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Current Chemical Exposures Among Ontario Construction Workers

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Current occupational exposures to chemical agents were assessed as part of an epidemiological study pertaining to the cancer and mortality patterns of Ontario construction workers. The task-based exposure assessment involved members from nine construction trade unions. Air samples were taken using personal sampling pumps and collection media. A DustTrak direct-reading particulate monitor was also employed. Exposure assessments included measurements of airborne respirable, inhalable, total, and silica dust; solvents; metals; asbestos; diesel exhaust and man-made mineral fibers (MMMF). In total, 396 single- or multi-component (filter/tube), 798 direct-reading, and 71 bulk samples were collected. The results showed that Ontario construction workers are exposed to potentially hazardous levels of chemical agents. The findings are similar to those reported by other researchers, except for silica exposure. In our study, silica exposure is much lower than reported elsewhere. The difficulty associated with assessing construction workers' exposures is highlighted.

Keywords Construction Workers, Occupational Exposure, Dust, Particulates, Silica, Metal, Solvent, Diesel Exhaust, Coal Tar Pitch Volatiles (CTPVs), Polycyclic Aromatic Hydrocarbons (PAHs), Asbestos, Man-made Mineral Fibers (MMMF), Synthetic Vitreous Fibers (SVF)

Construction workers are occupationally exposed to a variety of toxic substances including asbestos, man-made mineral fibers (MMMF), also referred to as synthetic vitreous fibers (SVF), silica, concrete, diesel fumes, and wood dust. Recent research has linked construction work with cancer and other occupational diseases.[(1–15)] Occupational exposure studies pertaining to construction have focused on dust-generating situations and controls.[(16–24)] Task-based sampling has been employed.[(25–28)] Exposure levels to respirable silica as high as 14.0 mg/m^3 from concrete sawing and abrasive blasting[(21)] and 26.2 mg/m^3 for painters[(29)] have been reported. Respirable silica dust levels have been reported to exceed occupational exposure guidelines.[(21,22,24,29)]

Comparison of results to American Conference of Governmental Industrial Hygienists (ACGIH®) threshold limit values (TLVs®) revealed a significant health hazard among trades exposed to welding and thermal cutting fume, manganese, nickel, and chromium VI.[(26)] A recent investigation reported scaffolders were exposed to lead from welders and other trades.[(31)] Other chemical agents such as asphalt fumes, diesel exhaust, MMMF, and organic solvents, and physical agents such as noise and vibration, have been studied.[(17,18,22,27,32–37)]

Studies of asbestos in drywall taping and decorative finishing in Alberta, Canada, were conducted.[(38,39)] Task-based samples of chrysotile asbestos used in joint compound during mixing, application, sanding, sweeping, and cleanup operations were collected, having concentrations as high as 19 fibers per cubic centimeter (f/cc).[(38)] Sweeping activities generated the highest airborne levels. Mean fiber concentrations were as high as 26 f/cc during mixing operations for ceiling and wall texture workers.[(39)]

Data on Ontario construction work environments is minimal. An Ontario study examining air concentrations of diphenylmethane 4,4′ diisocyanate (MDI) produced during spraying of polyurethane foam at both indoor and outdoor locations found sprayers had the highest exposure levels, followed by outdoor and indoor helpers.[(37)] In 1995, the Ontario Ministry of Labour (MOL) and the Construction Safety Association of Ontario (CSAO) investigated occupational exposure to lead and respirable silica during restoration of a government building.[(30)] Levels of silica and lead higher than the Ontario TLV occurred during tuck pointing, chipping, and grinding.

In June 2000, our group received a grant from the Workplace Safety and Insurance Board (WSIB) of Ontario to conduct a two-year study of cancer and mortality patterns among construction workers in Ontario and to assess current chemical exposures. A cohort of 123,715 construction workers from nine trade unions was constructed and the database sent to the Canadian Mortality Database and Statistics Canada for record linkage. The findings of the mortality part of the study will be reported separately.

The objective of this article is to summarize important findings of the current chemical exposure assessments, which have been detailed elsewhere.[40] Our work included consulting published papers and available technical reports, and conducting task-based air sampling using traditional filter/tube based equipment as well as by direct-reading instruments.

MATERIALS AND METHODS

Literature searches were conducted on published sources of information regarding occupational exposures for construction workers. Initial meetings were held with local business managers of various trade unions in Ontario where knowledgeable union members were asked to describe relevant exposures from both current and retrospective points of view. The research group reviewed collective agreements and consulted information sources at the CSAO and on the Internet. In consultation with major stakeholders, a list was compiled summarizing the important exposure factors for each trade.

Study sites were selected on the basis of convenience. An industrial hygienist visited each site in advance of sampling in order to familiarize himself with the process, hazards, and potential exposures, and assess the feasibility of carrying out an industrial hygiene sampling campaign. Potential contaminants and related processes were identified. Available material safety data sheets (MSDS) were consulted, and a date(s) arranged for sampling. Based on the initial site assessment, appropriate sampling methodologies were employed[41,42] as listed in Table I.

While on site, 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. Air samples were collected using SKC air sampling pumps, Models 52, 224-PCXR3, 224-PCXR4, 224-PCXR7, 224-43XR, 224-44XR, and Pocket Pump (SKC Inc., Eighty Four, PA) connected to appropriate sampling media via Tygon tubing. If they agreed, they were shown how to wear the instrument and how to operate it.

All pumps were calibrated before and after sampling with a DryCal DC-Lite Calibrator (BIOS International Corp., Pompton Plains, NJ) to ensure that air flow did not change significantly during sampling (±5%). In some cases, due to short duration of activities, it was not possible to re-calibrate after each filter was changed. Sampling volume was deemed acceptable if the daily pre- and postcalibration were within the 5 percent tolerance limits. In the event sample tampering was suspected, because it was not possible to observe the operation continuously, the sample was considered spoiled and excluded from the data set.

A direct-reading instrument was employed as a means of evaluating multiple exposures to the same agent on site and for those trades where traditional task-based sampling did not yield meaningful results because of the task duration being too small. A DustTrak Aerosol Monitor, Model 8520 (TSI Inc., Shoreview, MN) was used. It operates based on the light-scattering principle. The instrument was factory-calibrated for the respirable fraction of standard test dust (ISO 12103-1, A1). It is an active sampling instrument containing a pump operating at 1.7 L per minute. Depending upon the particle size of the aerosol being studied, different inlets are used. Thoracic particulates were estimated using a PM_{10} inlet, which has a median cutoff of 10 μm. Respirable particulates were evaluated using a 10-mm nylon cyclone connected by Tygon tubing to the PM_{10} inlet. The cyclone is designed so the respirable dust fraction meets the 4 μm (50%) cutoff criteria. Diesel particulate matter was estimated using a 1 μm inlet and impactor.

Before and after each sampling day, the DustTrak was zero-checked to ±0.001 mg/m^3 using a special filter. The flow was checked using the rotameter supplied with the instrument. The DustTrak has a data logging feature, which allows the user to collect specific information regarding sampling duration and average, minimum, and maximum aerosol concentrations. A 10-second data logging interval was used. The major benefits of using the DustTrak were that it allowed us to measure short duration high-exposure tasks with reasonable accuracy and permitted evaluation of changes in working conditions instantaneously. It also offered the flexibility to roam around each site to measure short-term exposures for multiple trades.

To verify the accuracy of the DustTrak, side-by-side sampling with the traditional sampling method was performed. During its use, the inlet to the instrument was held near the worker's breathing zone until an acceptable sample was collected. If the instrument could not be held near the breathing zone for safety reasons, it was placed in the general work area close to the worker. At the end of each sample period, which would last from one minute to several hours, the average, minimum, and maximum readings and sample duration were noted in a log book along with a description of the task performed. Bulk samples of interest were collected to document the presence of materials on-site and to provide supplementary information.

