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Occupational exposures during the World Trade Center disaster response

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Upon the request of the New York City Department of Health, the Centers for Disease Control and Prevention's National Institute for Occupational Safety and Health (NIOSH) monitored occupational exposures among emergency response workers during the rescue and recovery activities at the World Trade Center disaster site from September 18 through 4 October 2001. During this period, over 1200 bulk and air samples were collected to estimate or characterize workers' occupational exposures. Samples were collected and analyzed for asbestos, carbon monoxide (CO), chlorodifluoromethane (Freon® 22), diesel exhaust, hydrogen sulfide, inorganic acids, mercury and other metals, polynuclear aromatic hydrocarbons, respirable particulate not otherwise regulated (PNOR), respirable crystalline silica, total PNOR, and volatile organic compounds. Exposures to most of these potential hazards did not exceed NIOSH Recommended Exposure Limits or Occupational Safety and Health Administration Permissible Exposure Limits. However, one torch cutter was overexposed to cadmium and another worker (and possibly three others) was overexposed to CO. The elevated cadmium and CO levels were the result of workers using oxy-acetylene cutting torches and gasoline-powered cutting saws. Recommendations were made to ensure adequate ventilation and worker understanding when using these tools and, where possible, to substitute rechargeable, battery-powered cutting saws for gasoline-powered ones. *Toxicology and Industrial Health* 2001: **17**, 247–253.

Key words: *asbestos; cadmium; carbon monoxide; occupational exposure; World Trade Center*

Introduction

Immediately following the collapse of World Trade Center (WTC) buildings on 11 September 2001, the fires and the suspected presence of hazardous materials in the rubble pile generated concerns about exposures of persons working in and around the site. The New York City Department of Health (NYCDOH), which had overall responsibility for occupational safety and health, asked the Centers for Disease Control and Prevention (CDC) for assistance in evaluating occupational exposures and recommending preventive measures. The National Institute for Occupational Safety and Health (NIOSH) personnel were on site at the WTC the next day, September 12, to begin providing such assistance to the NYCDOH.

The WTC office complex consisted of seven large buildings, including the two prominent 110-floor towers. The WTC was constructed primarily of reinforced concrete, fireproofed steel, and glass. Other construction materials included gypsum board, suspended ceiling panels, and thermal insulation. The collapse of WTC buildings shaped the environment facing the workers responding to the disaster site, creating hazards to their health and safety. The individuals responding to the WTC disaster site were required to work in unstable, burning rubble amid the smoke and dust emanating from the collapsed debris. Work activities also included elements of confined space entry in some locations at the WTC disaster site.

NIOSH personnel and NYCDOH contractors collected samples from September 18 through 4 October 2001 at the WTC disaster site. During this period, over 1200 bulk and air samples were collected to estimate or characterize the WTC disaster site workers' occupational exposures. Bulk samples of undisturbed settled debris, fireproofing material, and paint were collected along with personal breathing zone (PBZ) and general area (GA) air samples for a wide range of potential hazards. The focus of this paper is the occupational exposures of workers at the WTC disaster site as measured by NIOSH (and NYCDOH contractor) personnel during this time period.

Methods

The potential hazards of concern for workers at the WTC disaster site included asbestos (from insulating and fireproofing materials), carbon monoxide (CO; from burning

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rubble and engine exhaust), chlorodifluoromethane (Freon® 22; from air conditioning systems), concrete (made from Portland cement and used in the buildings' construction) and the crystalline silica it contained, diesel exhaust (from vehicles and equipment), hydrogen sulfide (H_2S; from sewers, anaerobically decomposing bodies, and spoiled food), mercury (from fluorescent lights), other metals (from building materials), inorganic acids, polynuclear aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs) (from burning rubble and engine exhaust), and respirable and total particulate not otherwise regulated (PNOR) (from building materials, burning rubble, and engine exhaust).

