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Asbestos exposure risk from ceiling and other building materials

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Although much research has been conducted regarding asbestos removal and worker exposure, there are gaps in our understanding of the extent of asbestos-containing materials still present in building materials and the effectiveness of exposure controls used during the removal of these materials. We conducted a review of third party surveys and exposure assessment reports to: (1) Evaluate the exposure levels measured by personal and area asbestos air sampling during abatement of ceiling and other building materials to measure the effectiveness of site controls, (2) summarize the type and concentration of asbestos identified in residential and commercial buildings' building materials. A literature research was performed using Bing, Google, and Yahoo search engines to identify (commercially) unpublished asbestos survey reports and air sampling reports during asbestos removal to assess exposure potentials. The data extracted resulted in 3012 bulk samples assessed for concentration and type; 617 contained asbestos. Forty-one types of Asbestos-containing material (ACM) were identified. All ACMs identified were chrysotile. The chrysotile concentration in the bulk samples ranged from non-detectable to 100%. Air sampling exposure data from two asbestos abatement projects were assessed. The maximum unweighted (time) personal exposure measured was 0.0201 f/cc. Based on our evaluation of the exposure records from the removal of ACM in both commercial and residential settings where type and concentration of asbestos was known, the risk for overexposure is low based on the effectiveness of implemented risk management strategies.

Key words: Asbestos, abatement, occupational exposure , environmental monitoring.

INTRODUCTION

It is well documented in the scientific literature that asbestos was used in numerous building materials in the United States for many years until epidemiological evidence began to mount that associated human exposure to airborne fibers may increase risk of disease (GAO, 2018). Diseases related to exposure to ACM in the workplace identified by Irving Selikoff and other researchers helped to compel federal regulatory Protection

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Agency (EPA) in the 1970s to reduce exposures (GAO, 2018; Lemen and Landrigan, 2017). Of the three types of asbestos materials (chrysotile, amosite and crocidolite) that were used in building materials in the United States, chrysotile was used more than the others (EAI, 2015; USGS, 2005). Approximately, 95% of the asbestos that was used in building materials is chrysotile (ACGIH, 2013).

Other than demolition and renovation of ACM, there is no federal mandate that requires its removal because ACM that is in good condition pose a low risk (Mlynarek et al., 1996). As a result, given the pervasive use of ACM in the United States since the early twentieth century- with the continued installation of asbestos products to this day in select building materials- the full extent of the number of residential, public and commercial buildings with ACM is not fully quantified (EAI, 2015). According to OSHA (1994), 1,450,644 workers (estimated upper-bound) are potentially occupationally exposed to ACM during abatement, renovation, and routine maintenance work in industrial facilities.

Despite the large population at risk from workplace exposure, not much research has been conducted regarding the effectiveness of asbestos exposure controls during the removal of multiple types of ACM (Lange and Thomulka, 2002). A literature review by Roelofs et al. (2003) found limited information regarding the effectiveness of industrial hygiene exposure controls in general. More exposure data is needed to devise appropriate asbestos exposure control interventions and further assess worker health risk during abatement activities. The purpose of this study was to review asbestos building survey data to better understand the extent and concentration of asbestos in building materials across the United States. The study also sought to evaluate personal and area exposures collected during abatement projects where the concentration and type of asbestos were known to provide much needed information regarding the effectiveness of exposure controls.

MATERIALS AND METHODS

A literature search was performed using Bing, Google, and Yahoo search engines to identify (commercially) unpublished asbestos survey reports and air sampling (exposure assessment) reports during asbestos removal to assess exposure potentials. The search strategy was developed and adapted from the EPA's (2017) asbestos literature review guidance document that outlines the procedures for identifying and screening exposure data from grey literature sources for asbestos risk evaluations. Through a deliberate, iterative search process, the most effective search strategy was developed. The literature review was conducted using search terms such as "occupational asbestos exposure", "asbestos breathing zone exposure", "asbestos air sampling", "asbestos air monitoring", "asbestos survey", "asbestos inspection", "asbestos testing", "textured ceiling abatement", "popcorn ceiling abatement", "asbestos abatement", "asbestos exposure controls", and "asbestos containing materials". The search terms were used in multiple combinations to increase the sensitivity while attempting to maximize specificity.

Inclusion criteria

(i) Asbestos survey conducted by a third-party, state licensed asbestos inspector
(ii) Air sampling (personal and area) conducted by a third-party, state licensed asbestos supervisor with National Institute for Occupational Safety and Health (NIOSH) 582 training
(iii) The personal and area air sampling report that listed the type and percentage of asbestos in the materials being removed

Exclusion criterion

(i) Asbestos surveys and exposure assessment reports conducted in other countries

All search results from the literature review based on relevance to this study were assessed. Asbestos survey reports and exposure assessment reports that were judged as relevant had the entire document evaluated. In total, 36 asbestos surveys and 2 air sampling exposure assessment reports met the study inclusion criteria. The reports that met the inclusion criteria were evaluated for data quality before use in the review and analysis (Table 1).

Data quality assessment

The quality of the extracted data was assessed using criteria described in the Application of Systematic Review in TSCA Risk Evaluations (EPA, 2018). The survey and exposure assessment data from each report was evaluated and assigned a confidence level score (1-high confidence to 4 unacceptable) for each domain: reliability (methodology), representativeness (applicability), accessibility (data completeness), and variability/uncertainty (data completeness).

