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Current Man-Made Mineral Fibers (MMMF) Exposures Among Ontario Construction Workers

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Current occupational exposures to man-made mineral fibers (MMMF), including refractory ceramic fibers (RCF), were measured as part of an exposure assessment program for an epidemiological study pertaining to cancer and mortality patterns of Ontario construction workers. The assessments were carried out at commercial and residential sites. A total of 130 MMMF samples (104 personal and 26 area) was collected and included 21 RCF (16 personal and 5 area). The samples were analyzed by the World Health Organization method in which both respirable and nonrespirable airborne fibers are counted. The results show that Ontario construction workers' full-shift exposure to MMMF (excluding RCF) is generally lower than the American Conference of Governmental Industrial Hygienists' (ACGIH®) recommended threshold limit value–time-weighted average (TLV®-TWA) of 1 fibers/cc and thus should not present any significant hazard. However, approximately 40% of the occupational exposures to RCF are higher than ACGIH's TLV-TWA of 0.2 fibers/cc and present a significant potential hazard. Workers generally wore adequate approved respiratory protection, especially while performing particularly dusty tasks such as blowing, spraying, and cutting, so the actual exposure received by workers was lower than the reported values. Adequate control measures such as ventilation and respiratory protection should always be used when work involves RCF.

Keywords man-made mineral fibers, synthetic vitreous fibers, refractory ceramic fibers, construction, fiber counts, fiber counting rules

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INTRODUCTION

Man-made mineral fibers (MMMF) constitute a family of man-made, glass-like fibrous products. These fibers are noncrystalline, that is they are amorphous, unlike asbestos that has crystalline fibers. MMMF are made from molten glass (fibrous glass), molten rock (rock wool), molten slag (slag wool), or clay (ceramic fibers). The terms "man-made vitreous fibers" or "synthetic vitreous fibers" are often used in place of MMMF.

Health concerns about MMMF are based on the morphological and toxicological similarities it has with asbestos. Asbestos is well known to be a potent occupational carcinogen causing asbestosis, lung cancer, mesothelioma, and cancers at various sites.[(1)] Epidemiological evidence for human disease from fibrous glass is largely negative, with some association reported for slag and rock wool.[(2–4)] On the basis of epidemiological evidence, the U.S. Environmental Protection Agency (EPA)and the International Agency for Research on Cancer (IARC) classified mineral wool, glass wool, and special purpose glass fibers as either possible or probable human carcinogens.[(5,6)]

Recently IARC reevaluated the carcinogenic risk of airborne man-made vitreous fibers.[(7)] Epidemiological studies published since a 1988 monograph review,[(5)] plus research on newer developed materials, were evaluated. The IARC review concluded that only the more biopersistent materials such as refractory ceramic fiber (RCF) remain classified as *possible human carcinogens* (Group 2B). Continuous glass filaments and the more commonly used vitreous fiber wools such as insulation glass wool, rock (stone) wool, and slag wool are now considered *not classifiable as to their carcinogenicity to humans* (Group 3).[(7)]

The American Conference of Governmental Industrial Hygienists (ACGIH®)[(8)] has also classified various MMMF in categories ranging from classification A2—suspected human carcinogen, A3—confirmed animal carcinogen, and A4—nonclassifiable as a human carcinogen. The recommended threshold limit–value-time-weighted average (TLV®-TWA) for all MMMF except RCF is 1 fiber/cc, and 0.2 fibers/cc for RCF because it is a suspected human carcinogen.[(8)]

Taken as a whole, evidence suggests that the risk of lung diseases from MMMF exposure is very low in comparison with asbestos. In many commercial and residential construction operations such as insulating, fireproof spraying, taping, and texturing, MMMF has been substituted for asbestos to reduce the health risk and protect workers. Although the risk is much lower than with asbestos, there still remains a concern about MMMF exposure, thus the need to gather exposure data involving its use. Selikoff et al.[9] found that insulators had a very high rate of cancer from asbestos insulation. Verma and Middleton[10] found tapers to have high exposure to asbestos.[10] In the past, sprayed fireproofing operations entailed spraying asbestos or asbestos-containing materials on steel beams.[11,12] Oska et al.[13] found excessive occurrences of mesothelioma among asbestos sprayers, and the highest cancer incidence in a cohort study of Finnish asbestos sprayers and asbestosis and silicosis patients.The authors postulated that this was due to the high carcinogenic potential of crocidolite, which was the main type of asbestos sprayed in Finland prior to being prohibited, and high airborne dust concentration encountered in this operation. Since the mid-1970s, asbestos has been replaced with MMMF in insulation and fireproofing products to minimize the health hazard in these operations.

In June 2000, our group received a grant from the Workplace Safety and Insurance Board of Ontario to conduct a study entitled, "Cancer, Mortality, and Workplace Exposures Among Ontario Construction Workers." The objectives of this study were to assess the cancer and mortality patterns of union construction workers in Ontario (approximately 125,000 workers from nine unions), their cancer risks, and to assess both qualitatively and quantitatively the risks of current occupational exposure to chemical agents. To accomplish our quantitative assessment, we visited numerous construction sites and conducted a range-finding exercise using task-based exposure assessment methods, traditional sampling (pump and filter), and direct-reading instruments. The cumulative results of our exposure measurement study, including a summary of the data presented in this article, have been reported elsewhere.[14] The objectives of this article are to present exposure data for MMMF, including RCF, collected during this study and to compare the results with those published in literature.

MATERIALS AND METHODS

Workplace and Process Description

The installation of MMMF products is an important and routine operation in the construction industry. MMMF is found in all types of construction including residential, commercial, industrial, renovation, and major structural. In general, MMMF products can be categorized into three classes: sprayed/blown, batt, and reinforcing. Sprayed/blown products are applied directly to building surfaces using spraying or blowing techniques. The MMMF is usually mixed with water and some form of binding material such as cement, and then sprayed using hydraulic or pneumatic pressure. Structural insulation or fireproofing is typically applied in this manner. Batt insulation refers to a group of products applied in sheets, rolls, and/or panel forms to building surfaces. The MMMF may serve as acoustical or thermal protection and may contain fiberglass, rock wool, slag wool, and/or refractory fibers. The batt products are usually contained in protective backings such as aluminum foil or paper. Acoustic tiles, ceiling tiles, residential insulation, pipe insulation, duct insulation, and/or boiler wrapping are typical of batt MMMF products. In reinforcing material such as drywall, floor tiles, and roofing felts, MMMF helps improve structural integrity. The loose insulating fiberglass wool is used in residential construction in attic spaces and is installed by blowing using a pneumatic system.

In Ontario, construction workers are exposed to MMMF from primary and secondary sources. Construction workers directly involved in installation or application of MMMF materials are primarily exposed to MMMF. Workers not directly involved in the application of MMMF materials, but who are exposed by virtue of construction work going on nearby or who are in the presence of MMMF in unfinished construction, are secondarily exposed.