RESULTS

In total, 396 single or multi-component (filter/tube), 798 direct-reading, and 71 bulk samples were collected at the workplaces listed in Table II. Twenty of the 396 single- or multi-component samples were not included due to various sampling complications such as pump failure, breakthrough, and tampering. Bulk samples were analyzed for silica, lead, or fiber content and type depending upon the samples. The results of the air sampling are presented in Table III, which describes measured task-based exposures for each of the trades. The minimum and maximum task-based sample concentrations presented are values that were detectable, unless otherwise noted. Since refractory ceramic fibers (RCF) have a lower TLV than other MMMFs, they have been identified separately in the tables.

Data were analyzed using statistical package MINITAB version 12. Figures 1 to 6 illustrate concentration distributions of respirable dust, total dust, and respirable MMMF by task and

TABLE I
Air sampling methodology used

Agent sampled	Flow rate (Lpm)	Collection media	Analytical method used[40,41]
Diesel exhaust (elemental carbon)	2–4	37-mm ashed quartz-fiber filter in 3-piece cassette-open face	Thermo-optical analysis, NIOSH method 5040
Coal tar pitch volatiles as benzene soluble	2–4	37-mm Teflon Zefluor filter in 2-piece cassette and Orbo 43 XAD 2 Tube	Extraction/gravimetric, NIOSH method 5023 (with modifications)
PAHs	2	37-mm Teflon Zefluor filter in 2-piece cassette and Orbo 43 XAD 2 Tube	HPLC, UV/VIS detection, NIOSH method 5506 (with modifications)
Solvents	0.01–0.2	Small charcoal tube	Gas chromatography, FID, NIOSH methods 1500, 1450, 1402
Methyl ethyl ketone	0.05	Anasorb tube	Gas chromatography, FID, NIOSH method 2500
Isocyanates	1	Nitroreagent tube or Impinger & Marcali solution	HPLC, UV/VIS detection, NIOSH method 2535 regulation respecting isocyanates made under the OH&S act, 1987 (with modifications)
Metals	2	37-mm mixed cellulose ester filter in 2-piece cassette or 25-mm mixed cellulose ester filter in IOM cassette	Flame atomic absorption spectrophotometry, NIOSH methods 7048, 7024, 7082, 7030, P&CAM 173 (with modifications)
Hexavalent chromium	2	37-mm PVC filter in 2-piece cassette	Colorimetric, UV-visible spectrophotometry, NIOSH method 7600
Respirable dust	1.7	37-mm PVC filter in 2-piece cassette and nylon cyclone	Gravimetric analysis, NIOSH method 0600 (with modifications)
Respirable silica	1.7	37-mm PVC filter in 2-piece cassette and nylon cyclone	Infrared spectrophotometry, NIOSH method 7602 (with modifications)
Inhalable dust	2	25-mm mixed cellulose ester filter in IOM cassette (plastic or stainless steel)	Gravimetric analysis, NIOSH method 0500 (with modifications)
Total dust	2	25-mm mixed cellulose ester filter in 2-piece cassette	Gravimetric analysis, NIOSH method 0500 (with modifications)
Alkaline dust	2	37-mm Teflon Zefluor filter in 2-piece cassette	Titration with HCl, NIOSH method 7401
Asbestos	1–2	25-mm mixed cellulose ester filter in 3-piece cassette	Phase contrast microscopy, NIOSH method 7400 with modifications to comply with Ontario regulation respecting asbestos, revised 1990, 2000 edition
Man-made mineral fibers including refractory ceramic fibers	1–2	25-mm mixed cellulose ester filter in 3-piece cassette	Phase contrast microscopy, WHO reference methods

trade. Box plots 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 box plot 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 of the statistical range, are shown as a ♦ symbol. Outliers were predetermined automatically by the statistical analysis package used. In the box plot function, MINITAB considers any observation 1.5 to 3 times away from the middle 50 percent of data as a possible outlier. No observations were greater than 3 times away from the middle 50 percent of data in any of our plots, which would otherwise have been noted with a different symbol. Numerical values of outliers may or may not be shown. Outliers not shown on the graphs are noted as required.

The results of the DustTrak aerosol monitor are presented in Table IV. The results of our side-by-side sampling between gravimetric respirable dust and DustTrak respirable dust are shown in Figure 7.

TABLE II
Sites visited during exposure assessment surveys and major activities sampled

Site type	Activities sampled
Commercial demolition	Thermal cutting, hand demolition, machine demolition, welding
Building restoration	Stone chipping
Airport terminal construction	Fireproof spraying, concrete chipping, machine demolition, welding, drywalling, mechanical installation, insulating, concrete mixing, excavation, bricklaying
Industrial construction	Fireproof spraying
Garage construction	Concrete grinding, epoxy construction, terrazzo installation, mechanical installation
Commercial demolition	Machine demolition, welding, concrete cutting
Road construction	Grading and excavation, concrete cutting
Office construction	Form-building
Hospital construction	Bricklaying, insulating, fireproof spraying, mechanical installation, roofing, drywalling, cleanup
Industrial roofing	Hot asphalt roofing
Residential subdivision construction	Framing, bricklaying, excavating, foundation building, interior carpentry, insulating, drywalling, painting, plumbing
Commercial roofing	Phenolic roofing tear-off
Commercial renovation	Fireproof spraying, drywalling, shotblasting
Bridge painting	Shotblasting, spray painting

DISCUSSION

General

Susi et al.[27] described a process referred as Task-Based Exposure Assessment Methodology (T-BEAM) for evaluating occupational exposures in construction. They reasoned that time-weighted average (TWA) sampling would not be representative of day-to-day exposure levels because of the high variability in daily work activities by construction workers. T-BEAM involves determining major tasks and the scope of work to be performed, reviewing MSDSs and other production data to determine the sampling strategy, consultation with knowledgeable construction workers, and sampling that adapts in response to changing activities. The weakness of full-shift sampling is that very high exposures over short periods get missed.[28] Brief high levels of exposure could have a greater physiological effect than longer equivalent low-level exposures in some cases. The most direct application of T-BEAM is targeting specific tasks for intervention and verifying efficiency of controls.

In Ontario, with the exception of asbestos, the construction industry is exempt from Ontario regulations (based upon the 1999 ACGIH TLVs) regarding control of chemical substances in the workplace. The task-based samples collected were a snapshot of some very specific tasks. It would not be prudent to relate the results to the current ACGIH TLV-TWA exposure guidelines[43] directly without taking into account periods of time when workers are unexposed, such as downtime, the effect of extended work shift on adjustments to the TLVs, and the acute health effects from brief, high-exposure tasks. The exposure assessment study was directed toward finding an exposure range.

Airborne dust is the most prevalent chemical exposure hazard in construction. It not only affects the worker directly involved with the exposure-causing activity, but also other workers within the work vicinity. During the course of the study, many workers expressed concerns about the presence of dust in the workplace. They were especially concerned about dust arising from sources such as grinding and cutting activities, sweeping, fireproof spraying, and heavy machinery.

Task-Based Samples

The highest particulate levels (all classes) were observed during abrasive blasting, concrete grinding, cutting, chipping, and concrete mixing activities, referred to as dusty tasks (see Table III and Figures 1 to 4). Median respirable dust concentration levels of 13.5 and 11.9 mg/m^3 were recorded for compressed air cleaning and concrete cutting (see Figure 1). On a trade basis, laborers had the highest respirable dust levels with a median value of 2.1 mg/m^3 (see Figure 2). On a task basis, excluding abrasive blasting, total dust levels were observed as high as 848 mg/m^3 for a 54-minute fireproof mixing sample. High total dust levels were recorded during cleanup, demolition, compressed air cleaning, and mixing and spraying cement insulation (see Figure 3). One total dust sample for an operating engineer during "rock crushing" (325 mg/m^3) and two fireproof mixing samples (848 and 346 mg/m^3) could not be shown in Figure 3 due to their size in relation to other results. Five out of 42 total dust concentrations measured on laborers were shown as outliers (see Figure 4).

