en years ago this month, the collapse of the World Trade Center (WTC) towers and subsequent recovery efforts released huge quantities of particulate matter, combustion products, gases, vapors and other contaminants into the environment. Unfortunately, the industrial hygiene community was largely unprepared for the health and safety challenges, which included monitoring and protecting first responders from respiratory and other hazards and extended into the process of reclaiming surrounding buildings.

In the ensuing decade, much has been learned about what was in the dust, respondents’ exposures, and the resulting health effects. In addition, specialized training programs have been developed for workers who provide cleanup and support services to both natural and man-made disasters.

Airborne Exposures

The collapse of the twin towers generated enormous amounts of coarse and fine particulate matter and other airborne contaminants to which people in the immediate area were exposed. Photographs taken of the dense clouds of dust at street level immediately following the collapse suggest that the concentration of particles was easily on the order of many milligrams per cubic meter of air. Ongoing fires and smoke re-suspended dust and debris, and engine exhaust from cleanup equipment and vehicles became major sources of airborne contaminants.1

Unfortunately, since no air sampling was apparently performed immediately after the disaster, there is no data identifying which contaminants were present in the dust plume or their concentrations at that time. Available data suggest that contaminant concentrations within and around Ground Zero remained significantly higher than background levels for several days following the attacks.2 However, because only limited data was available during that initial period, the true exposures to the various contaminants, and potential health impacts from those exposures, cannot be accurately evaluated.

Soon after the attacks, myriad agencies and other public and private parties began sampling for contaminants including particulate matter, volatile organic compounds (VOCs), polychlorinated biphenyls (PCBs), dioxins and metals. Testing performed in September 2001 by the U.S. Public Health Service on workers sifting WTC debris at the Staten Island landfill indicated that twelve of twenty-one personal air samples exceeded the OSHA PEL for asbestos.3 In October 2001, air samples collected from streets bordering the site revealed high concentrations of particle matter less than 2.5 microns (µm) in aerodynamic diameter (PM$_{2.5}$). Also during that time, it was observed that the composition of the contaminant mixture changed as debris removal progressed and fires were extinguished. Analyses of 243 archived air sample filters for polycyclic aromatic hydrocarbons (PAHs) indicated very high concentrations from fires in the early days and lower levels later, most likely due to the exhaust from diesel engines of equipment used in the recovery efforts.4 By April 2002, the median PM$_{2.5}$ concentrations had decreased significantly.5

Between Sept. 18 and Oct. 4, 2001, NIOSH monitored occupa-
tional exposures among emergency response workers during rescue and recovery efforts at the WTC site. A total of 1,173 air samples were collected, including 804 for asbestos. Limited sampling for other contaminants, including inorganic acids, volatile organic compounds (VOCs), metals, silica and PAHs was also performed. Based on the results of the testing, the researchers concluded that the outdoor air at the 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."16

**Composition of the Dust**

The WTC towers contained thousands of tons of toxic materials, which were pulverized into dust when the towers collapsed. An estimated 400 tons or more of asbestos was used in sprayed-on fireproofing during the construction of the towers. More than 10,000 personal computers, each containing four or more pounds of lead, as well as numerous mainframe computers and servers were inside the WTC complex, along with some 500,000 fluorescent light bulbs. Additional sources of toxic materials at the site included a Secret Service shooting range, which stored various toxic munition, and a U.S. Customs Service shooting range, which contained millions of rounds of lead ammunition. A retrospective check of 1,173 air samples from four of seven previously analyzed WTC dust samples did not identify asbestos.7

An analysis published in Environmental Health Perspectives of three settled dust samples from the collapse, which were collected from areas downwind of the site days after the attack, indicated that the vast majority of the mass comprised pulverized building and construction materials, including cement, soil, rubber, gauze, asbestos, and glass fibers.7 Asbestos, PAHs, pesticides, PCBs, various metals and polychlorinated dioxins and furans were also identified in the samples. Between 0.88 and 1.30 percent of the total mass comprised PM$_{2.5}$, and the largest mass concentrations were greater than 53 µm in diameter. Chemical analysis of the PM$_{2.5}$ fraction indicated that it contained high levels of calcium and sulfur, as well as much lower levels of transition metals and other elements. Aqueous extracts of the material were found to have a pH ranging from 8.9 to 10.0.8

In May 2002, a group of scientists at UC Davis performed what they described as "the most thorough analysis yet" of the dust and smoke from the World Trade Center. The study was based on the analysis of air samples that were collected between Oct. 2 and mid-December 2001 from a rooftop air monitor located about a mile north-northeast of Ground Zero. The group identified the presence of high levels of coarse particles (including powdered concrete and glass) in the size range of 5 to 12 µm in diameter, which were coated with combustion products. They also noted that very fine particles were found at levels not previously seen in ambient air samples.9

