

Respiratory Health Outcomes among World Trade Center Disaster Workers
5-7 Years after September 11, 2001

by

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ABSTRACT

Background: Respiratory symptoms and diseases have been among the most examined health outcomes in studies of World Trade Center (WTC) disaster workers. WTC cough, pulmonary function abnormalities, newly-diagnosed asthma, and persistent respiratory symptoms have all been documented in epidemiologic studies of WTC disaster workers. A major limitation of these studies, however, has been their use of qualitative methods for exposure assessment.

Objective: This dissertation examined the relationship between chronic WTC dust exposure and reported respiratory outcomes among pile workers from the WTC Health Registry, a cohort of WTC-exposed persons.

Methods: Personal monitoring data combined with information collected from WTC Health Registry questionnaires were used to develop a semi-quantitative dust exposure index for 6,930 WTC disaster workers. Multivariable Log-binomial regression was used to estimate the independent effect of chronic WTC dust exposure on respiratory outcomes after September 11, 2001.

Results: Chronic dust exposure at the WTC site was associated with self-reported respiratory symptoms and newly diagnosed (after September 11, 2001) respiratory diseases among WTC pile workers. Workers in the High dust exposure category were

more likely to report lower ($PR_{adj} = 1.20$, 95% CI: 1.06-1.36) and upper ($PR_{adj} = 1.15$, 95% CI: 1.07-1.24) respiratory symptoms than workers in the Low dust exposure category.

Compared to Low dust exposed workers, there was an increased prevalence of new onset asthma ($PR_{adj} = 1.59$, 95% CI: 1.28-1.99), RADS ($PR_{adj} = 2.08$, 95% CI: 1.39-3.09), COPD ($PR_{adj} = 1.81$, 95% CI: 1.30-2.51), and chronic bronchitis ($PR_{adj} = 1.74$, 95% CI: 1.28-2.39) among High dust exposed workers.

Conclusions: Chronic dust exposure at WTC site was associated with respiratory symptoms and diseases among WTC Health Registry disaster workers. These findings provide an example of a semi-quantitative exposure index in retrospective exposure assessments after an environmental disaster. The exposure index developed in this dissertation has identified a highly dust-exposed group of WTC disaster workers that may be at greater risk for adverse respiratory outcomes than other WTC disaster workers. Epidemiologic studies along with continued surveillance will be vital in understanding the respiratory health burden associated with WTC dust exposure after the September 11, 2001 World Trade Center disaster.

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CHAPTER 1

INTRODUCTION

In the aftermath of the September 11, 2001 World Trade Center disaster, more than 90,00 disaster workers were estimated to have participated in rescue, recovery, and cleanup activities at the site of the World Trade Center in lower Manhattan (Ground Zero). Firefighters, police officers, construction workers, remediation workers, and sanitation workers were among the many groups of workers who responded to the disaster. These men and women responded to the events valiantly and performed their duties well. By the time cleanup and recovery activities at Ground Zero ended on May 30, 2002, workers had sifted through approximately 1.8 million tons of debris from the collapse of the World Trade Center (WTC) twin towers.

The collapse of the WTC twin towers resulted in the release of a variety of environmental toxicants. More than nine years after the disaster, epidemiologic studies of rescue, recovery, and cleanup workers have been vital in understanding the health effects of exposures to these suspected toxicants. To date, respiratory health symptoms and diseases have been among the most examined health outcomes in studies of WTC workers. Epidemiologic studies have reported on “World Trade Center cough”, pulmonary test abnormalities, new-onset asthma, acute eosinophilic pneumonia, Reactive Airways Dysfunction Syndrome, and “Sarcoid-like” granulomatous pulmonary disease.

The impact of Ground Zero pile work on respiratory health five-to-seven years after the disaster was evaluated in this study. A semi-quantitative dust exposure index was developed for WTC rescue, recovery, and cleanup workers. The relationship between chronic occupational exposure to WTC dust and selected respiratory health outcomes including new-onset lower and upper respiratory symptoms after September 11, newly diagnosed allergic rhinitis after September 11, newly diagnosed asthma after September 11, and new diagnosed chronic bronchitis after September 11 were examined. This study describes the respiratory health burden associated with chronic WTC dust exposure in a subset of 6,930 WTC workers who participated in rescue, recovery, and cleanup activities at the pile after September 11, 2001.

1.1 Literature Review

The September 11, 2001 World Trade Center Terrorist Attack

The former site of the World Trade Center in lower Manhattan is a 16 acre area located at the southwest tip of Manhattan adjacent to the Hudson River [1]. The WTC site contained the 7-building WTC complex bordered by Vescey Street on the north, Church Street to the east, Liberty Street to the south and West Street to the west. On September 11, 2001, two hijacked commercial airliners were intentionally flown into the WTC twin towers [1]. The first plane crashed into the north tower at 8:46 a.m. The second plane struck the south tower at 9:03 a.m.

Immediately after the planes struck the buildings, fires, ignited by jet and diesel fuel, engulfed the towers. Several buildings were destroyed on September 11, 2001 [1, 2]. WTC building #2 was the first to collapse at 9:59 A.M. WTC building #1 collapsed at 10:29 A.M. Later in the day, WTC building #7 collapsed at 5:20 P.M. In the days after the terrorist attacks, other buildings in the WTC complex were damaged as metals melted during building fires and surface temperatures remained as high as 240°C above ambient temperatures [2].

The collapse of the WTC twin towers resulted in a massive plume of building debris and particulates from the fires. Photographic images of plume transport were taken after the collapse [3]. On September 11, dark gray smoke covered lower Manhattan. During the first 12-18 hours after the attacks, winds blew to the East-Northeast carrying dust and smoke towards the East River [4]. Photographs taken in the morning on September 12, 2001 showed a plume moving from West-Northwest to the South-Southwest direction [2, 3]. By September 16, 2001, satellite images revealed a smaller, darker plume centered on the pile at Ground Zero [2, 3].

Environmental Exposures after the World Trade Center Disaster

The sources of pollutants associated with the WTC disaster varied over the months after the disaster [3, 5]. Liroy and Georgopoulos described the sequence of exposures that occurred after September 11, 2001 through five distinct periods (Table 1.1).

Period 1 began with the planes striking the WTC twin towers and continued for 12 hours after the collapse of WTC building #1. Period 2 began the evening of September 11, 2001 and ended on September 13, 2001. Period 3 began after a rain event on September 14, 2001. Another rain event on September 25, 2001 marked the beginning of Period 4. Finally, after the fires were extinguished in late December 2001, Period 5 began on January 1, 2002.

Table 1.1 Sequence of Environmental Exposures after the World Trade Center Disaster [3]

Period	Duration	Source of Pollutant(s)	Pollutant(s)
1	<12 hours after the collapse of the WTC twin towers	▪ Collapse of the twin towers ▪ Burning jet fuel ▪ Building fires (>1000°F) ▪ Resuspended dust and smoke	▪ Combustion products ▪ Evaporating gases ▪ Gaseous, fine, and supercoarse particles
2	September 11, 2001-September 13, 2001	▪ Burning jet fuel ▪ Building fires ▪ Resuspended dust and smoke	▪ Combustion products ▪ Evaporating gases ▪ Gaseous, fine, and supercoarse particles
3	September 14, 2001-September 25, 2001	▪ Building fires ▪ Resuspended dust and smoke	▪ Combustion products ▪ Gaseous, fine, and supercoarse particles
4	September 26, 2001-December 31, 2001	▪ Building fires ▪ Resuspended dust and smoke ▪ Debris removal by trucks and equipment	▪ Combustion products ▪ Some fine and coarse particles
5	January 1, 2002-July 31, 2002	▪ Debris removal by trucks and equipment ▪ Resuspended dust and smoke	▪ Combustion products ▪ Some fine and coarse particles

Composition of World Trade Center Dust and Aerosols

The scientific community's response to the disaster was swift. The United States Geological Survey (USGS), the Centers for Disease Control and Prevention's National Institute for Occupational Safety and Health (NIOSH), the New York City Department of Health and Mental Hygiene (NYC DOHMH), and the United States Department of Energy (DOE) were among the public health agencies that conducted environmental monitoring after the disaster. In addition to public agencies, New York City metropolitan area scientists studied the composition of the WTC dust and initiated biological monitoring among WTC rescue, recovery, and cleanup workers. Among the many components from the collapsed buildings were pulverized concrete, metal compounds, asbestos, polycyclic aromatic hydrocarbons, dioxins, and volatile organic compounds [3, 6, 7].

Particulate Matter following the World Trade Center Disaster

Analysis of fine particulates. After the collapse of the twin towers, up to 100,000 $\mu\text{m}/\text{m}^3$ of particles were estimated to have been present in the air [3]. McGee et al. described the chemical composition of fine, coarse, and large fragments settled dust collected from sites within 0.5 miles of Ground Zero on September 12, 2001 and September 13, 2001 [8].

The composition of lyophilized samples was different from aerosolized particles. Water-extracted WTC $\text{PM}_{2.5}$ included large crystals that contained calcium, sulfur,

oxygen, and metal particulates, including titanium, iron, zinc, lead, barium, and copper [8]. In contrast, aerosolized WTC PM_{2.5} particles were smaller than water-extracted particles and were mostly composed of calcium, carbon, and oxygen with sulfur [8].

X-Ray diffraction analyses highlighted the presence of crystalline materials, with calcium sulfate dehydrate (gypsum) and calcium (calcite) identified as the main constituents, and basinite (calcium sulfate hemihydrate) and quartz (silicon dioxide) identified as minor constituents [8]. Neutron activation and X-ray fluorescence analyses found large amounts of calcium (range 22-33%) in the WTC PM_{2.5} samples [8]. In addition, sulfate was present as 37.5% of WTC PM_{2.5} samples. Carbon fraction analysis revealed low total carbon content (range 1.5-8.5%). PM samples were found to be highly alkaline as the pH of water-extracted WTC PM_{2.5} samples ranged from 8.88 to 10.00. After reconstitution in unbuffered saline, the pH of lyophilized WTC PM_{2.5} was 7.36 [8].

According to McGee and colleagues, WTC workers could have been susceptible to inhalation hazards due to dust resuspension during cleanup efforts [8]. WTC PM_{2.5} samples consisted primarily of calcium-based compounds, with calcium and sulfate making up approximately two-thirds the weight of WTC PM_{2.5} [8]. The authors hypothesized that elements from cement, concrete aggregate, ceiling tiles, and wallboard were the main components of WTC PM_{2.5} [8]. WTC PM_{2.5} contained calcite, gypsum, and calcium carbonate, all known to irritate the upper airways, cause

eye, nose and throat irritation, and cause cough [8, 9]. The proportion of calcium among WTC PM_{2.5} sampled by McGee et al. was similar to calcium proportions reported by the USGS and Lioy et al. [8, 10, 11]. Sulfate among WTC PM_{2.5} samples in this study was also similar to Sulfate levels reported by Lioy et al., but 4-fold higher than Sulfate proportions later reported by the USGS [8, 10, 11].

USGS analyses. The United States Geological Survey (USGS) collected dust, debris, and beam-coating samples on September 17 and September 18, 2001 [10, 12].

Samples were analyzed for trace elements using reflectance spectroscopy, scanning electron microscopy with X-ray micro-analysis, X-Ray diffraction, chemical analysis, and chemical leach test techniques. Chemical leach tests indicated that outdoor dust samples had an alkalinity ranging from pH 9-11 [10].

Silicon, cadmium, sulfur, magnesium, aluminum, iron, and carbon were the predominant components of USGS dust samples [10]. There were no systematic spatial variations in the dust composition between sampling sites. At 3000 ppm, Zinc was the predominant metal in most of the dust samples [10]. Barium, lead, copper, and chromium were present at hundreds of parts per million, and other metals, including beryllium were present at tens of parts per million or less.

USGS girder coatings contained low concentrations of metals relative to the other dust samples. Dust from steel beam samples contained chrysotile asbestos levels as high as

20% by volume of the coating material [10]. The USGS concluded that the dust released from the collapse of the WTC buildings were composed of particles of glass fibers, gypsum, concrete, paper, and other miscellaneous materials commonly used in building construction [10].

NIOSH analyses. The Centers for Disease Control and Prevention's National Institute for Occupational Safety and Health (NIOSH) along with the New York City Department of Health and Mental Hygiene (NYC DOHMH) collected 36 air samples for total particulate and 18 samples for respirable particulates between September 18, 2001 and October 4, 2002 [13, 14]. Total particulates ranged from none detected to 2.3 mg/m³. Respirable particulates ranged from none detected to 0.32 mg/m³. Particulate results were reported as well below the Occupational Safety and Health Administration (OSHA) PEL for total particulates of 15 mg/m³ [13, 15]. However, the authors did not provide a description of their air sampling methods nor did they provide 8-hour time-weighted averages [13].

Analyses of aerosol sampling. Cahill et al. collected aerosol particles between October 2, 2001 and October 30, 2001 [2]. A DELTA Group-8 DRUM sampler was placed on the roof of 201 Varick Street, Manhattan, New York approximately 50 meters above street level [2]. Scanning transmission ion microscopy (STIM) was used to measure mass. Hydrogen was measured by proton elastic scattering analysis

(PESA), and element concentrations were measured by synchrotron X-ray fluorescence.

The mass distribution of particles collected by Cahill and colleagues was bimodal, with peaks in coarse levels, 5.0-2.5 μm in diameter, and "unusually" high levels of very fine aerosols, 0.26-0.09 μm in diameter [2]. At 5.0-2.5 μm in diameter, the coarse particles reported by Cahill et al. were approximately 10 times finer than particles reported by Lioy and colleagues [2, 11]. Using the Al/Ca, Ca/Si, and Ca/Fe ratios, Cahill et al. determined that there was an excess of calcium in coarse particles [2]. In the fine particle samples, there was an excess of silicon relative to other crustal elements. In addition, STIM analysis revealed high levels of sulfur making up about 10 percent of fine particles. Both PESA and LDI-TOF/MS analyses showed that sulfuric acid was the main sulfur compound [2].

Accounting for potential confounding of sources upwind of the WTC collapse site, Cahill and colleagues speculated on sources of sulfates, soot, and metals on aerosols [2]. Although these samples were collected more than one mile away from the WTC site, Cahill et al. hypothesized that components found in particles were likely the result of the burning of WTC building materials like concrete from cement floors, gypsum in the dry wall, and rounded glass shards from windows [2].

Particulate exposure among truck drivers. WTC truck drivers were monitored for particulate exposure by Geyh and colleagues during October 2001 and April 2002 [16]. In addition to questionnaires about work experiences, drivers wore personal monitors and area monitors were placed around the WTC site. Monitoring was conducted for total dust (TD), and particulate matter, PM₁₀ and PM_{2.5}. During October, PM₁₀ on the pile was 1.7 to 4.2 times higher than PM₁₀ at the perimeter of the site. Perimeter particulate concentrations were 21-321 µg/m³ for PM_{2.5}, 41-392 µg/m³ for PM₁₀, and 43-331 µg/m³ for TD. Pile concentrations for TD ranged from 72 to 790 µg/m³ [16].

By April, fires at the WTC site had been extinguished and debris removal activity had decreased. The overall PM concentrations at the WTC site in April 2002 were lower compared to WTC site concentrations in October 2002. April 2002 measurement ranges were 4-102 µg/m³ for PM_{2.5}, 13-144 µg/m³ for PM₁₀, and 14-195 µg/m³ for TD [16]. TD concentrations measures by Geyh et al., however, remained higher on the pile than TD concentrations at the perimeter.

Toxicological Studies of World Trade Center Dust

Among Ground Zero workers, inhalation exposure to WTC dust could have resulted in pulmonary inflammation and airway hyperresponsiveness. Potential respiratory health outcomes associated with exposure to WTC dust range from eye, nose, and throat irritation to lung cancer (Table 1.2).

Table 1.2 WTC Environmental Exposures and Associated Respiratory Outcomes [9, 17-21]

Exposure	Source	Respiratory Outcome(s)
Asbestos	▪ Insulator and fire retardant on steel beam infrastructure	▪ Asbestosis ▪ Lung cancer ▪ Lung scarring ▪ Mesothelioma
Metals	▪ Computer and video monitors ▪ Building construction materials ▪ Aluminum, Iron, Magnesium, Calcium, and Silicon ▪ Pigments in paint	▪ Metal poisoning
Particulate Matter, PM	▪ Dust, rubble, and debris from breakdown of WTC buildings ▪ Gases, dust, soot, and smoke formed as a result of fires at the WTC site ▪ Motor vehicle emissions from vehicles at the WTC site	▪ Eye, nose, throat, and lung irritant ▪ Coughing, wheezing, shortness of breath ▪ Asthma exacerbation
Silica and Man-Made Vitreous Fibers	▪ Cement and drywall dust ▪ Glass fibers	▪ Asthma ▪ Bronchitis

Mouse studies. Gavett et al. evaluated the potential health effects of respirable PM_{2.5} through a series of studies comparing the toxicity of WTC PM_{2.5} samples with three PM_{2.5} reference samples previously tested in mice (Mt. St. Helens dust, residual oil fly ash, and “Urban” PM from Washington D.C.) [22]. Bulk samples of WTC settled dust were collected from eight sites within 0.5 miles of Ground Zero between September 12, 2001 and September 13, 2001. Three experiments were conducted in female mice; a dose-response study comparing aspirated WTC PM_{2.5} samples with low- and high-toxicity reference PM_{2.5} samples; an acute inhalation study on one WTC PM_{2.5} sample; and a short-term time-course study was comparing aspirated WTC PM_{2.5} samples with

the Urban PM_{2.5} reference sample from Washington DC [22]. All experiments examined responsiveness of mice to increasing concentrations of aerosolized methacholine, bronchoalveolar lavage, and lung histopathology.

In the dose-response study, there was not a significant difference in breathing frequency between the WTC PM_{2.5} and reference PM_{2.5} exposed groups [22]. Bronchoalveolar lavage comparisons revealed significant differences in neutrophil numbers between a saline control group and the WTC PM_{2.5} exposed group ($p < 0.05$). In an assessment of responsiveness to methacholine aerosols, mice exposed to a 100- μ g dose of WTC PM_{2.5} were more reactive to methacholine than mice exposed to a 100- μ g dose residual oil fly ash ($p = 0.0001$). Finally, an examination of pathologic changes in the lungs revealed that there were no differences in focal acute bronchiolar inflammation between WTC PM_{2.5} samples and reference PM_{2.5} samples [22].

The second study by Gavett et al. examined the effects of nose-only inhalation of WTC PM_{2.5} samples in mice. Ventilatory patterns were examined in mice before and after exposure in a WTC PM_{2.5}-exposed mice group and an air -exposed mice group. Although ventilatory rates decreased more in the PM_{2.5}-exposed group, there were no significant differences between the WTC PM_{2.5}-exposed and air-exposed groups. An examination of bronchoalveolar lavage parameters six days after exposure to WTC PM_{2.5} revealed that the WTC PM_{2.5}-exposed group had significantly greater numbers of macrophages on day 6 than on day 1 ($p = 0.01$) [22]. WTC PM_{2.5}-exposed mice

also had greater numbers of lymphocytes on day 6 than the air -exposed mice group ($p = 0.02$) [22]. Nasal and lung pathology indicated minimal focal inflammation in the most proximal tissue examined in four of eight exposed mice indicating limited deposition further down the respiratory tract.

The final experiment by Gavett et al. studied the effect of geographical location on the variability of pulmonary responses associated with WTC PM_{2.5} samples. In terms of responsiveness to methacholine aerosol, seven of the eight WTC PM_{2.5} samples, as well as the Urban PM_{2.5} reference sample from Washington DC, resulted in similar degrees of hyperresponsiveness in mice [22]. Only one sample, from a site 0.1 miles southeast of Ground Zero, caused a lower degree of hyperresponsiveness [22].

Bronchoalveolar lavage revealed significant increases in neutrophils on day one exposure in all WTC PM_{2.5} samples compared to saline exposed mice. Three days after exposure, there were no significant differences among exposure groups. Compared to saline exposed mice, lymphocyte numbers increased in three WTC sites: 0.4 miles east, 0.1 miles southeast, and 0.25 miles southeast ($p = 0.0001$) and increased from day 1 to day 3 ($p = 0.0001$) [22]. There were no significant differences in eosinophil or macrophage numbers, and lung pathology indicated no significant differences among all WTC PM_{2.5} samples. In all individual site samples, there were focal bronchiolar pigmented macrophages and minimal focal acute bronchiolar inflammation [22].

In comparing the toxicological health effects of WTC PM_{2.5} to reference PM_{2.5} samples, Gavett and colleagues were able to assess the potential respiratory consequences of the WTC disaster. These studies were limited in that mice were exposed fine particulates, instead of coarse or larger particulates, and oropharyngeal aspiration was used instead of inhalation exposure methods. Taking these limitation into account, after finding that a 100-μg dose of WTC PM_{2.5} caused bronchiolar inflammation, and airway hyperresponsiveness in mice, the authors concluded that WTC site workers could have inhaled a dose of WTC PM equivalent to the 100-μg dose observed in mice [22].

Human lung cells. Payne and colleagues examined the mechanisms of WTC dust toxicity in human lung cells [23]. The aim of their study was to examine some of the effects of WTC dust on cells that have vital roles in defending the lung from the adverse effects of inhaled particles. In addition to examining the effect of WTC dust on human alveolar macrophages (AM), they also studied release of gamma-glutamyl transpeptidase (GGT) and cytokines by type II (TII) lung cells. Outdoor PM_{2.5}, PM_{10-2.5} and PM₅₃₋₁₀ fractions of WTC dust were collected from Park Row and Spruce Street in September 12, 2001 [23]. Human AM and TII epithelial cells were obtained from samples of human lung tissue. Cellular GGT and levels of interleukin (IL)-6, IL-8, and tumor necrosis factor (TNF)-α were assayed.

After being exposed to PM_{2.5} and PM₅₃₋₁₀, there were significant increases in GGT expression ($p < 0.001$) [23]. TII cells showed no significant GGT response to WTC dust. PM_{2.5} induced significant increases in IL-8 release by AM ($p = 0.007$) and TII ($p < 0.05$) cells. PM₅₃₋₁₀ exposure resulted in small increases in IL-6 from AM, but not from TII cells. PM_{2.5} also induced an increase in IL-6 release by AM ($p < 0.01$) and TII ($p < 0.05$) cells.

There was a significant increase in AM IL-6 ($p < 0.01$) associated with PM₅₃₋₁₀ exposure and no response in PM₅₃₋₁₀ exposed TII cells. PM_{2.5} ($p < 0.005$) and PM₅₃₋₁₀ ($p < 0.005$) induced TNF- α in AMs. TII cells did not show any significant levels of TNF- α . Doses of WTC PM_{2.5} and PM₅₃₋₁₀ stimulated expression of GGT, a marker of cellular stress, by AM. Payne et al. concluded that human cells exposed to WTC dust exhibited increased oxidative stress and cytokine release, mechanisms that can contribute to respiratory symptoms and increased incidence of respiratory illness [23].

Biological Monitoring of Workers Exposed to the World Trade Center Disaster

Plasma and Urine of firefighters. The only biomonitoring study performed during WTC rescue, recovery, and cleanup operations (September 11, 2001 - July 2002) examined New York City firefighters. Edelman and colleagues measured the internal dose of up to 110 fire-related chemicals in 321 New York City firefighters who responded to the WTC fires and collapse [24]. The purpose of the study was to

characterize the relationship of internal dose of fire-related chemicals to firefighter activities.

Firefighters who arrived within seven days of the collapse were compared to controls who did not work at or near the WTC because of assignments to office duties. Blood and urine were collected from study participants between October 1, 2001 and October 5, 2001 [24]. Urine was examined for PAH metabolites and metals. Blood was examined for volatile organics, metals, and cyanide. Serum was analyzed for PCBs and PCDDs/PCDFs.

Edelman et al. reported that PCDD/Fs such as heptachlorodibenzodioxins and heptachlorodibenzofurans (both $p < 0.01$) and PAH metabolites ($p < 0.01$) were significantly associated with early WTC exposure. Lead levels were also significantly higher in exposed firefighters [24].

Induced sputum. In June 2002, Fireman et al. examined induced sputum (IS) methodology to assess respired particulate matter and the particulate response of lung of firefighters after exposure to WTC dust [25]. The objective of the study was to examine the patterns of inflammation and particle matter decomposition 10 months after the WTC collapse in FDNY firefighters who has been highly exposed to WTC dust. The study population included 39 male FDNY firefighters, 12 male Tel-Aviv,

Israel firefighters, and 8 male Israeli hospital workers. All study participants were never smokers and had never reported a history of respiratory disease.

Induced sputum was examined for differential cell counts MMP-9 levels. Both firefighter groups had significantly higher cell counts and MMP-levels than the non-firefighter controls [25]. However, there were no significant differences between the firefighter groups ($p > 0.05$). Among the WTC firefighter group, differential counts for neutrophils ($p = 0.05$) and eosinophils ($p = 0.04$) increased with cumulative workday exposures [25].

In terms of particle size, more of the FDNY-firefighter sputum samples contained a higher percentage of particles greater than $2\ \mu\text{m}$ ($p = 0.0001$) and particles greater than $5\ \mu\text{m}$ ($p = 0.0001$) than the Tel-Aviv, Israel samples [25]. There were no significant associations between cumulative workday exposure and particle size distribution.

Fireman and colleagues found that FDNF firefighter exposed to WTC dust had significantly different markers of lung inflammation when compared to control firefighters. In addition, particle composition in Induced sputum were larger than control Tel-Aviv, Israel firefighters. These differences may have been due to unique exposures to pyrolysis products in the aftermath of the WTC collapse [25].

Plasma sampling of New York State employees. Between May 2002 and November 2002, Tao et al. analyzed 458 plasma samples of New York State employees and

National Guard personnel assigned to work at the WTC site between September 11 and December 23, 2001 for perfluorochemicals, manmade chemicals that are found in stain-resistant carpets and fabrics [26]. The objective of the study was to measure the serum concentrations of perfluorooctanesulfonate (PFOS), perfluorooctanoic acid (PFOA), perfluorohexanesulfonate (PFHxS) and perfluorononanoic acid (PFNS) [26].

PFOA and PFHxS concentrations measured in WTC exposed workers were approximately 2-times higher than concentrations reported for the general U.S. population [26]. Study participants were classified according to their dust and smoke exposure. The “more dust exposure” group had significantly higher concentration of PFHxS than the “less dust exposure” group ($p = 0.041$). The “more smoke exposure” group also had significantly higher concentration of PFNA than the “less smoke exposure” group ($p = 0.001$). Tao and colleagues concluded that New York State and National Guard personnel who responded to the WTC disaster were exposed to perfluorochemicals through dust and smoke inhalation [26]. The respiratory effects of PFOA, PFHxS and PFNA exposure, however, are unknown and adverse respiratory outcomes have yet to be reported[26].