The workers at the WTC disaster site were involved in a variety of activities including search and rescue, construction, demolition, and support services. Support service workers were from many different occupations such as health care professionals, safety and health professionals, engineers, armed forces personnel, perimeter control personnel, food service workers and clergy, among others. Much of the rescue work at the WTC disaster site was done by hand to search for survivors and the remains of the deceased. Debris was removed and passed to the perimeter of the rubble pile using 'bucket brigades.' Other tasks performed by hand included cutting steel beams and other metal debris using oxy-acetylene torches and gasoline-powered saws. Where there were no direct rescue efforts involving the search for survivors and the remains of the deceased, heavy equipment was used to move rubble and load trucks. This heavy equipment included grapplers, cranes, shovels, and bulldozers. Once the debris was removed from the rubble pile and loaded onto trucks, it was hauled to barges and transported to a landfill on Staten Island.

Bulk samples

Thirty-three bulk samples were collected of undisturbed settled debris resulting from the collapse of WTC buildings, and of fireproofing material and paint from steel beams in the rubble pile. These bulk samples were analyzed for asbestos using polarized light microscopy (PLM) as described in NIOSH method 9002, analyzed for metals using inductively coupled argon plasma (NIOSH method 7300) and analyzed for crystalline silica using X-ray powder diffraction as described in NIOSH method 7500 (NIOSH, 1994).

Air samples

A total of 1173 air samples were collected at the WTC disaster site, including 804 for asbestos. NYCDOH contractors collected most of the asbestos samples; NIOSH personnel collected all other samples. During each sampling period, the work tasks being performed were identified and air samples were collected from a representative number of workers performing each of those tasks. PBZ air samples were collected with the sampling device placed in the breathing zone of individual workers. Where it was difficult for the individual workers to wear an air sampling device (such as heavy equipment operators), GA air samples were collected with the sampling device placed at a height approximating their breathing zone, and as close to them as possible. These integrated air samples were collected and analyzed according to the methods described in the NIOSH Manual of Analytical Methods (with some modifications) by American Industrial Hygiene Association-accredited laboratories (NIOSH, 1994; AIHA, 2002). The personal sampling pumps used for these measurements were calibrated before and after each use. Field blanks and media blanks were collected for each analyte measured and provided to the analytical laboratories for quality assurance purposes.

Airborne asbestos was collected on mixed cellulose ester filters and analyzed by both phase contrast microscopy (PCM) and transmission electron microscopy (TEM), as described in NIOSH methods 7400 and 7402, respectively (NIOSH, 1994). In addition, 25 selected asbestos air samples [those with concentrations greater than 0.10 fibers per cubic centimeter (f/cm^3) of air] were also analyzed by PLM using a differential counting procedure that identifies each of the fibers counted (personal communication, Joseph E. Fernback, Physical Scientist, National Institute for Occupational Safety and Health, Cincinnati, OH, 1 May 2002).

Chlorodifluoromethane (Freon® 22) was collected on charcoal tubes and analyzed using thermal desorption and gas chromatography/mass spectrometry (GC/MS) as described in Environmental Protection Agency (EPA) method TO-17, modified (EPA, 1999). Diesel exhaust was collected on glass fiber filters and analyzed using an evolved gas procedure for elemental carbon as described in NIOSH method 5040 (NIOSH, 1994). Inorganic acids were collected on washed silica gel solid sorbent tubes and analyzed by ion chromatography as described in NIOSH method 7903 (NIOSH, 1994). Mercury samples were collected on Hopcalite solid sorbent tubes and analyzed by atomic absorption spectroscopy as described in NIOSH method 6009 (NIOSH, 1994).

Airborne metals were collected on mixed cellulose ester filters and analyzed using inductively coupled argon plasma as described in NIOSH method 7300 (NIOSH, 1994). PAHs were collected on polytetrafluoroethylene filters and XAD-2 solid sorbent tubes and analyzed using high-performance liquid chromatography as described in NIOSH method 5506 (NIOSH, 1994). Respirable PNOR and respirable crystalline silica were collected using Dorr–Oliver cyclone preselectors selectors with polyvinyl chloride (PVC) filters and analyzed using a gravimetric procedure for respirable PNOR, and by X-ray powder diffraction for respirable crystalline silica as described in NIOSH methods 0600 and 7500, respectively (NIOSH, 1994). Total PNOR was also collected on PVC filters and analyzed using a gravimetric procedure as described in NIOSH method 0500 (NIOSH, 1994).

Thermal tubes were used to screen the air for the presence of major VOCs and qualitatively analyzed using thermal desorption GC/MS, as described in NIOSH method 2549 (NIOSH, 1994).