TABLE III
Summary of all construction survey sample results by trade[A]

Agent sampled	Site(s)	Task(s)	N (NBDL)	Duration (minutes) Min	Max	Volume (L) Min	Max	Concentration (mg/m^3, unless otherwise noted) Min	Max
Bricklayer:									
Respirable dust	NCC	Concrete cutting	2P (0)	122	302	209	513	0.29	0.43
Total dust	NCC	Wall construction	1A (0)	—	122	—	242	—	9.69
Alkaline dust	NCC	Wall construction	1A (0)	—	122	—	242	—	3.48
MMMF	NCC	Wall construction, smoke sealing	3P (0)	28	308	43	465	0.01f/cc	0.15 f/cc
RCF	IR	Cutting and laying block	2P (0)	67	69	68	69	0.38f/cc	1.64 f/cc
Carpenters:									
Respirable dust	NCC	Drywalling, formwork	2P, 4A (0)	71	364	120	611	0.10	2.77
Respirable silica	NCC	Drywalling	1P (1)	—	233	—	396	—	BDL
Lead wipes	BRepair	Scaffold erecting	4P (0)	NA	NA	NA	NA	0.26 mg	0.88 mg
MMMF	NCC, NRC	Drywall installation, smoke sealing, insulation installation	6P (0)	30	92	43	132	0.06 f/cc	0.70/cc
Total hydrocarbons (THC)	NCC	Secondary exposure	1P (0)	—	98	—	3.14	—	3.18
Acetone	NCC	Secondary exposure	1P (1)	—	98	—	3.14	—	BDL
Ethyl benzene	NCC	Secondary exposure	1P (1)	—	98	—	3.14	—	BDL
n-Hexane	NCC	Secondary exposure	1P (1)	—	98	—	3.14	—	BDL
Xylene	NCC	Secondary exposure	1P (1)	—	98	—	3.14	—	BDL
Electricians:									
Total dust	NCC	Conduit installation	1P, 1A (0)	264	306	531	603	0.21	1.34
MMMF	NCC	Secondary exposure	5P (1)	37	232	37	223	0.02 f/cc	0.70 f/cc
THC	NCC	Secondary exposure	2A (0)	183	389	5.8	12.3	1.74	9.6
Toluene	NCC	Secondary exposure	2A (1)	183	389	5.8	12.3	—	47.8
Elevator workers:									
Respirable dust	NCC	Installing hardware	1A (1)	—	34	—	58	—	BDL
Glaziers:									
Respirable dust	NCC	Installing glass	1A (1)	—	95	—	164	—	BDL
Heating and frost workers:									
MMMF	NCC, I, NRC	Cutting batt, pinning ducts, insulating ducts, installing, polying, spraying, blowing	44P, 2A (5)	10	183	11	362	0.03 f/cc	0.07 f/cc
RCF	I	Installing, supervising	7P (0)	56	91	58	94	0.26 f/cc	0.65 f/cc
Ironworkers:									
Respirable dust	RC	Concrete mixing	1P (0)	—	78	—	133	—	0.97
Respirable silica	RC	Concrete mixing	1P (1)	—	78	—	133	—	BDL
Welding fume (inhalable)	D	Arc welding	1P (0)	—	70	—	140	—	8.14
Total dust	RC	Concrete mixing	1P(0)	—	29	—	58	—	14.0
Welding fume (total)	NCC	Arc welding, gouging	5P (2)	56	223	113	450	1.64	28.3
Hexavalent chromium	RC	Concrete mixing	1P (1)	—	29	—	58	—	BDL
MMMF	D	Arc welding	1A (0)	—	72	—	76	—	0.66 f/cc

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TABLE III
Summary of all construction survey sample results by trade[A] *(Continued)*

Agent sampled	Site(s)	Task(s)	N (NBDL)	Duration (minutes)		Volume (L)		Concentration (mg/m^3, unless otherwise noted)	
				Min	Max	Min	Max	Min	Max
Laborers:									
Respirable dust	D, NCC, RB	Concrete grinding, cutting, chipping, tearing out structures, compressed air use, cleanup	28P, 1A (6)	2	300	3.4	503	0.56	34.3
Respirable silica	D, NCC, RB	Concrete chiseling, cutting, grinding, tearing out structures	20P (18)	2	300	3.4	503	0.10	0.15
Inhalable dust	D, NCC	Cleanup, operate equipment, tearing out structures	5P, 1A (1)	54	290	106	540	2.20	63.6
Inhalable lead	D	Tearing out structures	2P (0)	100	290	206	580	0.01	0.06
Welding fume (inhalable)	D	Thermal cutting	2P (0)	116	268	241	536	5.99	17.3
Total dust	D, NCC	Epoxy mixing, expansion joint construction, assisting, tearing out structures, concrete chiseling, sweeping, setup	14P, 16A (2)	8	353	32	598	0.17	39.7
Alkaline dust	D	Tearing out structures, thermal cutting	3A (0)	33	138	66	276	3.79	5.98
Welding fume (total)	D	Thermal cutting	1P (0)	—	111	—	223	—	5.57
Diesel exhaust (elemental carbon)	D	Compressor use, excavation, cleanup, tearing down structures	1P, 9A (6)	50	330	100	903	4.9 μg/m^3	146 μg/m^3
MMMF	NCC, D, I	Cleanup, tearing out structures, removal, storing, loading, fireproof mixing, helping	32P, 9A (4)	15	151	23	152	0.04 f/cc	1.75 f/cc
RCF	I	Dumping, helping	3P (2)	10	58	10	59	—	0.59 f/cc
Coal tar pitch volatiles (CTPV-BSF)	NCC	Epoxy mixing, expansion joint construction, assisting	16P, 20A (20)	8	353	31	706	0.14	1.93
Benzo(a)pyrene	NCC	Epoxy mixing, expansion joint construction, assisting	11P, 12A (3)	8	353	31	706	0.07 μg/m^3	12.8 μg/m^3
THC	NCC	Epoxy mixing, expansion joint construction	3P, 1A (0)	35	297	3.39	9.5	8.85	26.9
Mason:									
Respirable dust	Building restoration	Stone chipping, cleanup	5P (0)	169	316	287	632	0.61	1.84
Respirable silica	Building restoration	Stone chipping, cleanup	6P (6)	166	316	281	632	—	BDL

TABLE III
Summary of all construction survey sample results by trade[A] *(Continued)*