Epidemiologic Studies

The public health research response to the WTC disaster began soon after the collapse of the twin towers with hospital emergency surveillance. Immediately after the disaster, public agencies including the National Institute of Environmental Health Sciences (NIEHS), the Centers for Disease Control and Prevention (CDC), and the New York City Department of Health and Mental Hygiene (NYC DOHMH) set aside funds for research, medical monitoring, and treatment of workers exposed to the WTC disaster. CDC's NIOSH has funded several WTC responder programs that have published epidemiologic studies of respiratory outcomes among WTC rescue, recovery, and cleanup workers [27].

Surveillance of First Responders. It has been estimated that 20% of all lower Manhattan hospital admissions in the four weeks after September 11, 2001 were due to occupational exposures at the WTC site [28]. Epidemiologic surveillance studies covering the immediate days and weeks after the WTC disaster indicate that there was a high incidence of new or worsening respiratory symptoms among WTC rescue, recovery, and cleanup workers after September 11, 2001 (Table 1.3).

Respiratory ailments documented in the initial months after the disaster included post-9/11 sinusitis, laryngitis, tracheitis, reactive upper airways dysfunction, bronchitis, reactive airways dysfunction syndrome, and irritant-induced asthma. On September 14, 2001, at the request of the US Office of the Surgeon General, the NYC DOHMH

Table 1.3 Epidemiologic Studies of First Responders

First Author [Reference]	Sample Size	Study Period	Exposure Metric	Outcome(s)	Control for Risk Factors	Results
Berrios - Torres [29]	5222	September 11, 2001-October 11, 2001	▪ Not Applicable ▪ Descriptive study	▪ Acute Respiratory infection ▪ Cough ▪ Smoke/dust inhalation ▪ Shortness of breath ▪ Wheezing ▪ Other respiratory illnesses	▪ Not Applicable	▪ Respiratory conditions were 16% of reported hospital visits. ▪ Construction workers (34%) and police officers (34%) reported the most visits for respiratory illnesses.
Salzman [30]	240	September 11, 2001-January 31, 2002	Exposure onset date ▪ September 11, 2001 before towers fell ▪ September 11, 2001 after towers fell ▪ September 12, 2001 - September 17, 2001 ▪ After September 17, 2001	▪ New or worsened Upper respiratory symptoms ▪ New or worsened Lower respiratory symptoms ▪ Spirometric obstruction	▪ Smoking status ▪ previous allergic or respiratory disorders	▪ 77.5% reported new or worsening respiratory symptoms on or after September 11, 2001. ▪ Dyspnea was the only symptoms significantly associated with exposure intensity.

and the CDC began injury and illness surveillance at both temporary medical facilities and local emergency departments throughout New York City for injuries and illness among workers assigned to rescue and recovery operations [29]. Volunteers, medical, military, sanitation, utilities, building security and other personnel were excluded from these analyses.

A total of 5222 (out of 7673 total, 68%) rescue worker medical records collected between September 11, 2001 and October 11, 2001 were reviewed [29]. After musculoskeletal injuries (n=1009, 19.3%), respiratory illnesses (n=816, 16%) were the second leading cause of visits. Construction workers and police officers had the highest prevalence of respiratory conditions (n=276, 34%) followed by firefighters (n=225, 28%). Acute respiratory infections (n=288, 6%) was the most common respiratory illness followed by cough (n=248, 5%), smoke/dust inhalation symptoms (n=135, 3%), and shortness of breath/wheezing (n=120, 2%). The authors estimated incidence rates based on total illnesses reported. Acute respiratory infections (28.5%) and Cough (24.4%) were estimated to be the most observed respiratory illnesses in the four weeks following the disaster [29].

Police officers from the New York Police Department's Emergency Services Unit (ESU) participated in the study of respiratory symptoms and spirometry [30]. A total of 240 study participants were asked about their respiratory health history and questions about WTC exposures such as: time of first arrival at the WTC site; duration

of exposure on September 11 and subsequent days, and use of respirators or other personal respiratory-protection devices. Police officers then underwent clinical evaluations and pulmonary function testing at Beth Israel Medical Center at a mean of 69 ± 27.6 days (range: 31 - 140) after September 11, 2001.

Approximately 87% (206/237) of these police officers arrived at Ground Zero on September 11, 2001; 77.5% of the study population reported new or worsening respiratory symptoms on or after September 11, 2001. Cough (62%) was the most common symptom followed by hoarseness (25%) and dyspnea (23.3%) [30].

Mean spirometric values for all study participants were within the range of normal. Abnormal spirometric patterns were seen in 69 (28.8%) participants and obstructive patterns were observed in 28 (11.7%) participants [30]. Of the subjects with obstructive dysfunction, obstruction was mild except in one person who had a history of asthma. Abnormal spirometry was associated with current smokers ($p < 0.05$), those with a history of asthma ($p < 0.04$) and those with a history of pulmonary disease (asthma, pneumonia, COPD, recurrent bronchitis or reported wheeze, $p < 0.0006$). Dyspnea was the only symptom related to the intensity of exposure ($p = 0.01$) [30].

Iron Workers. In October 2001, clinical evaluations for ironworkers with respiratory complaints began at the Mount Sinai-Irvin J. Selikoff Center for Occupational and

Environmental Medicine (COEM) [31]. The COEM began a study of ironworkers who were present at Ground Zero for at least one day between September 11, 2001 and September 14, 2001 and had worked at least 3 total days at ground zero. The COEM, Mount Sinai's Division of Pulmonary Medicine, and the International Ironworkers Union Local 40 identified potential pilot study participants and distributed exposure questionnaires to the ironworkers. Occupational histories and medical examinations including physical examinations, chest x-rays, and pulmonary function testing were performed.

Five months after 9/11, 26% percent of the 97 pilot study participants reported visiting a physician after WTC exposure [31]. Over half of the study population reported "persistent" respiratory symptoms. Among this population of ironworkers, 52% reported rhinitis/sinusitis, 64% reported cough, 51% reported dyspnea on exertion, 45% reported chest tightness, 45% reported wheezing, and 45% reported "provocable" symptoms [31].

Skloot et al. described the respiratory abnormalities in a similar cohort of ironworkers who participated in cleanup activities at the WTC site [32]. This study included 104 male WTC ironworkers who were evaluated at the Mount Sinai Medical Center between February 9 and February 10, 2002 (Table 1.4). Ninety-six ironworkers arrived at ground zero during the first week after 9/11 and 57.3% (55/96) reported

Table 1.4 Epidemiologic Studies of Iron Workers

First Author [Reference]	Sample Size	Study Period	Exposure Metric	Outcome(s)	Control for Risk Factors	Results
Levin [31]	97	February 2002	Pilot study of ironworkers who were present at Ground Zero for at least 1 day from 9/11-9/14 and had worked at least 3 days at Ground Zero	▪ Upper respiratory symptoms ▪ Lower respiratory symptoms	▪ Not Applicable	▪ 52% of ironworkers reported rhinitis/sinusitis. ▪ 64% reported Cough. ▪ 45% reported Wheezing. ▪ 55% reported “Provocable” symptoms.
Skloot [32]	96	September 11, 2001- February 8, 2002	Exposure onset date ▪ September 11, 2001 ▪ After September 11, 2001 Exposure duration ▪ Cumulative days	▪ Respiratory symptoms ▪ Spirometric obstruction ▪ Forced oscillation	▪ Use of respirator with a canister ▪ Smoking history	▪ 77% reported 1 or more respiratory symptoms. ▪ Significant relationship between September 11, 2001 exposure and new respiratory symptoms.

wearing a mask or respiratory during the first week. Of the ironworkers who reported respiratory protection during the first week, 60% (33/55) wore a dust mask, 30.9% (17/55) wore a respirator with a canister, and 9.1% (5/55) wore both during the first week [32].

Iron workers underwent physical examinations, spirometry and radiographs. Medical and exposure history were collected via questionnaire with a trained industrial hygienist assessing exposure onset (day of arrival at WTC site) and total exposure duration (days). Pulmonary function data included FEV₁, FVC, and forced expiratory flow during 25% to 75% of the FVC (FEF_{25-75%}). Each study participant also underwent posteroanterior and left lateral chest radiographs.

The main outcome variables in this study by Skloot et al. were new onset of respiratory symptoms after September 11 and the presence of spirometric obstruction. A total of 74 (77.1%) ironworkers reported at least one respiratory symptom [32]. Cough (62/96, 64.6%) was the most common symptom, followed by dyspnea (48/96, 50%), and chest tightness and wheezing (44/96, 45.8 % each). Physical examinations revealed upper respiratory ailments (28/96, 29.2%) were more prevalent than lower respiratory ailments (10/96, 10.4%). Radiographic evaluations documented parenchymal changes in 5 (5.2%), pleural abnormalities in 7 (7.3%), and subcentimeter lung nodules in 7 (7.3%) ironworkers. FEV₁ and FVC percentage of predicted were normal in 51 of the study participants. Four patients presented with

airways obstruction and four others had borderline airways obstruction. Of the eight who met the criteria for obstruction or borderline obstruction, seven were current or former smokers [32].

Among iron workers, there was no significant difference in the prevalence of respiratory symptoms between smokers and nonsmokers. There were no significant associations between duration of exposure and respiratory symptoms or between type of respiratory protection and respiratory symptoms (both $p > 0.05$). There was, however, a significant relationship between the date on exposure onset and the prevalence of cough ($p = 0.02$) [32].

Logistic regression modeling indicated that exposure on 9/11 was significantly associated with new onset respiratory symptoms after 9/11 after adjusting for exposure duration, use of a respirator with a canister, and history of smoking (Adjusted OR =5.46, $p=0.0007$) [32]. Also, exposure on 9/11 was significantly associated with Cough after 9/11, after adjusting for exposure duration, use of a respirator with a canister, and history of smoking (Adjusted OR =3.64, 95%CI 1.35-9.83, $p=0.011$). None of the pulmonary function tests were associated with date of exposure onset or exposure duration (all $p > 0.05$) [32].

Physical examinations and objective measures of spirometric obstruction were the main strengths of epidemiologic studies of iron workers in the five months after

September 11, 2001. In the absence of baseline respiratory symptom data before September 11, 2001, there was a significant association between early WTC exposure and respiratory symptoms five months after the disaster. Cough, in particular, was associated with early arrival at the WTC site among ironworkers.

Cleanup Workers. In October 2001, Herbstman and colleagues examined the respiratory symptoms and pulmonary function among 183 WTC site cleanup and recovery workers who worked on the WTC site after September 11, 2001 [33]. The World Trade Center Clean Up and Recovery Worker Health Assessment Survey recruited workers from local New York City labor unions and the New York City Department of Sanitation (Table 1.5). The study questionnaire included standardized American Thoracic Society questions, and questions about WTC exposure, smoking history and respirator use. Questionnaires were interviewer-administered and spirometry was conducted on site between December 11 and December 17, 2001.

A total of 119 workers who started working at the WTC site were asymptomatic for lower respiratory symptoms. Among them, the most prevalent new lower respiratory symptom reported was cough (n = 40, 40%), followed by phlegm (n = 29, 24%) and wheeze (n = 22, 40%) [33]. To explore the relationship between working at the WTC site and lower respiratory symptoms, the 98-day exposure period was divided into three equal day-groups: 1-32 days; 33-64 days; and 65-96 days. Cough showed an

Table 1.5 Epidemiologic Studies of Cleanup Workers

First Author [Reference]	Sample Size	Study Period	Exposure Metric	Outcome(s)	Control for Risk Factors	Results
Herbstman [33]	183	September 11, 2001- December 17, 2001	Exposure duration 1-32 days of WTC work 33-64 days of WTC work 65-96 days of WTC work Job Category	- Upper respiratory symptoms - Lower respiratory symptoms - Spirometric obstruction	- Job categories - Respirator use - Smoking status	- Higher prevalence of new-onset URS than new-onset LRS. - Among asymptomatic workers, cough (34%) was the most prevalent lower respiratory symptom and nasal congestion (54%) was the most prevalent upper respiratory symptom.
Tao [34]	1327	September 11, 2001- June 2003	WTC site exposure “never” worked at the WTC “ever” worked at the WTC Exposure duration - Cumulative months Location of WTC Work	Lower respiratory symptoms	- Age - Gender - Race - Marital status - Education - Household income - Respiratory history - Smoking status	- Exposed workers were three times as likely to report any LRS than workers who never worked at the WTC. - Significant relationship between duration of work and any LRS. - Significant relationship between pile work and any LRS.

increase in prevalence associated with exposure, increasing from 24% (95% CI: 6%, 42%) among the 1-32 day exposure group to 37% (95% CI: 26%, 48%) among the 65-96 day exposure group [33]. The development of new phlegm and new wheeze were independent of time. The relationship between working at the WTC site and upper respiratory symptoms was not assessed. However, among workers who were asymptomatic prior to 9/11, the prevalence of upper respiratory symptoms was higher than the prevalence of lower respiratory symptoms [33].

In the final analyses of cleanup workers by Herbstman and colleagues, spirometry was obtained from 175 workers (95.6%) [33]. FEV₁ /FVC ratios suggested that obstruction was mild. Compared to those who were asymptomatic, the mean percentage of predicted FEV₁ was 6% lower (p=0.05) and the percentage of predicted FVC was 5% lower (p=0.06) for workers who developed new respiratory symptoms. Also, there was no significant relationship between the job category and the development of new lower respiratory symptoms and there was no significant relationship between smoking status and the development of new lower respiratory symptoms [33].

Similar to studies of WTC iron workers, cough was the most prevalent new lower respiratory symptom among this group of WTC cleanup workers in the three months after September 11, 2001. In a follow-up study, Tao et al. compared the respiratory health symptoms of workers involved in cleanup operations at the WTC site after

September 11 and workers who were never involved in WTC activities [34]. Truck drivers, heavy equipment operators, laborers, and sanitation employees were recruited to participate in the study. The mail-administered survey included questions on demographics, work history, work experiences at the disaster site, WTC exposure, general health history, and respiratory health. Current respiratory health was determined using the American Thoracic Society ATS-DLD-78-A respiratory health questionnaire. WTC exposure was assessed as "never" worked at the WTC site or "ever" worked at the WTC, "duration" at the WTC site, and "location of work" at the WTC site.

A total of 1114 WTC site workers (25% response rate) and 248 non-WTC site workers (12% response rate) responded to the survey. For reported cough (RR = 2.26, 95% 1.55-3.28), phlegm (RR = 1.91, 95% 1.31-2.76), shortness of breath (RR = 2.67, 95% 1.82-3.92), and wheezing (RR = 2.25, 95% 1.57-3.24), the RRs for exposed workers were significantly higher compared to unexposed workers [34]. After adjusting for confounding variables, the RR for exposed workers to develop any lower respiratory symptom was 3.40 (95% CI: 2.33-4.94) compared to unexposed workers and duration of exposure was significantly associated with developing LRS ranging from 2.04 (95% CI: 1.28-3.24) for those exposed 1 to 7 days to 5.79 (95% CI: 3.59-9.35) for those exposed over 240 days compared to those never exposed. Compared to those who never worked at the WTC site, the RR of any LRS for workers who worked in an enclosed area beneath the WTC debris pile was 1.78 (95% CI: 1.20-2.08). The

authors also reported an increased LRS risk for workers who started working at the WTC site beginning in 2002 compared to those who never worked at the WTC site (RR = 1.78, 95% CI: 1.20-2.08) [34].

Lower respiratory symptoms were associated with WTC exposure after September 11, 2001 among cleanup workers. Although both studies reported low response rates and evidence of selection bias, Tao and colleagues performed rigorous sensitivity analyses that indicated that there was not an overestimation of relative risks in this population of WTC cleanup workers [34].

New York State Employees. New York State employees and New York State National Guard personnel who responded to the World Trade Center disaster between September 11, 2001 and December 23, 2001 were offered medical monitoring and evaluation by the New York State Department of Civil Service Employee Health Service (NYS EHS) of the New York State Department of Health (NYS DOH) [35]. Medical evaluations included clinical laboratory tests, physical examinations, and pulmonary function tests. Study participants also completed health surveys and exposure questionnaires.

A total of 4533 NYS employees and 5269 NYS National Guard personnel were recruited for the medical monitoring program [35]. Of those, 1677 (17%) were evaluated and 1423 (15%) agreed to participate in the long-term epidemiologic study

(Table 1.6). The study population was made up of mostly white, non-Hispanic males with some college education. Almost half of this cohort arrived at the WTC site after September 16, 2001, and, of the 1423 participants, 897 (63%) used at least some type of respiratory protection during WTC site work. The most commonly reported mask type was a one-strap dust mask (n=401, 28.2%). Compared to other WTC worker cohorts, this cohort contained fewer first responders and may have experienced lower levels of WTC dust and smoke exposure than other cohorts [35].

Mauer and colleagues described respiratory outcomes at the first wave (administered in 2003) of the NYS DOH WTC Medical Monitoring program [35]. Among the 1423 participants in the epidemiologic study, 47.4% (n=674) reported at least one new or worsening lower respiratory symptom (LRS) and 42.6% (n=606) reported at least one new or worsening upper respiratory symptom (URS). Cough was the most commonly reported symptom (n=434, 30.5%). Lower respiratory symptoms (PR=1.23, 95%CI 1.03-1.46) and upper respiratory symptoms (PR=1.29, 95%CI 1.08-1.55) were more likely to be reported by participants caught in the cloud of dust [35]. Through November 2003, new self-reported physician diagnoses of WTC-related conditions included 165 lower respiratory conditions (11.6%) and 102 upper respiratory conditions (7.2%). Also, a total of 182 (n=14.4%) study participants exhibited abnormal spirometry [35]

Table 1.6 Epidemiologic Studies of New York State Employees

First Author [Reference]	Sample Size	Study Period	Exposure Metric	Outcome(s)	Control for Risk Factors	Results
Mauer [35]	1423	May 2002 - November 2003	Dust Cloud Exposure ▪ Caught in Cloud of Dust ▪ Not Caught in Cloud of Dust	▪ Respiratory Symptoms ▪ Spirometric obstruction	▪ Race ▪ Education ▪ Age ▪ Smoking Status	▪ Lower and upper respiratory symptoms were more likely to be reported by those caught in the dust cloud.
Mauer [36]	1390	May 2002 - November 2003	Semi-Quantitative ▪ Dust Exposed > mean ▪ Dust Exposed < mean ▪ Dust non-Exposed ▪ Smoke Exposed > mean ▪ Smoke Exposed < mean ▪ Smoke non-Exposed	▪ Respiratory Symptoms ▪ Asthma ▪ RADS	▪ Race ▪ Education ▪ Smoking Status ▪ Household allergens ▪ Psych. symptom	▪ Exposed workers with Dust and Smoke exposure scores above the mean were more likely to report lower respiratory symptoms.
Mauer [37]	248	May 2002 - 2006	Semi-Quantitative ▪ Dust Exposed > mean ▪ Dust Exposed < mean ▪ Dust non-Exposed ▪ Smoke Exposed > mean ▪ Smoke Exposed < mean ▪ Smoke non-Exposed	▪ Respiratory Symptoms ▪ Asthma ▪ RADS	▪ Race ▪ Education ▪ Age ▪ Ethnicity ▪ Smoking Status ▪ Household allergens ▪ Psych. Symptom	▪ Dust and Smoke exposed WTC workers were more likely to report persistent lower respiratory symptoms.

Table 1.6 continued Epidemiologic Studies of New York State Employees

First Author [Reference]	Sample Size	Study Period	Exposure Metric	Outcome(s)	Control for Risk Factors	Results
Mauer [38]	1144	June 2007- October 2007	Semi-Quantitative ▪ Dust Exposed > mean ▪ Dust Exposed < mean ▪ Dust non-Exposed ▪ Smoke Exposed > mean ▪ Smoke Exposed < mean ▪ Smoke non-Exposed	▪ Respiratory Function	▪ Gender ▪ Smoking history ▪ Obesity	▪ Significant association between reduced respiratory function and use of a respirator without a canister.

During the first wave of the NYS DOH WTC Medical Monitoring program, study participants were mailed a brief asthma-related questionnaire in 2003 to assess asthma and the persistence and severity of lower respiratory symptoms among New York State responders [36]. Questions were based on the CDC's National Asthma Survey including questions about asthma and reactive airways dysfunction syndrome (RADS) diagnosis. The survey included questions about asthma severity, asthma-related medication use, asthma-related lower respiratory symptoms (persistent coughing, wheezing, shortness of breath, or chest tightness), and potential confounders such as race, ethnicity, smoking, education, history of allergies or eczema, family history of asthma, and psychological symptoms. Participants received a \$10 gift card after returning completed questionnaires [36].

Among the 1,023 NYS responders solicited, 578 (57%), agreed to participate. Of the 5498 non-exposed potential study participants solicited, 812 (14.8%) agreed to participate in the study. Exposure was characterized using an exposure method developed by Herdt-Losavio et al [39]. There was no significant difference in the proportion of participants with self-reported asthma after September 11, 2001 or self-reported current asthma between the exposure groups (both $p > 0.05$). A greater proportion of exposed participants (32.5%) reported at least one respiratory symptom than non exposed participants (17.1%) ($p < 0.0001$) [36].

After adjustment for potential confounders, participants with dust exposure scores above the mean were three times (POR=3.26, 95%CI 2.15-4.92) more likely to report

any lower respiratory symptom than non exposed participants, and participants with smoke exposure scores above the mean were four times (POR=4.14, 95%CI 2.71-6.33) more likely to report any lower respiratory symptom than non exposed participants [36].

In 2004 and 2005, the NYS DOH mail administered follow-up surveys during the second and third waves of the NYS DOH WTC Medical Monitoring program. The fourth wave, administered in 2006, involved study participants completing computer-assisted telephone interviews [37]. All interviews collected information about asthma, reactive airways dysfunction syndrome (RADS), and lower respiratory symptoms experiences in the absence of respiratory infection, and confounding variables such as age, ethnicity, smoking status, education, personal/family history of allergies or eczema, household conditions like the presence of mold or pets, and the reporting of at least one psychological symptom in the past 12 months.

A total of 518 exposed and 626 non-exposed participants participated in all four phases of the study through 2006 [37]. Loss to follow-up was not significantly different between the two exposure groups. The non-exposed group was more female, younger, and more likely to be current smokers than the exposed group. The exposed group was also more likely to report a respiratory symptom than the unexposed group ($p < 0.001$). Gender and a previous diagnosis of asthma before September 11, 2001 were effect modifiers (p-values not reported) [37].

Among men without a diagnosis of asthma before September 11, 2001, WTC exposure was associated with persistent cough (RR = 4.5, 95% CI: 1.5-12.6), persistent wheeze (RR = 6.8, 95% CI: 1.5-29.6), and at least one persistent lower respiratory symptom (RR = 5.5, 95% CI: 2.2-14.3) compared to non-exposed groups [37]. Study participants with dust exposure above the mean (RR = 2.8, 95% CI: 1.8-4.4) and smoke exposure above the mean (RR = 3.0, 95% CI: 1.9-4.8) were more likely to report a lower respiratory symptom than non-exposed study participants. Five years after September 11, only study participants with smoke exposure above the mean (RR = 3.1, 95% CI: 1.1-9.2) were more likely to report the use of a new breathing medication in the past 12 months [37].

Another study of WTC responders by Mauer and colleagues tested whether an impulse oscillometry system (IOS) technique might reveal signs of respiratory disease in WTC responders [38]. Impulse oscillometry is a noninvasive technique that measures airways obstruction and small airways disease [38]. Impulse oscillometry is different from conventional methods of pulmonary function testing in that it is an effort independent technique that can assess distal airway dysfunction [40]. Study participants were evaluated between June and October 2007. Respiratory function was measured according to European Respiratory Society recommendations for impulse oscillometry system testing. A total of 99 exposed and 149 unexposed study participants were included in the analysis. Each participant also completed a

questionnaire about respiratory and psychological symptoms, medical history, medication use, smoking history and other possible confounders.

WTC-exposed New York State WTC responders were three times as likely to report new or worsening cough (95% CI: 1.68, 3.00) and twice as likely to report a cough consistent with chronic bronchitis (95% CIL 2.39, 4.47) than non-WTC exposed New York State Employees [38]. After controlling for gender, smoking history, and obesity, there was no significant difference in IOS results between WTC-exposed and WTC-unexposed participants. There were no significant differences in IOS results between symptomatic and asymptomatic participants. There were also no significant differences in IOS results between the WTC-exposure groups compared with the WTC-unexposed group. IOS results, however, did demonstrate a significant difference in respiratory function between those who used a respirator with a canister and those who did not use a respirator with a canister (all $p < 0.05$) [38].

Asthma was not found to be associated with WTC exposure in this cohort. Persistent lower respiratory symptoms, however, were associated with above average dust and smoke exposure five years after September 11, 2001 WTC exposure. Six years after September 11, 2001, impulse oscillometry detected a difference in respiratory function between those who used a respirator with a canister and those who did not use a respirator with a canister [38].

Strengths and Limitations of New York State DOH Studies. Epidemiologic studies of NYS DOH WTC-exposed workers, to date, have been plagued by low response rates and differential response rates between exposed and non-exposed groups. Limitations notwithstanding, NYS DOH studies have employed a semi-quantitative exposure index and a control group of WTC-unexposed works in their epidemiologic analyses. Results of these epidemiologic studies suggested that WTC-exposed workers continued to present with poor respiratory health outcomes more than five years after September 11, 2001.

World Trade Center Responder Health Consortium. In 2002, NIOSH funded a medical screening program for World Trade Center responders at five New York City metropolitan area locations: Bellevue Hospital, Mount Sinai School of Medicine, City University of New York at Queens, State University of New York at Stony Brook, and University of Medicine and Dentistry of New Jersey [27, 41]. In order to be eligible for the World Trade Center Medical Monitoring and Treatment Program, a responder had to fall into one of two exposure categories [41]:

For the first category, the responder must have been a rescue, recovery, debris cleanup and related support services worker, or volunteer in lower Manhattan, the Staten Island Landfill, and/or the barge loading piers, and must have worked and/or volunteered on-site for 4 hours between September 11 and September 15, for at least 24 hours during the month of September, or for at

least 80 hours during the months of September, October, November, and December combined [41].

