample concentration of 0.0017 asbestos f/cc was detected under sub-standard ventilation parameters, a known modulator of airborne contaminant concentrations (Cherrie et al., 2005; Klein et al., 2009), which, was well below the OSHA PEL. These results denote minimal asbestos exposure for bystanders. Accompanying PBZ sampling likewise did not suggest elevated asbestos exposure, even during the period expected to have the highest ambient fiber concentration, i.e., the first hour included opening the wire gauze pad packages and executing the initial two iterations of burning and manipulation. Since manipulating four wire gauze pads simultaneously did not produce elevations in asbestos exposure under almost stagnant airflow, the use of one or two simultaneously would likely result in even lower exposures than observed. Indeed, short-term PBZ simulated measurements from a single well-worn pad (scenario 3) under ideal ventilation parameters supports this interpretation. Unfortunately, since we were able to only find one used asbestos-containing wire gauze pad, addition of more well-worn pads during the simulation would have benefitted comparison against the first scenario – and added confidence to our findings.

Considering the results from the first scenario, we characterized asbestos exposure of new asbestos-containing wire gauze pads to more relevant ventilation parameters (scenario 2). Two pads were identified for inclusion, and were tested together. Unfortunately, these pads contained tremolite at a much lower concentration than observed in scenario 1. Nonetheless, these pads did generate ambient asbestos fiber concentrations, with a maximum TEM-adjusted PCM concentration of 0.023 f/cc. All other ambient samples did not contain identifiable asbestos. As for scenario one the results suggest that asbestos exposure to tremolite-containing pads is minimal during routine use. Again, PBZ measurements, which were expected to report the highest asbestos concentrations (Cherrie et al., 2011), did not detect asbestos fibers within the breathing zone of the technician. These results suggest laboratory worker exposure is *de minimis*.

Results from all three tests agree with preliminary analysis by the Texas Department of Health in the early 1980's. Their tests did not find elevated airborne asbestos levels above background levels (0.02 asbestos f/cc) in a chemistry laboratory where asbestos-containing wire gauze pads were actively used (Yager, 1981). While it cannot be presumed that those pads analyzed in the Yager (1981) report were unused, results of our scenario 3 simulated PBZ measurements of the well-worn pad likely corroborate those findings with higher relevance than either scenario 1 or 2. Under test conditions, asbestos-containing wire gauze pads are not expected to generate airborne asbestos exposure above current OSHA regulatory limits. Irrespective of the potential pathogenic potential of differing asbestos species, e.g., chrysotile versus amphibole asbestos (Baur et al., 2012; Berman and Crump, 2008; McDonald et al., 1989), health risks are likely to be low or negligible.

We reported that the well-worn pad contained substantially little chrysotile asbestos, but we may only speculate on the cause behind this observation. Post-test bulk analyses from scenarios 1 and 2 suggest that heating the wire gauze pads with a laboratory Bunsen burner may lead to progressive reductions in chrysotile and tremolite as a direct result of the heating. Sampling or statistical errors were not characterized, and either could potentially explain our findings. However, the substantially lower chrysotile content (15%) of the scenario 3 wire gauze pad may offer insight into the fate of chrysotile, or asbestos in general, in research laboratory pads, should the well-worn pad have had chrysotile concentrations comparable to new pads used in scenario 1.

No research on the thermal decomposition of wire gauze pad asbestos exists. We observed consistent reductions in asbestos content of 7.7% in chrysotile- and 60% in tremolite-containing pads after testing. The thermal fate of asbestos has been characterized in general experimentation, particularly in cement-based products. For example, thermal decomposition of chrysotile occurs above 600 °C (Kozawa et al., 2010). Above 600 °C, the primary decomposition product is forsterite (Zaremba et al., 2010) with further decomposition to enstatite above 950 °C (Gualtieri et al., 2008). Tremolite decomposes to non-fibrous silicate clinopyroxenes at temperatures exceeding 740 °C (Gualtieri and Tartaglia, 2000; Xu et al., 1996). These temperatures were not unattainable, as maximal Bunsen burner temperatures can reach 900–1000 °C (Dixon-Lewis and Wilson, 1951). The extent, if any, of thermal decomposition occurring in the current investigation remains inconclusive, but is a prudent consideration for characterizing sample-specific asbestos exposure risks to asbestos-containing wire gauze pads as well as other products used in high-heat applications. Further research on thermal decomposition in laboratory equipment is required to corroborate these preliminary observations.