The type of construction worker performing a certain task is determined by the winning contractor and by union rules regarding the substrate to be used in the construction. Some contractors may employ one type of trade such as laborers, whereas another firm may employ another type of trade such as cement masons. Therefore, the type of tradesperson doing the work depends largely on the firm that wins the tender. Furthermore, provincial collective agreements between employers (contractors) and employees (tradespeople) list the types of work performed and the bounds of that work. The bounds are often set by the major material being worked on or substrate. Different substrates, such as wood, steel, concrete, piping, or ductwork, will dictate which trade is allowed to perform the work. For example, if studs against a concrete fascia are being insulated with batt insulation, a cement mason will perform the work. However, if drywall or wood panel is being insulated, a carpenter will insulate the wall. In both cases the same MMMF material may be used (i.e., fiberglass) but the trade will be different.

Table I lists the most common uses of MMMF in the Ontario construction industry and the corresponding trades primarily exposed to the materials. Various tasks sampled in this study included blowing, mixing, spraying, installing, cutting, handling, sweeping, and wrapping MMMF. Figure 1 shows some of the typical tasks.

Sampling and Analysis

Air Sampling

The majority of samples were collected January 2000 to May 2002. Prospective subjects were approached and informed of the nature and purpose of the study. They were asked to wear air sampling equipment and advised that participation was voluntary. Both personal and area samples were taken for fiber counts using portable personal air sampling pumps. Air samples for fiber counts were taken using a 25-mm, 3-piece open-face cassette at a flow rate of 1–2 L/min. Mixed cellulose ester filters of 0.8-μm pore size (Millipore Corporation,

TABLE I. Primary Uses of MMMF in the Ontario Construction Industry

MMMF Category	Type of MMMF	Use	Affected Trades	Worker Task Specialization
Sprayed	Rock wool	Thermal insulation, structural fireproofing, acoustic insulation	Painters, cement masons, laborers	Foreman, sprayer, mixer, helper
	Slag wool	Thermal insulation, structural fireproofing	Painters, cement masons, laborers	Foreman, sprayer, mixer, helper
	Mineral wool	Thermal insulation, acoustic insulation, structural fireproofing	Painters, cement masons, laborers	Foreman, sprayer, mixer, helper
Blown	Fiberglass	Thermal	Insulators	Sprayer, loader, helper
Batt	Rock wool	Moisture barrier, acoustic insulation, thermal insulation	Carpenters, cement masons	Installer, helper
	Fiberglass	Pipe insulation, boiler lagging, duct insulation, framing insulation	Insulators, carpenters, boilermakers	Foreman, installer, helper
	RCF	High-heat thermal insulation, duct insulation, structural insulation	Insulators, laborers	Foreman, installer, helper
Brick	RCF	High-heat thermal brick	Bricklayers	Foreman, installer, cutter, helper
Panel	Rock wool	Acoustic insulation, moisture barrier	Insulators, cement masons	Installer, helper
	Fiberglass	Duct wrap, ceiling tiles	Insulators, laborers, painters	Installer, helper
Structural panel	Fiberglass	Drywall	Carpenters, painters	Drywaller, helper
Structural felt	Fiberglass	Roofing membrane	Roofers, waterproofers	Foreman, roofer, helper
Structural tile	Fiberglass	Floor tile	Floorlayers	Floorlayer, helper

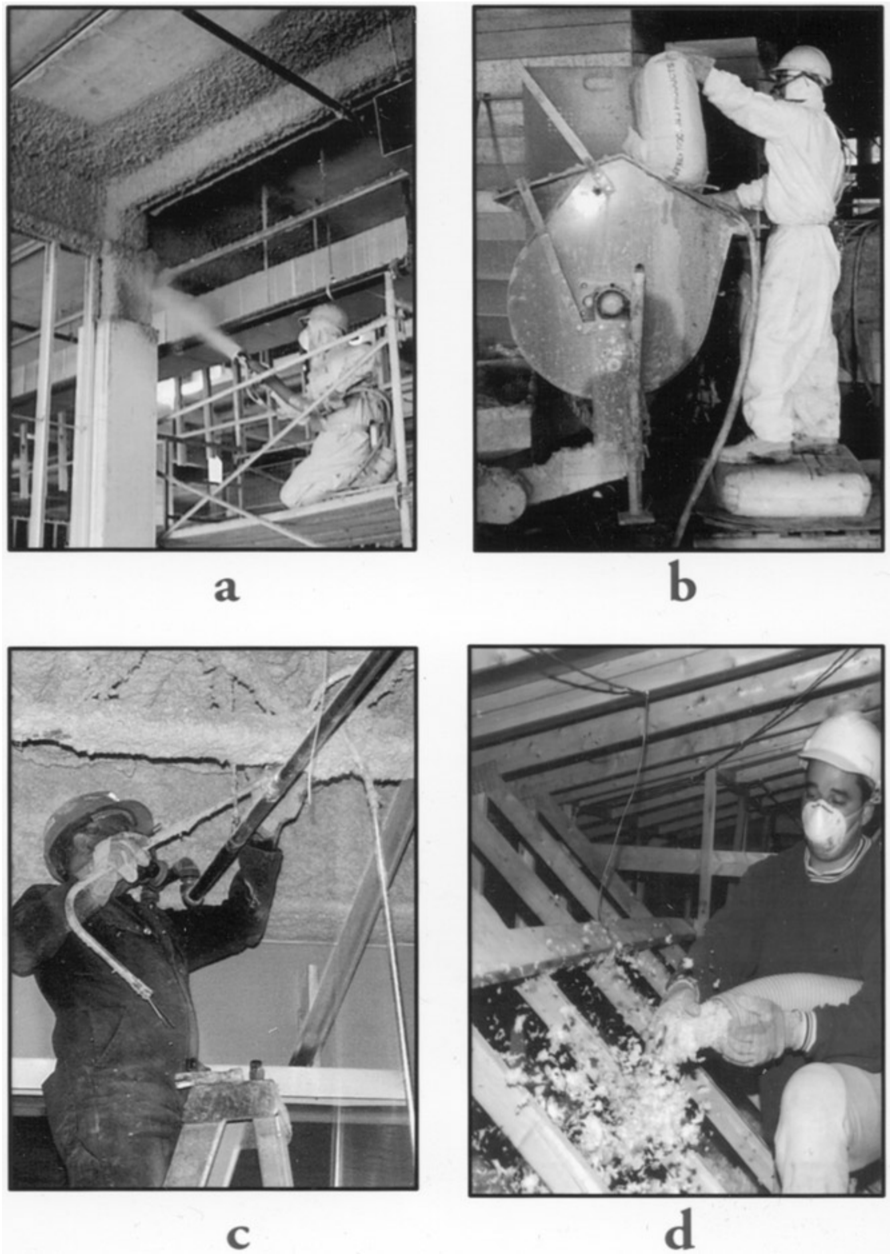
Bedford, Mass., or Pall Corporation, Ann Arbor, Mich.) were used. Since it is important not to overload the filter for fiber counting, the appropriate sampling duration was determined by trial and error to ensure that filters could be counted. Thus, the sampling time varied depending on the expected dustiness of the operation and location. An attempt was made to sample for the total duration of the task or for as long as possible without overloading the filter. Where possible, personal samples were taken; otherwise, area samples that were representative of the subject worker's exposure were taken.