For the second category, the worker must have been an employee of the Office of the Chief Medical Examiner (OCME), involved in the examination and processing of human remains, or other morgue worker who performed similar post-September 11 activities for the OCME staff; a worker in the Port Authority Trans-Hudson Corporation tunnel through July 1, 2002 for a minimum of 24 hours ; or a vehicle-maintenance worker with post-September 11 functions within the requisite timeframes and exposed to WTC debris while retrieving, driving, cleaning, repairing, and maintaining contaminated vehicles [41].

Participants received clinical screening evaluations and interviewer-administered exposure and medical questionnaires. The interview-administered questionnaire were used obtain information about selected diagnoses, upper and lower respiratory conditions, smoking history, and pre- and post-September 11 occupational and environmental histories. Spirometric examinations were also performed. A total of 9,443 responders were consented and examined between June 2002 and April 2004 [41] (Table 1.7).

Table 1.7 Epidemiologic Studies of Responders from the World Trade Center Responder Health Consortium

First Author [Reference]	Sample Size	Study Period	Exposure Metric	Outcome(s)	Control for Risk Factors	Results
Herbert [41]	9443	July 2002- April 2004	Exposure onset date ▪ September 11 arrival and in the dust cloud ▪ September 11 arrival and not in the dust cloud ▪ September 12-13 ▪ September 14-30 ▪ After September 30	▪ Lower respiratory symptoms ▪ Upper respiratory symptoms ▪ Spirometric obstruction	▪ Not Applicable	▪ 695 reported new or worsening upper or lower respiratory symptoms. ▪ Respiratory symptoms were persistent in 59% of these workers. ▪ 28% of workers had abnormal spirometry.
Mendelson [42]	29	January 2003- October 2003	Exposure duration ▪ Cumulative weeks	▪ Airway trapping ▪ Spirometric obstruction	▪ Smoking history	▪ Significant association between duration of WTC dust exposure and airway trapping.
De La Hoz [43]	554	January 2003- January 2004	Exposure onset date ▪ Arrival at the WTC site within the first 48 hours ▪ Arrival at the WTC site after the first 48 hours Exposure duration	▪ Upper airway disease ▪ GERD ▪ Lower airways disease	▪ Not Applicable	▪ 78.5% diagnosed with upper airway disease. ▪ 48.9% diagnosed with lower airway disease. ▪ Early arrival to the WTC was associated with lower airway disease.

Table 1.7 continued Epidemiologic Studies of Responders from the World Trade Center Responder Health Consortium

First Author [Reference]	Sample Size	Study Period	Exposure Metric	Outcome(s)	Control for Risk Factors	Results
De La Hoz [44]	136	January 14, 2003- January 24, 2005	Exposure onset date ▪ Arrival at the WTC site within the first 48 hours ▪ Arrival at the WTC site after the first 48 hours Exposure duration	▪ Upper airway disease ▪ Lower airway disease ▪ Atopy	▪ Age ▪ Sex ▪ Race/ Ethnicity ▪ Smoking status ▪ Asthma history	▪ Atopy was associated with upper airway disease.
Skloot [45]	3,160	July 2002- December 2008	Exposure onset date ▪ September 11 arrival and in the dust cloud ▪ September 11 arrival and not in the dust cloud ▪ September 12-13 ▪ September 14-30 ▪ After September30	▪ Spirometric obstruction	▪ Gender ▪ Age ▪ Race ▪ Height ▪ BMI ▪ Smoking status ▪ Occupation	▪ Abnormal spirometry was present in 34% of study participants.

Approximately 40% (3812/9442) of the participants arrived at the WTC site on September 11, 2001. Of those who arrived on September 11, 49% (1878/3812) reported that they were in the dust cloud. Among workers who were previously asymptomatic, 32% reported developing new lower respiratory symptoms and 44% reported developing new upper respiratory symptoms in the months prior to the clinical examination. Time of arrival at the WTC site was significantly associated with new or worsening symptoms (trend $p < 0.001$). Time of arrival at the WTC site was also significantly associated with low FVC (trend $p < 0.001$). By 2004, rates of new respiratory symptoms after 9/11 among WTC workers and volunteers were high and persistent, and there was a strong relationship between exposure intensity at the site and respiratory symptoms [41].

Airway trapping is characteristic of airway obstruction [42]. Mendelson et al. reported on the correlation of air trapping (AT) on paired inspiratory and end-expiratory chest computed tomography (CT) in 29 WTC workers with lower respiratory symptoms who participated in the World Trade Center Medical Monitoring and Treatment Program. Study participants were referred for CT evaluation if their clinical diagnosis could not be characterized and their spirometry was either normal or showed a decreased vital capacity or a mild obstructive impairment, without either clear spirometric or clinical response to bronchodilator administration [42].

Pulmonary function testing (PFT) by Mendelson and colleagues included spirometry

plethysmographic lung volume measurement, diffusion capacity by single-breath method, and methacholine bronchoprovocation testing (in 14 out of the 29 participants). Tests were conducted according to American Thoracic Society recommendations. PFT showed obstruction or overinflation in 8 participants, restriction in 12 participants, decreased diffusion capacity in 8 participants, and significant bronchial hyperreactivity in 4 (out of 14) participants [42].

Airway Trapping (AT), indicating small airways dysfunction, was present in symptomatic workers exposed to WTC dust. Lifetime nonsmokers were more likely to have high AT scores. A chest CT scan-derived AT score was correlated with the duration of participant's WTC-dust exposure, and there was a statistically significant relationship between AT score and duration of WTC dust exposure ($p = 0.02$) [42].

De La Hoz and colleagues reported on airway disease among 554 World Trade Center Medical Monitoring and Treatment Program participants [43]. Upper airway disease (UAD) was physician diagnosed based on the presence of three symptoms of rhinitis, persistent symptoms for more than 8 weeks unrelated to an infection, and associated symptoms of sinusitis, pharyngitis, or laryngitis. Lower airway disease (LAD) was diagnosed based on the presence of symptoms of dyspnea associated with cough and/or wheezing, and the exclusion of infectious diseases. Pulmonary function tests were conducted according to American Thoracic Society recommendations.

A total of 168 patients (30% of the study population) were randomly selected to assess asthma, irritant-induced asthma, bronchitis or small airway disease and to examine the relationship between smoking and WTC dust exposures. More than three quarters of the study population (78.5%) was diagnosed with an Upper airways disorder and 57.6% was diagnosed with a lower airway disease [43]. The most frequently diagnosed upper airway disease was chronic perennial rhinitis with associated sinusitis and/or pharyngitis. The most frequently diagnosed lower airway disease was irritant-induced asthma (n = 217, 34%). A total of 62 patients (11.2%) of the population were diagnosed with both upper and lower airway disease. Pulmonary function abnormalities were present in 66 patients (39.3% of the PFT subsample), and obstructive impairment was associated with early arrival to the WTC site [43].

Cigarette smoking history and early arrival at the WTC site were associated with lower airway disease in this study. Lifetime smokers were less likely to develop lower airway disease than ever smokers (45.7% vs. 60.9%, $p = 0.048$) [43]. Patients who arrived at the WTC site within the first 48 hours of the attack were more likely to develop lower airway disease than those who arrived later (74.1% vs. 32.5%, $p < 0.001$) [43].

In addition to pulmonary exams, a total of 136 patients enrolled in the World Trade Center Medical Monitoring and Treatment Program underwent an allergy evaluation [44]. Atopy was evaluated in by a radioallergosorbent (RAST) test (n = 127), skin

prick testing (n = 45), or both (n = 36) . For RAST, the immunocapture techniques was used with a panel of 17 common allergens. In order to classify a patient as atopic, sensitization to at least one aeroallergen by either RAST, skin prick test, or both was required.

Atopy was present in more than half the study population (n = 74, 54.4%) [44].

Atopic patients had significantly higher RSA scores and serum IgE levels than patients who were not atopic. Multivariate analyses revealed that atopy was significantly associated with WTC-related upper airway diagnoses [44]. However, atopic patients were not more likely to have been diagnosed with a WTC-related upper or lower airway disease than non-Atopic patients. De La Hoz and colleagues concluded that atopy was a risk factor for upper airway disease, but not lower airway disease in this WTC exposed study population, suggesting an irritant induced mechanism for LAD and a “atopic” mechanism for upper airway disease[44].

Skloot et al. assessed spirometric changes between two evaluations of participants in the World Trade Center Worker and Volunteer Medical Screening Program [45].

Baseline examinations occurred between July 2002 and April 2004 and follow-up examinations occurred between September 2004 and December 2007. There was a minimum of 18 months between the two evaluations. Study investigators assessed abnormal spirometric findings at exams one and two, and average changes in FEV1 and FVC between exams one and two.

There were significant differences between patients who participated in both examinations (n = 3160) and patients who only participated in the first examination (n = 5194) [45]. Those who participated in both surveys were more likely to be overweight and less likely to be African-American. Of the participants who completed both exams, more than one third had abnormal spirometry results at either examination (34%, 1062/3108). Low FVC was the predominant abnormality with 20% at the first exam (633/3108) and 16% at the second exam (499/3108). Of those who had normal spirometry findings at the first exam, 5% (112/2224) had low FVC at the second exam. The mean change in prebronchodilator FEV₁ between exams was 13 mL/yr. The mean change in prebronchodilator FVC between examinations one and two was 2 mL/yr. Postbronchodilator changes were similar to prebronchodilator changes. Exposure, however, was not associated with the decline in pulmonary function [45].

Bronchodilator responsiveness may be an indicator of asthma or RADS. After adjusting for gender, age, race, height, BMI, smoking status, occupation, and WTC exposures, Skloot and colleagues reported that the variables associated with lung function changes were bronchodilator responsiveness and weight gain [45].

Respiratory symptoms at the first examination were not associated with change in lung function.

Strengths and Limitations of World Trade Center Medical Monitoring and Treatment Program Studies. Studies of responders in the World Trade Center Medical Monitoring and Treatment Program have several strengths. The cohort includes a heterogeneous group of workers from a variety of WTC-related occupations. With participating clinical centers throughout the New York City metropolitan area, all members of the cohort have undergone standardized medical examinations for respiratory symptoms and pulmonary function. The limitations of most of these studies include the absence of complete occupational exposure information before September 11, 2001 and the absence of a WTC-unexposed control group of workers. Also, results may have been subject to participation bias as participants experiencing adverse health outcomes or participants interested in Worker's Compensation may have been more likely to participate in the monitoring activities offered by the consortium.

Fire Department of New York Employees.

Cross-Sectional Studies. More than 10,000 firefighters and 3000 paramedics participated in rescue, recovery, and cleanup activities after September 11, 2001 [46]. Banauch and colleagues conducted surveillance of FDNY firefighters after the WTC disaster [47]. In the immediate 48 hours following the September 11 attacks, 90% of the 10,116 FDNY firefighters that were present at the WTC site reported an acute chronic cough with nasal congestion, chest tightness, or chest burning [47].

One FDNY firefighter who worked 16-hour days was admitted for acute eosinophilic pneumonia after two weeks at the WTC site, and 3 months after the attacks, 13 firefighters were treated for pneumonia [47, 48]. All firefighters recovered following corticosteroid treatment and antibiotic therapy. In the 6 months after the attack, 332 firefighters and one EMS worker had WTC-related cough that required 4 or more weeks of medical leave [47].

Three weeks after the September 11 disaster, Feldman et al. distributed a self-administered questionnaire to a stratified random sample of firefighters from the FDNY [49]. Study participants underwent medical evaluations, including chest radiography, spirometry, and blood/urine collection for biomonitoring assays. Firefighters were sampled according to arrival time at the WTC site: those who arrived the morning of September 11 and were present during the collapse, those who arrived in the first 48 hours and were present after the collapse, and those who arrived 3 to 7 days after the collapse. This study group also included a comparison group of firefighters who were not present at the WTC site because prior injuries and illnesses limited them to office duties. Data was collected on work activities, number of exposure days, respirator use, and newly reported respiratory symptoms such as cough, shortness of breath, and chest pain after September 11, 2001 [49].

A total of 362 firefighters participated in the study by Feldman et al [49]. Study participants were 100% male and 91% white. A total of 319 (88%) firefighters were

in the exposed group and 43 (12%) firefighters were in the unexposed group. The unexposed group had higher mean age and work years than the exposed group (p value not reported). Study investigators developed a summary score that averaged respirator use over the first 2 weeks. According to the summary score, 19% of firefighters did not use any respirator during the first 2 weeks and 50% of firefighters reported using a respirator but wore it rarely during their work time [49].

Among exposed firefighters, 54% reported sore throat, 53% reported daily cough, 29% reported shortness of breath, and 21% reported wheeze [49]. A dose-response pattern was observed between the time of arrival and reported respiratory symptoms. In multivariable models that included arrival time, age, and smoking status, the number of days of exposure was a significant predictor of respiratory symptoms [49].

Among both exposed and unexposed groups, there were no differences observed between pre-WTC exposure and post-WTC exposure chest radiographs. The mean declines in both FEV₁ and FVC were significantly greater for exposed firefighters compared to unexposed firefighters ($p = 0.01$) [49]. Similarly, those arriving at the collapse and on days one or two had significant mean declines in both FEV₁ and FVC compared to the unexposed group ($p < 0.05$). In multivariable analyses, days of exposure, work tasks assignment, and post-WTC exposure spirometry did not predict changes in FEV₁ and FVC [49].

WTC exposed firefighters reported symptoms at higher rates than WTC unexposed firefighters. Early arrival at the WTC site was associated with an increase in reported respiratory symptoms and a decrease in pulmonary function (Table 1.8) [47, 49, 50]. The FDNY along with CDC's NIOSH established the FDNY WTC Medical Screening and Treatment program in October 2001 [46]. A total of 10,993 firefighters were evaluated as part of the program [50]. WTC exposure among FDNY employees was characterized into four exposure groups based on arrival time at the WTC site: High exposed arrived on the morning of September 11, 2001; Moderate exposed arrived during the afternoon of September 11, 2001 or on September 12, 2001; Low exposed arrived between September 13, 2001 and September 18, 2001; and No exposed did not arrive at the site during the first two weeks [50].

Prezant and colleagues were the first to document the incidence of WTC cough and bronchial hyperreactivity among FDNY firefighters after short term exposure to WTC irritants [50]. Prezant et al. defined World Trade Center cough as persistent cough that developed after exposure to the site that was accompanied by respiratory symptoms severe enough that FDNY physicians to place the worker on medical leave for at least four consecutive weeks [50]. WTC exposed firefighters were examined using airway-responsiveness testing, and chest imaging, questionnaires and spirometry. WTC cough cases were ascertained between September 11, 2001 and March 11, 2002.

A total of 332 firefighters were diagnosed with WTC cough [50]. WTC cough was

Table 1.8 Cross-Sectional Studies of Fire Department, City of New York Employees

First Author [Reference]	Sample Size	Study Period	Exposure Metric	Outcome(s)	Control for Risk Factors	Results
Banauch [47]	10,116	September 11, 2001- August 28, 2002	Exposure onset date ▪ High exposure arrived during collapse of the WTC on September 11, 2001 ▪ Moderate exposure arrived after collapse but within the first two days ▪ Low exposure arrived between days three and seven ▪ No exposure not at the site during the first two weeks	▪ Respiratory illnesses ▪ WTC-related cough ▪ Chest tightness ▪ Chest burning ▪ Chest radiograph abnormalities	▪ Not Applicable	▪ 90% of FDNY employees who responded to the WTC disaster reported a respiratory system. ▪ Significant association between level of exposure and bronchial hyperreactivity between high and moderate exposed groups.
Feldman [49]	362	3 weeks after September 11, 2001	Exposure onset date ▪ High exposure arrived during collapse of the WTC on September 11, 2001 ▪ Moderate exposure arrived after collapse but within the first two days ▪ Low exposure arrived between days three and seven ▪ No exposure not at the site during the first two weeks	▪ Eye, nose, and throat symptoms ▪ Respiratory symptoms	▪ Current tobacco use ▪ Age	▪ Significant dose response relationship between exposure groups and reporting of Eye, Nose/Throat, and Respiratory symptoms.

Table 1.8 continued Cross-Sectional Studies of Fire Department, City of New York Employees

First Author [Reference]	Sample Size	Study Period	Exposure Metric	Outcome(s)	Control for Risk Factors	Results
Prezant [50]	332	September 11, 2001- March 11, 2002	Exposure onset date ▪ High exposure arrived during collapse of the WTC on September 11, 2001 ▪ Moderate exposure arrived after collapse but within the first two days ▪ Low exposure arrived between days three and seven ▪ No exposure not at the site during the first two weeks	▪ World Trade Center Cough ▪ Upper-airway symptoms ▪ Lower-airway symptoms ▪ Spirometric obstruction	▪ Sex ▪ Age ▪ Smoking status ▪ Respirator use	▪ Exposure response relationship between WTC exposure and WTC cough. ▪ Significant association between level of exposure and bronchial hyperreactivity between high and moderate exposed groups.

significantly related to exposure ($p < 0.01$) as a greater percentage of firefighters with a high level of exposure developed WTC cough (8%, 128/1636) than firefighters with a moderate level of exposure (3%, 187/6958) and firefighters with a low level of exposure (1%, 17/1320) [50].

Of the 9784 firefighters who did not have WTC cough, 102 were tested for bronchial hyperreactivity and underwent methacholine and bronchodilator challenge. After adjusting for age, smoking status, and the presence or absence of airflow obstruction, there was a significant association between high exposure level and bronchial hyperreactivity (RR 21, 95% CI 1.8-164). Bronchial hyperreactivity was present in 23% of firefighters with a high level of exposure compared to 8% of firefighters with a moderate level of exposure [50].

Among the firefighters in this study, 237 firefighters with WTC cough underwent additional postbronchodilator spirometry [50]. There were no significant differences in spirometric values or the magnitude of declines among the four exposure groups. Also, chest radiographs and spirometry were performed in all 332 firefighters diagnosed with World Trade Center cough and there were no significant differences in values between firefighters with abnormal findings on chest radiography and those with normal findings [50].

Within seven months after the collapse of the World Trade Center, 48 percent

of firefighters with World Trade Center cough had returned to active duty [50].

Firefighters with upper respiratory symptoms were more likely to return to firefighting activities than firefighters with lower respiratory symptoms, after adjustment for age, smoking status, and the presence or absence of airflow obstruction (RR = 22, 95% CI 1.5-327). Of those with predominantly upper respiratory symptoms, 93% (27/29) had returned to active duty. Of the firefighters with predominately lower respiratory symptoms, 34% (32/95) had returned to active duty. Firefighters without bronchial responsiveness (65%, 62/95) were more likely to return than those with bronchial responsiveness (20%, 31/154) (RR = 4.8, 95% CI 2.5-9.2) [50].

Longitudinal Studies. By 2002, employee participation in the FDNY WTC Medical Monitoring and Screening Program was 85% [51]. A representative sample of WTC rescue workers participated in testing for nonspecific bronchial hyperreactivity 1, 3, 6, and 12 months after September 11, 2001 [52] (Table 1.8). A total of 179 FDNY completed symptom questionnaires and underwent methacholine challenge testing. Nonspecific bronchial hyperreactivity was defined as methacholine PC20 < 8 mg/mL.

At 12 months after the disaster, highly exposed FDNY rescue workers were more likely to present with nonspecific bronchial hyperreactivity (23%) compared to the moderately exposed (11%) and control (4%) groups (both $p < 0.01$). Also, nonspecific bronchial hyperreactivity was more likely to predict reactive airways dysfunction

Table 1.9 Longitudinal Studies of Fire Department, City of New York Employees

First Author [Reference]	Sample Size	Study Period	Exposure Metric	Outcome(s)	Control for Risk Factors	Results
Banauch [47]	179	1, 3, 6, and 12 months after September 11, 2001	Exposure onset date ▪ High exposure arrived during collapse of the WTC on September 11, 2001 ▪ Moderate exposure arrived after collapse but within the first two days ▪ Low exposure arrived between days three and seven ▪ No exposure not at the site during the first two weeks	▪ Nonspecific Bronchial Hyperreactivity ▪ Reactive Airways Dysfunction Syndrome	▪ Not Applicable	▪ Twelve months post WTC collapse, highly exposed were more likely than moderately exposed and controls to have bronchial hyperreactivity. ▪ Exposure response relationship between WTC exposure and RADS development.
Banauch [52]	12,079	12 months after September 11, 2001	Exposure onset date ▪ High exposure arrived during collapse of the WTC on September 11, 2001 ▪ Moderate exposure arrived after collapse but within the first two days ▪ Low exposure arrived between days three and seven ▪ No exposure not at the site during the first two weeks	▪ Spirometric obstruction ▪ Lower respiratory symptoms	▪ Sex ▪ Race ▪ Height ▪ Smoking status ▪ Age as of 9/11/2001	▪ Exposure response relationship between WTC exposure decline in pulmonary function. ▪ Functional decline was 12 times more than what would be expected from normal aging.

Table 1.9 continued Longitudinal Studies of Fire Department, City of New York Employees

First Author [Reference]	Sample Size	Study Period	Exposure Metric	Outcome(s)	Control for Risk Factors	Results
Aldrich [53]	12,782	March 12, 2000 - September 11, 2008	Exposure onset date ▪ High exposure arrived during collapse of the WTC on September 11, 2001 ▪ Moderate exposure arrived after collapse but within the first two days ▪ Low exposure arrived between days three and seven ▪ No exposure not at the site during the first two weeks	▪ Spirometric obstruction	▪ Sex ▪ Race ▪ Height ▪ Smoking status ▪ Age as of 9/11/2001	▪ Little recovery in average lung function 6 years after WTC exposure. ▪ Arrival time and work duration were not associated with FEV₁ decline 6 years after WTC exposure.
Webber [54]	10,378	October 2, 2001- September 11, 2005	Exposure onset date ▪ High exposure arrived during collapse of the WTC on September 11, 2001 ▪ Moderate exposure arrived after collapse but within the first two days ▪ Low exposure arrived between days three and seven ▪ No exposure not at the site during the first two weeks	▪ Lower respiratory symptoms ▪ Upper respiratory symptoms ▪ GERD Symptoms	▪ Respiratory symptoms at year 1 ▪ Current Smoking ▪ Months of work at WTC site ▪ Days between surveys	▪ Earlier arrival was associated with lower respiratory symptoms, upper respiratory symptoms, and GERD symptoms 4 years after WTC exposure.

syndrome in highly exposed workers (20%) compares to moderately exposed workers (8%) ($p = 0.021$) [52].

Banauch and colleagues conducted a longitudinal study of pulmonary function among FDNY WTC rescue workers [51]. A total of 12,079 FDNY rescue workers who were employed on or before September 11, 2001 underwent pulmonary function testing. Those who did not participate were significantly older, more nonwhite, female, EMS assigned, and longer tenured in the FDNY. WTC exposure intensity was classified as early, high-intensity exposure (arrived the morning of 9/11/01), intermediate-intensity (arrived later on 9/11/01 or on 9/12/01), late low-intensity (arrived on or after 9/13/01), and no exposure (no presence at the WTC site between 9/11/2001 and 6/30/2002) [51]. Nonexposed workers were shorter, more female, more nonwhite, more smokers, and had shorter tenure than exposed workers (all $p < 0.0001$). In addition to exposure intensity, work assignments were characterized as Special Operations Command, non-Special Operations Command, and EMS units. Finally, reported mask/respirator use was classified as protected if they reported wearing a disposable hardware store-type dust mask, N95 mask, or half-face respirator. Workers were considered unprotected if they did not report any mask use [51].

Among FDNY rescue workers, FEV₁ reductions after 9/11/2001 were associated with a significant exposure intensity-response gradient. Early-arrival, high-intensity workers experienced a greater decrease than lower intensity workers (linear trend $p =$

0.048) [51]. Among the various FDNY work assignments, Firefighters (383 ml, 95% CI, 374-393 ml) had an adjusted average FEV₁ reduction significantly larger than EMS workers (319 ml, 95% CI, 299-340 ml). There were no significant differences among other work assignments, and there was no significant protective effect of mask use on adjusted average FEV₁ or FVC after September 11, 2001 [51].

Symptoms assessed included daily cough, nearly constant cough, wheeze, shortness of breath, chest tightness, and sleep disturbances caused by any of the other symptoms. FDNY WTC rescue workers in the high-intensity and immediate-intensity exposure groups had significantly more frequent ($p<0.001$) and severe ($p<0.001$) respiratory symptoms than the late group [51].

In another study of FDNY WTC responders, Webber et al. described the evolution and persistence of WTC respiratory symptoms in a prospective cohort study of 10,378 WTC-exposed Firefighters [55]. The primary exposure of interest in this study was the FDNY-WTC exposure intensity index. Two respiratory studies were reported in this paper: a cross-sectional analysis of respiratory symptom prevalence at each of the four years, and a longitudinal analyses respiratory symptom patterns over the four year study period.

The FDNY-WTC exposure intensity index was characterized into four exposure groups based on arrival time at the WTC site: Group 1 arrived on the morning of

September 11, 2001; Group 2 arrived during the afternoon of September 11, 2001; Group 3 arrived on September 12, 2001; and Group 4 arrived between September 13, 2001 and September 24, 2001 [55]. In addition to the FDNY-WTC exposure intensity index, two duration variables were used to describe exposure: The first was based on the number of months participants reported working at the WTC site, on or off duty; The second multiplied each month the participant reported working on the site by 1.0, 0.75, or 0.25, depending on the reported mask/respirator use frequency of “never,” “rarely,” or “mostly” during that month. Over 75% of the participants arrived on September 11, 2001. The late arrival group differed significantly from the early arriving group in terms of duration of work at the WTC site ($p < 0.0001$) [55].

Respiratory symptom prevalence was measured through a self-administered questionnaire. The questionnaire asked participants about lower respiratory symptoms (LRS) and upper respiratory symptoms (URS) using the question: “Since the disaster, have you had any of the following new or worsening respiratory symptoms?” LRS outcomes included “wheezing,” “shortness of breath,” “daily cough,” and “no respiratory symptoms”. URS included “nasal drip,” “nasal congestion,” “sore throat,” “hoarse throat with change or loss of voice,” or “no nose or throat symptoms”. Multiple positive answers were allowed for each symptom category. GERD symptoms were confirmed by a positive response to “chest tightness or pain” or “stomach upset or heartburn”.

Webber and colleagues analyzed respiratory symptom patterns in a sub-cohort of 3,722 firefighters who completed questionnaires during both the first and fourth years [55]. The 2002, 2003, and 2004 questionnaires asked participants if any of the above symptoms were present during “the last 4 weeks” prior taking the questionnaire. There were four symptom patterns analyzed: early onset/resolved, early onset/persistent, delayed onset, and asymptomatic initially and at 4 years.