From this screening procedure, benzene, ethyl benzene, styrene, toluene, xylenes, and total hydrocarbons were then selected for quantitative analysis. These six VOCs were collected on charcoal tubes and quantitatively analyzed using gas chromatography with flame ionization detection, as described in NIOSH method 1501 for hydrocarbons and NIOSH method 1550 for naphthas (NIOSH, 1994).

Direct-reading instruments were used to instantaneously collect air samples for H_2S and CO according to NIOSH method 6604, Electrochemical Sensor Technique (NIOSH, 1994). Data from these instruments were then downloaded to laptop computers and imported into a spreadsheet for analysis. The direct-reading instruments were calibrated before and after deployment at the WTC disaster site – not before and after each use as with the personal sampling pumps.

Results

Bulk samples

A total of 33 bulk samples were obtained from the WTC disaster site. Twenty-nine bulk samples of undisturbed settled material thought to represent the dust created by the collapse of WTC buildings were analyzed for asbestos, and 27 of them were also analyzed for crystalline silica and metals. Twenty-six (90%) of the bulk samples had less than 1% asbestos (by mass); the three others had between 1% and 3% (EPA does not consider building materials containing <1% asbestos to be asbestos-containing) (EPA, 1993). Additional analysis of seven of these bulk samples for nonasbestos fibers indicated that the majority of fibers contained in the settled dust were fibrous glass, gypsum, and cellulose – materials used in the construction of the WTC buildings. All but 1 of 27 samples contained crystalline silica with concentrations (by mass) ranging from not detected (ND) to 18%, with a median (for all 27 samples) of 3.2%. The most abundant metals found in the bulk samples were calcium, magnesium, aluminum, iron, sodium, and zinc. Lead, arsenic, and cadmium concentrations (by mass) were less than 0.1%, 0.01%, and 0.001%, respectively. Additionally, three bulk samples of fireproofing material from steel beams were analyzed for asbestos; one had no detectable asbestos, and the other two had <1%. Finally, a sample of paint from a metal beam had 0.3% lead (EPA does not consider paint containing less than 0.5% lead to be lead-based paint) (EPA, 2001).

Air samples

A total of 804 air samples were collected for asbestos, most of which were collected by NYCDOH contractors for NIOSH (Table 1). PCM analysis revealed fibers to be present in 358 (45%) of them. Excluding the 30-min short-term exposure limit (STEL) samples, 25 of these air

Table 1. Selected air sample results (WTC disaster site, New York, NY, September 18 through 4 October 2001).

Potential hazard	*n*	Concentration	NIOSH REL	OSHA PEL
Asbestos[a] (f/cm^3)	636	ND–0.54	0.10	0.10
Asbestos[b] (f/cm^3)	114	ND–0.024[c]	0.10[c]	–
Asbestos[d] (f/cm^3)	168	ND–0.89	–	1.0
CO (ppm)	99	0.16–242	35[e]	50
Chlorodifluoromethane (ppm)	5	ND	1000	–
Crystalline silica[f] (mg/m^3)	18	ND	0.050[g]	[h]
Diesel exhaust (mg/m^3)	8	ND–0.023[i]	–	–
Hydrogen sulfide (ppm)	10	ND–3.0	10[j]	20[j]
Mercury (mg/m^3)	16	ND–0.0020	0.10[j]	0.10[j]
Respirable PNOR (mg/m^3)	18	ND–0.32	5.0[k]	5.0
Total PNOR (mg/m^3)	36	ND–2.3	10[k]	15

[a]Time-weighted average air samples analyzed by PCM.
[b]Time-weighted average air samples analyzed by TEM.
[c]Fibers identified by TEM as asbestos.
[d]Short-term exposure limit air samples analyzed by PCM.
[e]NIOSH-recommended ceiling limit is 200 ppm.
[f]Respirable fraction of crystalline silica.
[g]NIOSH considers crystalline silica a suspected human carcinogen.
[h]OSHA PEL for crystalline silica is 10 mg/m^3$\div$%SiO_2+2.
[i]Diesel exhaust expressed as elemental carbon.
[j]NIOSH RELs and OSHA PELs are ceiling limits.
[k]NIOSH RELs for Portland cement.