Agent sampled	Site(s)	Task(s)	N (NBDL)	Duration (minutes)		Volume (L)		Concentration (mg/m^3, unless otherwise noted)	
				Min	Max	Min	Max	Min	Max
Operating Engineers:									
Respirable dust	NCC, RC, D	Operate machinery, operate hoist, operate crusher	2P, 6A (2)	159	715	269	1438	0.15	4.21
Respirable silica	NCC, RC, D	Operate machinery, operate crusher	1P, 2A (1)	159	204	269	347	0.04	0.06
Total dust	D	Operate crusher	1P (0)	—	159	—	313	—	325
Diesel exhaust (elemental carbon)	NCC, RC	Operate machinery	7A (2)	29	313	100	900	4.3 $\mu g/m^3$	7.8 $\mu g/m^3$
Painters:									
Respirable dust	IC, NCC	Spraying, mixing cement	3P, 4A (1)	176	383	299	651	0.07	2.9
Respirable silica	IC, NCC	Mixing cement	3P, 1A (4)	177	383	287	651	—	BDL
Total dust	IC, NCC	Mixing cement, mix paint, spray paint, spraying fireproof, sweep, scraping, setup	19P, 6A (0)	5.2	414	11	799	0.06	848
Alkaline dust	IC, NCC	Mixing, shoveling, spraying fireproofing	13P, 3A (2)	105	414	210	799	0.19	26.7
Abrasive blasting dust	BRepainting	Operate blaster, use compressed air	5P, 2A (0)	10	114	20	228	0.35	2220
Lead (total)	BRepainting	Operate blaster, use compressed air	6P, 2A (2)	5.2	114	11	228	0.40	60.3
Cadmium (total)	BRepainting	Operate blaster, use compressed air	6P, 2A (2)	5.2	114	11	228	0.001	0.03
Chromium (total)	BRepainting	Operate blaster, use compressed air	6P, 2A (2)	5.2	114	11	228	0.05	0.42
Hexavalent chromium	NCC	Concrete mixing	1P (1)	—	325	—	641	—	BDL
Manganese (total)	BRepainting	Operate blaster, use compressed air	6P, 2A (2)	5.2	114	11	228	0.01	1.51
Zinc (total)	BRepainting	Operate blaster, use compressed air, spray paint	7P, 3A (1)	5.2	124	11	236	0.01	43.6
Diesel exhaust (elemental carbon)	NCC	Operate mixer	1P, 2A (0)	195	325	386	624	3.6 $\mu g/m^3$	19.0 $\mu g/m^3$
n-Butanol	BRepainting	Spray paint steel, mix paint	1P, 1A (0)	90	124	9.5	12.8	1.6	36
n-Butyl acetate	BRepainting	Spray paint steel, mix paint	2P, 2A (0)	86	146	6.2	13	4.7	554
Ethyl benzene	BRepainting	Spray paint steel, mix paint	1P, 1A (0)	90	124	9.5	12.8	2.4	56.1
HDI (isocyanates)	BRepainting	Spray paint steel, mix paint	1P, 1A (1)	86	106	86	105	—	0.002

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TABLE III
Summary of all construction survey sample results by trade[A] *(Continued)*

Agent sampled	Site(s)	Task(s)	N (NBDL)	Duration (minutes) Min	Max	Volume (L) Min	Max	Concentration (mg/m^3, unless otherwise noted) Min	Max
Isopropyl alcohol	BRepainting	Spray paint steel, mix paint	2P, 2A (0)	86	146	6.2	13	2.6	496
MEK	BRepainting	Spray paint steel, mix paint	3P, 3A (0)	86	146	6.2	13	95.3	791
Toluene	BRepainting	Spray paint steel, mix paint	3P, 3A (0)	86	146	8.9	15	146	2020
Xylene	BRepainting	Spray paint steel, mix paint	3P, 3A (0)	86	146	8.9	15	8.6	266
Pipefitters:									
Inhalable dust	NCC	Hanging pipe	1P (0)	—	139	—	278	—	3.13
Total dust	NCC	Secondary exposure	1A (0)	—	344	—	688	—	0.70
MMMF	NCC	Secondary exposure	1P (0)	—	113	—	113	—	0.03 f/cc
CTPV-BSF	NCC	Secondary exposure	1A (0)	—	344	—	688	—	0.10
Benzo(a)pyrene	NCC	Secondary exposure	1A (0)	—	344	—	688	—	0.48
THC	NCC	Secondary exposure	2P (0)	209	396	6.6	12.4	1.5	31.6
Toluene	NCC	Secondary exposure	2P (0)	209	396	6.6	12.4	1.6	7.5
Plumbers:									
Welding fume (total)	NCC	Cutting copper pipe & soldering	1P (1)	—	47	—	96	—	BDL
MMMF	NCC	Secondary exposure	1P (0)	—	315	—	473	—	0.01 f/cc
Roofers:									
Respirable dust	C	Tear roof, shovel, sweep, cleanup	5P (4)	13	249	22	426	—	0.08
Total dust	C, I	Tear roof, shovel, sweep, cleanup	8P, 1A (0)	6	177	13	342	0.29	15.3
CTPV-BSF	I	Operate kettle, mopping, roll felt	4P, 1A (0)	97	257	199	530	0.41	9.89
Benzo(a)pyrene	I	Operate kettle, mopping, roll felt	4P, 1A (5)	97	257	199	530	—	BDL
THC	NCC	Install membrane roof	1P (0)	—	91	—	2.9	—	62.5
Acetone	NCC	Install membrane roof	1P (1)	—	91	—	2.9	—	BDL
Ethyl benzene	NCC	Install membrane roof	1P (1)	—	91	—	2.9	—	BDL
n-Hexane	NCC	Install membrane roof	1P (1)	—	91	—	2.9	—	BDL
Toluene	NCC	Install membrane roof	1P (1)	—	91	—	2.9	—	BDL
Xylene	NCC	Install membrane roof	1P (1)	—	91	—	2.9	—	BDL
Sheet metal workers:									
Total dust	NCC	Install ductwork	1A (0)	—	285	—	690	—	0.42
MMMF	NCC	Secondary exposure	1P (0)	—	160	—	152	—	0.08 f/cc
THC	NCC	Install ductwork	2P (0)	284	290	9.1	9.3	7.5	15.4
Acetone	NCC	Install ductwork	2P (0)	284	290	9.1	9.3	0.9	0.9
Ethyl benzene	NCC	Install ductwork	2P (2)	284	290	9.1	9.3	—	BDL
n-Hexane	NCC	Install ductwork	2P (0)	284	290	9.1	9.3	1.1	1.1
Toluene	NCC	Install ductwork	2P (0)	284	290	9.1	9.3	2.2	3.3
Xylene	NCC	Install ductwork	2P (1)	284	290	9.1	9.3	—	1.3

TABLE III
Summary of all construction survey sample results by trade[A] *(Continued)*

Agent sampled	Site(s)	Task(s)	N (NBDL)	Duration (minutes) Min	Max	Volume (L) Min	Max	Concentration (mg/m^3, unless otherwise noted) Min	Max
Terrazzo workers:									
Respirable dust	NCC	Mixing, grinding	6P, 6A (2)	29	707	49	1187	0.26	3.04
Respirable silica	NCC	Grinding, mixing	4P, 1A (5)	92	235	156	397	—	BDL
Total dust	NCC	Epoxy mixing	1P, 1A (0)	20	707	39	1396	0.19	4.57
THC	NCC	Troweling, setup, cleaning, mixing epoxy	10P (0)	22	262	2.1	24.8	3.6	49.1
Diacetone alcohol	NCC	Troweling, setup, cleaning, mixing epoxy	6P (3)	52	262	4.8	24.8	3.2	35.8
Ethoxyethyl acetate	NCC	Cleaning	1P (1)	—	22	—	2.1	—	BDL
MDI (isocyanates)	NCC	Squeegee on sealant	2P, 1A (3)	93	110	94	111	—	BDL
Toluene	NCC	Troweling, setup, cleaning, mixing epoxy	9P, (1)	52	262	4.8	24.8	2.3	26.6
Various:									
Respirable dust	NCC	Various	3A (0)	263	322	450	631	0.05	0.09
Inhalable dust	NCC	Various	2A (0)	302	322	589	631	0.35	0.41
MMMF	NCC	Various	2A (0)	263	322	250	483	0.02 f/cc	0.02 f/cc
CTPV-BSF	NCC	Various	1A (1)	—	60	—	119	—	BDL
Benzo(a)pyrene	NCC	Various	1A (1)	—	60	—	119	—	BDL

[A]Only samples with detectable results are shown unless noted.

Abbreviations: BRepainting = Bridge Repainting. BRepair = Bridge Repair. C = Commercial. D = Demolition. I = Industrial. IR = Industrial Refit. NCC = New Commercial Construction. RB = Road Building. RC = Road Construction. NRC = New Residential Construction. N = Number of Samples. NBDL = Number of Samples Below Detection. A = Number of Area Samples. P = Number of Personal Samples. BDL = Value Below Detection Limit.

Extreme values noted under normal operations.