Early arrival was associated with higher symptom prevalence in all years ($p < 0.01$) [55]. The mean number of symptoms decreased between years 1 and 4 from 2.5 to 2.2 per person ($p > 0.0001$). Cough prevalence declined by 68.9%. However the prevalence of dyspnea and wheeze increased significantly ($p < 0.001$). Similarly, among URS, the prevalence of sore throat declined by 37.4% and the prevalence of rhinosinusitis and GERD increased ($p < 0.001$). Earlier arrival was significantly related to persistent LRS (OR = 1.8, 95% CI, 1.5-2.2) URS (OR = 1.5, 95% CI, 1.3-1.8), and GERD (OR = 1.9, 95% CI, 1.5-2.2) [55].

Aldrich and colleagues examined the lung function of 12,781 WTC FDNY firefighters and EMS workers who were hired before September 25, 2001 and had undergone spirometry at least once before September 11, 2001 [53]. Spirometric indices from a minimum of three measurements for each participant were collected from occupational health assessments scheduled every 12 to 18 months.

Study investigators determined whether a participant's FEV₁ fell below the lower limit of the normal range based on a reference population from the National Health and Nutrition Examination Survey. Each participant's percent of predicted FEV₁ was calculated based on the age at examination, height, sex, and race for white workers and black workers. Linear mixed modes were used to estimate changes during the first six and twelve months after 9/11, during the seven years after 9/11, and during the six years between September 12, 2002 and September 11, 2008. Models were adjusted for FEV₁ for age on 9/11, sex, height, race, FEV₁ and predicted FEV₁ for weight, smoking status, arrival time, and duration of work [53].

Average FEV₁ values were higher for firefighters compared to EMS workers ($p < 0.001$) and lowest for smokers after 9/11 ($p < 0.001$) [53]. Adjusted FEV₁ declined the 6 years between September 11, 2002 and September 11, 2008 among nonsmoking firefighters (26ml/year, 95% CI 20-30 ml/year) and EMS workers (40ml/year, 95% CI 38-42 ml/year). Multivariable analysis of FEV₁ in the last 2 years of analysis revealed a significant relationship between FEV₁ value and sex, calendar age, race, height, and weight, but not with arrival time at the WTC site. Study investigators, therefore, concluded that there was no relationship between arrival time or work duration on decreases in FEV₁ 6.5 years after September 11, 2001 [53].

Strengths and Limitations of FDNY Employee Studies. Longitudinal FDNY WTC studies report high participation rates and minimal loss to follow-up. For some FDNY

WTC studies, pre-911 exposure and spirometric data were not available for all study participants. For others, reported symptoms and respirator use may have been subject to recall or reporting bias. Nevertheless, the large sample size in addition to annual medical examinations are major strength of studies of FDNY employees who responded to the WTC disaster.

World Trade Center Health Registry. The World Trade Center Health Registry (Registry) was established by the NYC DOHMH and the CDC's Agency for Toxic Substances and Disease Registry (ATSDR) to document and evaluate the long-term health consequences of the September 11, 2001 terrorist attacks [56]. The Registry targeted populations that were exposed to the actual event, exposed to the immediate aftermath of the attack, exposed to exposures related to rescue, recovery, and cleanup of the WTC site, or living, working, or attending school in the lower Manhattan area. A total of 71,437 people enrolled in the Registry between September 2003 and November 2004 [56].

A total of 30,665 rescue and recovery workers and volunteers met the exposure criteria for inclusion in the Registry [56]. Excluding workers and volunteer who never worked at Ground Zero (n=942), 29,723 (41.6% of the Registry) workers and volunteers were involved in rescue, recovery, cleanup, or other disaster-related activities at the WTC site for at least one shift anytime from September 11, 2001 through June 30, 2002 [57].

Wheeler et al. described the 3-year risk of newly diagnosed Asthma among WTC site workers and volunteers from the Registry [54]. Asthma risk and its association with timing, duration of work, and mask use was described among 25,748 workers and volunteers who conducted rescue, recovery, cleanup, or volunteer tasks at the Ground Zero WTC site, on the Staten Island Fresh Kills landfill site, or on transport barges and trucks between the two sites.

A total of 926 enrollees reported a new diagnosis of asthma after September 11, 2001 resulting in a 3-year risk of 3.6% [54]. After adjusting for female sex, age, NYC residence on September 11, and other WTC-work related factors, workers who arrived at the WTC on September 11, were 1.81 times (95% CI: 1.19-2.74) more likely to report a new diagnosis of asthma after September 11, 2001. Enrollees who worked more than 90 days at the WTC site were 1.74 times (95% CI: 1.43-2.12) more likely to report a new diagnosis of asthma after September 11, 2001. Pile work (OR = 1.30, 95% CI: 1.11-1.53) and exposure to the 9/11 dust cloud (OR = 1.28, 95% CI: 1.09-1.50) were also significantly more associated with reported newly-diagnosed asthma after September 11, 2001 [54].

Workers who arrived on September 11 (OR = 1.64, 95% CI: 1.32-2.02) or September 12 (OR = 1.51, 95% CI: 1.21-1.89) and did not report wearing a mask or a respirator were significantly more likely to report a new diagnosis of asthma [54]. Also, workers with a 1-16 week delay of mask or respirator use were more than two times more

likely to report a new asthma diagnosis after September 11, 2001 (OR=2.28, 95% CI: 1.22-4.25). The authors performed two sensitivity analyses. In a Firefighters only analysis, a significant association was observed between not wearing a mask on September 11 (OR=1.48, 95% CI: 1.02-2.15) and newly diagnosed asthma, and a 1-16 week delay of mask or respirator use (OR=3.70, 95% CI: 1.68-8.12) and newly diagnosed asthma. Finally, in a separate analysis that was limited to enrollees who were identified from work roster lists, a non-significant association was observed between not wearing a mask on September 11 (OR=1.87, 95% CI: 0.69-5.08) and newly diagnosed asthma. However, a significant association was observed between not wearing a mask on September 12 and newly diagnosed asthma (OR=1.85, 95% CI: 1.02-3.34) [54].

Brackbill and colleagues reported on the 5-6 year incidence of newly-diagnosed asthma or Reactive Airways Dysfunction Syndrome among WTC rescue, recovery, and cleanup workers [58]. Participants completed Wave One interviews between September 2003 and November 2004. Wave Two surveys were completed between November 2006 and December 2007. Participants reported a physician diagnosis of asthma or reactive airways dysfunction syndrome after September 11, 2001.

The 5-6 year incidence of asthma after September 11, 2001 among workers and volunteers was 12.2% [58]. Among participants who reported a year of diagnosis, those who were diagnosed with asthma between 2001 and 2003 had a higher

prevalence of lower respiratory symptoms such as wheeze, shortness of breath, and persistent cough than participants who were diagnosed between 2004 and 2006 [58]. There was a significant association between WTC exposures and newly-diagnosed asthma after September 11, 2001. Compared to those with no dust cloud exposure, multivariable analysis revealed that intense dust cloud exposure was associated with an elevated risk for self-reported diagnosis of asthma (adjusted OR = 1.5, 95% CI: 1.4-1.7). After adjusting for sex, age, race/ethnicity, income, current smoking, and other exposure factors, those who arrived at the pile on September 11, 2001 had a higher asthma risk than those who arrived to any WTC site after September 18, 2001 (adjusted OR = 2.2, 95% CI: 1.9-2.6). Also, those who worked more than 90 days at a WTC site were more likely to report asthma than those who worked less than seven days (adjusted OR = 1.9, 95% CI: 1.6-2.1) [58].

Strengths and Limitations of WTC Health Registry Studies. The Registry is a volunteer cohort and selection bias is a concern as workers with elevated WTC exposures or poor health outcomes may have been more likely to enroll. However, analysis of participation rates through 2007 show that WTC-related experiences were not associated with participation [58]. The Registry contains one of the largest and most diverse cohort of WTC rescue, recovery, and cleanup workers and volunteers ever assembled, and analyses to date have yielded significant dose-response relationships between WTC-related exposure and respiratory outcomes (Table 1.10).

Table 1.10 Epidemiologic Studies of Rescue, Recovery and Cleanup Workers from the World Trade Center Health Registry

First Author [Reference]	Sample Size	Study Period	Exposure Metric	Outcome(s)	Control for Risk Factors	Results
Wheeler [54]	25,283	September 5, 2003- November 20, 2004	Exposure onset date ▪ 9/11/2001 ▪ 9/12/2001 ▪ 9/13-9/17/2001 ▪ 9/18-12/31/2001 ▪ 1/1-6/30/2002 Exposure duration ▪ 1-7 days ▪ 8-30 days ▪ 31-90 days ▪ > 90 days	▪ Newly Diagnosed Asthma	▪ Sex ▪ Age ▪ NYC residence ▪ Affiliation ▪ Exposure duration ▪ Dust cloud exposure ▪ Work on pile	▪ 3.6% of workers reported newly-diagnosed asthma over a 3 year period. ▪ Earlier arrival and longer duration of work were positively associated with asthma, as was working on the pile.
Brackbill [58]	21,605	September 5, 2003- December 2007	Exposure onset date ▪ 9/11/2001, on pile ▪ 9/11/2001, other site ▪ 9/12-9/17/2001, any site ▪ 9/18-6/30/2002, any site Exposure duration ▪ 1-7 days ▪ 8-30 days ▪ 31-90 days ▪ > 90 days	▪ Newly Diagnosed Asthma	▪ Sex ▪ Age ▪ Race/ Ethnicity ▪ Income ▪ Current smoking ▪ Dust cloud exposure ▪ Enrollment mode ▪ Survey mode	▪ 12.2% of workers reported newly diagnosed asthma over a 5-7 year period. ▪ Newly diagnosed asthma was associated with intense dust cloud exposure, pile work on September 11, 2001 and longer duration of work.

Conclusions and Further Research Needs

The rescue, recovery, and cleanup activities associated with the World Trade Center disaster resulted in the release of large amounts of particulates from pulverized building materials, fires, and resuspension of settled dust [7]. Analyses of the components of the settled dust collected from the vicinity of the WTC site indicated that WTC dust was composed of known respiratory irritants such as calcium and sulfates [8, 11].

The impact of the disaster on the respiratory health of disaster workers has been well documented. Syndromic surveillance, sponsored by the CDC and NYC DOHMH, reported respiratory illnesses in one-sixth of all conditions reported in the first month after the disaster [29]. Epidemiologic studies conducted in the years after the disaster reported associations between new-onset respiratory symptoms and diseases and self-reported qualitative measures of WTC exposure such as arrive date at the WTC site, cumulative number of days worked at the WTC site, work location at the WTC site, job categories, and occupational group categories [35, 41, 50, 54, 58].

The absence of environmental monitoring data in the days immediately following the WTC disaster has led to crude exposure assessments across the different WTC research studies [35, 41, 50, 54, 58]. WTC qualitative exposure assessments have been limited because of their inability to account for the complexity of airborne contaminants at the site and the variability of exposures within the nine month disaster

rescue, recovery, and cleanup effort. Herdt-Losavio and colleagues improved on WTC exposure assessment methods by developing an exposure assessment method for New York State workers who responded to the WTC disaster [39]. The method established an algorithm for smoke and dust from two data sources: a mailed questionnaire and US Environmental Protection Agency (US EPA) air monitoring data [39]. The major limitation of this method, however, was the use of USEPA air monitoring data to assess individual-level exposures and the inability to account for individual job tasks at the site.

In one of the few studies of individual-level exposure to particulates, personal air samples of 69 WTC truck drivers conducted by Geyh et al. revealed that total dust concentrations were higher in the pile than in the perimeter of the WTC site [16]. To date, this study by Geyh and colleagues is the only WTC disaster worker study that has utilized personal air monitoring data in exposure assessment.

What This Study Adds. This dissertation presents a new strategy for evaluating occupational exposure to WTC dust after the 9/11 disaster. Over 60 studies have examined the impact of WTC exposure on respiratory symptoms and diseases after 9/11, and only two studies have included quantitative exposure measurements [59]. This study will improve on previous methods of exposure assessment by utilizing personal monitoring data in conjunction with work history questionnaires to create a job-exposure matrix for WTC dust exposure.

The construction of a job-exposure matrix is an approach to exposure assessment that has been regularly used in occupational epidemiology, particularly when exposure monitoring data are scarce and individual exposure assessment is not feasible [60]. The job-exposure matrix is a two dimensional grid on which some quantitative value for exposure is entered for each job title [61]. The goal of the job-exposure matrix is to increase the precision of exposure assessments by classifying exposure to specific toxic agents given a job title [60]. Job-exposure matrices for dust exposure assessment have been employed in studies of respirable dust among German uranium miners [62], respirable dust among United States coal miners [63], and silica dust among industrial san industry employees[64].

There are several ways to evaluate the validity of a job-exposure matrix. One approach is to apply different thresholds to a dichotomous exposure classification and examine the sensitivity and specificity of these thresholds in comparison to the original job-exposure matrix. A different evaluation technique is to compare the performance of the matrix to the results of an independent review by a group of experts [65]. Another evaluation method is to examine the epidemiologic performance of the job-exposure matrix after manipulating the exposure thresholds [66]. In the absence of the gold standard of environmental monitoring data for each worker, it is important to evaluate the job-exposure matrix under several exposure misclassification scenarios [67].

The exposure assessment methods developed in this study will account for differences among job tasks, duration of WTC dust exposure, and temporal changes in WTC dust exposure. This study will clarify the current knowledge of the impact of WTC dust on respiratory health outcomes among WTC disaster workers by enhancing the use of a dust-specific job-exposure matrix for WTC exposure assessment.

1.2 Study Aims and Hypotheses

Occupational exposure methods for epidemiological studies of World Trade Center disaster workers have yet to quantitatively account for dust exposure associated with working at the site. In this study, personal monitoring data of respirable dust from the Occupational Safety and Health Administration (OSHA) WTC samples combined with information collected from questionnaires administered to WTC disaster workers were used to develop a semi-quantitative WTC Chronic Dust Exposure Index.

Specific Aims. The aims of this study were to:

1. Develop a WTC Chronic Dust Exposure Index for evaluation of respiratory health outcomes among WTC disaster workers,
2. Examine the exposure-response relationship between chronic dust exposure categories (High, Medium, and Low) and respiratory symptoms among WTC disaster workers, and

3. Examine the exposure-response relationship between chronic dust exposure categories (High, Medium, and Low) and respiratory diseases among WTC disaster workers.

Research Questions and Hypotheses. The following were the study research questions and hypotheses:

Question 1: Is there a relationship between WTC chronic dust exposure and respiratory symptoms among WTC rescue and recovery workers?

Hypothesis: There will be a significant, positive, exposure-response relationship between WTC chronic dust exposure categories and new-onset lower respiratory symptoms such as shortness of breath, wheezing, and persistent cough.

Question 2: Is there a relationship between WTC chronic dust exposure and respiratory disease among WTC rescue and recovery workers?

Hypothesis: There will be a significant, positive, exposure-response relationship between WTC chronic dust exposure categories and newly diagnosed asthma and chronic bronchitis after September 11, 2001. There will not be a significant association between WTC chronic dust exposure categories and newly diagnosed allergic rhinitis after September 11, 2001.

Public Health Significance. Occupational exposure assessments can be used to monitor and evaluate the health status of a working population, as well as identify high risk segments of that population. This study will clarify the relationship between WTC chronic dust exposures and the prevalence of respiratory symptoms and diseases after September 11, 2001 among WTC rescue and recovery workers. Knowledge of occupational exposures that are predictors of respiratory morbidity may lead to modifications that improve worker safety and guide disaster response during future disaster rescue, recovery, and cleanup efforts.

CHAPTER 2

METHODS

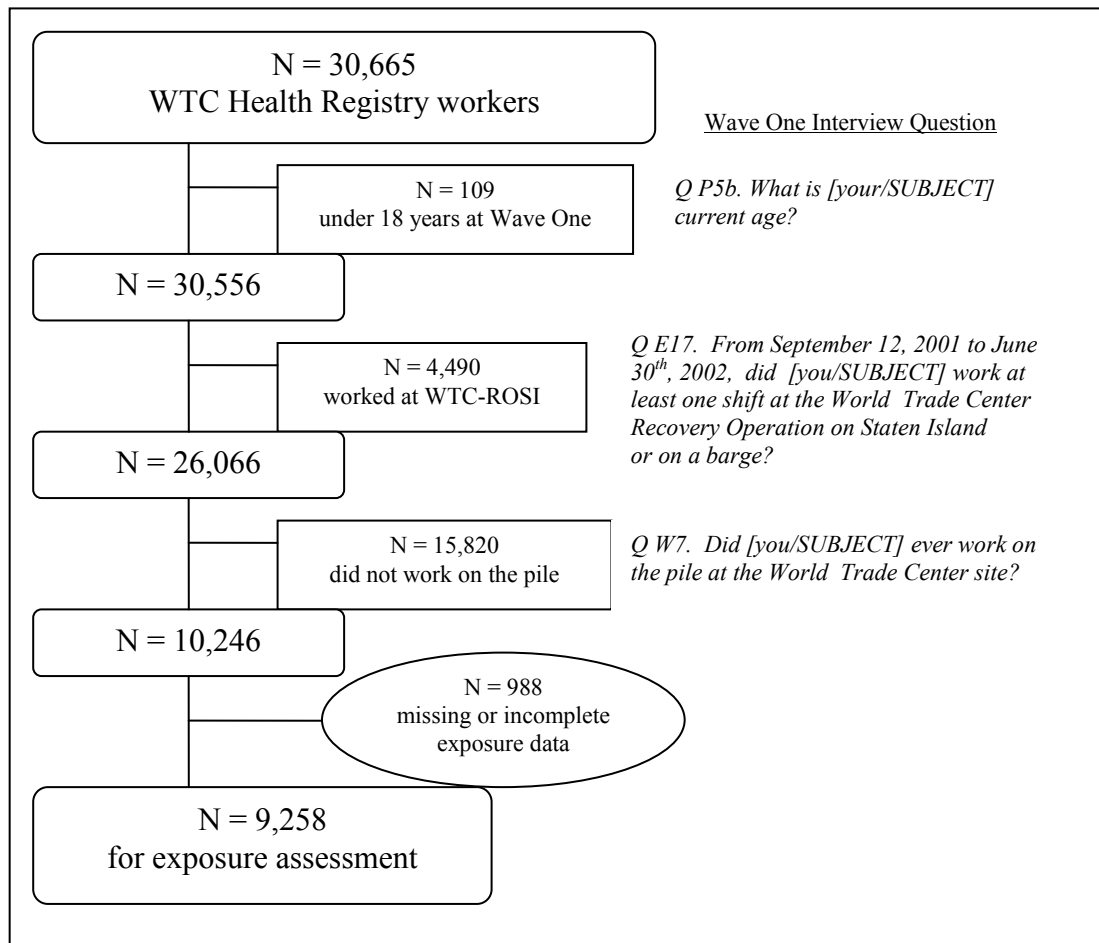
2.1 Study Population

The World Trade Center Health Registry (Registry) enrolled 30,665 WTC rescue, recovery, and clean-up workers between September 2003 and November 2004 [56].

The Registry used multiple methods to enroll workers, including recruiting from employment lists of eligible persons (list-identification) and encouraging workers to enroll themselves (self-identification) through public outreach efforts. Informed consent was obtained from all enrollees, and the Institutional Review Boards of the Centers for Disease Control and Prevention and the New York City Department of Health and Mental Hygiene approved the Registry.

Dust exposure assessment was restricted to adult enrollees whose exclusive work location after September 11, 2001 was on the pile at Ground Zero. Figure 2.1 displays the study population for exposure assessment. Of the 30,665 workers who enrolled in the Registry, 109 were under the age of 18 at the time of the Wave One interview, 4,490 reported working at least one shift at the World Trade Center Recovery Operation on Staten Island (WTC-ROSI) or on a barge that transported debris, and 15,820 enrollees did not report working on the pile in lower Manhattan [57]. A total of 988 enrollees with missing or incomplete data were excluded from this analysis, leaving 9,258 pile workers in the exposure assessment dataset.

Figure 2.1 Study Population for Exposure Assessment [56]



2.2 Exposure Assessment

Exposure Time Periods. Wave One interviews collected information on WTC-related work factors such as area location of work at site, arrival date at site, duration of work at site, and type of task activities performed at site. In questionnaires administered by the Registry, work dates at the WTC site were classified into five analytical time periods (Table 2.1). These time periods represented a gradient of exposure to respiratory irritants from the most intense period (September 11, 2001) to the least intensive period (January 1, 2001-June 30, 2002) [54].

Table 2.1 WTC Exposure Time Periods

Exposure Time Period	Date Range
Period 1	September 11, 2001
Period 2	September 12, 2001
Period 3	September 13, 2001-September 17, 2001
Period 4	September 18, 2001-December 31, 2001
Period 5	January 1, 2002-June 30, 2002

In addition to the exposure time periods, each worker was asked to estimate how many days they worked in each period. For the fourth and fifth time periods, days worked were reported in interval categories (Table 2.2). The midpoint duration of each interval was used as a surrogate for the number of days worked during these time periods.

Table 2.2 WTC Exposure Time Period Interval Categories

Exposure Time Period	Interval Categories
Period 4	0 Days
	1 – 2 days
	3 – 6 days
	7 – 30 days
	31 – 60 days
Period 5	0 Days
	1 – 2 days
	3 – 6 days
	7 – 30 days
	31 – 60 days
	61 – 181 days

Occupational Tasks. The Registry collected information on tasks performed at the lower Manhattan WTC site from each WTC rescue, recovery, and cleanup worker. Tasks were characterized into five Registry occupational task categories: Firefighting, Heavy Equipment Operation, Light Construction, Search and Rescue, and Welding/Steelcutting/Torch Operation (Table 2.3).

The OSHA WTC database recorded one job title for each personal sample [68]. In consultation with a Certified Industrial Hygienist, OSHA WTC database job titles were reviewed in detail and assigned to one of these five Registry occupational task categories [69](Table A.1).

Table 2.3 WTC Occupational Task Categories

Task Category
Firefighting
Heavy Equipment Operation
Light Construction
Search and Rescue
Welding / Steelcutting / Torch Operation

Sampling Locations. Registry rescue, recovery, and cleanup workers were also asked about the area of the WTC site where they performed their post-disaster work activities. Site locations included the Tully Sector (WTC 2, WTC 4, and WTC 5), the Amec Sector (WTC 1 and WTC 6), the Bovis Sector (WTC 3), and the Turner Sector (WTC 7). In these analyses, WTC buildings were assigned to one of three sampling locations: East, Northwest, or Southwest (Table 2.4).

Table 2.4 WTC Sampling Locations

Sampling Location	WTC Building(s)
East	WTC 2, WTC 4, WTC 5
Northwest	WTC 1, WTC 6, WTC 7
Southwest	WTC 3

The OSHA WTC database recorded one job title for each personal sample [68]. In

consultation with a Certified Industrial Hygienist, OSHA WTC database job titles were reviewed in detail and assigned to one of these five Registry occupational task categories [69] (Table A.1).

Environmental Monitoring Data. The Occupational Safety and Health Administration (OSHA) collected measurements of occupational exposures among workers at the WTC site between September 18, 2001 and July 23, 2002 [70]. The OSHA WTC database included area and personal samples of asbestos, carbon monoxide, dioxins, total dust, freon-22, hydrogen fluoride, inorganic acids, ionizing radiation, metals, nitrogen oxides, noise, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, phosgene, respirable silica, sulfur oxides, and volatile organic compounds [71].

To estimate exposure to dust at the WTC site, respirable dust was chosen as a surrogate because it was the most biologically relevant fraction of dust exposure. Respirable particles are small enough to deposit within the gas- exchange region of the respiratory system well beyond the body's natural clearance mechanism [72]. Respirable dust was sampled according to the American Congress of Governmental Industrial Hygienists (ACGIH) sampling criteria: particulates with a median aerodynamic diameter of 4 micrometers (maximum 10 micrometers) [73].

The OSHA WTC database included personal monitoring samples of respirable dust (n = 751) collected between September 22, 2001 and June 12, 2002. Samples were collected using a cyclone to remove non-respirable particles and a pre-weighed PVC filter to retain the respirable dust fraction [74]. X-ray diffraction (XRD) spectrometry was used for quantitative determination of respirable dust containing crystalline silica [74]. Eight-hour time-weighted averages of respirable dust were reported. All personal samples collected between September 22, 2001 and June 12, 2002 were used in this analysis [68].

Statistical Analyses of Respirable Dust Data. In this study, statistical analyses of OSHA WTC database dust sampling results were conducted for the two time periods when OSHA sampling results were available: September 18, 2001-December 31, 2001 (Period 4) and January 1, 2002-June 30, 2002 (Period 5). For each exposure time period, summary statistics (arithmetic mean, geometric mean, median, minimum, and maximum) were calculated for each of the five occupational task categories (Appendices A.2-A.5). The results indicated that dust concentrations were log-normally distributed and that the geometric mean provides the best estimate of central tendency. Figures 2.2 (for Period 4) and 2.3 (for Period 5) display the cumulative probability plots of the distribution of dust concentrations. The graphs indicated that the respirable dust concentration data were positively skewed. As a result of this lognormal distribution, the dust concentration data was log-transformed for regression analyses (Figure 2.4 for Period 4 and Figure 2.5 for Period 5).