Data extraction

We summarized all of the asbestos survey and air sampling (exposure assessment) data identified from the literature search in an Excel spreadsheet. The data were organized by industry type (commercial or residential) for the asbestos survey and work task or exposure source for the personal and area air sampling. The year the data was collected was also included, project site, study population, geography (state), personal and area asbestos exposure concentration, bulk sample description, bulk asbestos concentration, type of building material, and analysis method. For the personal and area air sampling data, the number of asbestos abatement workers present each day were recorded during the exposure assessment, the project exposure controls, the work activities occurring during the air sampling, and the personal protective equipment worn at each location. All but one of the reports was rated as high (Table 2).

Sampling collection and analysis

All of the asbestos surveys and air sample and analysis reports

Table 1. Data quality level.

Overall quality level	Definition	Overall quality score
High	No notable deficiencies or concerns are identified, and the data therefore could be used in the study with a high degree of confidence.	≥ 1 and < 1.7
Medium	Possible deficiencies or concerns are noted, and the data therefore could be used in the study with a medium degree of confidence.	≥ 1.7 and < 2.3
Low	Deficiencies or concerns are noted, and the data therefore could be used in the study with a low degree of confidence.	≥ 2.3 and ≤ 3
Unacceptable	Serious flaw(s) are identified and therefore, the data cannot be used for the study.	4

(exposure assessment) were conducted between 2007 and 2018. The reported personal and area air sample flow rates ranged from 2.1 to 2.3 L per minute during the scraping/removal of asbestos-containing textured ceiling material at a commercial property. The air sampling durations ranged from 89 to 578 min. The air sampling durations varied due to the length of time it took the abatement contractor's workers to complete specific work tasks for the day. Air samples were collected using battery-operated pumps connected to a 25 mm diameter, 0.8 µm mixed cellulose ester filter following NIOSH Method 7400. The air samples were analyzed via phase contrast microscopy (PCM). Workers removed asbestos for 4 days at the Oklahoma site with a crew size ranging from 7 to 9 people. The flow rates for the area air samples at the residential property asbestos abatement project ranged from 3 to 6 L per minute. Air samples were collected using battery-operated air sampling pumps connected to a 25 mm diameter, 0.8 µm mixed cellulose ester filter following NIOSH Method 7400. The area air sample pumps and cassettes were attached to stands and positioned to approximate breathing zone exposures. The air sample pumps were field calibrated with a rotameter. The air samples were analyzed on-site by the third-party consulting firm that was retained by the owner to monitor the asbestos contractor's removal activities. Asbestos removal was conducted for 39 days with a crew size ranging from 14 to 33 workers.

For each project included in this study, bulk samples were collected by a licensed asbestos inspector and analyzed by a National Voluntary Laboratory Accreditation Program (NVLAP) lab via polarized light microscopy (PLM). In general, the bulk sampling protocol used in the asbestos surveys followed those prescribed in 40 CFR 763.86 for the sampling of friable surfacing materials, thermal systems insulation, and miscellaneous materials. Samples of suspect ACM were collected from homogeneous sampling areas – with sample locations selected at random.

Exposure controls and exposure modifiers

The abatement contractors (commercial and residential projects) used a containment constructed of polyethylene sheeting maintained under negative pressure during removal through the final clean up. All ACM were wetted before removal, and double bagged as it was removed. The asbestos containments at both sites were maintained under negative pressure. During the asbestos abatement of the commercial building, workers wore a full-face air-purifying respirator and a Tyvek suit. For the residential project, the project field notes referred to the fact the workers "donned PPE" before exposure each day, but did not list the type of personal protective equipment worn. A decontamination trailer was set up for the exposed abatement workers to shower and change into clean clothes.

Data analysis

A statistical analysis was performed using the American Industrial Hygiene Association's Multilingual IHSTAT + MS Excel application (2010) and Expostats Bayesian Calculator (2019). Descriptive statistical techniques were used to characterize the personal and area exposure distribution to assess the effectiveness of exposure controls during asbestos abatement. The proportion of positive samples was also assessed from each asbestos survey. The evaluation did not consider the size of the survey, only the proportion of samples testing positive for asbestos. The proportion was analyzed data using a classical random-effects meta-analysis of proportions, which accounts for sample sizes, and random effects for differences between the different studies (asbestos surveys).

RESULTS

Commercial buildings – asbestos surveys

Table 3 presents a summary of the concentration and type of asbestos in bulk samples collected from 23 commercial buildings in 11 states. All but two of the surveys identified asbestos- containing building materials. Of the 1739 samples collected for analysis, 339 (19.5%) contained asbestos – all of which were chrysotile. All of the samples were analyzed by polarized light microscopy (PLM). The concentration of chrysotile in the bulk samples ranged from non-detectable to 100%. Twenty seven unique asbestos containing building materials were identified. The most common building materials that contained asbestos (>1%) identified in the surveys (materials identified in more than 3 surveys) were vinyl floor tile mastic (n=12), vinyl floor tile (n=11), textured popcorn ceiling material (n=10), roof mastic (n=9), and caulk (n=8). The asbestos concentration for these materials ranged from non-detectable to 41%. The highest asbestos concentration (100% chrysotile) was collected from a powder that covered an old steam pipe encased by an insulation wrap. All twenty-seven of the

Table 2. Survey and exposure reports data quality level.