samples had fiber concentrations that exceeded the NIOSH Recommended Exposure Limit (REL) and Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) of 0.10 f/cm^3 (NIOSH, 1997; OSHA, 2002). None of the 30-min sample concentrations exceeded the OSHA STEL of 1.0 f/cm^3 (OSHA, 2002). Eighteen of the 25 samples with fiber concentrations >0.10 f/cm^3 (as determined by PCM) were also analyzed by TEM, a method that can distinguish between asbestos and non-asbestos fibers; all 18 had asbestos concentrations <0.10 f/cm^3 (range of 0.0022–0.063 asbestos f/cm^3). (The seven samples not analyzed by TEM had fiber concentrations ranging from 0.10 to 0.20 f/cm^3.) Differential analysis by PLM (another method which can distinguish between asbestos and nonasbestos fibers) of these same 25 air samples revealed that the majority of nonasbestos fibers were fibrous glass, gypsum, and cellulose – again, materials used in the construction of the WTC buildings. Additionally, 96 of the air samples with fiber concentrations <0.10 f/cm^3 (as determined by PCM) were also analyzed by TEM; all 96 had asbestos concentrations <0.10 asbestos f/cm^3 (range ND–0.024 asbestos f/cm^3), with no asbestos fibers detected in over 60% (56) of them.

Ninety-nine air samples were collected for CO with concentrations ranging from 0.16 to 242 parts per million (ppm); the highest result (in a 32.5-min PBZ sample from a gasoline-powered cutting saw operator) exceeded the NIOSH-recommended ceiling limit of 200 ppm and would have exceeded the NIOSH REL of 35 ppm and the OSHA PEL of 50 ppm had it been sustained for 2 h (NIOSH, 1997; OSHA, 2002) (Table 1). CO concentrations of 41 and 45 ppm in PBZ samples from oxy-acetylene torch cutters and 40 ppm in a GA sample near a gasoline-powered cutting saw operator – with sampling durations of 30 min, 5 h, and 2.5 h, respectively – would also have exceeded the NIOSH REL of 35 ppm had they represented 8-h, full-shift exposures (NIOSH, 1997). Two instantaneous peak CO measurements (1239 and 1368 ppm) exceeded 1200 ppm, the level NIOSH considers immediately dangerous to life and health (NIOSH, 1997). One was from an oxy-acetylene torch cutter and the other from an operator of a gasoline-powered cutting saw.

Five air samples were collected for chlorodifluoromethane (Freon® 22); none was detected in any of the samples. Since this analysis was initially meant to be a qualitative scan of the samples, no limit of detection (LOD) for chlorodifluoromethane (Freon® 22) was accurately determined.

Eight air samples were collected for diesel exhaust (Table 1). The range of elemental carbon (an indicator of diesel exhaust) concentrations was ND (three of eight samples) to 0.023 mg/m^3 elemental carbon. Neither NIOSH nor OSHA currently has a numeric occupational exposure limit for diesel exhaust, but the American Conference of Governmental Industrial Hygienists (ACGIH®) has proposed a Threshold Limit value of 0.02 mg/m^3 (measured as elemental carbon) (ACGIH, 2001).

Ten air samples were collected for H_2S with concentrations ranging from ND (3 of 10 samples) to 3.0 ppm, well below the NIOSH-recommended ceiling limit of 10 ppm and the OSHA ceiling limit of 20 ppm (NIOSH, 1997; OSHA, 2002) (Table 1).

Twenty-seven air samples were collected for six different inorganic acids that included hydrobromic, hydrochloric, hydrofluoric, nitric, phosphoric, and sulfuric acids (Table 2). One or more of these inorganic acids were detected in all 27 air samples. Only trace concentrations of hydrobromic, hydrochloric, hydrofluoric, nitric, and phosphoric acids were detected. However, low concentrations of sulfuric acid were detected in the air samples ranging from ND (1 of 27 samples) to 0.89 mg/m^3. These were all below the NIOSH REL and OSHA PEL of 1.0 mg/m^3 (NIOSH, 1997; OSHA, 2002). However, the highest exposure (0.89 mg/m^3), collected on an oxy-acetylene torch cutter, was above the OSHA action level of 0.50 mg/m^3 (defined as one-half the OSHA PEL) (OSHA, 2002).