Figure 2.2 Probability Plot of Respirable Dust Concentrations, Period 4

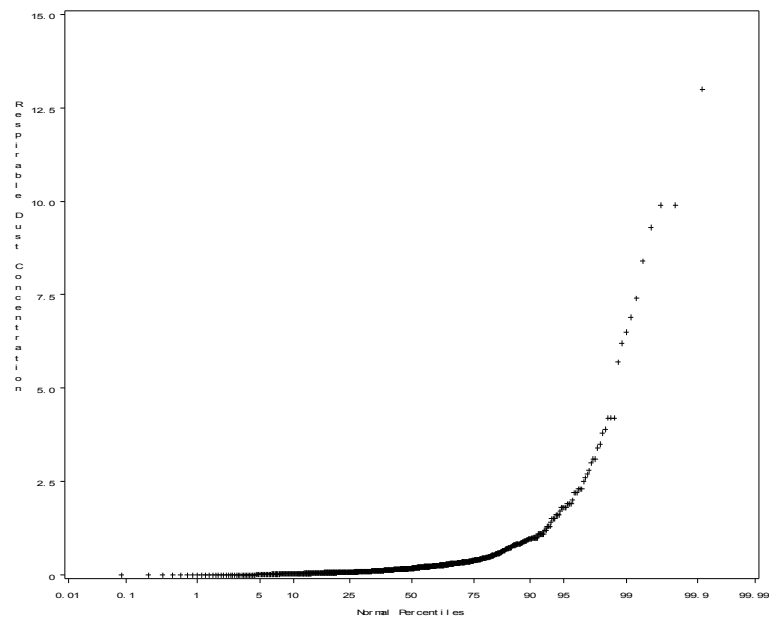


Figure 2.3 Probability Plot of Respirable Dust Concentrations, Period 5

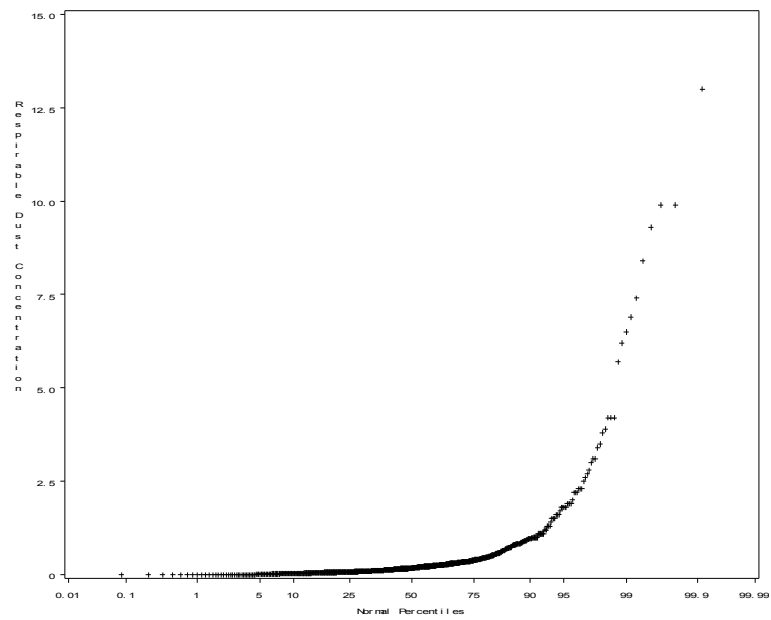


Figure 2.4 Log Plot of Respirable Dust Concentrations, Period 4

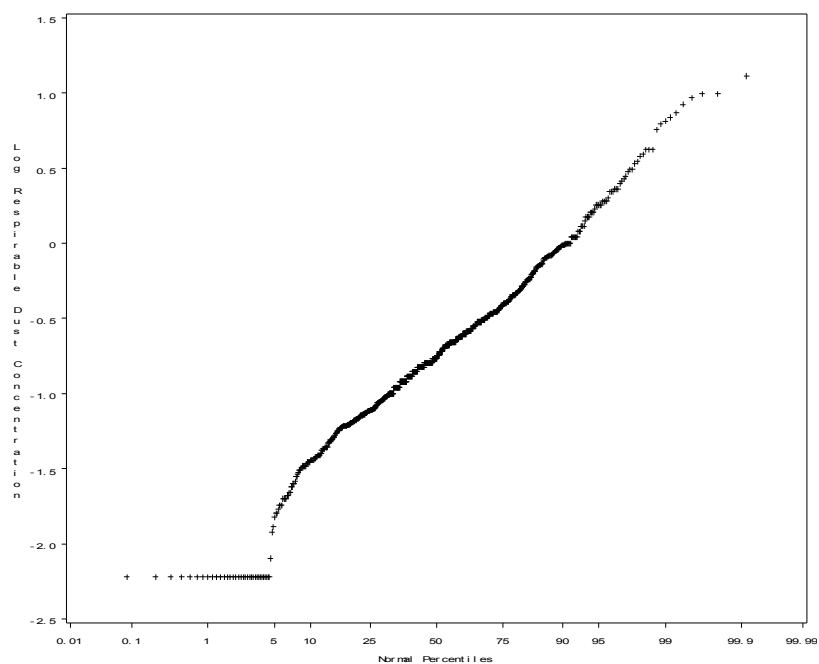


Figure 2.5 Log Plot of Respirable Dust Concentrations, Period 5

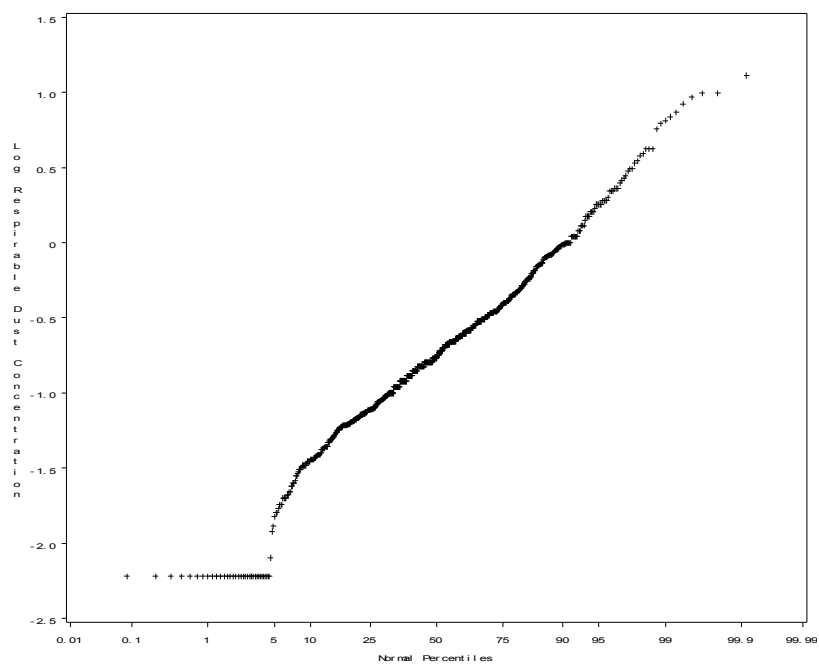
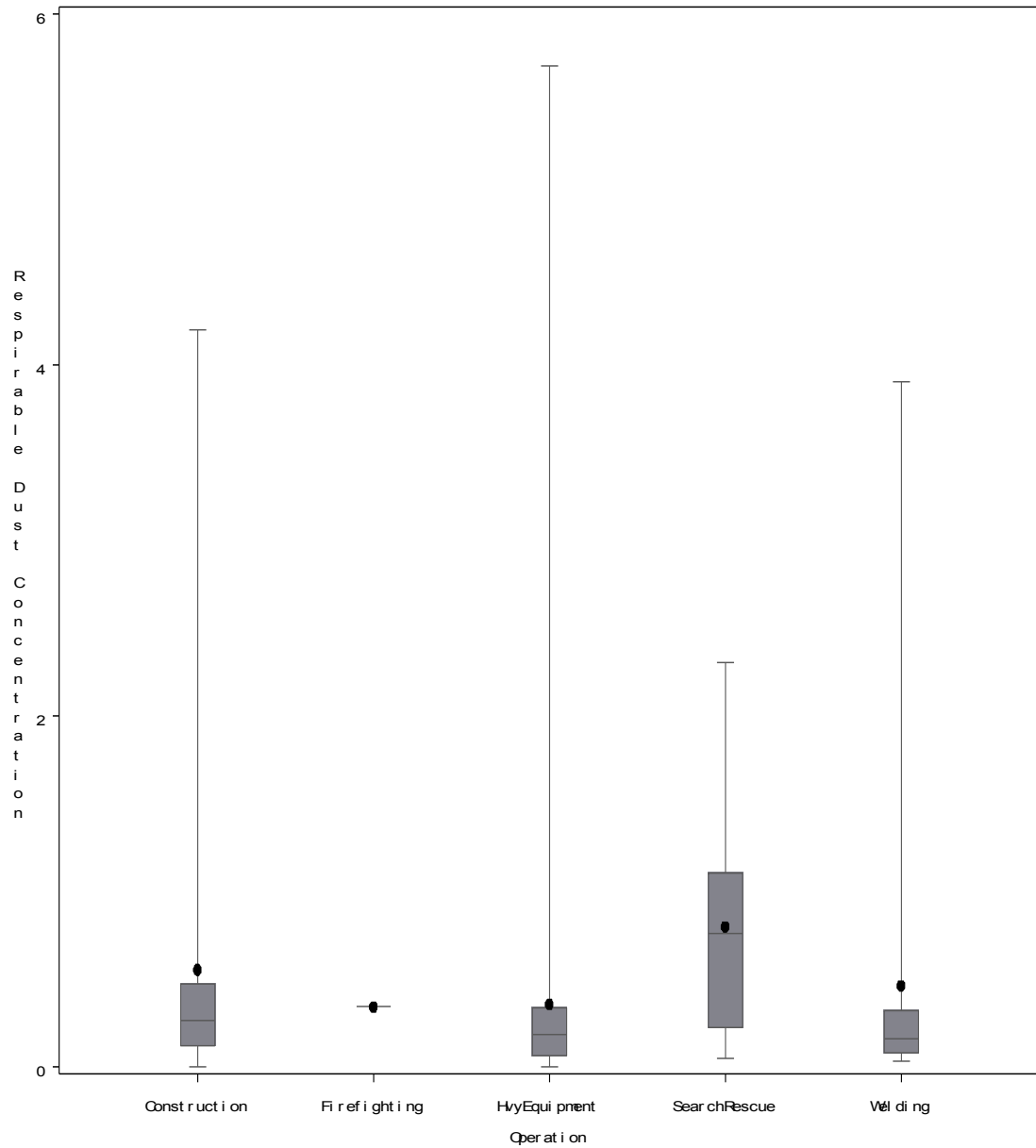


Figure 2.6 shows the box plots of dust concentrations for each occupational task category during Period 4.

Figure 2.6 Mean Respirable Dust Concentration (mg/m^3) by Occupational Task, Period 4

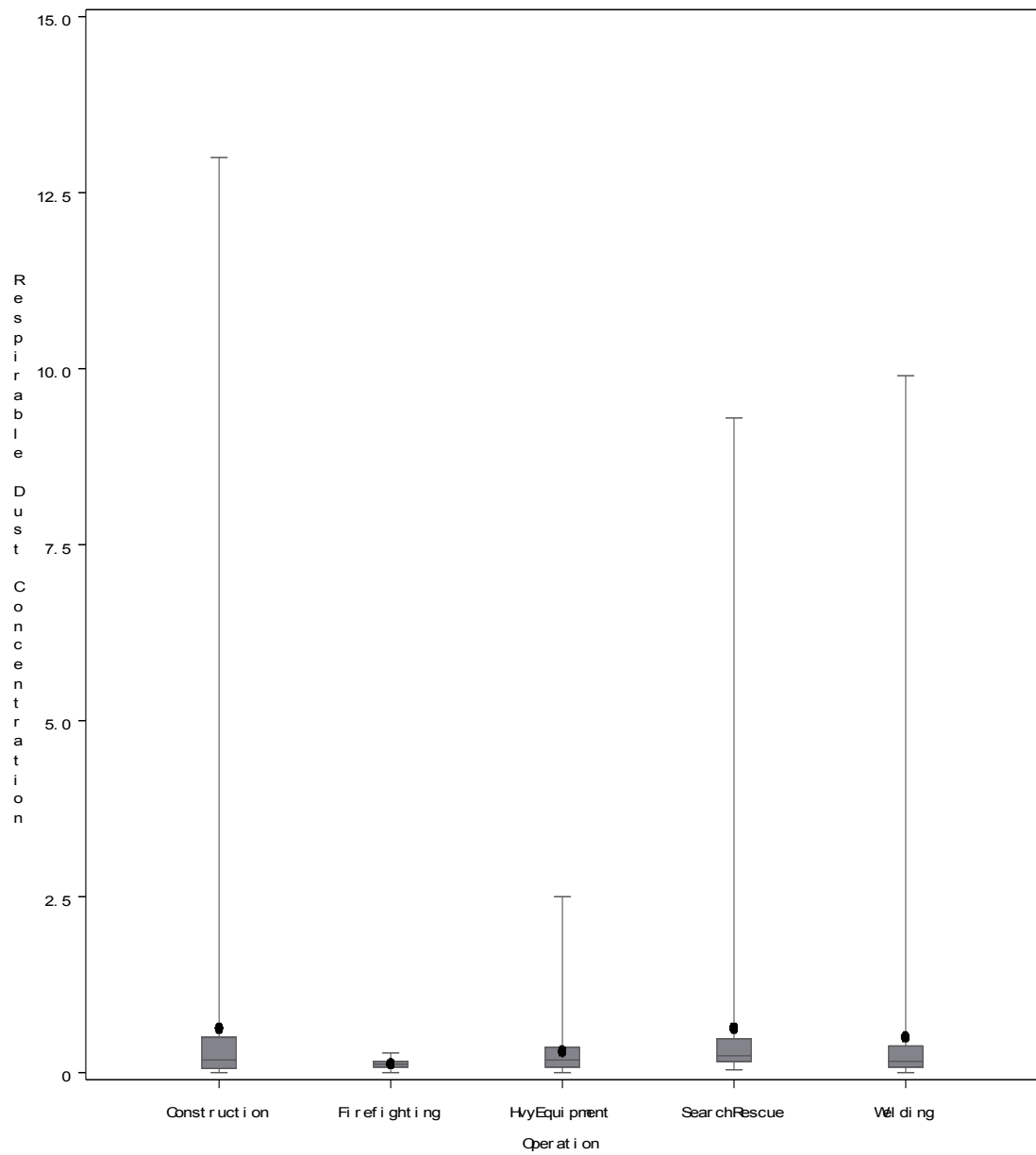


Kruskal-Wallis tests revealed that there were significant differences in dust concentrations by occupational task category and time period (both $p < 0.0001$). During time period 4 (September 18, 2001-December 31, 2002), the Search and Rescue task group had the highest mean concentrations of respirable dust (0.51 mg/m^3), followed by the Firefighting group (0.34 mg/m^3), the Light Construction group (0.25 mg/m^3), the Welding group (0.18 mg/m^3), and the Heavy Equipment Operator group (0.14 mg/m^3) (Table A.3).

Dust concentrations decreased slightly between periods 4 and 5. Figure 2.7 shows the box plots of dust concentrations for each occupational task category during period 5 (January 1, 2002-June 30, 2002). For time period 5, the Search and Rescue task group again had the highest mean concentrations of respirable dust (0.30 mg/m^3), followed by the Welding group (0.17 mg/m^3), the Light Construction group (0.15 mg/m^3), the Heavy Equipment Operator group (0.14 mg/m^3), and the Firefighting group (0.14 mg/m^3) (Table A.3).

The decrease in mean dust concentrations between time periods 4 and 5 may reflect the shift in tasks and activities after fires on the pile were extinguished in late December.

Figure 2.7 Mean Respirable Dust Concentration (mg/m³) by Occupational Task, Period 5



There were also significant differences in dust concentrations associated with sampling locations (Kruskal-Wallis $p < 0.001$). The mean concentration for the East

sampling location (0.55 mg/m³) was significantly higher than the Northwest (0.34 mg/m³) and Southwest (0.33 mg/m³) locations.

WTC Exposure Regression Model. A multivariable linear regression model was used to examine the association between work-related factors and respirable dust concentrations. The regression model was developed using the GLM procedure in SAS version 9.1 (SAS Institute Inc., Cary, NC, USA). Occupational task category, sampling area, and work date period were included as predictor variables in the model:

$$\text{Log (respirable dust TWA)} = \alpha + \beta_1 \text{Area} + \beta_2 \text{Time Period} + \beta_3 \text{Task Category} + \varepsilon$$

Table 2.5 shows the linear relationship between the three predictor variables and log-transformed dust concentrations. All three predictor variables were independently associated with log-dust concentrations. There were, however, several limitations associated with using a regression model to predict WTC dust exposure. The linear regression model only explained a small fraction of the variability in respirable dust concentrations ($R^2 = 0.06$, $p < 0.0001$). The poor R^2 suggests that the linear regression model would be an unstable predictor of dust exposures. An unstable model would introduce bias to the fitted dust concentrations, and it is not known if this bias would result in differential (or nondifferential) misclassification of exposure.

Table 2.5. Multiple Regression Model for Estimation of Exposure to Respirable Dust

Predictor	d.f.	Parameter Estimate	Standard Error	F Test	p value
Model	7	—	—	7.31	< 0.0001
Intercept	—	-0.953	0.062	—	—
Area	2	—	—	7.09	0.0009
East	—	0.226	0.062	—	—
Northwest	—	0.042	0.072	—	—
Southwest	—	Ref.	Ref.	—	—
Date Period	1	—	—	5.93	0.0151
Period 4	—	0.139	0.057	—	—
Period 5	—	Ref.	Ref.	—	—
Task	4	—	—	7.76	< 0.0001
Firefighting	—	-0.177	0.115	—	—
HE Operation	—	-0.095	0.059	—	—
Lt Construction	—	0.019	0.072	—	—
Welding	—	0.317	0.074	—	—
Search/Rescue	—	Ref.	Ref.	—	—

Because the level of exposure misclassification bias introduced by this unstable regression model is unknown, job-exposure matrices, with the variables of occupational task category, sampling area, and work date period as strata, were used to estimate dust exposure among Registry WTC rescue, recovery, and cleanup workers.

Job-Exposure Matrices. Job-exposure matrices were developed to estimate dust exposure by WTC job task and WTC time period. OSHA personal environmental sampling did not commence until September 22, 2001. In order to estimate dust exposure (intensity*duration) prior to OSHA sampling, exposure concentrations (mg/m^3) for time periods prior to September 22, 2001 (Periods 1-3) were imputed based on a review of the literature and environmental monitoring data [68]:

1. Lorber and colleagues estimated $\text{PM}_{2.5}$ concentrations on September 11, 2001 at $5 \text{ mg}/\text{m}^3$ [75]. For all tasks and locations, $5 \text{ mg-d}/\text{m}^3$ was assigned as the exposure for Period 1.
2. For Periods 2 and 3, environmental monitoring data was not available. The matrix cells for these two periods were filled with a conservative estimate, the geometric mean of available environmental monitoring data (OSHA's 751 respirable dust personal samples). The geometric mean of the 751 respirable dust samples measured by OSHA was $0.17 \text{ mg}/\text{m}^3$. For Periods 2 and 3, the exposure of $0.17 \text{ mg-d}/\text{m}^3$ was assigned. Analyses were later conducted to test the sensitivity of both exposure and effect measures to this conservative exposure estimate.

A separate job-exposure matrix was developed for each WTC sampling area with WTC occupational tasks on one axis of the matrix and WTC time periods on the other axis. The job-exposure matrices used for exposure assessment in this study are presented below in Table 2.6 (East sampling area), Table 2.7 (Northwest sampling area, and Table 2.8 (Southwest sampling area).

Table 2.6. East Sampling Area Job-Exposure Matrix

	Period 1	Period 2	Period 3	Period 4	Period 5
Firefighting	5 mg-d/m ³	0.17 mg-d/m ³	0.17 mg-d/m ³	0.34 mg-d/m ³	0.10 mg-d/m ³
Heavy Equipment Operation	5 mg-d/m ³	0.17 mg-d/m ³	0.17 mg-d/m ³	0.23 mg-d/m ³	0.16 mg-d/m ³
Light Construction	5 mg-d/m ³	0.17 mg-d/m ³	0.17 mg-d/m ³	0.40 mg-d/m ³	0.17 mg-d/m ³
Search and Rescue	5 mg-d/m ³	0.17 mg-d/m ³	0.17 mg-d/m ³	0.56 mg-d/m ³	0.29 mg-d/m ³
Welding	5 mg-d/m ³	0.17 mg-d/m ³	0.17 mg-d/m ³	0.25 mg-d/m ³	0.19 mg-d/m ³

Several firefighter cells in Tables 2.7 (Northwest sampling area) and 2.8 (Southwest sampling area) were missing exposure assignments because OSHA did not sample firefighters in these areas during Periods 4 or 5. The lowest dust concentration measured all workers during this time period was assigned to these cells. Analyses were later conducted to test the sensitivity of both exposure and effect measures to the value of this exposure estimate, which was likely a substantial underestimate.

Table 2.7. Northwest Sampling Area Job-Exposure Matrix

	Period 1	Period 2	Period 3	Period 4	Period 5
Firefighting	5 mg-d/m ³	0.17 mg-d/m ³	0.17 mg-d/m ³	No Data	0.10 mg-d/m ³
Heavy Equipment Operation	5 mg-d/m ³	0.17 mg-d/m ³	0.17 mg-d/m ³	0.07 mg-d/m ³	0.14 mg-d/m ³
Light Construction	5 mg-d/m ³	0.17 mg-d/m ³	0.17 mg-d/m ³	0.15 mg-d/m ³	0.24 mg-d/m ³
Search and Rescue	5 mg-d/m ³	0.17 mg-d/m ³	0.17 mg-d/m ³	0.48 mg-d/m ³	0.39 mg-d/m ³
Welding	5 mg-d/m ³	0.17 mg-d/m ³	0.17 mg-d/m ³	0.12 mg-d/m ³	0.17 mg-d/m ³

Table 2.8. Southwest Sampling Area Job-Exposure Matrix

	Period 1	Period 2	Period 3	Period 4	Period 5
Firefighting	5 mg-d/m ³	0.17 mg-d/m ³	0.17 mg-d/m ³	No Data	No Data
Heavy Equipment Operation	5 mg-d/m ³	0.17 mg-d/m ³	0.17 mg-d/m ³	0.19 mg-d/m ³	0.10 mg-d/m ³
Light Construction	5 mg-d/m ³	0.17 mg-d/m ³	0.17 mg-d/m ³	0.15 mg-d/m ³	0.06 mg-d/m ³
Search and Rescue	5 mg-d/m ³	0.17 mg-d/m ³	0.17 mg-d/m ³	0.48 mg-d/m ³	0.26 mg-d/m ³
Welding	5 mg-d/m ³	0.17 mg-d/m ³	0.17 mg-d/m ³	0.15 mg-d/m ³	0.08 mg-d/m ³

Dust Exposure Estimation. The following methods were used to estimate dust exposure among Registry rescue, recovery, and cleanup workers:

For Registry workers who reported being present at the lower Manhattan WTC site on September 11, 2001, a dust concentration of 5 mg/m³ was assigned:

$$\text{Period 1 Dust Exposure} = 5 \text{ mg-d/m}^3$$

For Registry workers who reported being present at the lower Manhattan WTC site on September 12, 2001, dust concentration of 0.17 mg was assigned:

$$\text{Period 2 Dust Exposure} = 0.17 \text{ mg-d/m}^3$$

For Registry workers who reported being present at the lower Manhattan WTC site between September 13, 2001 and September 17, 2001, a dust concentration of 0.17 mg/m³ was assigned. The cumulative dust exposure for each enrollee was determined by multiplying 0.17 mg/m³ by the reported number of days worked during this period:

$$\text{Period 3 Dust Exposure} = [0.17 \text{ mg/m}^3 * \text{day(s)}]$$

For Registry workers who reported being present at the lower Manhattan WTC site during Period 4 (September 18, 2001 and December 31, 2001), Job-exposure matrices (Tables 2.6-2.8) were used to assign dust exposure. Total dust exposure for each enrollee was determined by multiplying the dust concentration by the reported number of days worked during this period:

$$\text{Period 4 Dust Exposure} = [\text{mean dust (mg/m}^3) * \text{day(s)}]$$

For Registry workers who reported being present at the lower Manhattan WTC site during Period 5 (January 1, 2002 and June 30, 2002), job-exposure matrices were used

to determine dust exposure. Total dust exposure for each enrollee was determined by multiplying the mean dust concentration (Tables 2.6-2.8) by the reported number of days worked during this period:

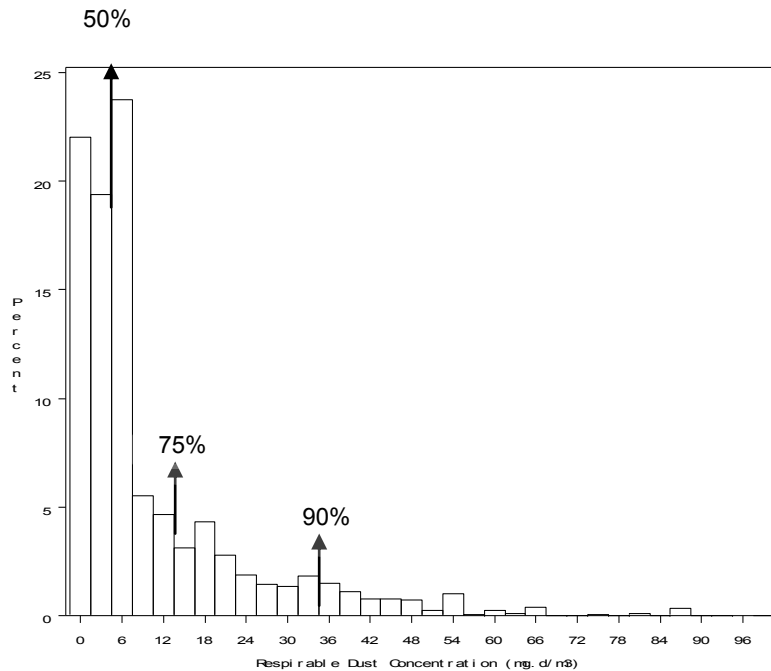
$$\text{Period 5 Dust Exposure} = [\text{mean dust (mg/m}^3\text{)} * \text{day(s)}]$$

Cumulative Dust Exposure Estimation. Cumulative dust exposure (CDE) was determined for each WTC disaster worker in the Registry using the following formula:

$$\text{CDE} = \text{Period 1 Dust Exposure} + \text{Period 2 Dust Exposure} + \\ \text{Period 3 Dust Exposure} + \text{Period 4 Dust Exposure} + \text{Period 5 Dust Exposure}.$$

The frequency plot of cumulative dust exposure is shown in Figure 2.8. Cumulative dust exposures ranged from 0.17 mg-d/m³ to 99.22 mg-d/m³. The mean CDE was 10.1 mg-d/m³ (SD = 14.2 mg-d/m³), the median was 5.5 mg-d/m³, and the mode was mg-d/m³.

Figure 2.8 Frequency Plot of Cumulative Respirable Dust Concentrations



Dust Exposure Index. Based on the distribution of cumulative exposures, chronic dust exposure categories of *Low Dust Exposure*, *Medium Dust Exposure*, and *High Dust Exposure* were assigned to each Registry pile worker. Table 2.9 displays the number of workers in each chronic dust categories. Workers were divided into categories based on the tertiles of distribution of CDE. The *Low Dust Exposure* category was comprised of workers whose CDE was below 1.02 mg-d/m³. The *Medium Dust Exposure* Category included workers whose CDE was between 1.02 mg-d/m³ and 7.31 mg-d/m³. The *High Dust Exposure* category consisted of workers with a CDE above 7.31 mg-d/m³.