Study	Reference	Data quality level
Commercial building asbestos surveys		
1	Envirovue (2018)	High
2	CSC (2010)	High
3	Coastal Coast Environmental (2017)	High
4	Klienfelder (2013)	High
5	Flint Inspection Consulting Services (2016)	High
6	ECS (2015)	High
7	S&ME (2018)	High
8	Get the Lead Out (2016)	High
9	TexAirCon (2017)	High
10	CB&I (2014)	High
11	Southern Earth Sciences (2016)	High
12	LL&J (2015)	High
13	Anderson Environmental (2013)	High
14	Northwest Colorado Consultants (2007)	High
15	E Sciences (2015)	High
16	Industrial Hygiene and Safety Technology (2016)	High
17	Bay Environmental (2017)	High
18	APEX (2016)	High
19	GMR and Associates (2012)	High
20	EE&G (2018)	High
21	S&ME (2013)	High
22	Lakeland Environmental (2016)	High
23	New Horizons Enterprises (2016)	High
Residential building asbestos surveys		
1	HSW Engineering (2015)	High
2	AKT Peerless (2013)	High
3	ASTI Environmental (2013)	High
4	ATC Associates (2016)	High
5	Apex Environmental Management (2016)	High
6	EHP Consulting (2013)	Medium
7	Harenda Management Group (2012)	High
8	Impact 7G (2018)	High
9	Anderson Property Inspections (2015)	High
10	Amex Foster Wheeler (2015)	High
11	Crane Environmental Services (2018)	High
12	Environmental Health Testing Services (2012)	High
13	Security Storage Service (2017)	High
Exposure assessment reports		
1	Environmental Action Inc (2015)	High
2	American Environmental Consulting (2016)	High

building materials had at least one sample with an asbestos concentration ≥3%. Of the 27 building materials, 14 (52%) had at least one sample with an asbestos concentration ≥20%, 7 (26 %) had at least one sample with an asbestos concentration ≥40%, and 3 (11 %) had at least one sample with an asbestos concentration ≥75%.

Table 3. Asbestos Surveys - Commercial Buildings (Bulk Material Analysis).

Study	State	No. of samples analyzed	No. of analyzed samples contained asbestos	Material	Asbestos[1]
		(n=1739)	(n=339)	Description	(%)
1	CA	2	2	TPCM	7
2	AZ	30	3	CT	25-30
				RM	8-11
3	NC	10	0	C, CT, JC, TPCM, VFT, VFTM	ND
4	CA	138	15	CO, SC	2
				JC	2-3
				TPCM	10
				VFT	2-5
				VFTM	3-5
5	TX	29	10	C	5
				GA	75
				JC	2-3
				VFTM	2-10
6	VA	152	27	C	2-7
				CO, JC	2
				PI	55
				VFT	2-20
				VFTM	2-3
7	SC	56	10	VFT	3-10
				VFTM	0.71-4
8	NC	15	1	RM	10
9	TX	16	7	TPCM, TWB	3
				VFTM	7
10	CA	104	63	C, JC	2
				RM	2-5
				TPCM	2-3
				SF	20
				VFT	2-4
				VFTM	5
11	FL	22	3	RM	7
				VFTM	3
12	NC	33	2	C	5
				TPCM	2
13	CA	135	9	PI	30
				TPCM	5
				SV	7-22
				TP	35
				VFT	2-15
				VFTM	12
14	CO	50	5	SC, PL	3
15	FL	100	7	C	2-7
				DM	5-10
16	TX	103	15	CT, PL	2
				C, RM, VFTM	5
				SV	45-65
				VFT	10-15

Table 3. Contd.

17	TX	266	45	CT	0.25-2
				JC	0.5- 2
				P	100
				PI	5-60
				PM	5-10
				TPCM	3
				VD	80
				VI	40
				VFT	2-10
18	CA	103	14	C, RM, VFTM	5
				RM	5
				VFT	2-15
				WP	2-3
				TPCM	3
19	OK	59	17	VFT	4-15
				VFTM	6-8
20	FL	109	8	CO, WF	2-5
				RM	5
				C	3
				CM	25
				FHP	22
21	SC	65	42	BUR	20
				TPCM	5-10
				RM	10-20
				VFT	2-41
				VFTM	5-15
22	NY	26	0	JC, VFT, VFTM, TPCM	ND
23	NE	116	34	CO, CARM, TPCM	5
				CM	3-5
				VFT	5-8

[1]All samples were analyzed by PLM. Chrysotile was the only type of asbestos detected in the bulk samples. Abbreviations: BUR= built up room material; C=caulk; CM=concrete mastic; CO=coating; CT= ceiling tile; CARM=carpet mastic; DM=duct mastic; FHP= fume hood panel; GA=gasket; JC=joint compound; ND=None detected; P=powder covering pipe; PI= pipe insulation; PL=plaster; PM=pipe mastic;; RM= roof mastic/sealant; RACM= regulated asbestos containing materials; SC=skim coat; SF=subfloor; SV=sheet vinyl fiber backing; TP=transite panel; TWB= textured wallboard; TPCM=textured/popcorn ceiling material; VD: woven vibration dampener material; VI= woven vibration isolator material on HVAC unit; VFT=vinyl floor tile; VFTM=vinyl floor tile mastic; WF=wall flashing; WP=window putty.