Welding tasks, and in particular gouging tasks, generated high particulate levels. Abrasive blasting was observed to be a very hazardous dusty task, especially when leaded paint was involved. Measurements taken inside and outside of the blasting helmet during this activity showed positive pressure suits effectively reduce total particulate levels, although workers needed to be cognizant with respect to initiating the pressure suit before entering the work enclosure.

Another major finding was that water suppression, when used properly, effectively reduced dust levels during grinding activities. Terrazzo workers were observed using water extensively while polishing terrazzo. The water reduced respirable particulate levels to less than one-third the recommended exposure limit of 3 mg/m^3, whereas dry grinding resulted in dust levels as high as 10 mg/m^3. The dusty activities, listed previously, generated levels of contaminants that could result in both acute and chronic health problems if observed exposure levels persisted throughout a worker's career (see Figures 1 to 4).

Only 4 out of 40 respirable dust samples analyzed for silica showed detectable concentrations of silica. On a mass percentage basis, those samples were between 1 to 4 percent silica by weight and none were at or above the TLV of 0.05 mg/m^3. The highest task-based sample for respirable dust was observed during dry concrete grinding (34 mg/m^3), but silica content for that sample was below detection. It is possible that nondetectable silica samples were due to undersampling, but it is more likely that the aggregates and concrete had low silica content.

Several dust samples associated with concrete activities were also analyzed for alkaline dust. Alkaline dust levels were considerably lower than the total particulates on the filters, but in some cases were high enough that respiratory protection would be advised. The highest alkaline dust sample was 26.7 mg/m^3 during fireproof mixing. Unfortunately, wood dust was not measured in a meaningful way due to time and resource constraints during this study. Based on our observations, wood dust could be a significant exposure factor in residential

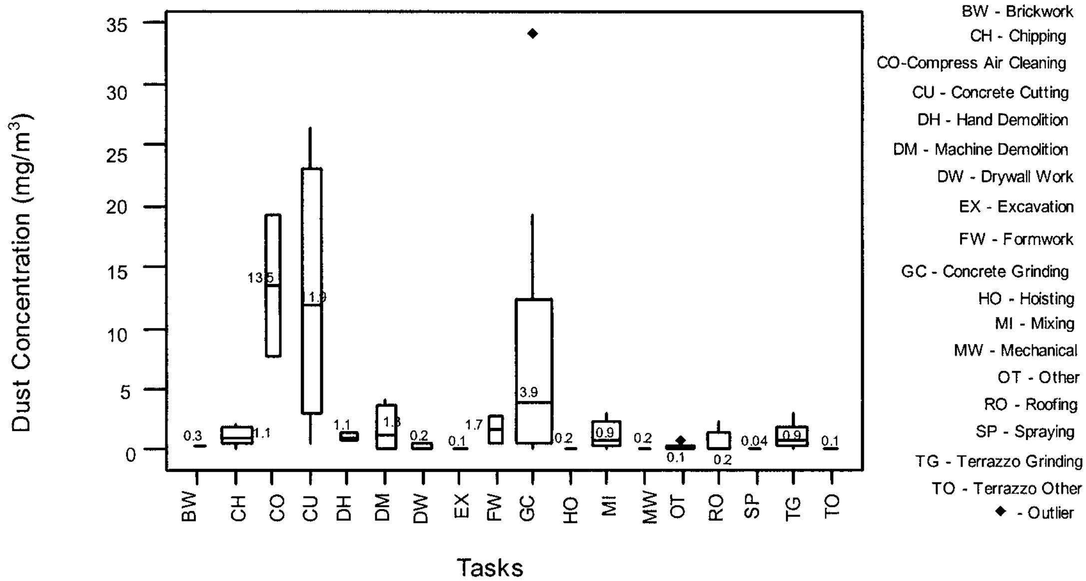

FIGURE 1
Box plot of respirable dust sample distribution by task (boxes represent 25th–75th percentiles).

construction industry or in commercial construction during form-work activities.

Measurement for inhalable nuisance particulates and certain metals like nickel requires the use of inhalable samplers, such as the Institute for Occupational Medicine Scotland, U.K. (IOM) sampling head. The TLVs for many substances were previously based on total dust but are now being gradually replaced based on inhalable dust. IOM cassettes are relatively expensive and limitations have been noted with regard to weighing imprecision and handling.[44–46] It is recommended that they should only be used for gravimetric analysis when high loadings (several milligrams) are expected.[46]

We observed several additional limitations of this device during the study. Marking of the cassettes for identification is a problem. Handling of the cassette in hot-work environments also presents difficulties. It is recommended that in hot-work environments the hygienist handle IOM cassettes with sterile nitrile or latex gloves to prevent contamination. This is not very practical in reality. The cassette clips were small, and manual dexterity, often aggravated by poor lighting or temperature conditions on

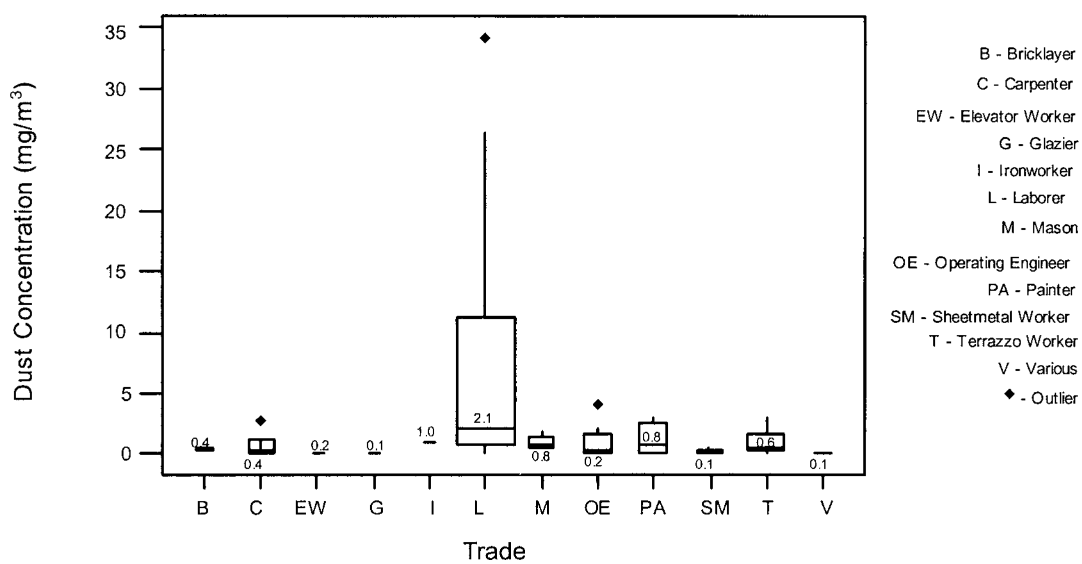

FIGURE 2
Box plot of respirable dust sample distribution by trade (boxes represent 25th–75th percentiles).