Table 2.9 Chronic WTC Dust Exposure Categories

Exposure Category	n	%
High	3,138	33.9
Medium	2,834	30.6
Low	3,286	35.5
Total	9,258	100

Table 2.10 displays the number of workers in each chronic WTC dust exposure categories by WTC Organization Group.

Table 2.10 Chronic WTC Dust Exposure Categories by Organization Group (column %)

	High Exposure		Medium Exposure		Low Exposure		Total*	
Organization Group	N	%	N	%	N	%	n	%
Fire and rescue	1469	46.9	841	29.8	510	15.6	2,820	30.6
EMS and medical, medical examiner	115	3.7	221	7.8	129	3.9	465	5.0
Law Enforcement and military	473	15.1	657	23.2	698	21.3	1,828	19.8
Construction, utilities, remediation	743	23.7	295	10.4	519	15.9	1,557	16.9
Sanitation	78	2.5	79	2.8	312	9.5	469	5.1
Public Agency, not already specified	169	5.4	393	13.9	466	14.3	1,028	11.1
Volunteer and Miscellaneous	84	2.7	341	12.1	637	19.5	1,062	11.5

*n=29 missing organization group data

Firefighters made up 47% of the *High Dust Exposure* category (Table 2.10).

Firefighters (30%) were also the majority group of workers in the of the *Medium Dust Exposure* category followed by Police/Law Enforcement workers (23%). The *Low Dust Exposure* category was predominantly made up of and Law Enforcement and military workers (21%) followed by Volunteers (20%).

Table 2.11 provides mean CDE concentrations by occupational group. Construction workers had the highest mean CDE levels (14.7 mg-d/m³, SD 17.3 mg-d/m³) followed by Fire and rescue workers (13.8 mg-d/m³, SD 15.9 mg-d/m³). Volunteers had the lowest average CDE (3.8 mg-d/m³, SD 7.7 mg-d/m³).

Table 2.11 Mean Cumulative Dust Exposure by Organization Group (column %)

	Cumulative Dust Exposure	Total*	
Organization Group	Mean (SD)	n	%
Fire and rescue	13.8 mg-d/m ³ (15.9)	2,820	30.6
EMS and medical, medical examiner	8.3 mg-d/m ³ (11.6)	465	5.0
Law Enforcement and military	8.5 mg-d/m ³ (11.8)	1,828	19.8
Construction, utilities, remediation	14.7 mg-d/m ³ (17.3)	1,557	16.9
Sanitation	5.5 mg-d/m ³ (11.4)	469	5.1
Public Agency, not already specified	5.4 mg/m ³ (8.9)	1,028	11.1
Volunteer and Miscellaneous	3.8 mg-d/m ³ (7.7)	1,062	11.5

*n=29 missing organization group data

Table 2.12 summarizes the exposure categories by Ground Zero arrival date. While workers who arrived during the fifth exposure time period reported the highest average number of days worked during the period (82.3 days, SD 48.5 days), those who arrived on September 11, 2001 had the highest mean dust exposure per day (0.7 mg/m³, SD 0.9 mg/m³) (Table 2.12).

Table 2.12 Mean Cumulative Dust Exposure by Arrival Date

	Cumulative Dust Exposure	Days Worked	Dust Exposure / Day
Arrival Date	Mean (SD)	Mean (SD)	Mean (SD)
September 11, 2001	14.8 mg-d/m ³ (15.3)	54.3 days (60.5)	0.7 mg/m ³ (0.9)
September 12, 2001	6.0 mg-d/m ³ (11.5)	46.2 days (60.4)	0.2 mg/m ³ (0.2)
September 13, 2001 – September 17, 2001	5.3 mg-d/m ³ (10.9)	47.8 days (64.1)	0.1 mg/m ³ (0.1)
September 18, 2001 – December 31, 2001	16.6 mg-d/m ³ (17.7)	78.9 days (76.8)	0.3 mg/m ³ (0.1)
January 1, 2001 – June 30, 2002	13.6 mg-d/m ³ (9.3)	82.3 days (48.5)	0.2 mg/m ³ (0.05)

Exposure Misclassification Analyses. Sensitivity analyses were conducted to assess the reliability of the predicted chronic exposure categories (Table 2.13). Spearman rank correlation coefficients (with dust exposure categories reported in Table 2.9 as the reference) were determined for the following exposure misclassification scenarios:

Misclassification of Period 1 Exposure. The dust concentration for Period 1 was estimated at 5 mg/m^3 . This concentration was based on an estimated visibility of 1 block on the morning of September 11, 2001 [REF]. Exposure categories were reevaluated using estimates $\frac{1}{2}$ block visibility (Scenario 1 = 10 mg/m^3) and $\frac{1}{4}$ block visibility (Scenario 2 = 20 mg/m^3) for this time period.

Misclassification of Periods 2 and 3 Exposure. Dust concentrations for Periods 2 and 3 were estimated using the geometric mean (0.17 mg/m^3) of monitoring data from OSHA. Exposure categories were reevaluated using estimates an order of magnitude higher (1.70 mg/m^3) than OSHA respirable dust concentrations for these time periods (Scenario 3).

Consolidated Edison reported average area respirable dust concentrations for September 15, 2001 (0.296 mg/m^3) and September 17, 2001 (0.342 mg/m^3) [76]. The mean dust concentration for these samples was 0.320 mg/m^3 . Exposure categories for Periods 2 and 3 were reevaluated by substituting Consolidated Edison sampling mean (0.32 mg/m^3) in place of the OSHA sampling mean (0.17 mg/m^3) for these time periods (Scenario 4).

Misclassification of Firefighter Exposure. Data were not available to fill several Firefighter cells in the job-exposure matrices (Tables 2.7-2.8). Firefighter exposure may have been assigned to a lower exposure category

because of missing data. Firefighters were excluded from the analytical dataset, and exposure categories were reevaluated for the worker subset without firefighters (Scenario 5).

Misclassification of Exposures prior to September 18, 2001. Dust concentrations for Periods 1, 2, and 3 were based on a review of the literature and available environmental monitoring data. These estimates were estimated using statistical models and area samples. Dust exposure categories were reevaluated for a subset of workers excluding those who arrived on September 11, 2001 (Scenario 6), workers who arrived before September 13, 2001 (Scenario 7), and workers who arrived before September 18, 2001 (Scenario 8).

Exposure misclassification scenarios are presented in Table 2.13. Results of these sensitivity analyses indicate that exposure misclassification was limited using this semi-quantitative exposure assessment approach. All scenarios were highly correlated to the Dust Exposure Categories with Spearman correlation coefficients ranging from 0.826 (Scenario 8) to 0.970 (Scenario 1).

Table 2.13 Exposure Misclassification Scenarios

	Total (n)	Spearman's rank coefficient
Reference Scenario: Dust Exposure Categories (Table 2.9)	9,258	1.000
Scenario 1. Period 1 = 10 mg/m ³ instead of 5 mg/m ³	9,258	0.970
Scenario 2. Period 1 = 20 mg/m ³ instead of 5 mg/m ³	9,258	0.938
Scenario 3. Periods 2 & 3 = 1.70 mg/m ³ instead of 0.17 mg/m ³	9,258	0.834
Scenario 4. Periods 2 & 3 - ConEd instead of OSHA data	9,258	0.927
Scenario 5. Subset excluding Firefighters	6,654	0.960
Scenario 6. Subset excluding those who arrived on 9/11/2001	5,638	0.855
Scenario 7. Subset excluding those who arrived before 9/13/2001	2,925	0.872
Scenario 8. Subset excluding those who arrived before 9/18/2001	741	0.826

2.3 Outcome Assessment

Respiratory Symptoms. Respiratory symptoms were self-reported by enrollees at both survey waves (Wave One: 2003 = 2004 and Wave Two: 2006 = 2007). Enrollees reported any new respiratory symptom(s) after September 11, 2001 during the Wave One interview. Table 2.14 presents the Wave One symptom questions.

Table 2.14 New Respiratory Symptoms after September 11, 2001 Questions (Wave One)

Symptom	Question
Persistent Cough	Since 9/11, have you had persistent cough?
Shortness of Breath	Since 9/11, have you had shortness of breath?
Wheezing	Since 9/11, have you had wheezing?
Eye Irritation	Since 9/11, have you had eye irritation?
Sinus problems, nose irritation, or post-nasal irritation	Since 9/11, have you had sinus problems, nose irritation, or post nasal irritation?
Throat Irritation	Since 9/11, have you had throat irritation?

During the Wave Two survey, enrollees were asked whether they experienced respiratory symptoms in the last 30 days. Table 2.15 presents the Wave Two symptom questions.

Each symptom (persistent cough, shortness of breath, wheezing, heartburn, eye irritation, sinus problems, or throat irritation) was assessed as a dichotomous outcome, with an affirmative response indicating the presence of a symptom. In addition, symptoms were classified into lower (any persistent cough, shortness of breath, or wheezing) and upper (any eye irritation, sinus problems, or throat irritation) respiratory symptom categories.

Table 2.15 Respiratory Symptoms in the last 30 days Questions (Wave Two)

Symptom	Question(s)
Persistent Cough	Have you experienced a persistent cough in the last 30 days?
Shortness of Breath	Have you experienced any of these symptoms in the last 30 days? Choice F. Shortness of Breath?
Wheezing	Have you experienced any of these symptoms in the last 30 days? Choice I. Wheezing?
Eye Irritation	Not Asked
Sinus Problems, nose post-nasal irritation (Sinus Problems)	Have you experienced any of these symptoms in the last 30 days? Choice D. Sinus Problems?
Throat Irritation	Have you experienced any of these symptoms in the last 30 days? Choice G. Throat Irritation?

Longitudinal Course of Respiratory Symptoms. The longitudinal course of respiratory symptoms through Wave Two was characterized as Recurrent (affirmative response to symptom question(s) at both waves), Resolved (affirmative response to symptom question(s) at Wave One only), Late Onset (affirmative response to symptom question(s) at Wave Two only), and Asymptomatic (no affirmative response to symptom question(s) at both waves).

Respiratory Disease Outcomes. Respiratory diseases after September 11, 2001 were assessed from the responses to the self-administered Wave Two Survey. Enrollees with pre-existing allergic rhinitis, asthma (including RADS, Reactive Airways

Dysfunction Syndrome) or Chronic Obstructive Pulmonary Disease (chronic bronchitis, emphysema) were excluded from disease outcome analyses.

Enrollees with newly diagnosed respiratory diseases after September 11, 2001 were identified by self-report of a physician diagnosis. The respiratory diseases examined in these analyses included allergic rhinitis, asthma (including RADS, Reactive Airways Dysfunction Syndrome) or Chronic Obstructive Pulmonary Disease (chronic bronchitis, emphysema), and chronic bronchitis. Table 2.16 presents the Wave Two disease outcome questions.

Table 2.16 Newly Diagnosed Respiratory Disease Outcome Questions (Wave Two)

Symptom	Question(s)
Allergic Rhinitis	Have you ever been told by a doctor or other health professional that you had Hay Fever or Allergic Rhinitis? <u>and</u> Was this before September 11, 2001?
Asthma (including RADS)	Have you ever been told by a doctor or other health professional that you had Asthma? RADS? <u>and</u> Was this before September 11, 2001?
Reactive Airways Dysfunction Syndrome (RADS)	Have you ever been told by a doctor or other health professional that you had RADS? <u>and</u> Was this before September 11, 2001?
Chronic Obstructive Pulmonary Disease (COPD)	Have you ever been told by a doctor or other health professional that you had Chronic Bronchitis? Emphysema? <u>and</u> Was this before September 11, 2001?
Chronic Bronchitis	Have you ever been told by a doctor or other health professional that you had Chronic Bronchitis? <u>and</u> Was this before September 11, 2001?

Affirmative responses to symptom and diseases questions were coded as 1. All other responses, including the response of “don’t know”, were coded as 0. For all analyses, missing respiratory outcome data was also coded as 0 to get the best estimates assuming missing responses meant no disease outcome. The proportion of missing outcome data ranged from 1% (lower respiratory symptoms) to 6.2% (allergic rhinitis). Sensitivity analyses were conducted by excluding enrollees with missing outcome data to explore the robustness of results.

2.3 Statistical Analyses

Multivariable Analyses using Prevalence Ratios as the Measure of Effect.

The odds ratio is a measure of association that is commonly used in case-control studies to approximate relative risk. In cross-sectional studies, the prevalence odds ratio is the ratio of the proportion of a population that has a disease to the proportion of the population that does not have the disease [77, 78] (Table 2.17). It has also been shown that the prevalence odds is equal to the incidence rate times the mean duration of an illness [77, 78].

Table 2.17 Contingency Table for Cross-sectional Studies [78]

	Exposed	Non-exposed	Total
Present	a	b	M_1
Absent	c	d	M_0
Total	N_1	N_0	T
Prevalence among the exposed: $P_1 = a/N_1$			
Prevalence among the unexposed: $P_0 = b/N_0$			
Prevalence odds ratio: $POR = (P_1/(1 - P_1))/(P_0/(1 - P_0)) = I'D$			
Prevalence ratio: $PR = (a/N_1)/(b/N_0)$			

If the prevalence is small (<10 percent) and there is no migration in or out of the prevalence pool, then the prevalence odds will approximate the prevalence ratio, and the prevalence odds ratio can be used in cross-sectional studies [77, 78].

It is rare, however, that a prevalence pool remains in a steady state, a condition in which the incidence rate and disease duration are constant over time [78, 79]. The prevalence of an outcome may be a function of a factor that affects migration in or out of the pool. Rothman cites age-related diseases as examples of outcomes that may violate the steady state assumption as age may affect migration in and out of the pool [77]. Another example of a potential violation of the steady state assumption occurs when workers take steps to reduce their symptoms according to their exposure status [78]. The duration of a disease could differ by exposure status, the duration would not

be constant over time, and as a result, the prevalence odds ratio would not approximate the relative risk. The prevalence ratio was chosen as a measure of association between chronic dust exposure and respiratory outcomes because of its appropriateness for comparing multiple groups in cross-sectional studies [77, 80].

When studying outcomes in a cross-sectional study, Logistic Regression and Log-binomial Regression are two models commonly used to estimate prevalence ratios (Table 2.18). Proportional Hazards Regression was not an option for this study because of limited time to event data.

Table 2.18 Comparison of Logistic Regression to Log-binomial Regression

	Logistic Regression	Log-binomial Regression
Error Distribution	Binomial	Binomial
Link function	Logit $\ln(P/(1-P)) = a + b \cdot X$	Log $\log(P) = a + b \cdot X$
Measure of association	Odds Ratio $\exp(b) = (P_1/(1 - P_1))/(P_0/(1 - P_0))$	Prevalence/`Risk Ratio $\exp(b) = P_1/P_0$
Strengths	Model relatively easy to use. Available in most statistical software.	Direct estimate of the relative risk
Limitations	Overestimation of the relative risk when outcome prevalence > 10%	Failure to converge when Maximum Likelihood Estimate is outside restricted parameters
Study Type	Case-control study Cohort study Cross-sectional study	Cohort study Cross-sectional study

Limitations associated with Logistic Regression Modeling. There are several limitations associated with using Logistic Regression modeling to estimate the

prevalence ratio. First, in studies of outcomes common (> 10 percent) in the study population, the odds ratio can overestimate the prevalence ratio. Second, because confounding and interaction are dependent on the measure of effect, controlling for a variable may have an effect on the odds ratio that is statistically different from its effect on the prevalence ratio. Theoretically, the choice of the measure of effect (odds ratio versus prevalence ratio) could therefore have an impact on whether a covariate is recognized as a confounder or an effect modifier [79, 81, 82].

An additional limitation involves the interpretation of the odds ratio. Interpreting the odds ratio as a measurement of risk can be misleading, especially with regard to implications for public health policy. For example, if the prevalence ratio is 5, the proper interpretation is that "exposed" participants in the study population are 5 times more likely to report the outcome in question than "unexposed" participants.

However, if the odds ratio is 5, the proper interpretation is that the outcome ratio (outcome/no outcome) in the "exposed" population is 5 times as high as the outcome ratio in the "unexposed" population. Especially when comparing the results among different studies and outcomes, prevalence ratios are more germane to public health communication than odds ratios.

Log-Binomial Regression Modeling of Prevalence Ratios. The Log-Binomial model directly estimates the relative risk while allowing for the adjustment of several confounders and the assessment of effect modification. Spiegelman and Hertzmark

have demonstrated that the GENMOD procedure in the analysis software, SAS (SAS Institute, Cary, North Carolina) can be used to estimate the prevalence ratio through log-binomial regression modeling [83]. Furthermore, in the rare instances where the log binomial model fails to converge, Spiegelman and Hertzmark have recommended a Poisson link function and Peterson and Daddens have developed a SAS macro to fit the Log-binomial model [84, 85].

In these analyses, multivariable log-binomial regression was used to estimate adjusted prevalence ratios for each chronic dust exposure category. Prevalence ratios, accompanied by 95% confidence intervals, were calculated for the ‘High’ and ‘Medium’ chronic dust exposure categories with the ‘Low’ dust category as the referent category. The statistical software package, SAS version 9.1.3 (SAS Institute, Cary, NC), was used to carry out all statistical analyses.

Model Building Strategy. Multivariate models for each outcome were developed. In order to permit uniform comparisons among the outcomes, covariates that had been shown to be associated with reported symptoms and diseases among WTC disaster workers were included in all models. These covariates for adjustment include the variables of gender, dust cloud, age group, race/ethnicity, education, smoking status, NYC residence on September 11, and respirator use after September 11 (see Appendix B for survey questions).

The dust cloud variable was based on dust cloud questions from the Wave One and Wave Two surveys. At Wave One, workers reported their geographical location within the dust cloud on the morning of September 11, 2001. Reported locations were geocoded, and a presence in the dust cloud was defined as a location within 2 standard deviational ellipses from the WTC site [56]. At Wave Two, workers were asked additional questions about their experiences within the dust cloud (see Appendix B for survey questions). Based on the reported location at Wave One and the dust cloud questions at Wave Two, the dust cloud was classified into three categories at Wave Two; Intense dust cloud, Some dust cloud, and No dust cloud [58].

Reference levels for covariates were: Female (gender), 18-24 yrs old (age group), White, non-Hispanic (race/ethnicity), Some High School or below (education), Never smoked (smoking status), Non-NYC residence (NYC residence on September 11), No dust cloud exposure (presence in the September 11 dust cloud), and No respirator use (respirator use after September 11).

Effect modification of the relationship between chronic dust exposure categories and symptom risk at Wave One was evaluated by gender, dust cloud exposure (present in the dust cloud versus not present in the dust cloud), PTSD status (probable PTSD versus no probable PTSD, see Appendix B for definition), smoking status (ever smoker versus never smoker), and Respirator use (respirator use versus no respirator use). Multiplicative interaction terms between the dichotomous modifier variable and

the dust exposure categories were included in the model. If the interaction terms were statistically significant (p value <0.05), results stratified by the effect modifier were reported.

Respiratory Symptoms at Wave One. For each respiratory symptom (shortness of breath, wheezing, persistent cough, heartburn, sinus problems, eye irritation, or throat irritation) and symptom category (lower respiratory or upper respiratory), the period prevalence between September 11, 2001 and the Wave One survey (2003-2004) was determined. Multivariable log-binomial regression for each symptom outcome was used to estimate adjusted prevalence ratios for lower and upper respiratory symptoms for each chronic dust exposure category. Interactions between chronic dust exposure categories, gender (male versus female), dust cloud (dust cloud versus no dust cloud), PTSD status (probable PTSD versus no PTSD), smoking status (ever smoker versus never smoker), and respirator use (respirator use versus no respirator use) were evaluated.

Respiratory Symptoms at Wave Two. For each respiratory symptom (shortness of breath, wheezing, persistent cough, heartburn, sinus problems, or throat irritation) and symptom category (lower respiratory and upper respiratory), 30-day prevalences at Wave Two (2006-2007) were determined. Multivariable log-binomial regression for each symptom outcome was used to estimate adjusted prevalence ratios for lower and upper respiratory symptoms for each chronic dust exposure category. Interactions

between chronic dust exposure categories, gender (male versus female), dust cloud (dust cloud versus no dust cloud), PTSD status (probable PTSD versus no PTSD), smoking status (ever smoker versus never smoker), and respirator use (respirator use versus no respirator use) were evaluated.

Longitudinal Course of Respiratory Symptoms. The course (Recurrent, Early Onset, Late Onset, or Asymptomatic) of respiratory symptoms was determined for each dust exposure category. For each individual symptom (shortness of breath, wheezing, persistent cough, heartburn, sinus problems, eye irritation, or throat irritation) and each symptom category (lower respiratory and upper respiratory), the Cochran–Armitage test for trend was used to examine the exposure-response relationship between dust exposure category and symptom outcomes. A 2-sided *p value* less than 0.05 was considered statistically significant.

Respiratory Disease Outcomes. The incidence of each disease outcome, allergic rhinitis, asthma (including RADS), RADS only, COPD (chronic bronchitis and emphysema), and chronic bronchitis only, between September 11, 2001 and the Wave Two survey was determined.

Multivariable log-binomial regression was used to estimate adjusted prevalence ratios for the ‘High’ and ‘Medium’ chronic dust exposure categories, with the ‘Low’

category as the referent category. Covariates for adjustment include the variables of gender, dust cloud, age group, race/ethnicity, education, smoking status, NYC residence on September 11, and respirator use after September 11 (see Appendix B for survey questions).

Interactions between chronic dust exposure categories, gender (male versus female), dust cloud (dust cloud versus no dust cloud), PTSD status (probable PTSD versus no PTSD), smoking status (ever smoker versus never smoker), and respirator use (respirator use versus no respirator use) were evaluated. Stratified results were reported by modifying variables (p value <0.05).

Sensitivity Analyses. Wave Two surveys were conducted five to seven years after the events of September 11. Respiratory health outcomes were self-reported, and responders to the Wave Two survey may have been more likely to report respiratory outcomes than nonresponders if participation was motivated by poor health status. The following sensitivity analyses were conducted to examine potential biases:

Response Bias. There was the potential for reporting excess respiratory health outcomes among rescue and recovery workers, a group that has many incentives through workers compensation programs to report symptoms after 9/11 (i.e. workers in the “High Exposure” category may have been more inclined to report more respiratory outcomes than workers in the “Low

Exposure” category). Prevalence ratios for a non-WTC covered condition [86], newly-diagnosed Diabetes after September 11, 2001, were reported.

Enrollment Bias. The Registry used multiple methods for recruitment including public health outreach, collection of lists of eligible persons, and self-identification. Stratified analyses by mode of enrollment (i.e. list-identification versus self -identification) were conducted to examine possible selection and reporting bias.

Exposure Assessment. Respirable dust exposure was estimated for several time periods prior to when OSHA data collection began. Prevalence ratios for selected respiratory outcomes were evaluated using the exposure group assignments from Exposure Misclassification Scenario 3 (Periods 2 and 3 estimates an order of magnitude higher (1.70 mg/m^3) than OSHA respirable dust concentrations (0.17 mg/m^3)), Exposure Misclassification Scenario 6 (Workers who arrived before September 12, 2001 excluded from the analytical dataset), and Exposure Misclassification Scenario 8 (Workers who arrived before September 18, 2001 excluded from the analytical dataset) (see Table 2.13 for Exposure Misclassification Scenarios).

CHAPTER 3

RESULTS

3.1 Wave Two Participation Rates

A total of 6,930 (74.9% participation rate) WTC pile workers completed the Registry's Wave Two survey between November 2007 and December 2008. There were significant demographic differences between participants and non-participants (Table C.1). Wave Two participants were more likely to be non-Hispanic white, older, wealthier, more educated, and married (all $p < 0.0001$). Workers who had never smoked at Wave One were more likely to participate in Wave Two than former and current smokers ($p < 0.0001$). There were no significant differences in participation rates by gender ($p = 0.55$) (Table C.1)

Workers whose primary residence was outside of New York City on September 11, 2001 were more likely to participate in the Wave Two survey than New York City residents ($p < 0.0001$) (Table C.2). Wave Two participants were more likely to have been present in the dust and debris cloud on the morning of September 11, 2001 ($p = 0.005$). Fire and rescue affiliated workers (83.4%) had the highest Wave Two participation rate, followed by EMS and medical workers (80.0%), Public agency workers (76.5%), Law enforcement and military workers (75.4%), Volunteers (71.0%), and Construction workers (63.1%). Sanitation affiliated workers had the lowest Wave Two participation rate at 62.5%. There was no significant difference

between participants and non-participants with respect to mask use ($p=0.13$) (Table C.2).

Participation also varied by method of enrollment in the Registry. List-identified workers were less likely to participate in the Wave Two survey than self-identified workers (63.1% versus 78.3%, $p < 0.0001$) (Table C.3).

Wave Two participation was examined jointly by exposure group and symptom status at Wave One (Table C.4). Workers in the Low Exposure group who reported at least one respiratory symptom at Wave One (participation rate 71.8%) were less likely to participate in the Wave Two survey than all of the other exposure-symptom groups ($p = 0.003$) (Table C.4). There were no significant differences in participation rates among the other five exposure-symptom groups (participation rate range: 75.3%-78.0%, $p = 0.79$) (Table C.4).

3.2 Characteristics of the Study Population

The study population was made up of the 6,930 rescue, recovery, and cleanup workers who completed both the Wave One and Wave Two surveys. Demographic characteristics of the study population are displayed in Table 3.1. Approximately 94% of participants were men. The average age at Wave Two was 45.2 years ($SD = 8.7$ years, min. = 22 years, max. = 100). Non-Hispanic Whites made up 82.1% of the study population, followed by Hispanic (9.5%), and Non-Hispanic Blacks (4.3%).