Residential buildings – asbestos surveys

Table 4 presents a summary of the concentration and type of asbestos in bulk samples collected from 13 residential buildings in 10 states. Eleven out of the 13 surveys measured asbestos in the building materials. Of the 1273 samples collected for analysis, 278 (21.8%) contained asbestos – all of which was chrysotile. All of the samples were analyzed by polarized light microscopy (PLM). The concentration of chrysotile in the bulk samples ranged from non-detectable to 70%. Also, 24 unique asbestos containing building materials were identified. The most common building materials that contained asbestos (>1%) identified in the surveys (materials identified in more than 3 surveys) were textured popcorn ceiling material (n=6) and joint compound (n=4). The asbestos concentration for these materials ranged from non-detectable to 5%. The highest asbestos concentration (70% chrysotile) was collected from a variety of tapes (duct, exhaust fan and thermal). Twenty-four of the building materials had at least one sample with an asbestos concentration $\geq$ 2%. Of the 24

Table 4. Asbestos surveys - residential buildings (bulk material analysis).

Study	State	No. of samples analyzed (n= 1273)	No. of analyzed samples contained asbestos (n=278)	Material Description	Asbestos[1] (%)
1	FL	792	84	CO, RM	2
				JC, VFT, VFTM,	2-5
				TPCM	0.25-5
				DT, EFT	70
				S	5
				DM	0.8-5
				VFTB	35
2	MI	27	0	DW, VFT, VFTM, TPCM	ND
3	MI	50	8	JC	1.25-2.25
				LC	2.25
4	IA	134	134	C	3-20
				CO	5-15
				DT	30-65
				EP	45
				ES	2-25
				FP	5-8
				JC	2-3
				RM	3
				RFF	15-60
				SV	10-65
				SVBM	12-60
				VFT	3-10
				VFTM	4-15
				TT	65-70
				TPCM	2-10
				WG	2-3
5	SC	41	6	RM	5
				TPCM	3
				WG	2
				VFT	10
6	TX	66	14	JC	1.25-3
				TPCM	1.5-3
7	WI	36	4	WG	2
				DP	65
8	IA	23	3	SI, TPCM	2
				SS	20
9	CO	12	9	TPCM	3
10	FL	54	14	C	3
				SV, SVBM	25
11	IN	10	2	TPCM	3
12	MN	21	0	JC, TPCM, VFT	ND
				VFTM	
13	MO	7	0	TPCM, VFT , VFTM	ND

[1]All samples were analyzed by PLM. [2]Project No. 4 : Only positive asbestos samples were included in the report. Abbreviations: C=caulk; CO=coating; DM= duct mastic; DP=duct paper; DT=duct tape; DW=drywall, EP= elbow piping; ES= exterior siding; EFT= exhaust fan tape; FP=flue packing ; JC=joint compound; LC=leveling compound; ND=None detected; RM= roof mastic/sealant; RFF=roof flashing and felt; RACM= regulated asbestos containing materials; S=sealant; SI= sink insulation; SS=slate siding; SV=sheet vinyl; SVBM-sheet vinyl backing and mastic; TT=thermal tape; TPCM=textured/popcorn ceiling material; VFT=vinyl floor tile; VFTB= vinyl floor tile backing ; VFTM=vinyl floor tile mastic; WG=window glaze.

Table 5. Mean percentage of asbestos containing materials by State.

State	Commercial survey mean	Standard deviation	Residential survey mean	Standard deviation
AZ	18.5	12.7		
CA	8.3	8.9		
CO	3	0	3	-
FL	4.9	1.8	18.1	24.5
IA			19.3	19.6
IN			3	-
MI			0.7	1.04
MN			0	0
MO			0	0
NC	1.9	3.5		
NE	5.1	0.89		
NY	0	0		
OK	6.5	3.3		
SC	13.3	8.5	5	3.6
TX	18.2	28.0	2.2	0.09
VA	12.8	20.9		
WI			33.5	44.5

building materials, 12 (50%) had at least 1 sample with an asbestos concentration $\geq$ 20% asbestos, 8 (33 %) had at least one sample with an asbestos concentration $\geq$ 40%, and 7 (29 %) had at least one sample with an asbestos concentration $\geq$ 60%. Table 5 presents the mean percentage of asbestos found in the building materials, with its standard deviation, measured for each state in the commercial and residential surveys. For states with a mean and no standard deviation, there was only one study that reported asbestos in that category.

Survey reports- analysis of positive samples

The proportion of positive samples from each asbestos survey was assessed. The evaluation did not consider the size of the survey, only the proportion of samples testing positive for asbestos. The proportion data was analyzed using a classical random-effect meta-analysis of proportions, which accounts for sample sizes, and random effects for differences between the different studies (surveys/reports) (Figures 1 and 2). Accounting for variation between surveys, and sample size, the overall estimated proportion of samples testing positive for asbestos is 20% (95% CI 13 to 27). A similar analysis for the residential surveys was performed. Accounting for variation between surveys and sample sizes, the overall proportion of samples testing positive for asbestos was roughly 24% (95% CI 8 to 40).