Analysis

The evaluation of the membrane filter for fiber counting was carried out in accordance with the World Health Organization (WHO) MMMF reference method.(15) In this method both respirable fibers having a diameter $<3\ \mu$m and a length $>5\ \mu$m with an aspect ratio (length to diameter) of 3:1, and nonrespirable fibers having a diameter $\geq 3\mu$m and a length $>5\ \mu$m with an aspect ratio (length to diameter) of 3:1, are counted using phase contrast microscopy at a magnification of 450×. If respirable and nonrespirable fiber counts of the WHO method are combined, then the result would approximate the fiber counts by National Institute of Occupational Safety and Health (NIOSH) 7400 A rule method in which all fibers $>5\ \mu$m length with an aspect ratio of 3:1 irrespective of diameter are included.(16) The WHO method is one of the two methods recommended in ACGIH's documentation of TLVs of synthetic vitreous fibers.(8) The other recommended method of analysis is the NIOSH method 7400 using B rules for counting.(16) Using NIOSH 7400 B counting rules, fibers are counted with diameters $<3\ \mu$m, length $>5\ \mu$m, but with an aspect ratio (length to diameter) of 5:1. Thus, all else being equal, NIOSH 7400 B rules give lower results than the WHO method since the WHO method includes fibers with a shorter aspect ratio. It should be noted that respirable fibers have been defined in the documentation of the TLVs(8) as those with lengths $>5\ \mu$m and with an aspect ratio of 3:1. Strictly speaking, the WHO method meets the definition more closely than 7400 B rules method. The 7400 B method is generally used in North America, while the WHO method is used in Europe and elsewhere. In earlier studies, however, the NIOSH 7400 A rule method was generally applied.

Quality Control

Appropriate quality control procedures were adhered to in the field sampling and in the analyses of collected samples in the analytical laboratory. During the field sampling all air sampling pumps were calibrated pre- and postsampling. Hygiene technical personnel observed the sampling. McMaster University Occupational and Environmental Health Laboratory (OEHL) performed the analysis for fiber counts. The OEHL, an American Industrial Hygiene Association accredited facility,



a b c d

FIGURE 1. (a) Insulator spraying fireproofing, (b) Painter mixing sprayed fireproofing, (c) Laborer demolishing building, and (d) Insulator blowing insulation

is experienced in the analysis of fiber counting procedures and participates in a proficiency analysis testing program for fiber counting.

RESULTS

A total of 130 MMMF samples (104 personal, 26 area) was collected that included 21 RCF (16 personal, 5 area) samples. Only respirable concentration results are summarized in Table II. The table shows the range of results for specific tasks by trade, along with an assessment as to whether the exposure was primary or secondary. Residential, commercial, industrial, and demolition sites were assessed. Fifteen of the 130 MMMF samples including 2 out of 21 RCF samples are from secondary exposure in which workers sampled were not directly involved in MMMF work. Most of these samples were taken when other operations such as insulating, mixing, and spraying were being carried out in the vicinity at the commercial site. A value of half the detection limit for the method was used to calculate the mean respirable fiber concentrations (shown in Table II) where concentrations were reported as below detection limit.

TABLE II. Distribution of Respirable MMMF Concentration by Trade and Material Used

MMMF Category	Trade/ Occupation	Site Type	Major Tasks	Sample Size	Type	Sampling Duration (min) Min	Max	Respirable Fiber Concentration (f/cc) Mean	Median	Min	Max
			MMMF (excluding RCF)								
Batt	Bricklayer	C	Installing/smokesealing	1	P	—	28	—	—	—	0.09
	Carpenter	R,C	Installing	2	P	47	59	0.12	—	0.06	0.18
		C	Smokesealing	1	P	—	52	—	—	—	0.70
	Foreman	I	Cleaning/handling	1	P	—	80	—	—	—	0.10
		I	Vacuuming	1	P	—	94	—	—	—	0.05
	Insulator	I	Cutting	1	P	—	86	—	—	—	0.19
		I	Handling	2	P	66	105	0.23	—	0.22	0.24
		I,R	Installing	7	P	41	97	0.19	0.17	BDL	0.59
				1	A	—	83	—	—	—	BDL
		I	Installing/cutting/handling	9	P	70	98	0.29	0.24	0.13	0.64
		R	Polying	3	P	39	95	BDL	BDL	BDL	BDL
	Laborer	I	Removing	4	P	133	151	0.15	0.15	0.13	0.18
		I	Storing	6	P	74	126	0.09	0.08	0.05	0.13
Blown	Insulator	R	Blowing (R)	5	P	14	27	0.66	0.62	0.46	0.95
Ceiling tiles	Laborer	I	Cleaning	1	P	—	15	—	—	—	1.75
				1	P	—	15	—	—	—	0.49
		I	Helping	3	P	18	42	0.49	0.29	0.25	0.93
		I	Removing	3	P	16	28	0.78	0.68	0.40	1.25
				3	A	16	42	0.66	0.40	0.32	1.26
Drywall	Carpenter	C	Cutting/installing	3	P	30	92	0.15	0.10	0.10	0.26
Duct wrap	Insulator	C	Cutting/wrapping	1	P	—	46	—	—	—	BDL
		C	Pinning	3	P	12	124	0.04	0.06	BDL	0.07
		C	Wrapping	2	P	13	167	BDL	—	BDL	0.03
				2	A	62	130	0.04	—	BDL	0.08
Pipe wrap	Insulator	C	Wrapping	1	P	—	66	—	—	—	0.06
Sprayed fireproof	Bricklayer	C	Secondary exposure-working on wall	2	P	76	308	0.08	—	0.01	0.15
	Electrician	C	Secondary exposure-working overhead	4	P	37	232	0.19	0.03	BDL	0.70
	Insulator	I	Spraying	4	P	10	18	0.68	0.66	0.35	1.08
	Laborer	I	Helping/loading/mixing	2	P	25	35	0.31	—	0.25	0.36
		I	Loading/mixing	2	P	32	73	0.23	—	0.11	0.34
		C	Mixing	1	P	—	30	—	—	—	0.05
		C	Sweeping	1	P	—	27	—	—	—	0.22
		I	Sweeping/set up	1	P	—	27	—	—	—	0.35