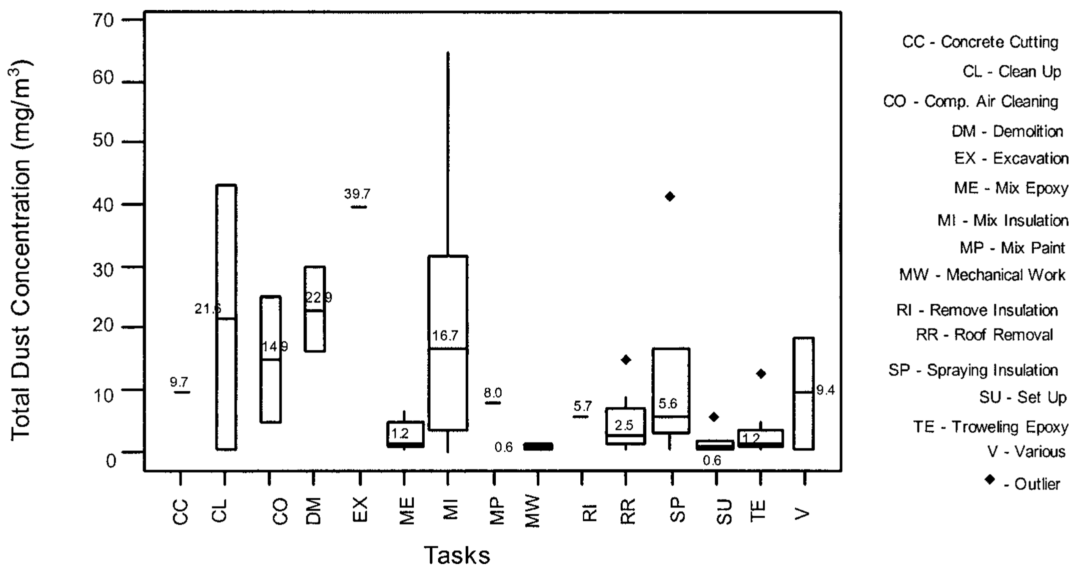

FIGURE 3
Box plot of total dust sample distribution by task (boxes represent 25th–75th percentiles).

construction sites, made handling difficult. Hot-work sampling, such as thermal cutting, sometimes damaged the plastic on the IOM cassettes.

An alternative inhalable sampler such as the GSP sampler (Gesamt Staub Probenehmer translated means Total Dust Sampler) (Deha-Haan and Wittmer GmbH, Friolzheim, Germany available in United States from BGI Inc., Waltham, Massachusetts), where the sample is entirely collected on the filter paper, may be a better alternative if proven to give equivalent results to the IOM sampler in the construction work environment. These devices (IOM and GSP), however, have been shown to be equivalent in the carbon black industry.[47]

Data collected on MMMF during this study included fiberglass, rock wool, slag mineral wool, and refractory ceramic fibers (RCF). They were combined with recent sampling data from the CSAO. The pooled results indicate that during most fiber application processes, workers are exposed to MMMF levels (excluding RCF) less than the recommended TLV of 1 f/cc (see Table III, Figures 5 and 6). Excursions were noted, which would be expected from a large data set. Airborne levels of RCF insulation, however, were higher than the recommended exposure limit of 0.2 f/cc. The samples were taken during the lining of a reheat furnace, illustrating not just the potential for hazardous exposures to bricklayers, but also the need to address

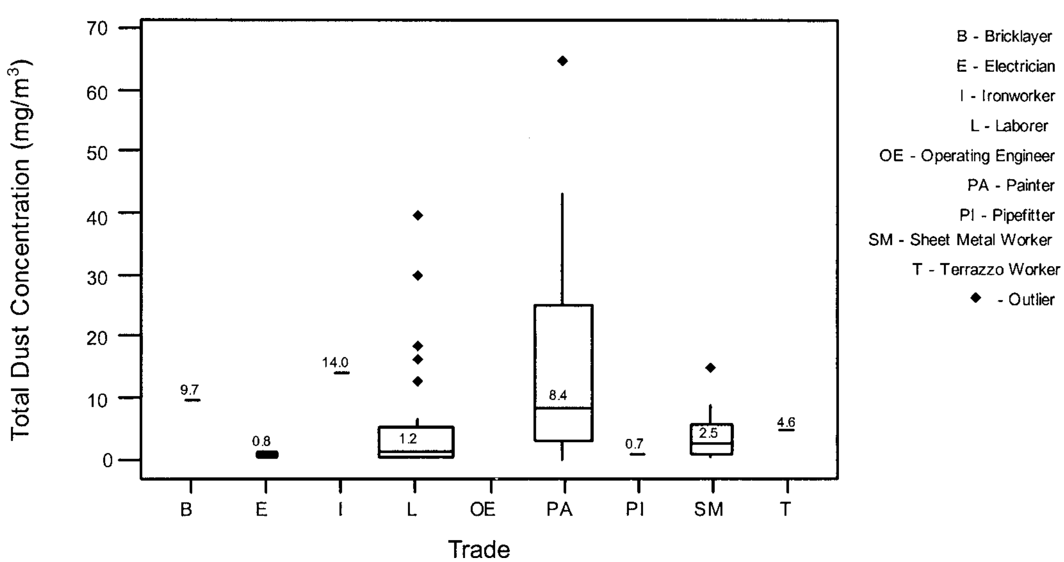

FIGURE 4
Box plot of total dust sample distribution by trade (boxes represent 25th–75th percentiles).

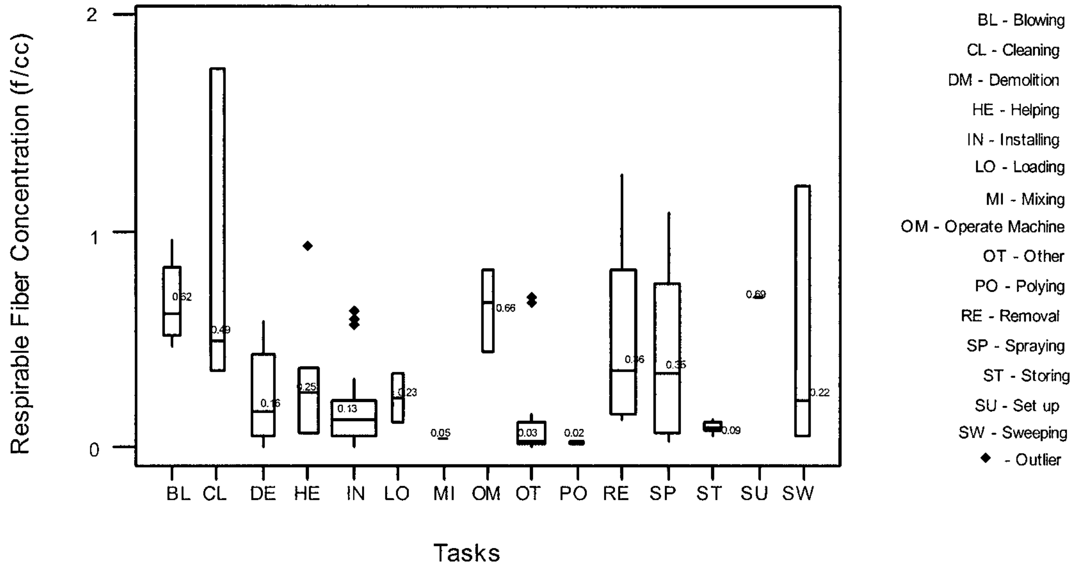

FIGURE 5

Box plot of respirable MMMF (excluding RCF) sample distribution by task (boxes represent 25th–75th percentiles).

occupational exposures to construction workers in industrial environments.

Direct-Reading Instruments

The DustTrak aerosol monitor was a very useful tool for evaluating dust conditions on construction sites. The data indicated many construction workers not directly involved in dusty activities were exposed to low levels of environmental dust (see Table IV). Some workers such as electricians and glaziers were exposed to large volumes of particulates generated by other trades. Most importantly, the DustTrak made it possible to evaluate changes in environmental conditions instantly and provide immediate feedback to workers, informing them of the effects of their work practices on their personal exposure. As shown in Figure 7, the DustTrak data correlates well with those measured using a traditional pump and filter system ($r = 0.96$).