Commercial building – personal and area exposures

Personal and area exposures measured during the removal of asbestos from a commercial building are presented in Table 6. A total of 27 air samples were collected during asbestos removal. Eighteen of the 27 samples collected were below the method's (NIOSH 7400) detection limit. The maximum unweighted (time) personal exposure and area exposure inside of the active work containment were 0.0201f/cc and 0.011f/cc. The 95th percentile (point estimate) for the unweighted personal exposures was 0.03 f/cc. Based on a Bayesian analysis of the personal exposure data, the likelihood that the 95th percentile exposure during hand scraping is $\geq$ OSHA's asbestos Permissible Exposure Limit (PEL) (0.1 f/cc) is 3.4%. Figure 3 depicts time-weighted personal and area (inside containment) asbestos exposures. All exposures outside of the work containment were less than the method's (NIOSH 7400) detection limit. The limit of detection for the samples in question ranged from <0.0038 f/cc to <0.0263 f/cc. Ten clearance air samples were also collected at the completion of asbestos abatement; all air samples were less than the analytical method's detection limit range (< 0.0034 f/cc - <0.0038 f/cc). All exposures were below OSHA's asbestos PEL (0.1 f/cc). The exposure variability (geometric standard deviation) was moderate for the personal exposures and low for the area samples inside of the containment (Table 6).

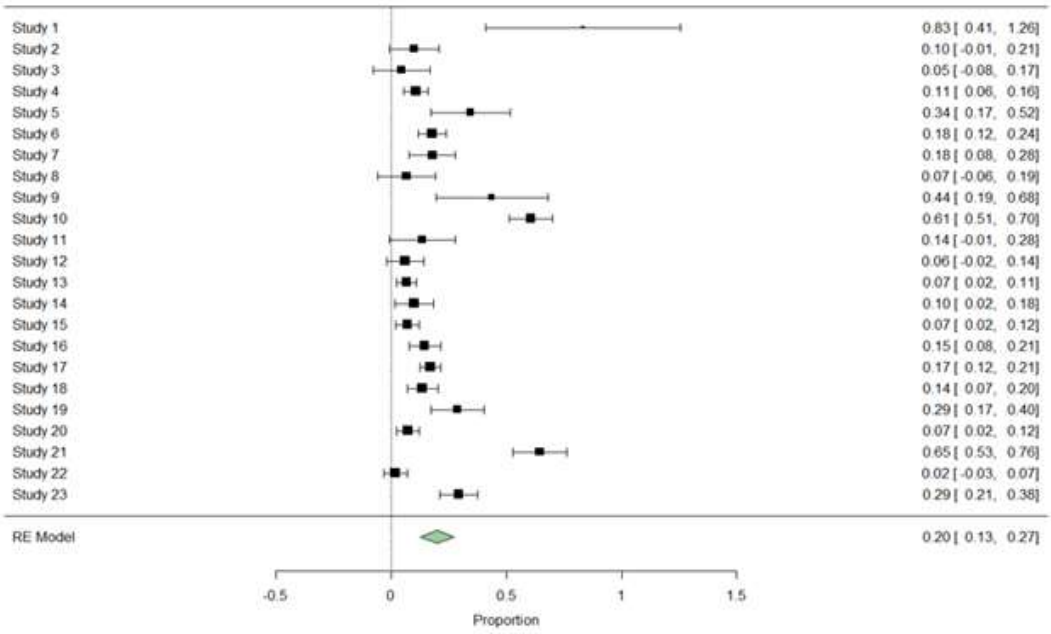

Figure 1. Forest plot of proportion of positive asbestos samples in commercial buildings.

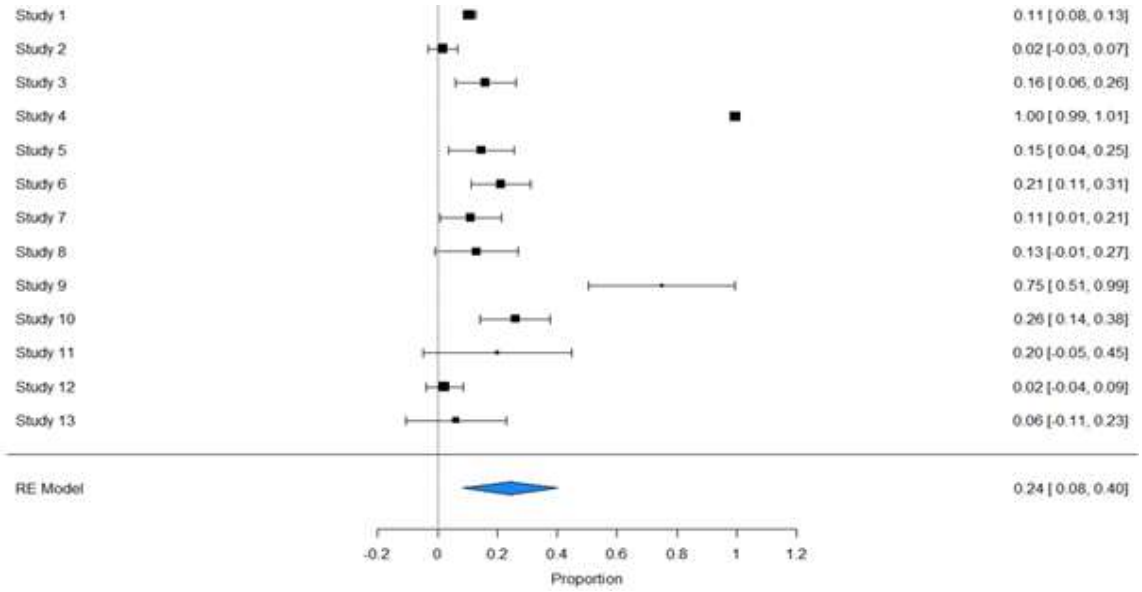

Figure 2. Forest plot of **proportion** of positive asbestos samples in residential buildings.