	Multiple workers	C	Secondary exposure-working overhead	2	A	263	322	0.02	—	0.02	0.02
	Painter	C	Spraying	1	P	—	66	—	—	—	0.06
				2	A	15	96	0.04	—	0.02	0.06
		C	Helping spray	1	P	—	53	—	—	—	0.07
	Pipe fitter	C	Secondary exposure-working overhead	1	P	—	113	—	—	—	0.03
	Plumber	C	Secondary exposure-working overhead	1	P	—	315	—	—	—	0.01
	Sheetmetal worker	C	Secondary exposure-working overhead	1	P	—	160	—	—	—	0.08
Various	Electrician	C	Secondary exposure-working on wall	1	P	—	95	—	—	—	0.06
	Ironworker	D	Secondary exposure-working on ground	1	A	—	72	—	—	—	0.67
	Laborer	D	Demolishing structures	2	P	45	201	0.29	—	BDL	0.58
				2	A	27	28	0.16	—	0.12	0.20
		D	Demolishing/operates machines	3	A	47	81	0.64	0.66	0.45	0.82
		C	Sweeping	2	P	76	131	0.63	—	0.06	1.21
	Supervisor	D	Demolishing/setting up	1	P	—	40	—	—	—	0.69
	Multiple workers	D	Demolishing/various	4	A	36	68	0.22	0.19	0.04	0.48
			RCF								
Batt	Laborer	C	Finishing	1	P	—	143	—	—	—	0.08
		C	Folding/preparation	2	P	130	182	0.05	—	0.04	0.06
				3	A	96	321	BDL	BDL	BDL	BDL
		C	Installing	2	P	326	333	0.05	—	0.03	0.06
	Multiple workers	C	Secondary exposure-beyond enclosure	2	A	87	127	0.02	—	BDL	BDL
Brick	Bricklayer	I	Cutting	1	P	—	69	—	—	—	1.64
		I	Installing	1	P	—	67	—	—	—	0.38
	Foreman	I	Supervising	1	P	—	63	—	—	—	0.28
	Laborer	I	Helping	1	P	—	58	—	—	—	0.59
Pipe wrap	Insulator	I	Installing	5	P	56	91	0.42	0.40	0.26	0.65
Sprayed	Laborer	I	Dumping	2	P	10	14	0.11	—	0.10	0.13

Notes: Site type: R = residential; C = commercial; I = industrial; D = demolition.
P = personal; A= area; BDL = below detection limit.

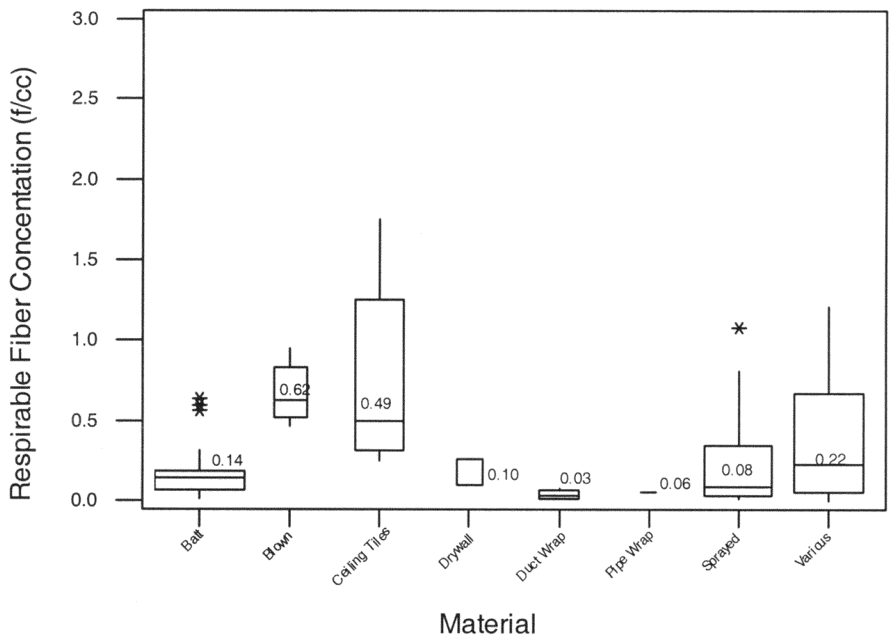


FIGURE 2. Boxplot of MMMF (excluding RCF) respirable fiber distribution by material used. Outliers are shown as*

Data were analyzed using the statistical package Minitab®[17] version 12. Figure 2 shows boxplots of the distribution of the combined personal and area samples by material type for MMMF (excluding RCF). Figure 3 shows similar information for RCF. Boxplots illustrate the statistical range of data between the 25th and 75th percentiles, with whiskers extending out showing the general range of all data. The numerical value shown at the center of each boxplot is the median value. The width of each box is proportional to the square root of the number of observations in the box.

Outliers, specific data outside the statistical range, are shown as a * symbol. Outliers were predetermined automatically by the statistical analysis package used. In the boxplot function, Minitab considers any observation 1.5 to 3 times away from