Secondary Exposures

To illustrate the importance of secondary exposures on construction sites, monitoring for fibers was conducted on a hospital construction site where mechanical workers such as sheet metal workers, electricians, and pipefitters were working in the vicinity of other trades using fibrous construction materials. Selecting airborne fibers as the target exposure agent was important

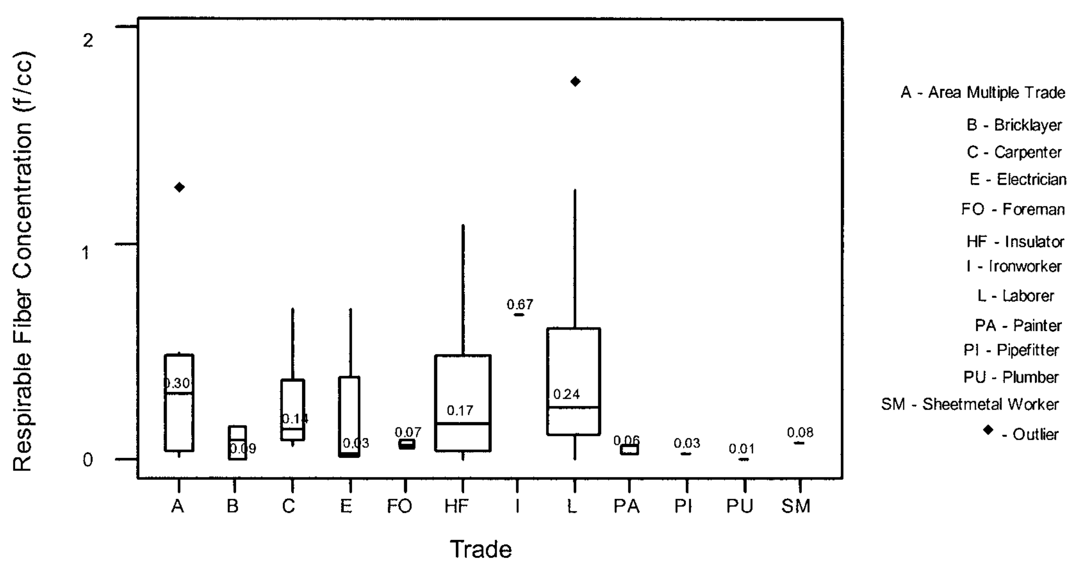

FIGURE 6

Box plot of MMMF (excluding RCF) sample distribution by trade (boxes represent 25th–75th percentiles).

TABLE IV
Summary of direct-reading instrument data from TSI DustTrak

	Respirable particulates					PM_{10} as thoracic particulates				
		Duration (seconds)		Concentration (mg/m^3)			Duration (seconds)		Concentration (mg/m^3)	
Trade	N	Min	Max	Min	Max	N	Min	Max	Min	Max
Bricklayer	19	81	1408	0.09	6.0	115	56	337	0.10	1.4
Cabinet maker	1	439	439	0.75	0.75	1	177	177	1.08	1.08
Carpenter	64	20	4080	0.01	11.8	50	16	901	0.03	6.9
Carpet layer	2	223	379	1.1	3.2	2	145	271	2.2	3.5
Cement mason	5	100	968	0.14	0.30	1	111	111	0.39	0.39
Electrician	28	31	3600	0.07	2.4	22	46	541	0.11	1.1
Elevator worker	9	74	2002	0.13	1.02	6	76	184	0.25	2.6
Engineer/supervisor/other	7	59	540	0.04	2.8	7	40	158	0.05	6.9
Glazier	7	113	746	0.05	1.7	3	87	119	0.11	0.64
Insulator	6	92	1084	0.03	0.30	3	70	507	0.05	0.59
Ironworker	15	36	520	0.04	1.3	15	16	280	0.05	16.9
Laborer	119	21	3660	0.01	61	86	25	1553	0.03	32.7
Operating engineer	16	29	2789	0.04	5.3	5	41	740	0.09	0.71
Painter	10	136	583	0.07	8.2	13	223	5040	0.09	6.6
Pipefitter/steamfitter	17	53	639	0.05	0.59	14	69	454	0.19	0.59
Plumber	10	61	462	0.10	0.81	7	63	701	0.14	1.0
Roofer	11	240	2508	0.01	0.13	8	53	1751	0.03	0.25
Sheet metal worker	16	57	572	0.06	2.1	13	35	659	0.08	4.1
Siding installer	1	133	133	0.03	0.03	1	94	94	0.07	0.07
Teamster	2	119	307	0.01	0.09	—	—	—	—	—
Terrazzo worker	46	51	3595	0.05	11.8	4	110	240	0.13	2.0

Abbreviations: N = Number of samples.

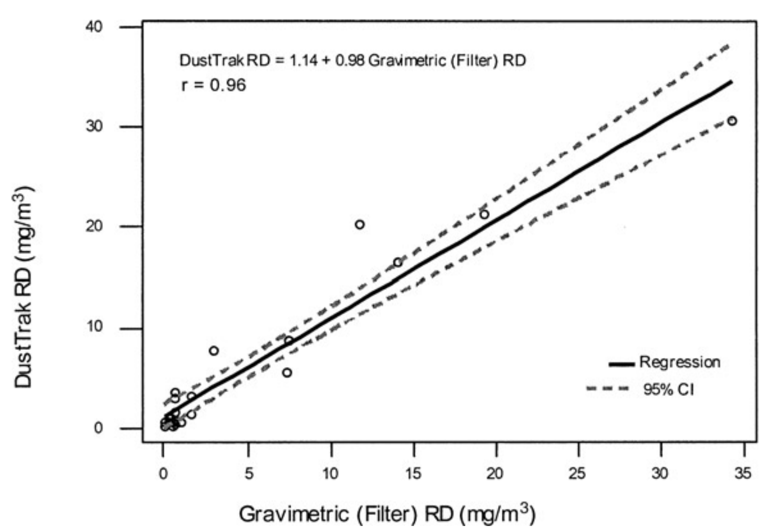

FIGURE 7
Regression plot of paired measurements of DustTrak respirable dust (direct-reading) and gravimetric respirable dust (filter weighing).

because it is a contaminant unique to construction. Results showed that electricians, bricklayers, pipefitters, and other trades were exposed to the man-made mineral fibers, but their exposures were low and did not exceed the recommended guideline of 1 f/cc. It is our opinion that secondary exposure may only be important in some cases, and protocols for using personal protective equipment and good housekeeping while performing overhead work, drilling, or mechanical installations, need to be developed.

Bulk Sampling

A variety of suspected silica-containing materials were collected in Toronto and in Thunder Bay in northern Ontario for subsequent analysis. During an information session, it was postulated that silica content in aggregates and concrete mined in the Toronto area contained different levels of silica compared to similar materials used in other Ontario jurisdictions where supply sources would be different. Although bulk sampling was limited in scope, our findings indicate silica content is source-dependent. Concrete block used in northern Ontario contained up to 20 percent silica, whereas silica content in Toronto concrete block ranged from <1 to 4 percent by weight. More extensive work in this area is required. The majority of bulk silica samples collected from the Toronto area contained from <1 to 4 percent silica by weight, considerably lower than content reported elsewhere in the literature.[20,24,48] Respirable silica has been shown to be a major hazard internationally in the construction industry.[15,20–24,29,48]

In one of the most recent publications on exposure to silica in the U.S. construction industry, Rappaport et al.[29] have demonstrated excessive exposure above the U.S. occupational exposure limit (OEL) of 3 mg/m^3 (respirable dust) and 0.05 mg/m^3 (respirable silica) for the four construction trades studied, namely painters, laborers, bricklayers, and operating engineers. They estimated the probability of overexposure to respirable dust to be between 8.2 and 89.2 percent, and for respirable silica to be between 64.5 and 100 percent. The median value of respirable silica for four trades are reported as 1.28 mg/m^3 for painters, 0.35 mg/m^3 for laborers, 0.32 mg/m^3 for bricklayers, and 0.075 mg/m^3 for operating engineers, well above the U.S. OEL of 0.05 mg/m^3.

Our limited results, however, could imply that respirable silica may not be a serious hazard in the Toronto area. This is almost certainly due to the limitation of our study being conducted at only a few sites where silica in bulk happened to be low (<1–4%). Further work at more sites in Toronto is needed to clarify this observation. High levels of respirable and total particulates, however, were observed during operations such as grinding and cutting and for laborers, painters, and bricklayers.