Table 3.1 Demographic Characteristics of the Study Population by Dust Exposure Group (n=6,930)

	Low		Medium		High		Total		
	n	%	n	%	N	%	n	%	p value*
Gender									<0.0001
Male	2,144	89.8	2,028	93.7	2,327	97.9	6,499	93.8	
Female	244	10.2	136	6.3	51	2.1	431	6.2	
Age Group									<0.0001
< 30	178	7.5	168	7.8	112	4.7	468	6.6	
30 - 34	277	11.6	267	12.3	280	11.8	824	11.9	
35 - 39	449	18.8	404	18.7	478	20.1	1,331	19.2	
40 - 44	498	20.9	502	23.2	586	24.6	1,586	22.9	
45 - 49	441	18.5	424	19.6	503	21.2	1,368	19.7	
50 - 54	284	11.9	229	10.6	241	10.1	754	10.9	
55+	261	10.9	170	7.9	178	7.5	609	8.8	
Race / Ethnicity									
White, Non-Hispanic	1,885	78.9	1,759	81.3	2,042	85.9	5,686	82.1	<0.0001
Black, Non-Hispanic	121	5.1	95	4.4	83	3.5	299	4.3	
Hispanic	287	12.0	204	9.4	165	6.9	656	9.5	
Asian	29	1.2	34	1.6	26	1.1	89	1.3	
Multiracial	26	1.1	33	1.5	33	1.4	92	1.3	
Other	40	1.7	39	1.8	29	1.2	108	1.6	
Household Income									<0.0001
< \$25,000	98	4.1	77	3.6	32	1.4	207	3.0	
\$25,000-< \$50,000	311	13.0	251	11.6	180	7.6	742	10.7	
\$50,000-< \$75,000	607	25.4	510	23.6	526	22.1	1,643	23.7	
\$75,000-< \$150,000	1,089	45.6	1,044	48.2	1,349	56.7	3,482	50.3	
\$150,000+	131	5.5	145	6.7	142	6.0	418	6.0	
Missing	152	6.4	137	6.3	149	6.3	438	6.3	

*Chi – Square test comparing exposure groups

Table 3.1 continued Demographic Characteristics of the Study Population by Dust Exposure Group

	Low		Medium		High		Total		
	n	%	n	%	n	%	n	%	<i>p</i> value*
Education									0.002
non High School Graduate	74	3.1	55	2.5	83	3.5	212	3.1	
High School Graduate	625	26.2	502	23.2	601	25.3	1,728	24.9	
Some College	800	33.5	810	37.4	910	38.3	2,520	36.4	
College grad / post Graduate	875	36.6	780	36.0	768	32.3	2,423	35.0	
Marital Status									<0.0001
Married / Cohabiting	1,751	74.0	1,619	75.3	1,943	82.1	5,314	77.1	
Divorced / Widowed / Separated	239	10.1	229	10.7	207	8.8	675	9.8	
Never Married	384	16.2	302	14.1	216	9.1	902	13.1	
Smoking Status**									0.17
Never Smoker	1,252	71.8	1242	74.8	1,367	75.6	3,861	74.1	
Former Smoker	109	6.3	96	5.8	106	5.9	311	6.0	
Resumed Smoker	86	4.9	72	4.3	65	3.6	223	4.3	
Consistent Smoker	297	17.0	251	15.1	270	14.9	818	15.7	

*Chi – Square test comparing exposure groups

** Smoking Status at Wave Two. Former Smoker reported lifetime smoking prior to Wave Two. Resumed Smoker did not report smoking at Wave One and reported smoking at Wave Two. Consistent Smoker reported smoking at Wave One and Wave Two.

Compared to Medium and Low dust exposed workers, High dust exposed workers were more likely to be men, significantly older, and Non-Hispanic White (all $p < 0.0001$). More than half of the study population reported a household income greater than \$75,000. High income participants were more likely to be classified as High dust exposed than participants with incomes below \$75,000 (Table 3.1).

Approximately 71% of Registry pile workers reported some or more college education. Married workers represented 77.1% of the study population, and a significantly higher proportion (82.1%, $p < 0.0001$) of the High dust exposure group. At Wave Two, 20% (4.3% Resumed and 15.7% Consistent) of workers were current smokers. There was no significant difference between the dust exposure groups with regard to smoking status ($p = 0.17$) (Table 3.1).

New York City residency status on September 11 was examined as a surrogate for access to New York City area monitoring and treatment programs. Workers whose primary residence was outside of New York City on September 11, 2001 made up 57.6% of the study population (Table 3.2). The remaining participants lived in New York City, with approximately 1.3% of these residents living near the WTC site in Lower Manhattan below Canal street. Over 40% of Registry pile workers reported that they were in the dust and debris cloud on the morning of September 11, 2001 (31.9% Intense dust cloud, 9.6% Some dust cloud).

Approximately 30% of Registry pile workers reported wearing a respirator during their WTC-related work. Respirator use significantly differed by dust exposure category, with high dust exposed workers more likely to have reported wearing a respirator than medium and low dust exposed workers ($p < 0.0001$) (Table 3.2).

Table 3.2 Peri-disaster Characteristics of the Study Population by Dust Exposure Group

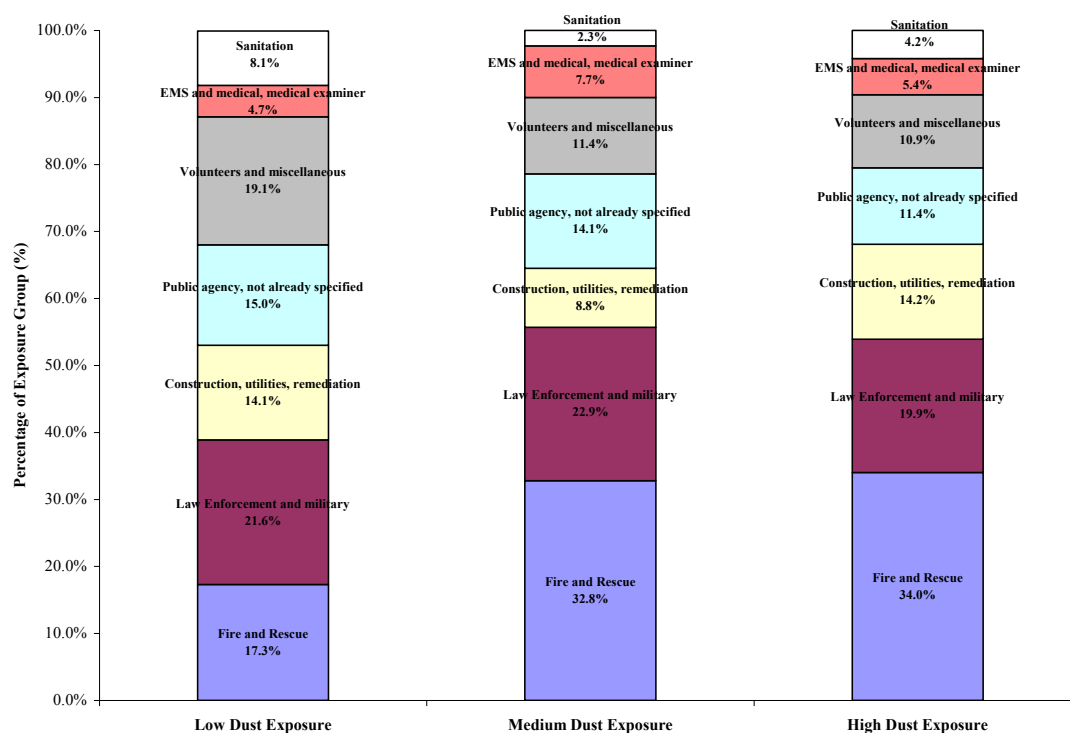
	Low		Medium		High		Total		
	n	%	n	%	n	%	n	%	<i>p</i> value*
Residence on 9/11									<0.0001
Lower Manhattan below Canal	43	1.8	35	1.6	10	0.4	88	1.3	
New York City	979	41.0	887	41.0	987	41.5	2,853	41.2	
Outside New York City	1,366	57.2	1,242	57.4	1,381	58.1	3,989	57.6	
Dust Cloud Experience									<0.0001
Intense	316	13.9	867	42.5	905	40.5	2,088	31.9	
Some	168	7.4	224	11.0	233	10.4	625	9.6	
None	1,786	78.7	949	46.5	1,096	49.1	3,831	58.5	
Occupational Group									<0.0001
Fire and rescue	413	17.3	708	32.8	1,231	51.8	2,352	34.0	
EMS and medical, medical examiner	112	4.7	167	7.7	93	3.9	372	5.4	
Law Enforcement and military	515	21.6	494	22.9	370	15.6	1,379	19.9	
Construction, utilities, remediation	336	14.1	191	8.8	456	19.2	983	14.2	
Sanitation	194	8.1	49	2.3	50	2.1	293	4.2	
Public Agency, not already specified	357	15.0	305	14.1	124	5.2	786	11.4	
Volunteers and miscellaneous	455	19.1	246	11.4	53	2.2	754	10.9	
Respirator Use									<0.0001
Yes	417	17.5	544	25.1	1,135	47.7	2,096	30.3	

*Chi – Square test comparing exposure groups

Over one-third (34.0%) of the study population were affiliated with Fire and rescue organizations at the WTC site (Table 3.2). Fire and rescue workers were more likely to be represented in the High and Medium dust exposure groups than the Low

exposure group ($p < 0.0001$). Volunteers made up approximately 11% of the study population and were more likely to be a part of the Low dust exposure group compared to the High and Medium dust exposure groups (Figure 3.1).

Figure 3.1 Occupational Groups of the Study Population by Dust Exposure Group



At Wave Two, self-identified enrollees made up 80.9% of the study population (Table 3.3). A higher proportion of self-identified workers (34%, 1963/5603) were in the High exposure group than list-identified workers (31.3%, 415/1327).

Workers completed the Wave Two survey through three modes: Mail, Web, and

Phone (Computer-Assisted Telephone Interview). Mail (49.7%) was the most popular survey mode, followed by Web (39.5%), and Phone (10.8%). Wave Two survey mode differed by exposure groups as High dust exposed workers were more likely to complete the survey by mail and Low dust exposed workers were more likely to complete the survey by phone ($p < 0.0001$) (Table 3.3).

Table 3.3 Enrollment and Mode Characteristics of the Study Population by Dust Exposure Group

	Low		Medium		High		Total		
	N	%	n	%	n	%	n	%	<i>p</i> value*
Method of WTC Health Registry Enrollment									<0.0001
List - Identified	570	23.9	342	15.8	415	17.5	1,327	19.2	
Self - Identified	1,818	76.1	1,822	84.2	1,963	82.6	5,603	80.9	
Mode of WTC Health Registry Wave 2 Survey									<0.0001
Mail	1,124	47.1	1,022	47.2	1,299	54.6	3,445	49.7	
Web	967	40.5	931	43.0	837	35.2	2,735	39.5	
Phone (Computer-Assisted Telephone Interview)	297	12.4	211	9.8	242	10.2	750	10.8	

*Chi – Square test comparing exposure groups

3.3 Respiratory Symptoms

Registry enrollees self-reported the new-onset of lower (persistent cough, shortness of breath, wheezing) and upper (eye irritation, sinus irritation, throat irritation) respiratory symptoms after September 11, 2001 at Wave One. At Wave Two, enrollees self-reported the present of lower (persistent cough, shortness of breath,

wheezing) and upper (sinus irritation, throat irritation) respiratory symptoms in the 30 days before the survey.

The following respiratory symptom outcomes are presented in this section: lower and upper respiratory symptoms at Wave One, lower and upper respiratory symptoms at Wave Two, and the longitudinal course of lower and upper respiratory symptoms at Wave Two.

Respiratory Symptoms at Wave One. The prevalence of new-onset respiratory symptoms among WTC pile workers at Wave One is shown in Table 3.4. Of the 6,930 workers in the study population, 71.2% (n=4,937) reported at least one new-onset lower respiratory symptom and 66.5% (n=4,605) reported at least one new-onset upper respiratory symptom after September 11, 2001.

Table 3.4 Prevalence of New-onset Respiratory Symptoms after September 11, 2001 at Wave One (n = 6,930)

Symptom Group	N	%
Lower Respiratory (any)	4,937	71.2
Persistent Cough	3,479	50.2
Shortness of Breath	3,753	54.2
Wheezing	3,636	52.5
Upper Respiratory (any)	4,605	66.5
Eye Irritation	2,446	35.3
Sinus Problems	3,120	45.0
Throat Irritation	3,229	46.6

Lower Respiratory Symptoms (any). Shortness of breath (54.2%) was the most commonly reported lower respiratory symptom, followed by wheezing (52.5%), and persistent cough (50.2%). Table 3.5 presents the prevalence ratios for new-onset lower respiratory symptoms after September 11, 2001. Compared to the Low dust exposure group, the adjusted prevalence ratios for reporting new-onset lower respiratory symptoms at Wave One was 1.44 (95% CI, 1.29-1.61) for the High exposure group and 1.27 (95% CI, 1.18-1.37) for the Medium exposure group (p trend <0.0001).

Table 3.5 Prevalence Ratios of Lower Respiratory Symptoms (any) at Wave One (n=6,930)

Peri-Disaster Experiences						
	n	%	Crude PR (95% CI)		Adjusted* PR (95% CI)	
Chronic Dust Exposure						
High	1935	81.4	1.44	1.32-1.57	1.44	1.29-1.61
Medium	1513	69.9	1.28	1.20-1.35	1.27	1.10-1.25
Low	1489	62.4	Reference		Reference	
Dust Cloud on 9/11						
Intense	1715	82.1	1.25	1.20-1.30	1.27	1.15-1.40
Some	442	70.7	1.15	1.13-1.19	1.17	1.05-1.18
None	2481	64.8	Reference		Reference	
Respirator Use						
Yes	1568	74.8	1.07	1.01-1.14	1.01	0.95-1.07
No	3369	69.7	Reference		Reference	
Residence on 9/11						
Lower Manhattan	62	70.4	0.93	0.89-0.98	0.96	0.91-1.02
New York City	2127	74.6	0.87	0.78-0.97	0.92	0.82-1.03
Outside New York City	2748	68.9	Reference		Reference	
Enrollment Characteristics						
	n	%	Crude PR (95% CI)		Adjusted* PR (95% CI)	
Method of Enrollment						
List	4112	73.4	1.18	1.10-1.27	1.18	1.09-1.27
Self	825	62.2	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment characteristics.

Table 3.5 continued Prevalence Ratios of Lower Respiratory Symptoms (any) at Wave One (n=6,930)

Demographic Characteristics	n	%	Crude PR	(95% CI)	Adjusted* PR	(95% CI)
Gender						
Male	4630	71.2	1.00	0.89-1.12	0.93	0.83-1.05
Female	307	71.2	Reference		Reference	
Age at Wave One						
55+	434	71.3	1.11	1.00-1.23	1.12	1.01-1.25
50-54	537	71.2	1.09	1.00-1.18	1.10	1.01-1.21
45-49	1000	73.1	1.07	1.00-1.15	1.08	1.01-1.16
40-44	1175	74.1	1.05	1.00-1.11	1.06	1.01-1.12
35-59	950	71.4	1.03	1.00-1.07	1.04	1.00-1.08
30-34	570	69.2	1.02	1.00-1.03	1.02	1.00-1.04
<30	271	59.2	Reference		Reference	
Race / Ethnicity						
Black, Non-Hispanic	209	69.9	1.11	0.94-1.31	1.15	0.96-1.36
Hispanic	490	74.7	1.09	0.95-1.23	1.12	0.97-1.30
Asian	60	67.4	1.07	0.96-1.20	1.10	0.98-1.23
Multiracial	71	77.2	1.05	0.97-1.15	1.07	0.98-1.17
Other	84	77.8	1.04	0.98-1.09	1.05	0.99-1.11
White, non-Hispanic	4023	70.8	Reference		Reference	
Education						
non High School Graduate	158	74.5	0.96	0.93-0.99	0.96	0.92-0.99
High School Graduate	1272	73.6	0.92	0.86-0.98	0.92	0.86-0.99
Some College	1848	73.3	0.88	0.80-0.97	0.89	0.80-0.98
College grad / post Graduate	1625	67.1	Reference		Reference	
Smoking Status at Wave One						
Current	884	78.0	1.11	1.03-1.19	1.12	1.03-1.20
Former	1301	70.6	1.05	1.01-1.09	1.06	1.02-1.10
Never	2730	69.6	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment characteristics.

Presence in the dust cloud on the morning of September 11, 2001 was also a significant independent predictor of lower respiratory symptoms, along with age, education, and smoking. List-identified workers who enrolled in the registry were more likely to report lower respiratory symptoms than Self-identified workers (Table 3.5).

Effect Modification Analyses. The effect of chronic WTC dust exposure on new-onset Lower respiratory symptoms was not modified by dust cloud, gender, PTSD status, smoking status, or respirator use. (Tables D.1-D.5).

Upper Respiratory Symptoms (any). Among reported upper respiratory symptoms at Wave One, throat irritation (46.6%) was the most common symptom, followed by sinus problems (45.0%) and eye irritation (35.3%)(Table 3.4). Approximately 76% of the High dust exposure group, 64% of the Medium dust exposure group, and 59% of the Low dust exposure group reported at least one new upper respiratory symptom (Table 3.6).

After adjustment for demographic characteristics, peri-disaster experiences, and enrollment characteristics, there was a significant exposure-response trend in new-onset upper respiratory symptom risk with High exposure ($PR_{adj} = 1.40$, 95% CI=1.31-1.49) and Medium exposure ($PR_{adj} = 1.25$, 95% CI=1.19-1.31) workers more likely to report symptoms than Low exposure workers (Table 3.6).

The dust cloud was a significant predictor of upper respiratory symptoms (Intense dust cloud $PR_{adj} = 1.26$, 95% CI=1.19-1.33; Some dust cloud $PR_{adj} = 1.17$, 95% CI=1.12-1.21). Significant demographic characteristics included gender (Female), age, race/ethnicity (non-White, non-Hispanic), and Education. List enrollment was also a significant independent predictor of Upper respiratory symptoms (Table 3.6).

Table 3.6 Prevalence Ratios of Upper Respiratory Symptoms (any) at Wave One (n=6,930)

Peri-Disaster Experiences						
	n	%	Crude PR (95% CI)		Adjusted* PR (95% CI)	
Chronic Dust Exposure						
High	1809	76.1	1.47	1.39-1.54	1.40	1.31-1.49
Medium	1378	63.7	1.29	1.25-1.34	1.25	1.19-1.31
Low	1418	59.4	Reference		Reference	
Dust Cloud on 9/11						
Intense	1602	76.7	1.27	1.21-1.33	1.26	1.19-1.33
Some	415	66.4	1.17	1.13-1.21	1.17	1.12-1.21
None	2315	60.4	Reference		Reference	
Respirator Use						
Yes	1456	69.5	1.07	1.03-1.10	1.01	0.97-1.04
No	3149	65.1	Reference		Reference	
Residence on 9/11						
Lower Manhattan	61	69.3	0.91	0.88-0.94	0.95	0.92-0.98
New York City	2013	70.6	0.83	0.78-0.88	0.90	0.85-0.96
Outside New York City	2531	63.5	Reference		Reference	
Enrollment Characteristics						
	n	%	Crude PR (95% CI)		Adjusted* PR (95% CI)	
Method of Enrollment						
List	3816	68.1	1.15	1.09-1.20	1.10	1.05-1.15
Self	789	59.5	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment characteristics.

Table 3.6 continued Prevalence Ratios of Upper Respiratory Symptoms (any) at Wave One (n=6,930)

Demographic Characteristics	n	%	Crude PR (95% CI)		Adjusted* PR (95% CI)	
Gender						
Male	4295	71.9	0.92	0.86-0.98	0.89	0.85-0.94
Female	310	66.1	Reference		Reference	
Age at Wave One						
55+	408	67.0	1.06	1.00-1.13	1.08	1.01-1.14
50-54	508	67.4	1.05	1.00-1.11	1.07	1.01-1.11
45-49	895	65.4	1.04	1.00-1.08	1.05	1.01-1.09
40-44	1097	69.2	1.03	1.00-1.06	1.04	1.01-1.07
35-59	890	66.9	1.02	1.00-1.04	1.03	1.01-1.05
30-34	541	65.7	1.01	1.00-1.02	1.01	1.00-1.02
<30	266	58.1	Reference		Reference	
Race / Ethnicity						
Black, Non-Hispanic	211	70.6	1.16	1.06-1.26	1.13	1.04-1.23
Hispanic	470	71.7	1.13	1.05-1.21	1.11	1.03-1.19
Asian	62	60.7	1.10	1.04-1.17	1.09	1.03-1.15
Multiracial	66	71.7	1.08	1.03-1.12	1.06	1.02-1.11
Other	74	68.5	1.05	1.02-1.08	1.04	1.01-1.07
White, non-Hispanic	3722	65.5	Reference		Reference	
Education						
non High School Graduate	154	72.6	0.96	0.95-0.98	0.97	0.94-0.98
High School Graduate	1157	67.0	0.93	0.90-0.97	0.93	0.90-0.97
Some College	1745	69.3	0.90	0.85-0.95	0.90	0.85-0.95
College grad / post Graduate	1520	62.7	Reference		Reference	
Smoking Status at Wave One						
Current	772	68.1	1.03	0.98-1.08	1.01	0.97-1.06
Former	1224	66.5	1.01	0.99-1.04	1.01	0.99-1.02
Never	2590	68.1	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment characteristics.

Effect Modification Analyses. The effect of WTC dust exposure on new-onset upper respiratory symptoms was modified by dust cloud (interaction $p=0.002$) (Table D.1) and gender (interaction $p=0.027$) (Table D.2). Prevalence ratios were significantly higher among workers who were present in the dust cloud on the morning of September 11, 2001 (Table 3.7).

Table 3.7 Prevalence Ratios of Upper Respiratory Symptoms (any) at Wave One by Dust Cloud

	Dust Cloud (n=3,281)		No Dust Cloud (n=3,636)	
	Adjusted* PR (95% CI)		Adjusted *PR (95% CI)	
Chronic Dust Exposure				
High	1.17	1.05-1.30	1.12	1.00-1.25
Medium	1.11	1.03-1.19	1.08	1.00-1.16
Low	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment.

The association between chronic dust exposure and reported upper respiratory symptoms at Wave One was significant among Male workers (Table 3.8). Among Females, there was not a significant exposure-response relationship between chronic dust exposure and upper respiratory symptoms (Tables D.1-D.5).

Table 3.8 Prevalence Ratios of Upper Respiratory Symptoms (any) at Wave One by Gender

	Male (n=6,499)		Female (n=431)	
	Adjusted* PR (95% CI)		Adjusted *PR (95% CI)	
Chronic Dust Exposure				
High	1.40	1.30-1.51	1.14	0.86-1.51
Medium	1.25	1.19-1.32	1.09	0.91-1.31
Low	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment.

There were no significant interactions between chronic dust exposure and PTSD status, smoking status, or respirator use (Tables D.1-D.5).

Respiratory Symptoms at Wave Two. At Wave Two, enrollees reported on the presence of respiratory symptoms in the 30 days prior to the survey (Table 3.9). The prevalence of each reported symptom and symptom group was lower at Wave Two than at Wave One (Table 3.4 versus Table 3.9). A total of 3,950 workers (57.0%) reported at least one lower respiratory symptom at Wave Two. A total of 4,289 workers (61.9%) reported at least one upper respiratory symptom at Wave Two.

Table 3.9 Proportion of the study population reporting respiratory symptoms in the past 30 days at Wave Two (n = 6,930)

Symptom Group	n	%
Lower Respiratory (any)	3,950	57.0
Persistent Cough	2,409	34.8
Shortness of Breath	2,945	42.5
Wheezing	2,337	32.3
Upper Respiratory (any)	4,289	61.9
Eye Irritation	Not Asked	Not Applicable
Sinus Problems	3,882	56.0
Throat Irritation	2,587	37.3

Shortness of breath (42.5%) was the most commonly reported lower respiratory symptom at Wave Two, followed by persistent cough (34.8%) and wheezing

(32.3%). Sinus problems (56.0%) was the most common upper respiratory symptom at Wave One, followed by throat irritation (37.3%). eye irritation was not measured at Wave Two.

Lower Respiratory Symptoms (any). Lower respiratory symptoms were reported in 62.2% of High exposure, 54.9% of Medium exposure, and 53.7% of Low exposure workers (Table 3.10). High ($PR_{adj} = 1.20$, 95% CI=1.06-1.36) and Medium exposure ($PR_{adj} = 1.13$, 95% CI=1.04-1.22) workers reported lower respiratory symptoms at significantly higher prevalences than Low exposure workers (Table 3.10) (Figure 4.1).

The dust cloud was a stronger predictor of Lower respiratory symptoms than High chronic dust exposure at Wave Two (Intense dust cloud $PR_{adj} = 1.38$, 95% CI=1.24-1.55 versus High chronic dust $PR_{adj} = 1.20$, 95% CI=1.06-1.36) (Table 3.10).

Significant demographic predictors of Lower respiratory symptoms at Wave Two included age, race/ethnicity (non-White, non-Hispanic), education, smoking, and Self-identified enrollment (Table 3.10).

Effect Modification Analyses. There were no significant interactions between chronic dust exposure and dust cloud, gender, PTSD status, or respirator use (Tables D.1-D.5).