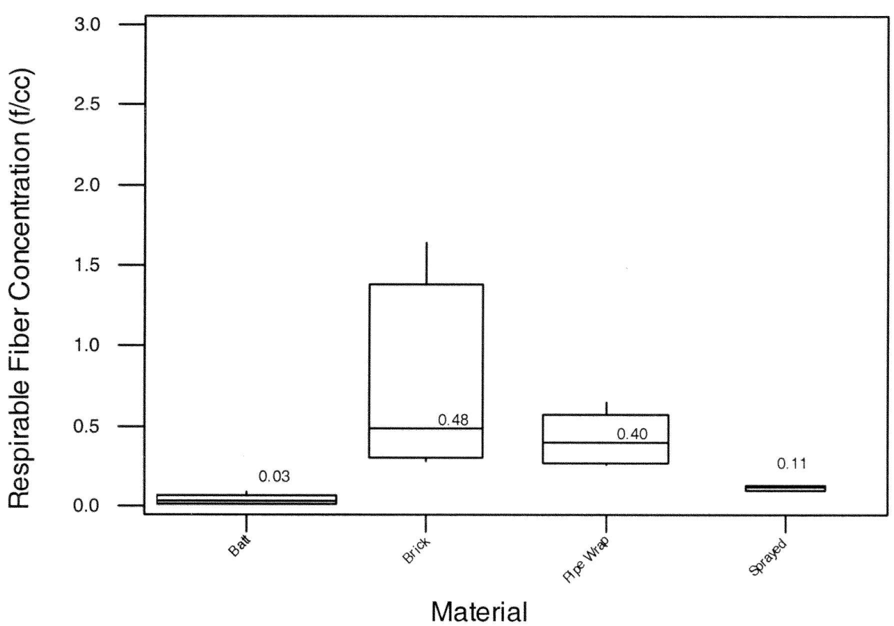


FIGURE 3. Boxplot of RCF respirable fiber distribution by material used

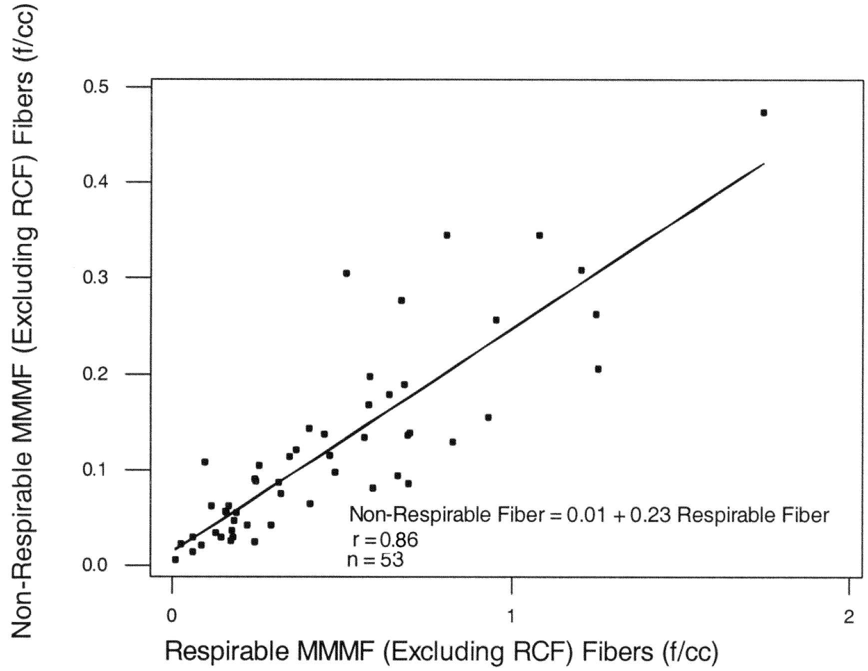


FIGURE 4. Relationship between respirable vs. nonrespirable MMMF fibers (excluding RCF)

the middle 50% of data as a possible outlier. Figures 4 and 5 show the relationships between respirable fiber counts and nonrespirable fiber counts for MMMF (excluding RCF) and RCF, respectively. Only comparisons between counts where both results are detectible are shown. In Table III, results of previous studies(18–28) relating to the construction and end user were tabulated.

DISCUSSION

Counts for MMMF were conducted by three methods: (1) NIOSH 7400 method with A counting rules or its predecessor P&CAM 239, (2) NIOSH 7400 with B counting rules, and (3) the WHO method. Studies were conducted to estimate the differences in fiber counts obtained by these

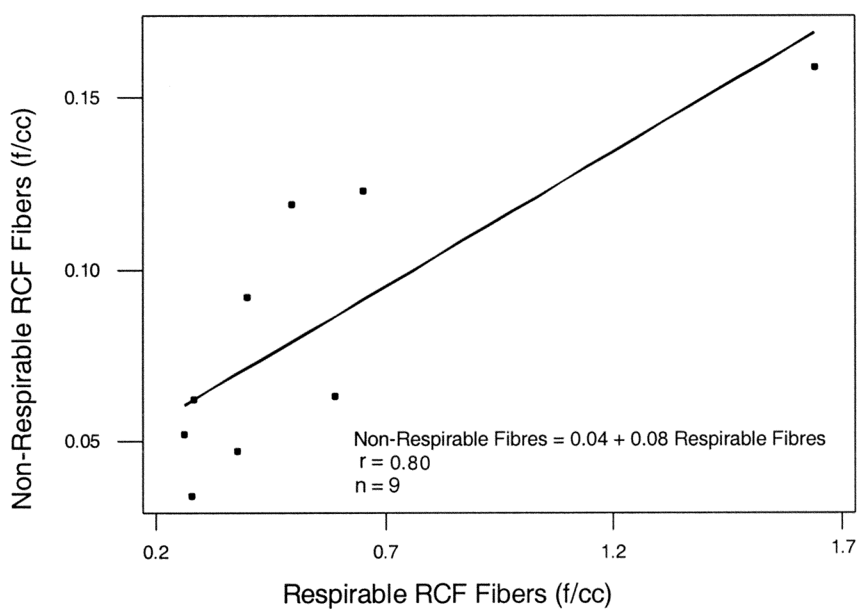


FIGURE 5. Relationship between respirable vs. nonrespirable RCF fibers

TABLE III. Summary of Respirable MMMF Concentration in Fibers/cc from Published Sources

Source Remarks	N	Class	Type	Respirable Concentration (Fibers/cc) AM	GM	GSD	Min	Max
UK—Head and Wagg (1980)[18]								
Applications in building works								
Domestic loft insulation (glass fiber blanket)								
Site 7	5	1	P+A	0.38			0.30	0.54
Site 8	7		P+A	1.02			0.24	1.76
Domestic loft insulation (loose fill mineral wool) — Site 9	6	1	P+A	8.19			0.54	20.9
Fire protection of structural steel (sprayed mineral wool)								
Site 10	11	1	P+A	0.82			0.17	2.57
Site 11	11	1	P+A	0.72			0.16	2.06
Applications in industrial products								
Industrial engine exhaust insulation (mineral wool)								
Plant 16	12	1	P+A	0.10			0.02	0.36
Plant 17	3	1	P	0.07			0.05	0.10
Furnace and kiln lining (mixed ceramic and mineral wool)								
Plant 13	1	2	P	1.70			1.70	—
Plant 14	4	1+2	P+A	1.03			0.39	1.47
Plant 15	13	1+2	P+A	2.58			0.97	5.23
Finishing vacuum formed mouldings (ceramic) – Plant 16	2	2	P+A	0.65			0.62	0.67
Industrial engine silencer insulation (alumina fiber) – Plant 16	3	2	P	1.07			0.57	1.72
USA—Esmen et al. (1982)*[19]								
Acoustical ceiling installer	12	1	P	0.01			0.0018	0.028
Duct installation								
Pipe covering	31	1	P	0.03			0.0046	0.11
Blanket insulation	8	1	P	0.05			0.012	0.078
Wrap around	11	1	P	0.04			0.014	0.064
Attic insulation (fibrous glass)								
Roofer	6	1	P	0.13			0.015	0.19
Blower	16	1	P	2.40			0.19	4.8
Feeder	18	1	P	0.086			0	0.25
Attic insulation (mineral wool)								
Roofer	9	1	P	0.57			0.041	2.03
Blower	23	1	P	5.3			0.44	20.0
Feeder	9	1	P	1.17			0.15	3.8
Building insulation installer	31	1	P	0.02			0	0.085
Aircraft insulation (Plant A)								
Sewer	16	1	P	0.20			0.05	0.59
Cutter	8	1	P	0.07			0.04	0.12
Cementer	9	1	P	0.12			0.04	0.20
Aircraft insulation (Plant B)								
Sewer	8	1	P	0.09			0.025	0.18
Cutter	4	1	P	0.56			0.38	2.00
Cementer	1	1	P	0.05			—	—
Isolated jobs	3	1	P	0.02			0.0087	0.031
Fibrous glass duct								
Duct fabricator	4	1	P	0.02			0.007	0.049
Sheet metal worker	8	1	P	0.02			0.0080	0.047
Duct installer	5	1	P	0.01			0.004	0.015
USA—Axten et al. (1990)*[20]								
Exposure of fibrous glass								
Batts – Installers	60	1	P+A	0.24				
Loose fill loaders – Cubed	86	1	P+A	0.87				
Milled	18	1	P+A	0.56				
Loose fill installers – Cubed	87	1	P+A	1.0				
Milled	20	1	P+A	1.8				