Then in 2005, the U.S. Geological Survey (USGS) attempted to quantitatively define the fine-particle fraction of WTC dust for the purpose of identifying a diagnostic signature. USGS concluded that the presence and relative abundance of certain man-made vitreous fibers (MMVF), specifically slag wool, rock wool, and soda-lime glass, along with the presence of concrete particles and gypsum, could be used as such a diagnostic signature.10 They also identified iron oxides (FeO$_x$), zinc oxide, silica and chrysotile as possible secondary signature components. Another study reported that components of the <150 µm size fraction of WTC dust consist of gyspsum, phases compatible with crushed concrete, MMVs, silica, lead, and chrysotile asbestos. Slag wool was reportedly the most common WTC MMVF identified, while soda-lime glass and rock wool were only minor to trace constituents.11

More recently, a 2010 case report on lung disease in WTC responders reported that carbon nanotubes (CNT) had been identified in lung tissue samples from four of seven previously healthy WTC responders who had developed lung disease. The CNT were found in concentrations ranging from 11,000 per gram to 230,000 per gram of wet weight. A retrospective check of lung specimens collected from 40 un-related asbestos cases involving construction workers was negative for CNT. Seven bulk WTC dust samples were subsequently analyzed, and CNTs were found in four.12 The authors noted that the high temperatures generated as a result of the combustion of jet fuel, in the presence of carbon and metals, would have been sufficient to locally generate large numbers of CNT.

**Health Effects**

An estimated 50,000 to 90,000 rescue and recovery workers were exposed to WTC dust and contaminants following the attacks. This includes not only firefighters, police and medical personnel but also construction, utility, building cleaning and other public and private sector workers. Although it’s still too early to determine any long-term effects, current studies demonstrate a strong link between exposure to WTC-derived airborne contaminants and respiratory disease.

An initial assessment and follow-up of firefighters who worked at the site showed that some of them had developed a syndrome described as “World Trade Center cough” and that exposure was associated with a substantial and probably permanent loss of lung function.13 Clinically, the condition is consistent with that of reactive airway disease (RADS), which can sometimes occur after a brief, high-level exposure to inhaled irritants. Follow-up testing of firefighters during the year following the attacks demonstrated a reduction in lung function about 10 times greater than would be expected for a single year of aging.14 Overall, those declines were found to be persistent, without substantial recovery, during the subsequent six years.15

In one study, involving 9,442 responders examined between July 2002 and April 2004, participants had exposure-related increases in respiratory symptoms and pulmonary function test abnormalities that persisted up to 2.5 years after the attacks.16 It was also noted that...
respiratory symptoms and spirometry abnormalities were significantly associated with early arrival at the site. In another clinical study, involving a group of 554 former workers and volunteers at the WTC site, five diagnostic categories were reported to clearly predominate: upper airway disease, gastroesophageal reflux disease (GERD), lower airway disease, and psychological and chronic musculoskeletal illnesses. Associations were found between arrival at the WTC site within the first 48 hours of the attack and lower airway and gastroesophageal reflux disease, as well as between past or present cigarette smoking and lower airway disease.17

Training Programs

The WTC attacks highlighted clear gaps in emergency planning and disaster preparedness. The scope of the attacks and subsequent destruction of the structures was beyond what anyone could have foreseen. The construction trades played a critical role in the response and recovery efforts following the WTC attacks. Ironworkers, heavy machinery operators, structural engineers, laborers, truckers, and other skilled support personnel spent months on end at the site as part of the response efforts.

Based on lessons learned at the WTC disaster, it became evident that a training program for workers, who provide skilled support services or site clean-up services in response to both natural and man-made disasters, needed to be developed. In particular, it was obvious that all workers at disaster sites need to be aware of the differences between regular construction/demolition worksites and disaster sites, the types of health and safety hazards they may encounter, the importance of respiratory and personal protective equipment, and proper decontamination procedures in order to mitigate hazards. This led to the development of two specific OSHA training courses for disaster site workers, a 16-hour course for workers and a Train-the-Trainer course.

Lessons Learned

In the decade since terrorists attacked and destroyed the WTC, much has been learned about the contaminants produced by the burning and collapse of the towers, as well as the adverse health effects that some first responders have experienced. Although most health and safety practitioners were unprepared for the extreme hazards of the WTC work site, we can use the lessons learned from that tragedy to help protect workers and the public in future disasters.

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