Most of the bulk samples analyzed for man-made mineral fibers showed a range of quantity and composition for fibers. Cellulose, refractory ceramic fibers, mineral wool, rock wool, and fiberglass-containing materials were collected. MMMF was found in common construction materials such as drywall, roofing materials, and thermal insulation. Only one demolition sample was found to contain chrysotile asbestos. This sample was collected in obvious uncontrolled conditions (along with lead paint) in a retail environment during renovations. Four skin/clothing wipe samples taken from carpenters erecting scaffolding under a bridge that was to be repainted tested positive for lead dust, and a similar finding has been observed elsewhere.[31] Three of seven paint chip samples to which bridge painters and demolition workers were exposed were analyzed for lead content and were found to contain lead in excess of the U.S. Housing and Urban Development (HUD) guidelines, which define lead-based paints as those containing greater than 0.5 percent lead by weight.

Agents not Measured

Asbestos was not measured during this study. Many of the construction sites we visited were in new construction only, where asbestos or other historically important agents such as lead and PCBs were not used. Our sampling campaign was limited in resources and scope and we were not able to diversify our sampling campaign as well as we would have liked. Asbestos is still important in sectors of the industry involved in demolition, decommissioning, or industrial renovations or maintenance as was recently reported for demolition workers at the World Trade Center. Painters, asbestos workers, or laborers will be exposed to asbestos or lead during paint removal operations and decommissioning projects. Mechanical workers such as electricians, pipefitters, sheet metal workers, ironworkers, and millwrights will be exposed to asbestos while repairing, removing, or installing mechanical equipment or other specialized structures in pre-existing asbestos-containing industrial or commercial facilities. Further, we recognize that we did very little in the way of residential construction or wood dust measurements due to resource, access, and time constraints. This does not imply that we consider such exposure unimportant. For example, although we did not measure wood dust exposures, it remains a major hazard for construction workers, especially in the residential construction sector.

Smoking

During the study, several workers were observed smoking at their workstations, which poses an added health risk. Smoking in other workplaces (non-construction) is generally not permitted, but it is normally accepted in construction. This industry has been shown to have the highest prevalence of cigarette smoking in the United States.[49] This has an important health hazard implication for construction workers, especially those who may be exposed to contaminants such as lead, asbestos, and PAHs. An example of such exposure during this study was the PAHs exposures during expansion joint making operations,[50] where workers did smoke in the presence of such exposure. Construction workers need to be made more aware of this added risk where workplace materials may act synergistically with cigarette smoke, posing an even greater health risk.

Occupational Exposure Limits (OELs)

Ontario is the most industrialized, and has the largest population, among all the provinces and territories of Canada. The Ontario government has promulgated regulations respecting control of exposure to biological and chemical agents in the workplace.[51] The occupations exposure limits as set out by this regulation are based (with some modifications) on the 1999 ACGIH TLVs. This regulation[51] applies to industrial and other workplaces (factories, offices, government agencies, schools) and mines, but it does not apply to the construction industry. Strictly speaking, then, there is no regulated occupational exposure limit for the Ontario construction industry as opposed to other jurisdictions in Canada (i.e., other provinces) and abroad (United States, United Kingdom, and Europe). This is perhaps one of the main reasons why so few occupational exposure studies have been conducted and reported from this important sector of Ontario.

Study Limitations

The construction industry is vast and encompasses an almost infinite range of activities and workplaces. One could characterize it as being the most heterogeneous and diverse industry in the country. During the study period, we had the opportunity to visit a variety of workplaces, but the sample of workplaces was by no means comprehensive. We acknowledge that a major limitation of our study is the lack of data for specific tasks or trades. Due to the diversity of work sites and variation in operations, and limited access in some cases, it was not always possible to obtain more than one or two samples, making interpretation of the data difficult. However, when compared to data gathered elsewhere (with the exception of respirable silica as previously described), our results fall within the range of results from other researchers. Almost all of our data were collected during typical conditions, as described by workers. On occasion, workers complained that conditions were not normal usually because they believed the environment was "too clean" and not representative of "worst-case" scenarios. All workers were instructed to perform their tasks "normally." Therefore, we believe that the aggregate of all sampling data can be used to describe construction sites under normal conditions and is representative of the operations studied.

Other Research Needs

The construction work environment can be characterized as highly variable. Many factors have the potential to influence the daily exposure for each worker, which makes contaminant sampling a complicated and challenging activity. The main reason is the complexity of the construction environment and the mode in which production takes place. Construction is not only defined as new construction, but also includes a range of activities such as plant refits, specialized and ongoing maintenance, renovations, and repairs.

It is common during annual plant shutdowns for construction workers to be contracted to perform specialized work. Work may often be performed in specific areas while other plant processes continue. In some environments, construction workers may be employed permanently in a maintenance capacity. As a result, not only will they be exposed to long-term construction specific exposures, but also to the industry-specific exposures. For example, pipefitters welding on a petrochemical refinery site may be exposed to hydrocarbon exposure including benzene, and bricklayers relining a kiln at a steel-making operation may be exposed to metal fumes in addition to the dust from refractory bricks. Limited resources did not permit us the opportunity to assess secondary exposures of construction workers at industrial sites such as petrochemical refineries, steel-making plants, and auto assembly plants. A study on non-production departments in pulp and paper industries, which involved 7293 unpublished hygiene measurements from 147 mills in 11 countries, found the greatest variety of agents measured was in the maintenance, construction, and cleaning departments.[52] In those areas, high exposures to asbestos, chromium [VI] compounds, copper, mercury, nitrogen dioxide, ozone, styrene, sulfur dioxide, trichloroethylene, and welding fumes were observed. The construction workers' exposure from secondary site-specific agents needs to be assessed more thoroughly.

CONCLUSIONS

Ontario construction workers are occupationally exposed to chemical substances at levels that are potentially hazardous. Particulates of varying size fractions, metals, man-made mineral fibers, and organic solvents were measured. The most prolific contaminants are particulates, including (in descending order of size) wood dust, abrasive blasting dust, gypsum and alkaline dusts, silicates, diesel exhaust, and welding fumes. Particulate concentrations were shown to occur at levels that could result in chronic lung diseases. Particulates may contain other hazardous materials such as lead or coal tar pitch. Respirable silica levels were observed at levels that were far lower than reported for similar tasks in the literature. We believe this may be due to regional factors, which warrant further investigation. MMMF (excluding RCF) were not generally a significant hazard. RCF was not assessed in detail and requires more research. Organic solvents and lead were observed during industrial painting operations at levels that could be hazardous to workers' health.

Little has been reported previously with respect to occupational exposures of demolition workers, concrete sprayers, or terrazzo workers. Work needs to be done assessing the effects of industrial contaminants on construction workers' occupational exposures when they work on industrial sites. Through our fiber sampling initiatives, we were able to confirm that some workers are exposed to contaminants generated by other trades on-site. Future considerations for research should include an assessment of constructions workers' exposures to industrial contaminants, demolition worker exposures to particulates, silica, airborne fibers and diesel exhaust, particulate exposures during concrete spraying/mixing operations, and a more detailed assessment of silica exposure.

Task-based exposure assessment (T-BEAM) method of sampling has its limitations with respect to sampling for short-duration or intermittent exposures. Many times, sampling duration was too short to yield detectable concentrations of chemical contaminants. Furthermore, this sampling methodology did not facilitate greater understanding of the macroscopic picture of occupational exposures on construction. A direct-reading instrument used as a tool for profiling various jobs on construction sites by taking instantaneous readings during different tasks was evaluated. By using the instrument (in this case the TSI Dust-Trak), we were able to identify occupations and activities that may present a hazard. In evaluating construction sites for occupational exposures, direct-reading instruments would be very useful as screening tools for determining which tasks to focus traditional sampling on and desired control measures.

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