Residential building - area exposures

A total of 385 air samples were collected during the removal of ACM. Area exposures measured during the removal of asbestos from a residential building are presented in Table 7. The maximum unweighted (time) area exposure inside of containment during asbestos removal was 0.0156 and 0.0045 f/cc outside of the containment. The maximum unweighted (time) area exposure near the negative air machine exhaust was 0.006 and 0.007 f/cc in the cleanroom. Figure 4 depicts time-weighted average asbestos exposures from area samples obtained inside and outside of the containment. Figure 5 depicts time-weighted average asbestos

Table 6. Commercial building – personal and area asbestos exposure concentration.

Work task (type of air sample)	No. of sample	% Censored data	Mean [1, 3, 5] f/cc (SD)	GM [1, 3, 5] f/cc (SD)	8 h TWA[2] Range f/cc
Scraping popcorn ceiling (personal- inside of containment)	8	38	0.009 (0.006)	0.008 (2.0)	<0.005-0.010
Scraping popcorn ceiling (area- inside of containment)	5	20	0.006 (0.006)	0.005 (1.5)	<0.004-0.008
Scraping popcorn ceiling (area- outside) [4]	14	100	<0.006	< 0.005	-

[1]Exposures resulted from the removal of material with 3% chrysotile (Table 1)- Commercial Project No. 19 (Oklahoma). Two personal samples were collected per workday. [2] The 8-hour time-weighted averages were calculated assuming zero exposure for the remainder of shift if the work shift was < 480 min. [3] The reported mean and geometric mean represent unweighted (time) exposures. [4] Area samples outside of containment include those immediately outside of the containment, near the negative air machine exhaust, worker change area, load out, and clean room. [5] All samples for scraping popcorn ceiling outside were less than the detection limit and did not allow calculation of SD and GSD. Abbreviations: CC= cubic centimeters; f=fibers; hr.=hour; GM= geometric mean; SD=standard deviation; < all samples less than the analytical method detection limit; TWA=time weighted average

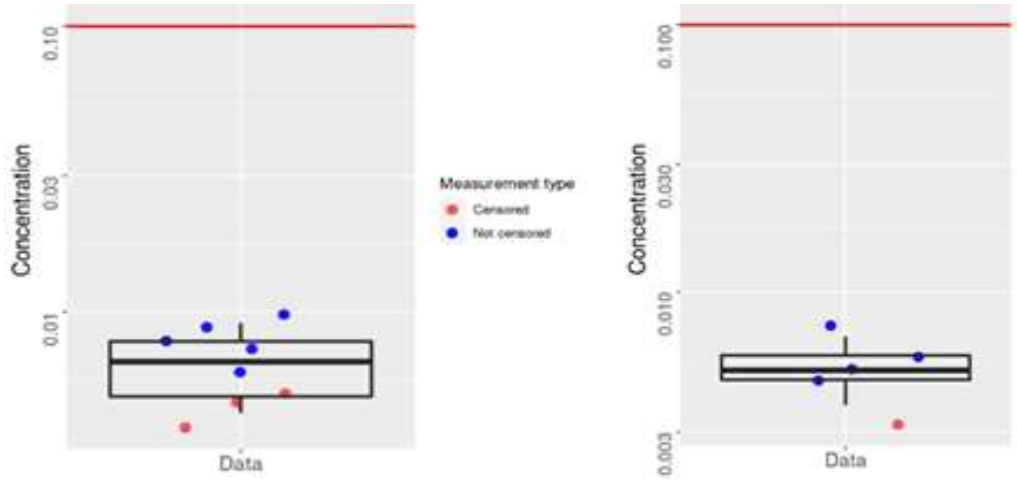

Figure 3. 8 h TWA Asbestos Exposures (f/cc) - Personal (left) and Area - Inside Containment (right). The box represents the 25th and 75th percentiles; whiskers represent the 10th and 90th percentiles. Red line denotes the OSHA permissible exposure limit.

exposures near the negative air machine exhaust and in the cleanroom. Fifty-four clearance air samples were also collected after the completion of abatement. The unweighted (time) airborne asbestos concentration ranged from <0.0019 to 0.0053 f/cc. All exposures were below OSHA's asbestos PEL (0.1f/cc). The exposure variability (geometric standard deviation) was moderate for the area sample exposures inside of the containment and low for all other sample locations (Table 7).