Sixteen air samples were collected for mercury with concentrations ranging from ND (11 of 16 samples) to 0.0020 mg/m^3, well below the NIOSH-recommended ceiling limit and OSHA ceiling limit of 0.10 mg/m^3 (NIOSH, 1997; OSHA, 2002) (Table 1).

Forty-five air samples were collected for metals and 27 different metals were included in the analysis for each air sample (Table 3). These 27 metals were aluminum, arsenic, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, molybdenum, nickel, phosphorus, platinum, selenium, silver, sodium, tellurium, thorium, titanium, vanadium, yttrium, zinc, and zirconium. One air sample from an oxy-acetylene torch cutter had a cadmium concentration of 8.6 μg/m^3, exceeding the OSHA PEL of 5.0 μg/m^3 (OSHA, 2002). Only trace amounts of the other metals were detected on the air samples; none exceeded applicable NIOSH RELs or OSHA PELs (NIOSH, 1997; OSHA, 2002).

Twelve air samples were collected for PAHs; 16 different PAHs were included in the analysis for each air

Table 2. Inorganic acids air sample results (WTC disaster site, New York, NY, September 18 through 4 October 2001).

Inorganic acid	*n*	Concentration	NIOSH REL	OSHA PEL
Hydrobromic acid (ppm)	27	ND–0.010	3.0[a]	3.0
Hydrochloric acid (ppm)	27	ND–0.080	5.0[a]	5.0[a]
Hydrofluoric acid (ppm)	27	ND–0.040	3.0	3.0
Nitric acid (ppm)	27	ND–0.020	2.0	2.0
Phosphoric acid (mg/m^3)	27	ND–0.0096	1.0	1.0
Sulfuric acid (mg/m^3)	27	ND–0.89	1.0	1.0[b]

[a]NIOSH RELs and OSHA PELs are ceiling limits.
[b]OSHA action level is 0.50 mg/m^3.

Table 3. Metals air sample results (WTC disaster site, New York, NY, September 18 through 4 October 2001).

Metal	*n*	Concentration (μg/m^3)	NIOSH REL (mg/m^3)	OSHA PEL (mg/m^3)
Aluminum	45	ND–105	5.0, 10	5.0, 15
Arsenic	45	ND–0.87	0.0020[a,b]	0.010
Beryllium	45	ND–0.011	0.00050[a,b]	0.0020
Cadmium	45	ND–8.6	Ca[a]	0.0050
Calcium (as silicate)	45	ND–1285	5.0, 10	5.0, 15
Chromium	45	ND–2.8	0.50	1.0
Cobalt	45	ND–0.24	0.050	0.10
Copper	45	ND–42	1.0	1.0
Iron	45	ND–1100	5.0	10
Lead	45	ND–27	0.10	0.050
Lithium	45	ND–0.49	–	–
Magnesium	45	ND–105	–	15
Manganese	45	ND–17	1.0	5.0[b]
Molybdenum	45	ND–3.3	–	15
Nickel	45	ND–8.0	0.015[a]	1.0
Phosphorus	45	ND–20	0.10	0.10
Platinum	45	ND–12	1.0	–
Selenium	45	ND–6.5	0.20	0.20
Silver	45	ND–0.10	0.010	0.010
Sodium	45	ND–45	–	–
Tellurium	45	ND–1.2	0.10	0.10
Thallium	45	ND	0.10	0.10
Titanium	45	ND–10	–	–
Vanadium	45	ND–0.40	0.050[b]	0.50[b]
Yttrium	45	ND–0.22	1.0	1.0
Zinc	45	ND–282	5.0	5.0, 15
Zirconium	45	ND–0.27	5.0	5.0

[a]NIOSH considers this compound a suspected human carcinogen.
[b]NIOSH RELs and OSHA PELs are ceiling limits.

sample (Table 4). The PAHs included acenaphthene, acenaphthylene, anthracene, benzo(*a*)anthracene, benzo(*b*) fluoranthene, benzo(*k*)fluoranthene, benzo(*g*,*h*,*i*)perylene, benzo(*a*)pyrene, chrysene, dibenzo(*a*,*h*)anthracene, fluoranthene, fluorene, indeno(1,2,3-*cd*)pyrene, naphthalene, phenanthrene, and pyrene. Trace to small amounts of various PAHs were present in all 12 samples, but not at concentrations that individually or collectively exceeded any applicable NIOSH REL or OSHA PEL (NIOSH, 1997; OSHA, 2002). The detected PAHs included the four suspected human carcinogens benzo(*a*)anthracene, benzo(*b*) fluoranthene, benzo(*a*)pyrene, and chrysene (ACGIH, 2001).