(Continued on next page)

TABLE III. Summary of Respirable MMMF Concentration in Fibers/cc from Published Sources *(Continued)*

				Respirable Concentration (Fibers/cc)				
Source Remarks	**N**	**Class**	**Type**	**AM**	**GM**	**GSD**	**Min**	**Max**
Canada—Perrault et al. (1992)[21]								
Construction sites								
Refractory fibers and glass wool	33	1+2	A		0.04	3.8		
Glass wool	17	1	A		0.01	1.9		
Rock wool (blown)	10	1	A		0.32	1.4		
Rock wool (sprayed-on)	16	1	A		0.15	1.7		
Refractory fibers								
Site A	40	2	A		0.64	2.6		
Site B	41	2	A		0.39	1.3		
Site C	46	2	A		3.51	3.4		
USA—Jacob et al. (1992)[21]								
Fiber concentrations associated with installation of cubed and milled blowing wool insulation								
Prior to installation	24	1	A	0.001				
Loader, cubed	49	1	P	0.12				
Loader, milled	16	1	P	0.22				
Installer, cubed	52	1	P	0.37				
Installer, milled	15	1	P	0.91				
Following installation	38	1	A	0.001				
Fiber concentrations associated with installation of batt insulation								
Prior to installation	15		A	0.002				
Installers	32		P	0.059				
Following installation	15		A	0.001				
USA—Lees et al. (1993)[23] (N = 401)								
Task length average exposure estimates by residential insulation product/occupation category								
Fiberglass batts – Installer		1	P	0.14	0.12	2.01	0.02	0.41
Mineral wool batts – installer		1	P	0.17	0.15	1.73	0.07	0.39
Fiberglass with binder loose (blowing) wool – installer		1	P	0.55	0.44	1.86	0.17	2.88
Fiberglass with binder loose (blowing) wool – feeder		1	P	0.18	0.15	1.89	0.06	0.67
Fiberglass without binder loose (blowing) wool – installer		1	P	7.67	5.98	2.18	1.32	18.4
Fiberglass without binder loose (blowing) wool – feeder		1	P	1.74	0.57	5.41	0.06	9.36
Mineral wool loose (blowing) wool – installer		1	P	1.94	1.16	2.81	0.32	6.16
Mineral wool loose (blowing) wool – installer		1	P	0.31	0.23	2.20	0.09	0.78
8-Hour TWA exposure estimates by residential insulation product/occupation category								
Fiberglass batts – installer		1	P	0.06	0.05	2.41	0.01	0.17
Mineral wool batts – installer		1	P	0.11	0.10	1.45	0.06	0.15
Fiberglass with binder loose (blowing) wool – installer		1	P	0.15	0.09	3.82	0.01	0.35
Fiberglass with binder loose (blowing) wool – feeder		1	P	0.05	0.03	3.06	0.01	0.13
Fiberglass without binder loose (blowing) wool – installer		1	P	1.96	1.52	2.56	0.40	3.23
Fiberglass without binder loose (blowing) wool – feeder		1	P	0.85	—	—	—	—
Mineral wool loose (blowing) wool – installer		1	P	0.97	0.52	3.76	0.13	2.44
Mineral wool loose (blowing) wool – installer		1	P	0.18	0.14	2.20	0.07	0.40
USA—Koenig and Axten (1995)[24]								
Installation of Commercial and Industrial Mineral Wool Products								
Installation of wet felted acoustical products	49	1	P	0.12			0.01	0.50
Installation of molded acoustical products	40	1	P	0.46			0.04	1.30
Installation of insulation products	83	1	P	0.10			0.01	1.10
USA—Maxim et al. (1997)[25]								
Finishing								
Internal	206	2	P	0.66	0.50		0.028	2.7
External	375	2	P	0.99	0.37		0.009	30
Combined	581	2	P	0.87	0.41		0.009	30

(Continued on next page)

TABLE III. Summary of Respirable MMMF Concentration in Fibers/cc from Published Sources *(Continued)*

				Respirable Concentration (Fibers/cc)				
Source Remarks	**N**	**Class**	**Type**	**AM**	**GM**	**GSD**	**Min**	**Max**
Installation								
External	288	2	P	0.41	0.20		0.003	2.5
Mixing/forming								1.4
Internal	231	2	P	0.30	0.19		0.007	4.1
External	186	2	P	0.32	0.16		0.10	4.1
Combined	417	2	P	0.31	0.18		0.007	3.2
Removal								
Internal	5	2	P	1.6	1.4		0.66	
External	103	2	P	1.2	0.78		0.027	5.4
Combined	108	2	P	1.2	0.80		0.027	5.4
Korea—Kim J.H. et al. (1999)*[26]								
Rock wool sprayed on building in construction industry								
Wet process	8	1	P		0.078	3.209	0.013	0.334
Semi-wet process	12	1	P		0.116	5.061	0.004	0.698
Continuos filament glass fiber users								
Cutting	15	1	P		0.007	2.730	0.001	0.065
Piling	10	1	P		0.003	4.467	0.001	0.040
Grinding	11	1	P		0.014	7.062	0.001	0.126
Others	10	1	P		0.002	2.450	0.001	0.010
USA—Breysee et al. (2001)[27]								
Installers (task length average exposure estimates)								
Fiberglass duct board	6	1	P	0.03	0.03	1.40	0.02	0.05
Fiberglass duct liner	7	1	P	0.32	0.32	1.17	0.28	0.42
Fiberglass duct wrap	10	1	P	0.68	0.35	3.33	0.17	2.13
Fiberglass pipe and vessel insulation	32	1	P	0.04	0.03	2.54	0.01	0.21
Mineral wool ceiling tiles	39	1	P	0.24	0.22	1.64	0.08	0.48
Fiberglass batts in prefabricated homes	10	1	P	0.19	0.19	1.33	0.16	0.26
Loose mineral wool in prefabricated homes	13	1	P	0.13	0.11	1.71	0.06	0.20
Mineral wool building safing	9	1	P	0.16	0.12	2.21	0.06	0.32
USA—Marchant et al. (2002)[28]								
Installation of mineral wool								
Ceiling panel/tile	33	1	P	0.23			0.02	0.82
Spray-on fireproofing	15	1	P	0.08			0.02	0.42
Insulation batt and blanket	12	1	P	0.09			0.04	0.16
Other insulation	14	1	P	0.11			0.02	0.40
Glass wool installation								
Air-handling products	11	1	P	0.28			0.02	1.23
Appliance insulation	31	1	P	0.08			0.01	0.06
Automotive insulation	17	1	P	0.02			0.01	0.05
Blowing wool with binder – feeder	6	1	P	0.09			0.04	0.19
Blowing wool with binder – installer	13	1	P	0.39			0.09	1.13
Blowing wool without binder – feeder	49	1	P	0.44			0.01	2.18
Blowing wool without binder – installer	84	1	P	0.99			0.04	7.49
Cavity loose fill insulation	12	1	P	0.15			0.04	0.47
Pipe insulation	28	1	P	0.05			0.01	0.19
Insulation batts and blankets	62	1	P	0.17			0.01	0.46
Other	25	1	P	0.05			0.01	0.16
Glass wool retrofit/removal	6	1	P	0.26			0.03	0.74
Mineral wool retrofit/removal	2	1	P	0.01			0.10	0.11