DISCUSSION

The purpose of this study was to review asbestos building survey data to better understand the extent and concentration of asbestos in building materials across the United States. The study also sought to evaluate personal and area exposures collected during abatement projects where the concentration and type of asbestos were known to provide much-needed information regarding the effectiveness of exposure controls during asbestos abatement. Due to inconsistent reporting requirements by public agencies within the United States, the full extent of the number of residential, public, and commercial buildings with ACM is not fully quantified (Perez et al., 2018). The assessed survey data provides vital information that could inform future exposure intervention efforts.

Table 7. Residential building – area asbestos exposure concentration.

Type of air sample	No. of samples	% censored data	Mean[1,3] f/cc (SD)	GM[1,3] f/cc (SD)	8 h TWA[1,2] Range f/cc
Area- inside of containment	109	2.8	0.007 (0.003)	0.006 (1.9)	<0.0018-0.013
Area- outside of containment	152	56	0.003 (0.001)	0.002 (1.3)	< 0.0004-0.004
Area- negative air machine exhaust	62	81	0.002 (0.001)	0.001 (1.3)	<0.001- 0.005
Area- clean room	62	44	0.003 (0.001)	0.002 (1.5)	<0.0014 -0.005

[1]Exposures from the removal of asbestos containing materials (0.25-70% asbestos): popcorn ceiling, floor tile, roof and duct mastic, drywall and joint compound, duct and exhaust fan tape, coating and sealant (Residential Project No. 1-Table 2). 2 The 8-hour time-weighted averages were calculated assuming zero exposure for the remainder of shift if the work shift was < 480 min. 3 The reported mean and geometric mean represent unweighted (time) exposures. Abbreviations: CC= cubic centimeters; f=fibers; hr.=hour; GM= geometric mean; SD=standard deviation.

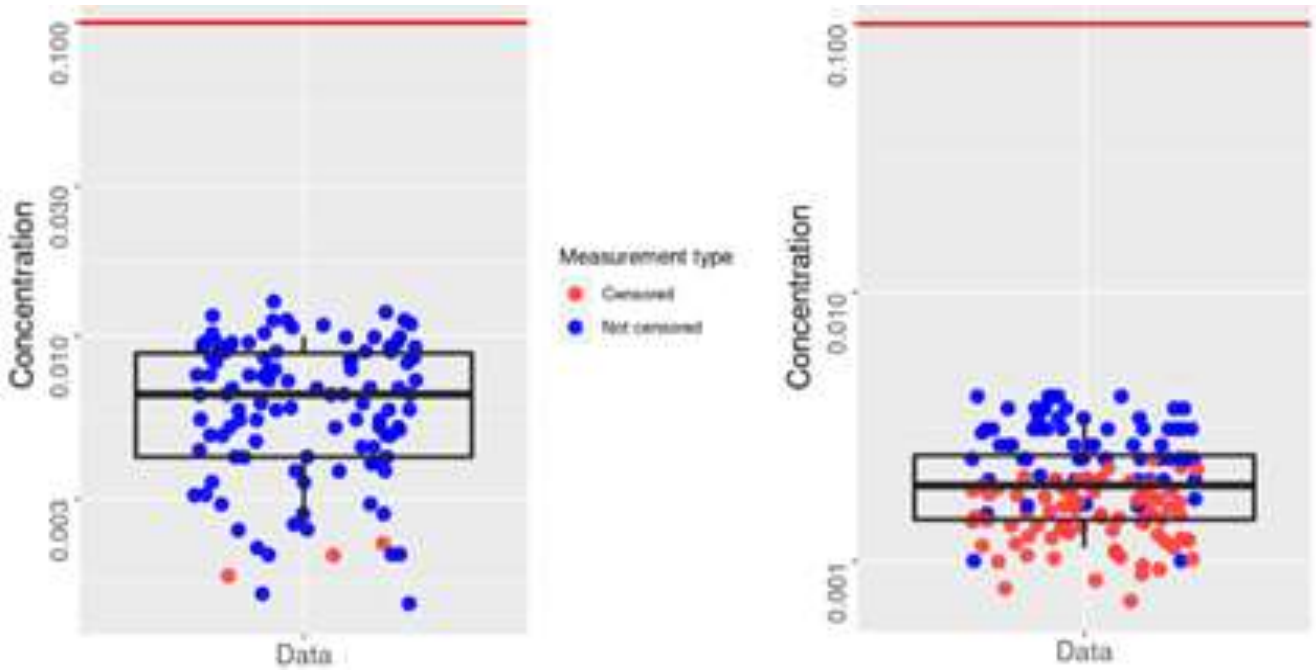

Figure 4. 8 h TWA Asbestos Exposures (f/cc) – Area - Inside Containment (left) Area – Outside Containment (right). The box represents the 25th and 75th percentiles; whiskers represent the 10th and 90th percentiles. Red line denotes the OSHA permissible exposure limit.

ACM were present in both commercial and residential buildings. The study identified 41 unique types of ACM after extracting data from both commercial and residential survey reports, all chrysotile. The highest asbestos concentration measured (100%) was found in a commercial building. The concentration and type of asbestos found in the surveys assessed for this study are consistent with previous research findings (HEI-AR, 1991; Jacobs et al., 2019). Many of the types of building materials that contained >1% asbestos were friable - meaning any renovation or demolition would trigger OSHA's asbestos removal standard that requires a hierarchy of control exposure mitigation approach (OSHA, 1994).