Table 4. PAHs air sample results (WTC disaster site, New York, NY, September 18 through 4 October 2001).

PAH	*n*	Concentration (μg/m^3)	NIOSH REL (mg/m^3)	OSHA PEL (mg/m^3)
Acenaphthene	12	ND–0.72	–	–
Acenaphthylene	12	ND–17	–	–
Anthracene	12	ND–1.2	–	–
Benzo(*a*)anthracene	12	ND–0.60	Ca[a]	–
Benzo(*b*)fluoranthene	12	ND–0.39	Ca[a]	–
Benzo(*k*)fluoranthene	12	ND–0.20	–	–
Benzo(*g*,*h*,*i*)perylene	12	ND–0.12	–	–
Benzo(*a*)pyrene	12	ND–0.25	Ca[a]	–
Chrysene	12	ND–0.62	Ca[a]	–
Dibenzo(*a*,*h*)anthracene	12	ND–0.24	–	–
Fluoranthene	12	ND–0.77	–	–
Fluorene	12	ND–4.4	–	–
Indeno(1,2,3-*cd*)pyrene	12	ND–0.14	–	–
Naphthalene	12	3.8–14	50	50
Phenanthrene	12	0.12–4.6	–	–
Pyrene	12	ND–0.58	–	–

[a]ACGIH® considers this compound a suspected human carcinogen.

Eighteen and 36 air samples were collected for respirable and total PNOR, respectively (Table 1). Respirable PNOR concentrations ranged from ND (1 of 18 samples) to 0.32 mg/m^3, far below the NIOSH REL of 5.0 mg/m^3 for respirable Portland cement (a constituent of concrete) and the OSHA PEL of 5.0 mg/m^3 for respirable PNOR (NIOSH, 1997; OSHA, 2002). Total PNOR concentrations ranged from ND (2 of 36 samples) to 2.3 mg/m^3, far below the NIOSH REL of 10 mg/m^3 for total Portland cement and the OSHA PEL of 15.0 mg/m^3 for total PNOR (NIOSH, 1997; OSHA, 2002). Additionally, all 18 respirable PNOR air samples were analyzed for respirable crystalline silica; none was detected in any of the air samples. The LOD for crystalline silica (quartz) was 0.010 mg per sample, which calculates to approximately 0.012 mg/m^3 given the average sample volume (0.82 m^3) for these air samples.

Thermal tubes were initially used to qualitatively screen the air for the presence of major VOCs (Table 5). The major VOCs identified in this qualitative screen included benzene, toluene, ethyl benzene, xylenes, styrene, phenol, napthalene, benzaldehyde, α-methylstyrene, furfural, benzonitrile, various aliphatic hydrocarbons, various PAHs, and benzofurans – VOCs that are typical of combustion and plastic degradation. From this screening procedure, benzene, ethyl benzene, styrene, toluene, xylenes, and total hydrocarbons were selected for quantitative analysis of the charcoal tubes that had been concurrently collected. A total of 76 charcoal tube air samples were collected for VOCs. Of these, trace concentrations of ethyl benzene, styrene, and toluene were detected in 14 of 76 samples. Xylene was not detected in any of the air samples. All the VOC concentrations were below applicable NIOSH RELs and OSHA PELs except for two benzene concentrations (0.11 and 0.14 ppm) that were higher than the NIOSH REL of

Table 5. VOCs air sample results (WTC disaster site, New York, NY, September 18 through 4 October 2001).