With respect to asbestos liberation during use, the effects of age or asbestos type in influencing wire gauze pad asbestos shedding is unknown. We conducted air sampling during the periods where airborne fiber capture would be expected to be the highest – during and after the time of peak sample manipulation. When not detecting fibers in PCM sampling, we did not evaluate accompanying TEM samples since TEM provides fiber identification for adjusting PCM fiber values; TEM-only concentrations are seldom reported, particularly in comparison against regulatory standards. The benefit of TEM analysis is that it measures only asbestos fibers, while PCM reports both asbestos and non-asbestos fibers, potentially overestimating the concentration of asbestos fibers. There are limitations to not having analyzed TEM samples. As mentioned elsewhere (Lemen, 2004), the PCM method is not without criticism. In excluding short ($< 5\,\mu m$ in length) and thin ($< 0.25\,\mu m$ in diameter) fibers, the worker could actually be exposed to more asbestos than is routinely detected via TEM-adjusted PCM, thus underestimating exposure. However, human health carcinogenic risk to fibers outside of the reportable parameters of the NIOSH method have been deemed largely inconsequential. The reason is likely due to the high lung clearance rate for asbestos fibers smaller than 5 μm in length (Finkelstein and Dufresne, 1999; Morgan et al., 1978) and thinner than 0.25 μm (Moorcroft and Duggan, 1984), denoting that the residency time associated with larger fibers is the quintessential property associated with pathophysiological lung injury attributed to asbestos.

Limitations of this study require discussion to qualify some of the findings presented. Firstly, we were limited in our sampling due to the number of wire gauze pads available to perform the testing scenarios. For the first scenario, we used four brand-new unopened pads. In an attempt to evaluate the reproducibility of the findings obtained in the new asbestos pads testing, we only found two additional pads, both of which contained a completely different species of asbestos. Therefore, the inter-test homogeneity is relatively weak, and for this reason, comparisons between tests were kept to a minimum. Further, since bulk samples were taken from pads used in scenarios 1 and 2, the tendency of biasing fiber shedding may be higher than would otherwise be observed under normal conditions. Under this assumption, our observations may have overestimated total fiber and asbestos fiber exposure compared to ordinary laboratory work conditions. Regarding the final scenario, since asbestos-containing materials are being deliberately disposed in the United States, we were only able to find a single chrysotile wire gauze pad to test in scenario 3. In its present condition, we were unaware of age or initial asbestos composition of the pad. As such, assertions of potential thermal decomposition are tentative, even if supported by the pre-versus post-testing bulk analyses from scenario 1. Additionally, a longer simulated PBZ sampling period in scenario 3 would have been valuable for comparing the results from scenario 1 and 3.

5. Conclusions

This study contributes to the growing wealth of data documenting occupational exposure to asbestos. We measured simulated asbestos exposure from routine use of new and well-worn wire gauze pads commonly found in laboratories decades ago under less-than-ideal working conditions that would bias toward over-exposure. In all, we found that exposure to asbestos from wire gauze pad use in research laboratories was below OSHA PEL and excursion limits. Our findings are consistent with previous studies that found similarly low exposure values from other non-construction occupations, including repair or changing of brakes, gaskets, sealants, and clutches.

Conflicts of interest

Some of the authors have served as expert witnesses in litigation regarding potential asbestos health hazards associated with various occupational exposures.

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