All exposures were less than OSHA's PEL of 0.1 f/cc during the removal of various ACM in commercial and residential buildings. The maximum, unweighted personal exposure measured was 0.0201 while hand scraping textured ceiling material. Out of the 122 personal and area samples collected inside of the active containment for both projects combined (commercial and residential), only 21 samples (17%) exceeded the project airborne clearance level of 0.01 f/cc during asbestos abatement activities. None of the area samples collected outside of the active containments (n=290) exceeded the 0.01 f/cc clearance level during asbestos removal activities.

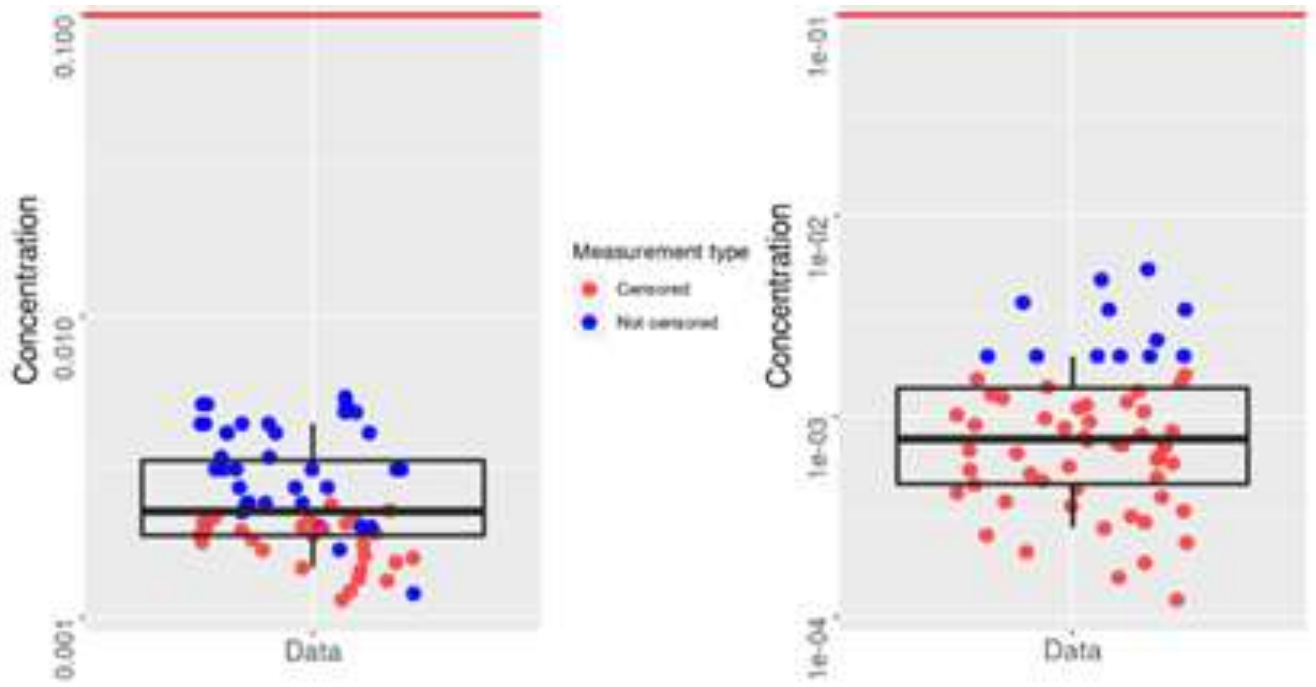

Figure 5. 8 h TWA Asbestos Exposures (f/cc) – Area - Clean Room(left) Area- Negative Air Machine Exhaust (right). The box represents the 25th and 75th percentiles; whiskers represent the 10th and 90th percentiles. Red line denotes the OSHA permissible exposure limit.

According to Paustenbach (2020), worker exposure to only chrysotile in evaluated industries to OSHA's asbestos PEL value of 0.1 f/cc, did not increase the risk of disease among those workers. As the 95th percentile personal airborne exposure level was three times less than OSHA's asbestos PEL, the risk to workers performing asbestos abatement with implemented exposure controls is low. The assessed exposures would be considered well-controlled by industrial hygiene practitioners using AIHA's exposure classification scheme (Bullock et al., 2015). The findings demonstrate the effectiveness of OSHA required control methods used to reduce the risk of overexposure to asbestos during the removal of building materials with varying asbestos concentrations. The asbestos exposures observed in this study are consistent with the findings of other researchers measured during similar asbestos removal activities (Perez et al., 2018; Lange, 2006).

Conclusion

The findings from this analysis of retrospective data provide vital information on exposure levels based on work tasks, asbestos type, and concentration of asbestos during the removal of textured ceilings and other building materials. Based on the evaluation of exposure records (air monitoring data) from the removal of ACM in both commercial and residential settings, the risk for overexposure is not significant based on the effectiveness of implemented risk management strategies. Given the potential for overexposure when workers remove friable asbestos, it is prudent for asbestos removal contractors to effectively implement and evaluate the effectiveness of exposure controls on removal projects. While risk may not be significant with adequate exposure controls, the continued evaluation of risk management strategies should be part of any acceptable compliance plan to mitigate potential overexposures.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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