VOC	*n*	Concentration (ppm)	NIOSH REL (ppm)	OSHA PEL (ppm)
Benzene	76	ND–0.14	0.10[a]	1.0
Ethyl benzene	76	ND–0.050	100	100
Styrene	76	ND–0.050	50	100
Toluene	76	ND–0.060	100	200
Xylene(s)	76	ND	100	100
Total hydrocarbons[b]	76	ND	–	–

[a]NIOSH considers benzene a suspected human carcinogen.
[b]Total hydrocarbons includes all others minus the five VOCs listed.

0.10 ppm but not the OSHA PEL of 1.0 ppm (NIOSH, 1997; OSHA, 2002). Both, however, were in GA samples taken directly in the smoke plume of a fire and did not represent any specific worker's exposure.

Discussion

The predominant components of the debris created by the collapse of WTC buildings were concrete, gypsum, fibrous glass, and cellulose – materials used in the construction of the WTC office complex. Considering these predominant components, the debris at the WTC disaster site would be alkaline and hygroscopic. [The USGS (2002) found that the pH of this debris was moderately alkaline to alkaline (range of 8.2–11.8; mean of 10.2).] Exposure to this type of debris through the air or direct skin contact would result in irritation to the mucous membranes and the skin. This was illustrated by the predominant medical treatment provided to the survivors and rescue workers within 48 h of the initial incident, respiratory injury or irritation (49%), and eye injury or irritation (26%) (CDC, 2002). Irritation to the mucous membranes and skin was likely for those individuals caught in the dust clouds created by the collapse of WTC buildings. Also, emergency response workers at the WTC disaster site after the dust clouds had dissipated may have experienced some irritation of the mucous membranes and the skin from this debris even at airborne concentrations below applicable occupational health criteria. Worker concerns regarding long-term health effects from exposure to the dust and debris at the WTC disaster site are currently being addressed by public health agencies and academic institutions.

Analysis of the limited number of bulk samples obtained of undisturbed settled debris and fireproofing material from steel beams at the WTC disaster site suggests that there was no substantial amount of asbestos-containing material to contaminate the air. Therefore, it is not surprising that extensive air sampling found no occupational exposure to asbestos (as determined by TEM), at least after September 18, in excess of either the NIOSH REL or OSHA PEL. The seven air samples that had fiber concentrations (as determined by PCM) higher than the NIOSH REL and OSHA PEL for asbestos most likely would have resulted in asbestos concentrations lower than 0.10 f/cm^3 if analyzed by TEM. In many other air samples, asbestos concentrations determined by TEM tended to be an order of magnitude or more lower than those determined by PCM. (These seven air samples are currently being analyzed by TEM to confirm this conclusion.) The NIOSH asbestos sampling provides no data about occupational exposures prior to 1 September 2001. Furthermore, it was designed to assess occupational exposures, not community exposures (which are likely to be lower).

The absence of exposure to respirable crystalline silica, despite its presence in the bulk samples, indicates that either the crystalline silica in the dust at the WTC disaster site consisted of larger, nonrespirable particles, or that work activities were not causing the dust containing crystalline silica to become airborne. In the absence of effective dust control measures, the former explanation seems more likely. Although the air sampling indicated the presence of respirable airborne particulate, this material was apparently not crystalline silica.

At the time of the NIOSH sampling (and considering only what was measured), the outdoor air at the WTC disaster site did not appear to be contaminated with hazardous materials from the buildings or their contents, or with combustion products, to an extent that posed an occupational health hazard. Nevertheless, one torch cutter was overexposed to cadmium and another worker (and possibly three others) cutting steel was overexposed to CO. These elevated cadmium and CO exposures were the direct result of workers using oxy-acetylene cutting torches and gasoline-powered cutting saws. Recommendations were made to ensure adequate ventilation and to train workers to understand the hazards associated with using these tools. And, where possible, rechargeable battery-powered cutting saws should be substituted for gasoline-powered ones, especially when used in an enclosed space.

Once again, this evaluation demonstrated the potential for overexposure to CO from internal combustion engine exhaust in inadequately ventilated spaces, even when outdoors (NIOSH, 1996; CDC, 2000). Further, our work at the WTC disaster site demonstrated the presence of occupational hazards related to specific work activities and thus the importance of assessing suspected occupational exposures in order to focus exposure control efforts appropriately. In response to the WTC disaster, NIOSH has issued guidelines for addressing a variety of occupational safety and health hazards at similar disaster sites (NIOSH, 2002).

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