Notes: Class 1 = MMMF (excluding RCF); Class 2 = RCF; * = "A" counting rules; P = personal; A = area.

various methods.[23,25,29] As stated earlier, if both respirable and nonrespirable fiber counts as determined by the WHO method are added together, it should approximate the result determined by NIOSH 7400 using A counting rule. The A rules have been shown to produce higher results (approximately 40% more based on computing A/B rules for task length or TWA exposure estimates measured by phase contrast microscopy) than counts by the B rules.[23] The NIOSH B rules method has also been shown to produce statistically significant lower counts of about 27% less than by the WHO method in a study conducted on an exchange of microscope slides prepared from MMMF airborne samples (mainly MMMF excluding RCF).[29]

Another study conducted on 200 samples using phase contrast optical microscopy for RCF showed the NIOSH 7400 method using B rules produced only 5% less than the WHO rule for respirable fibers.[24] The difference in these two studies is related to the materials involved indicating that RCF generates proportionally more thinner fibers (aspect ratio 5:1). The results of these studies could be used to convert fiber counts of various studies for a meta-analysis.

The aim of measuring total airborne fibers (both respirable and nonrespirable) was to provide a better index of MMMF nonrespiratory health hazards, namely skin and eye irritation, as they were often the major complaint. Total fiber measurement provides the necessary information and should be considered as the preferred method. Results of Figure 4 for MMMF (excluding RCF) show that the airborne concentration of nonrespirable fibers as a fraction of respirable fibers is about 23%. For RCF (Figure 5), the concentration of nonrespirable fibers as a fraction of respirable fibers is much less at about 8%. The total fibers would be higher in MMMF (excluding RCF). This is useful information to estimate total airborne fibers where only respirable fibers are measured.

The MMMF (excluding RCF) exposures measured in this Ontario study are generally lower than 1 fiber/cc with mean values ranging from 0.04 to 0.72 fibers/cc (see Table II and Figure 2). Blowing residential insulation and sweeping had the highest concentration, 0.95 and 1.75 fibers/cc, respectively. Very high arithmetic mean values of 5.3 fibers/cc,[19] 7.7 fibers/cc,[23] and 8.2 fibers/cc[18] have been reported previously (see Table III). These high values are mainly from residential blowing and feeding operations. In the case of RCF there were several samples that exceeded the recommended TLV-TWA of 0.2 fibers/cc (see Table II and Figure 3). About 42% of all samples (9 of 21) were above 0.2 fibers/cc, indicating that the RCF exposure needs to be controlled more rigorously. Exposure levels in excess of 0.2 fibers/cc have been prevalent as noted in other studies listed in Table III. All reported RCF exposures by Head and Wagg,[18] and some by Perrault et al.,[21] are in excess of 0.2 fibers/cc. The extensive data set of Maxim et al.[25] (almost 1400 samples) also shows all the mean values to be in excess of 0.2 fibers/cc. The exposure to RCF is thus of significant concern and needs special attention. It should be noted that the actual exposure received by workers would be lower than the reported values if they wore respirators. In this study, most workers in direct contact with MMMF wore NIOSH approved N95 disposable or half-mask cartridge respirators, especially during dusty tasks such as mixing, spraying, and blowing insulation. The assigned protection factors for these respirators are between 5 and 10.[30] Assuming the actual protection in field use of about 50%, the exposure received by the workers would be less than half of the reported exposure. Maxim et al.[31] also found that the use of respirators was substantially beneficial for many job categories. A high percentage wore respirators while engaged in removal activities, which had the highest exposures. The use of respirators reduced RCF exposure for removal activities from an average of 1.84 fibers/cc to 0.247 fibers/cc.[31] The exposure of 0.247 fibers/cc is, however, still above the current ACGIH TLV-TWA of 0.2 fibers/cc. The actual exposure received by Ontario workers to MMMF including RCF was lower than those listed in Table II, especially for dusty tasks. The potential of nonoccupational or para-occupational exposure to MMMF including RCF for those who work in the vicinity, or happen to be in the area, can be estimated by area and secondary exposure. The data in Table II shows that levels for trades and bystander areas are low, ranging from 0.01 to 0.68 fibers/cc for MMMF (excluding RCF) and below the limit of detection for RCF. It should be noted that the sample size for secondary exposure is small. Based on this data set the exposure to MMMF including RCF for workers not directly involved should not be of any significant concern.

CONCLUSIONS

Based on this data set and our observations it appears that full-shift occupational exposure to MMMF (excluding RCF) in Ontario is generally below the ACGIH TLV-TWA of 1 fibers/cc and therefore should not present a significant hazard. However, exposure to RCF could be a significant problem since several measured concentrations were in excess of the ACGIH TLV-TWA of 0.2 fibers/cc. The actual exposure received by workers to MMMF including RCF would likely be lower than the measured concentration due to respirator usage. It is important that workers' RCF exposure be controlled diligently through engineering control measures and use of respirators. The bystanders and other trades not directly involved, but in the vicinity of MMMF operations, generally have minimal exposure and therefore should not be of concern. Both respirable and nonrespirable fibers determined by the WHO method should be routinely measured since the method provides added information on total airborne fibers that is relevant from a skin and eye irritation hazard point-of-view. Studies of the relationships between various methods of counting exist, enabling conversion of fiber counts made by different methods. The ratios of respirable and nonrespirable fibers are different for MMMF (excluding RCF) and RCF. There are a lot more nonrespirable fibers as a percent of respirable fibers (about 23%) in MMMF (excluding RCF) than the RCF (about 8%) in airborne fibers.

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REFERENCES

1. **American Conference of Governmental Industrial Hygienists (ACGIH®):** Documentation of TLV for asbestos, all forms. In *Chemical Substances TLVs® and BEIs®*, 7th edition. Cincinnati, Ohio: ACGIH, 2002.
2. **Doll, R.:** Symposium on MMMF, Copenhagen, October 1986: Overview and conclusions. *Ann. Occup. Hyg. 31*:805–819 (1987).
3. **Lippman, M.:** Man-made mineral fibers (MMMF): Human exposures and health risk assessment. *Toxic Ind. Health 6*:225–246 (1990).
4. **Miettinen, O.S., and M.A. Rossiter:** Man-made mineral fibers and lung cancer. *Scand. J. Work Environ. Health 16*:221–231 (1990).
5. **World Health Organization (WHO):** *Environmental Health Criteria 77. Man-Made Mineral Fibers*. Geneva: WHO, 1988.
6. **Kojola, W.H., and J.B. Moran:** Exposure limits for man-made mineral fibers. Position of the Building and Construction Trades Department, AFL-CIO. *Appl. Occup. Environ. Hyg. 7*:724–733 (1992).
7. **International Agency for Research in Cancer (IARC):** Man-made vitreous fibres. In *IARC Monographs on the Evaluation of Carcinogenic Risk to Humans*, vol. 81. Lyons, France: IARC Press, 2002.
8. **American Conference of Governmental Industrial Hygienists (ACGIH):** Documentation of TLV for synthetic vitreous fibers. In *Chemical Substances TLVs and BEIs*, 7th edition. Cincinnati, Ohio: ACGIH, 2002.
9. **Selikoff, I.J., E.C. Hammond, and H. Seidman:** Mortality experience of insulation workers in the United States and Canada, 1943–1976. *Ann. NY Acad. Sci. 330*:91–116 (1979).
10. **Verma, D.K., and C. Middleton:** Occupation exposure to asbestos in the drywall taping process. *Am. Ind. Hyg. Assoc. J. 41*:264–269 (1980).
11. **Ritze, W.B., W.J. Nicholson, D.A. Holaday, and I.J. Selikoff:** Application of sprayed inorganic fiber containing asbestos: Occupational health hazards. *Am. Ind. Hyg. Assoc. J. 33*:178–191 (1972).
12. **Skidmore, J.W., and J.S.P. Jones:** Monitoring an asbestos spray process. *Ann. Occup. Hyg. 18*:151–156 (1975).
13. **Oksa, P., E. Pukkala, A. Karjalainen, A. Ojajarvi, and M.S. Huuskonen:** Cancer incidence and mortality among Finnish asbestos sprayers and in asbestosis and silicosis patients. *Am. J. Ind. Med. 31*:693–698 (1997).
14. **Verma, D.K., L.A. Kurtz, D. Sahai, and M.M. Finkelstein:** Current chemical exposures among Ontario construction workers. *Appl. Occup. Environ. Hyg. 18*:1031–1047 (2003).
15. **World Health Organization (WHO):** Reference methods for measuring airborne man-made mineral fibers (MMMF). In *EURO Technical Committee for Monitoring and Evaluating Airborne MMMF*. Copenhagen: WHO, 1985. pp 16–25.
16. **National Institute for Occupational Safety and Health (NIOSH):** Analytical method #7400: Asbestos and other fibers by PCM. In *NIOSH Manual of Analytical Methods*, 4th edition (Pub. No. 94-113), M.E. Cassinelli, editor. Cincinnati, Ohio: DHEW (NIOSH), 1994.
17. **Manufacturer:** *Minitab®*. [Computer Software.] Minitab, Inc., 1998.
18. **Head, I.W.H., and R.M. Wagg:** A survey of occupational exposure to man-made mineral fiber dust. *Ann. Occup. Hyg. 23*:235–258 (1980).
19. **Esmen, N.A., M.J. Sheehan, M. Corn, M. Engel, and N. Kotsko:** Exposure of employees to manmade vitreous fibers: Installation of insulation materials. *Environ. Res. 28*:386–398 (1982).
20. **Axten, C.W., J.R. Bender, P.F. Auborg, T.R. Jacobs, M.R. Kalinowski, and E.J. Klotz:** Exposures of end-users to airborne concentrations of fibrous glass during installation of insulation products and fabrication operations. *Proceedings of the VIIth International Pneumoconioses Conference*, Pittsburgh, Pa.: NIOSH, 1988. pp. 1094–1097.
21. **Perrault, G., C. Dion, and Y. Cloutier:** Sampling and analysis of mineral fibers on construction sites. *Appl. Occup. Environ. Hyg. 7*:323–326 (1992).
22. **Jacob, T.R., J.G. Hadley, J.R. Bender, and W. Eastes:** Airborne glass fiber concentrations during installation of residential insulation. *Am. Ind. Hyg. Assoc. J. 53*:519–523 (1992).
23. **Lees, P.S.J., P.N. Breysse, B.R. McArthur, et al.:** End user exposures to man-made vitreous fibers: I. Installation of residential insulation products. *Appl. Occup. Environ. Hyg. 8*:1022–1030 (1993).
24. **Koenig, A.R., and C.W. Axten:** Exposures to airborne fiber and free crystalline silica during installation of commercial and industrial mineral wool products. *Am. Ind. Hyg. Assoc. J. 56*:1016–1022 (1995).
25. **Maxim, L.D., J.N. Allshouse, W.P. Kelly, T. Walters, and R. Waugh:** A multiyear workplace-monitoring program for refractory ceramic fibers: Findings and conclusions. *Reg. Toxicol. Pharmacol. 26*:156–171 (1997).
26. **Kim, J.H., H.S. Chang, K.Y. Kim, et al.:** Environmental measurements of total dust and fiber concentration in manufacturer and user of man-made mineral fibers. *Ind. Health 37*:322–328 (1999).
27. **Breysse, P.N., P.S.J. Lees, B.C. Rooney, B.R. McArthur, M.E. Miller, and C. Robbins:** End user exposures to man-made vitreous fibers: II. Fabrication and installation fabrication of commercial products. *Appl. Occup. Environ. Hyg. 16*:464–470 (2001).
28. **Marchant, G.E., M.A. Amen, C.H. Bullock, et al.:** A synthetic vitreous fiber (SVF) occupational exposure database: Implementing the SVF health and safety partnership program. *Appl. Occup. Environ. Hyg. 17*:276–285 (2002).
29. **Breysse, P.N., J.W. Cherrie, P.S.J. Lees, and P. Brown:** Comparison of NIOSH 7400 "B" rules and WHO reference methods for the evaluation of airborne man-made mineral fibers. *Ann. Occup. Hyg. 38*:527–531 (1994).
30. **National Institute of Occupational Safety and Health (NIOSH):** *Respirator Decision Logic* (Pub. No. 87-108). Cincinnati, Ohio: NIOSH, 1987.
31. **Maxim, L.D., J.N. Allshouse, S.H. Chen, J.C. Treadway, and D.E. Venturin:** Workplace monitoring of refractory ceramic fiber in the United States. *Reg. Toxicol. Pharmacol. 32*:293–309 (2000).