Table 3.10 Prevalence Ratios of Lower Respiratory Symptoms (any) at Wave Two (n=6,930)

Peri-Disaster Experiences						
	n	%	Crude PR (95% CI)		Adjusted* PR (95% CI)	
Chronic Dust Exposure						
High	1478	62.2	1.33	1.19-1.48	1.20	1.06-1.36
Medium	1189	54.9	1.21	1.12-1.30	1.13	1.04-1.22
Low	1283	53.7	Reference		Reference	
Dust Cloud on 9/11						
Intense	1375	65.9	2.48	2.29-2.69	1.38	1.24-1.55
Some	331	53.0	1.83	1.74-1.93	1.24	1.15-1.34
None	2000	52.2	Reference		Reference	
Respirator Use						
Yes	1214	57.9	1.02	0.96-1.09	0.98	0.92-1.06
No	2736	56.6	Reference		Reference	
Residence on 9/11						
Lower Manhattan	47	53.4	0.94	0.89-1.00	0.99	0.93-1.05
New York City	1700	59.6	0.88	0.78-0.99	0.97	0.86-1.10
Outside New York City	2203	55.2	Reference		Reference	
Enrollment and Mode Characteristics						
	n	%	Crude PR (95% CI)		Adjusted* PR (95% CI)	
Method of Enrollment						
Self	3816	68.1	1.15	1.09-1.20	1.10	1.05-1.15
List	789	59.5	Reference		Reference	
Wave Two Survey Mode						
List	1550	58.6	0.89	0.81-0.98	0.93	0.85-1.02
List	382	50.9	0.84	0.73-0.97	0.90	0.78-1.03
Self	2018	56.7	Reference		Reference	

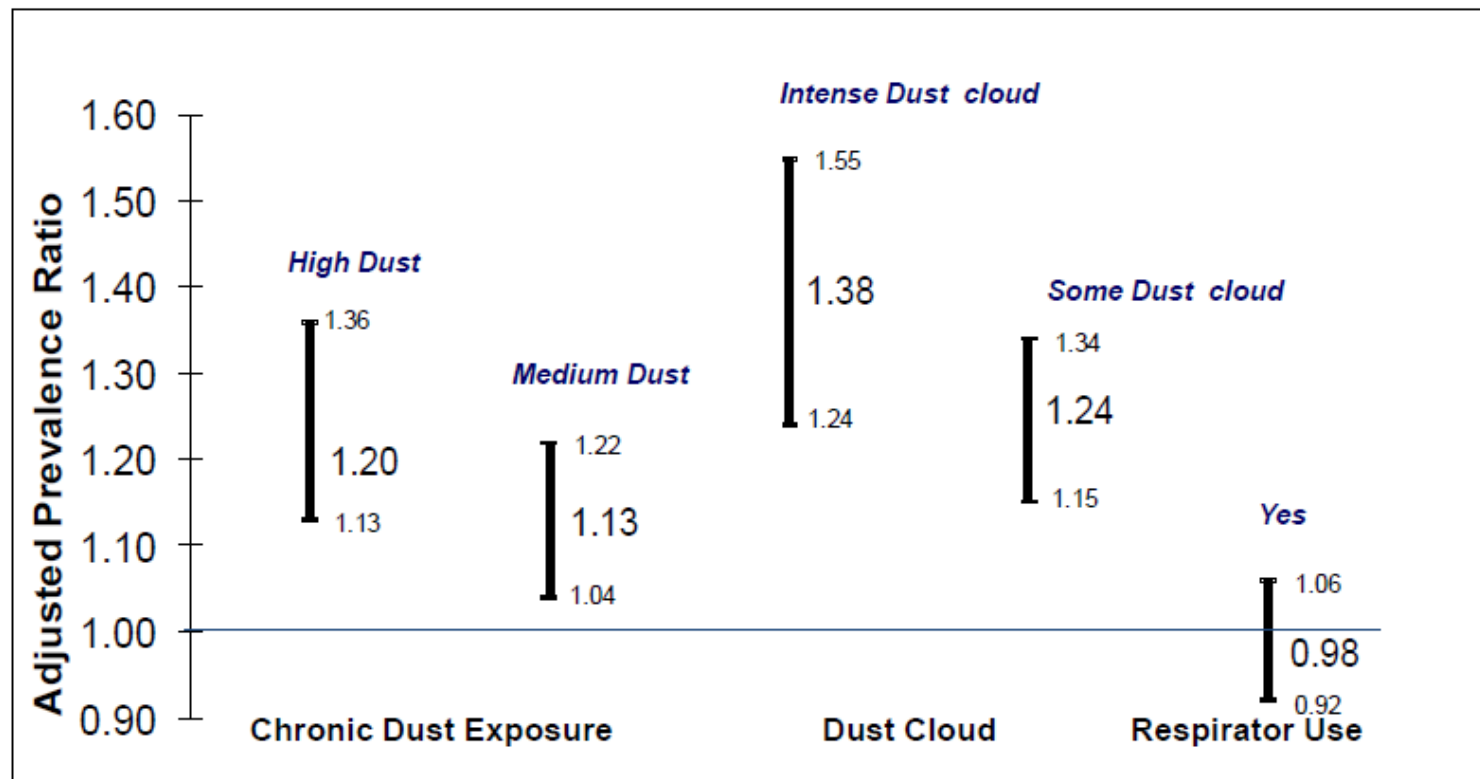
*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment and mode characteristics.

Table 3.10 continued Prevalence Ratios of Lower Respiratory Symptoms (any) at Wave Two (n=6,930)

Demographic Characteristics	n	%	Crude PR (95% CI)		Adjusted* PR (95% CI)	
Gender						
Male	3701	57.8	0.99	0.87-1.12	0.93	0.81-1.06
Female	249	57.0	Reference		Reference	
Age at Wave One						
55+	378	62.1	1.19	1.06-1.33	1.17	1.05-1.32
50-54	447	59.3	1.15	1.05-1.27	1.14	1.04-1.26
45-49	788	57.6	1.12	1.04-1.21	1.11	1.03-1.20
40-44	933	58.8	1.09	1.03-1.15	1.08	1.02-1.15
35-59	728	54.7	1.06	1.02-1.10	1.06	1.01-1.10
30-34	442	53.6	1.03	1.01-1.05	1.03	1.01-1.05
<30	234	51.1	Reference		Reference	
Race / Ethnicity						
Black, Non-Hispanic	174	58.2	1.23	1.03-1.47	1.24	1.02-1.50
Hispanic	403	61.4	1.19	1.02-1.38	1.20	1.02-1.40
Asian	49	55.1	1.15	1.02-1.30	1.15	1.02-1.31
Multiracial	59	64.1	1.11	1.01-1.21	1.11	1.01-1.22
Other	73	67.6	1.07	1.01-1.14	1.07	1.01-1.14
White, non-Hispanic	3192	56.1	Reference		Reference	
Education						
non High School Graduate	157	74.1	0.89	0.86-0.92	0.90	0.87-0.94
High School Graduate	1073	62.1	0.79	0.73-0.85	0.82	0.76-0.88
Some College	1506	59.8	0.70	0.63-0.78	0.74	0.66-0.82
College grad / post Graduate	1188	49.0	Reference		Reference	
Smoking Status at Wave Two						
Current	742	71.3	1.44	1.27-1.62	1.36	1.20-1.54
Former	1093	55.4	1.27	1.17-1.38	1.23	1.13-1.33
Never	2082	53.9	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment and mode characteristics.

Figure 4.1 Prevalence Ratios of Lower Respiratory Symptoms (any) at Wave Two



Upper Respiratory Symptoms (any). At least one upper respiratory symptom was reported in 61.9% of the study population at Wave Two (Table 3.9). Among the High dust exposure group, the presence of at least one upper respiratory symptom (Sinus Irritation or Throat Irritation) was reported in 65.5% of the study population ($PR_{adj} = 1.15$, 95% CI=1.07-1.24). Among the Medium exposure group, the presence of at least one upper respiratory symptom (sinus irritation or throat irritation) was reported in 61.6% of the study population ($PR_{adj} = 1.10$, 95% CI=1.05-1.15) (Table 3.11).

Similar to lower respiratory symptoms, the dust cloud was a stronger predictor of upper respiratory symptoms at Wave Two than chronic dust exposure (Intense dust cloud $PR_{adj} = 1.21$, 95% CI=1.13-1.29 versus High chronic dust $PR_{adj} = 1.15$, 95% CI=1.07-1.24) (Table 3.11) (Figure 4.2).

College graduates were more likely to report upper respiratory symptoms at Wave Two than workers who did not graduate from college. Current smokers ($PR_{adj} = 1.14$, 95% CI=1.06-1.23) and Former smokers ($PR_{adj} = 1.09$, 95% CI=1.04-1.15) were more likely to report Upper respiratory symptoms than Never smokers. More Self-identified workers reported upper Respiratory symptoms than List-identified workers (Self $PR_{adj} = 1.07$, 95% CI=1.02-1.13). Also, workers who completed the survey by Mail were more likely to report Upper Respiratory symptoms than workers who completed the survey by Web or Phone (Table 3.11).

Effect Modification Analyses. The relationship between chronic WTC dust exposure and reported upper respiratory symptoms at Wave Two was not modified by dust cloud, gender, PTSD status, smoking status, or respirator use (Tables D.1-D.5).

Table 3.11 Prevalence Ratios of Upper Respiratory Symptoms (any) at Wave Two (n=6,930)

Peri-Disaster Experiences						
	n	%	Crude PR (95% CI)		Adjusted* PR (95% CI)	
Chronic Dust Exposure						
High	1557	65.5	1.26	1.16-1.36	1.15	1.07-1.24
Medium	1333	61.6	1.16	1.10-1.23	1.10	1.05-1.15
Low	1399	59.6	Reference		Reference	
Dust Cloud on 9/11						
Intense	1602	76.7	1.44	1.39-1.49	1.21	1.13-1.29
Some	415	66.4	1.21	1.23-1.31	1.13	1.09-1.18
None	2315	60.4	Reference		Reference	
Respirator Use						
Yes	1319	62.9	1.02	0.98-1.07	1.00	0.96-1.04
No	2970	61.4	Reference		Reference	
Residence on 9/11						
Lower Manhattan	46	52.3	0.95	0.92-0.98	0.98	0.94-1.10
New York City	1849	64.8	0.90	0.84-0.96	0.95	0.89-1.02
Outside New York City	2394	60.0	Reference		Reference	
Enrollment and Mode Characteristics						
	n	%	Crude PR (95% CI)		Adjusted* PR (95% CI)	
Method of Enrollment						
Self	3523	62.9	1.09	1.04-1.15	1.07	1.02-1.13
List	766	57.7	Reference		Reference	
Wave Two Survey Mode						
Web	1730	63.3	0.91	0.86-0.96	0.92	0.87-0.97
Phone (CATI)	395	52.7	0.86	0.79-0.94	0.88	0.81-0.96
Mail	2164	62.8	Reference		Reference	

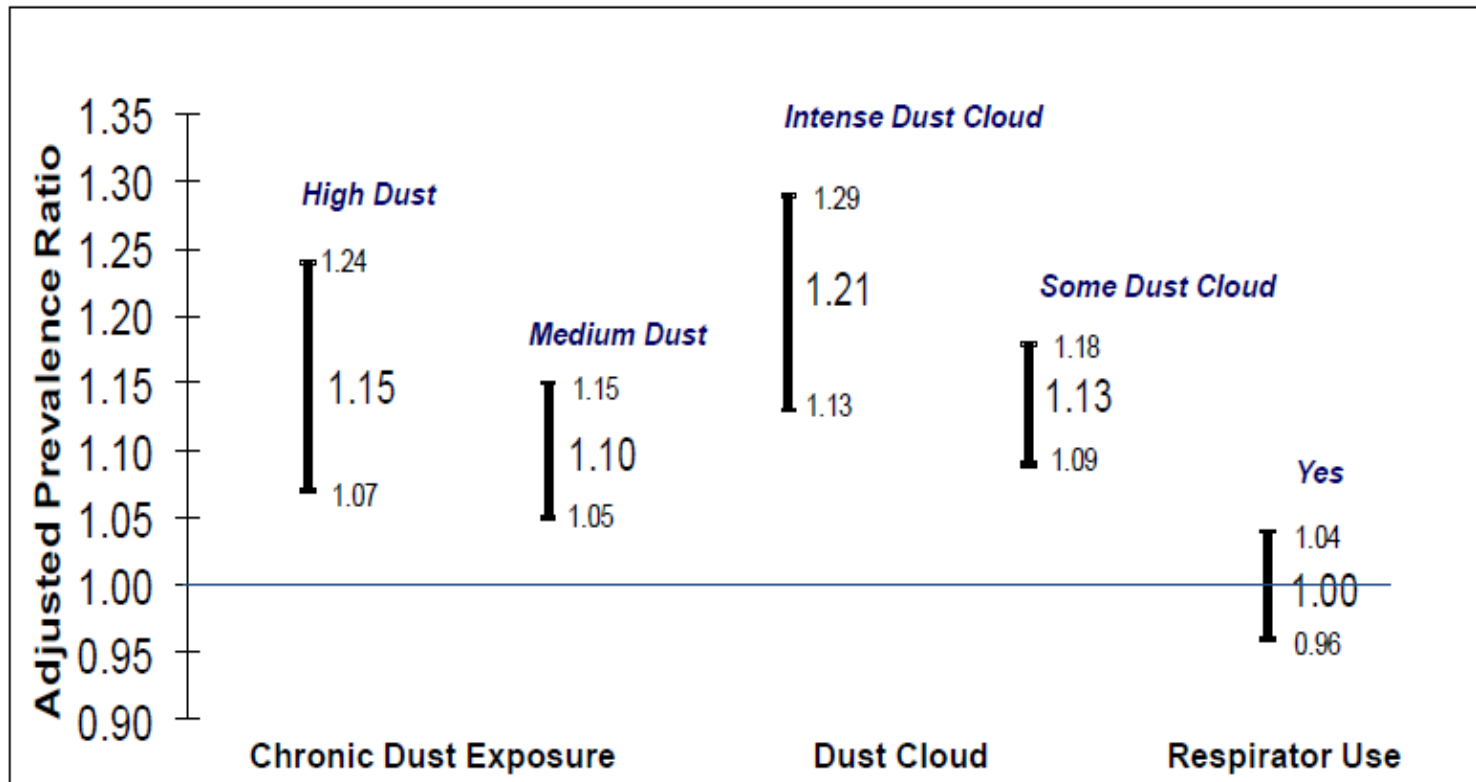
*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment and mode characteristics.

Table 3.11 continued Prevalence Ratios of Upper Respiratory Symptoms (any) at Wave Two (n=6,930)

Demographic Characteristics	n	%	Crude PR	(95% CI)	Adjusted* PR	(95% CI)
Gender						
Male	3997	61.5	0.91	0.85-0.97	0.87	0.82-0.93
Female	292	67.8	Reference		Reference	
Age at Wave One						
55+	361	59.3	0.97	0.91-1.04	0.98	0.91-1.04
50-54	452	60.0	0.97	0.92-1.03	0.98	0.93-1.04
45-49	853	62.4	0.98	0.94-1.02	0.98	0.94-1.03
40-44	998	62.9	0.98	0.95-1.02	0.99	0.96-1.02
35-59	840	63.1	0.99	0.97-1.01	0.99	0.97-1.01
30-34	510	61.9	0.99	0.98-1.01	1.00	0.99-1.01
<30	275	60.0	Reference		Reference	
Race / Ethnicity						
Black, Non-Hispanic	176	58.9	1.11	1.00-1.23	1.09	0.98-1.22
Hispanic	431	65.7	1.09	1.00-1.19	1.08	0.98-1.18
Asian	47	52.8	1.07	1.00-1.15	1.06	0.99-1.14
Multiracial	63	68.5	1.05	1.00-1.11	1.05	0.99-1.10
Other	73	67.6	1.03	1.00-1.07	1.03	0.99-1.07
White, non-Hispanic	3499	61.5	Reference		Reference	
Education						
non High School Graduate	146	68.9	0.95	0.93-0.97	0.96	0.94-0.98
High School Graduate	1091	63.1	0.91	0.87-0.95	0.92	0.89-0.96
Some College	1626	64.5	0.87	0.82-0.93	0.89	0.83-0.94
College grad / post Graduate	1397	57.7	Reference		Reference	
Smoking Status at Wave Two						
Current	705	67.7	1.16	1.08-1.25	1.14	1.06-1.23
Former	1216	61.6	1.11	1.05-1.16	1.09	1.04-1.15
Never	2334	60.5	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment and mode characteristics.

Figure 4.2 Prevalence Ratios of Upper Respiratory Symptoms (any) at Wave Two



Longitudinal Pattern of Respiratory Symptoms. The longitudinal patterns of lower and upper respiratory symptoms by Wave Two are presented in Tables 3.12 and 3.13. For each respiratory symptom (persistent cough, shortness of breath, wheezing, sinus problems, and throat irritation) and group (lower respiratory and upper respiratory), the exposure-response relationship between exposure category and outcome (Recurrent, Early Onset/Resolved, Late Onset, or Asymptomatic) was reported.

Approximately 48% (3,349/6,930) of reported lower respiratory symptoms among workers were Recurrent; 22.9% (1,588/6,930) were Early Onset, 8.7% (601/6,930) were Late Onset, and 20.1% (1,392/6,930) were Asymptomatic. Across all lower respiratory symptoms, there were significant exposure-response relationships between exposure and symptom outcomes (all p trend <0.05) (Table 3.12). There were positive exposure-response associations among the Recurrent and Early Onset/Resolved outcomes (Table 3.12).

The prevalence of Recurrent upper respiratory symptoms among workers was 47.5% (3,290/6,930) (Table 3.13). Early Onset/Resolved upper respiratory symptoms were present in 19.0% (1,315/6,930), and Late Onset upper respiratory symptoms were present in 14.4% (999/6,930) of the study population. Approximately 19% (1,326/6,930) of workers were asymptomatic at Wave Two (Table 3.13).

Table 3.12 Longitudinal Pattern of Lower Respiratory Symptoms at Wave Two (n = 6,930)

	Recurrent		Early Onset		Late Onset		Asymptomatic	
	n	row %	n	row %	n	row %	N	row %
Persistent Cough								
High Exposure	704	29.6	743	31.2	221	9.3	710	29.9
Medium Exposure	495	22.9	590	27.3	229	10.6	850	39.3
Low Exposure	470	19.7	477	20.0	290	12.1	1151	48.2
<i>p value*</i>	<0.0001		<0.0001		0.001		<0.0001	
Shortness of Breath								
High Exposure	948	39.9	618	26.0	173	7.3	639	26.9
Medium Exposure	655	30.3	449	20.8	228	10.5	832	38.5
Low Exposure	622	26.1	461	19.3	319	13.4	986	41.3
<i>p value*</i>	<0.0001		<0.0001		<0.0001		<0.0001	
Wheezing								
High Exposure	701	29.5	843	35.5	148	6.2	686	28.9
Medium Exposure	505	23.3	586	27.1	177	8.2	896	41.4
Low Exposure	462	19.4	539	22.6	244	10.2	1143	47.9
<i>p value*</i>	<0.0001		<0.0001		<0.0001		<0.0001	
Any								
High Exposure	1,340	56.4	595	25.0	138	5.8	305	12.8
Medium Exposure	998	46.1	515	23.8	191	8.8	460	21.3
Low Exposure	1,011	42.3	478	20.0	272	11.4	627	26.3
<i>p value*</i>	<0.0001		<0.0001		<0.0001		<0.0001	

*Cochran-Armitage test for trend.

There were positive exposure-response associations among the Recurrent and Early Onset upper respiratory symptom outcomes (Table 3.13).

Table 3.13 Longitudinal Pattern of Upper Respiratory Symptoms at Wave Two (n = 6,930)

	Recurrent		Early Onset		Late Onset		Asymptomatic	
	n	row %	N	row %	n	row %	n	row %
Sinus Problems								
High	915	38.5	375	15.8	490	20.6	598	25.2
Medium	655	30.3	278	12.9	548	25.3	683	31.6
Low	586	24.5	311	13.0	688	28.8	803	33.6
<i>p value*</i>	<0.0001		<0.0001		<0.0001		<0.0001	
Throat Irritation								
High	702	29.5	648	27.3	265	11.1	763	32.1
Medium	476	22.0	467	21.6	316	14.6	905	41.8
Low	458	19.2	478	20.0	370	15.5	1082	45.3
<i>p value*</i>	<0.0001		<0.0001		<0.0001		<0.0001	
Any								
High	1,311	55.1	498	20.9	246	10.3	323	13.6
Medium	996	46.0	382	17.7	337	15.6	449	20.8
Low	983	41.2	435	18.2	416	17.4	554	23.2
<i>p value*</i>	<0.0001		0.02		<0.0001		<0.0001	

*Cochran-Armitage test for trend.

3.4 Respiratory Disease Outcomes

Of the 6,930 who completed the Wave One and Wave Two surveys, 8.4% reported newly diagnosed allergic rhinitis, 15.5% reported newly diagnosed asthma (including RADS), 5.6% reported newly diagnosed Reactive Airways Dysfunction Syndrome (RADS only), 9.1% reported Chronic Obstructive Pulmonary Disorder (COPD, including chronic bronchitis and emphysema), and 8.8% reported newly diagnosed chronic bronchitis between September 11, 2001 and the Wave Two survey (Table 3.14).

Table 3.14 Wave Two Prevalence of Newly Diagnosed Respiratory Disease Outcomes after September 11, 2001 (n = 6,930)

Disease Outcome	n	%
Allergic Rhinitis	548	7.9
Asthma	1,072	15.5
Reactive Airways Dysfunction Syndrome (RADS)	389	5.6
Chronic Obstructive Pulmonary Disease (COPD)	629	9.1
Chronic Bronchitis	581	8.8

Allergic Rhinitis. The association between WTC dust exposure and allergic rhinitis risk is presented in Table 3.15. A total of 223 cases of allergic rhinitis were reported among the High exposure group, 152 cases were reported among the Medium exposure group, and 173 cases were reported among the Low exposure group.

Compared to the Low dust exposure group, the prevalence ratio was a non-significant 1.11 (95% CI, 0.80-1.52) for the High exposure group and a non-significant 1.07 (95% CI, 0.86-1.32) for the Medium exposure group, after adjusting for covariates (Table 3.15) (Figure 4.3).

Exposure to the dust and debris cloud on the morning of September 11 was a significant predictor of allergic rhinitis at Wave Two. The prevalence ratio was 1.75 (95% CI, 1.32-2.31) for Intense dust cloud and 1.45 (95% CI, 1.20-1.75) for Some dust cloud (Table 3.15).

Workers who used a Respirator reported an allergic rhinitis diagnosis at a higher prevalence than those who did not report wearing a respirator ($PR_{adj} = 1.20$, 95% CI=1.01-1.43). Gender was also associated with allergic rhinitis as a greater proportion of Women reported a diagnosis than men (Male $PR_{adj} = 0.64$, 95% CI=0.48-0.86). The mode of survey administration was a significant predictor as workers who completed the Wave Two survey by Web ($PR_{adj} = 0.71$, 95% CI=0.56-0.90) or Phone ($PR_{adj} = 0.60$, 95% CI= 0.41-0.86) were less likely to report an allergic rhinitis diagnosis than workers who completed the survey by Mail (Table 3.15).

Effect Modification Analyses. The relationship between chronic WTC dust exposure and allergic rhinitis was not significantly modified by dust cloud, gender, smoking status, or respirator use (Tables D.1-D.5).

Table 3.15 Prevalence Ratios of Allergic Rhinitis at Wave Two (n=6,930)

Peri-Disaster Experiences						
	n	%	Crude PR (95% CI)		Adjusted* PR (95% CI)	
Chronic Dust Exposure						
High	223	11.2	1.50	1.12-2.01	1.11	0.80-1.52
Medium	152	8.7	1.31	1.08-1.59	1.07	0.86-1.32
Low	173	9.1	Reference		Reference	
Dust Cloud on 9/11						
Intense	217	11.8	3.40	2.57-4.51	1.75	1.32-2.31
Some	42	7.7	2.26	1.88-2.73	1.45	1.20-1.75
None	257	7.7	Reference		Reference	
Respirator Use						
Yes	191	11.2	1.23	1.04-1.45	1.20	1.01-1.43
No	357	9.1	Reference		Reference	
Residence on 9/11						
Lower Manhattan	5	7.1	0.90	0.78-1.05	0.96	0.82-1.12
New York City	247	10.7	0.82	0.61-1.11	0.92	0.68-1.26
Outside New York City	296	9.0	Reference		Reference	
Enrollment and Mode Characteristics						
	n	%	Crude PR (95% CI)		Adjusted* PR (95% CI)	
Method of Enrollment						
Self	463	10.1	1.34	1.07-1.67	1.19	0.94-1.50
List	85	8.0	Reference		Reference	
Wave Two Survey Mode						
Web	267	12.0	0.70	0.55-0.89	0.71	0.56-0.90
Phone (CATI)	11	1.8	0.59	0.41-0.84	0.60	0.41-0.86
Mail	270	9.6	Reference		Reference	

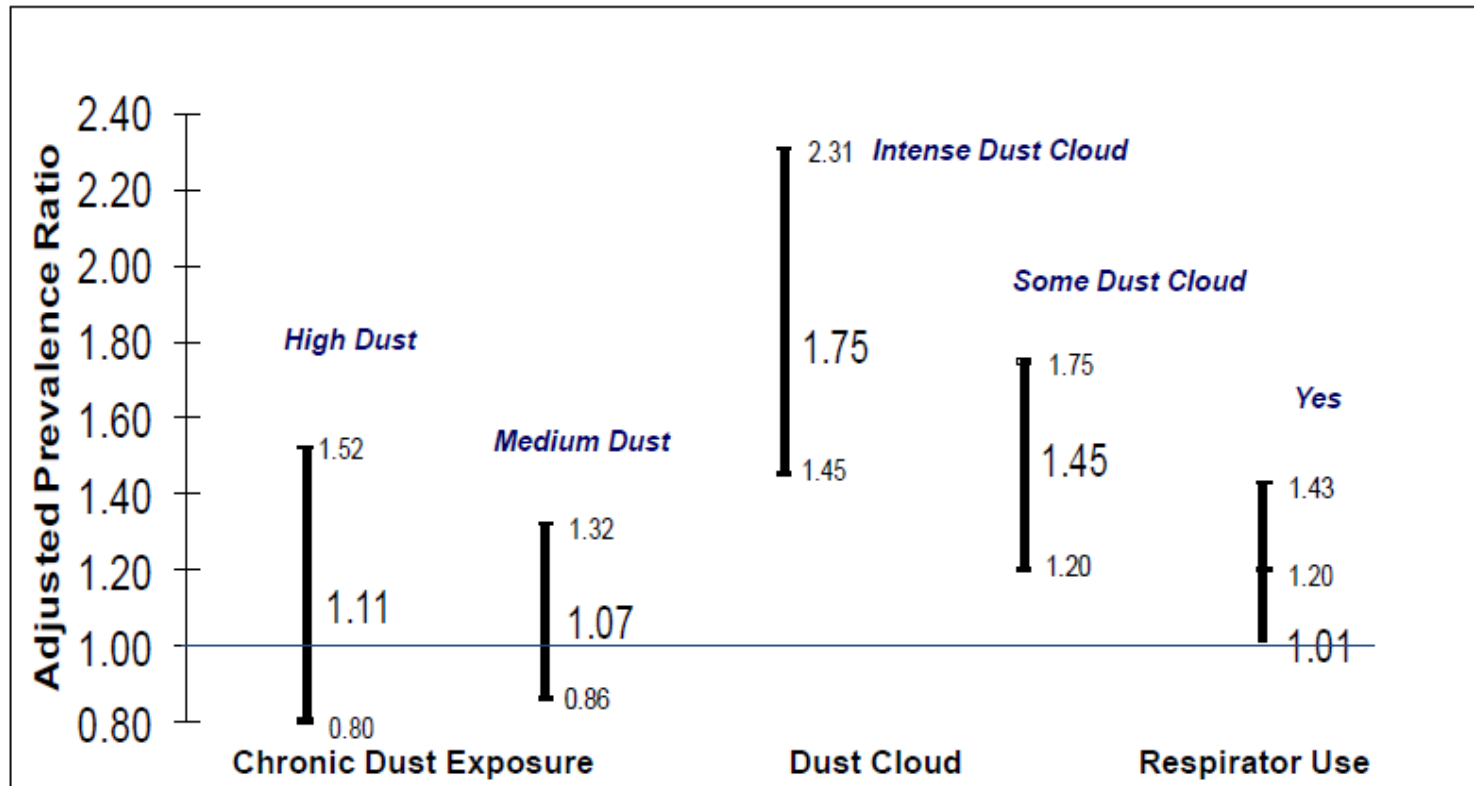
*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment and mode characteristics.

Table 3.15 continued Prevalence Ratios of Allergic Rhinitis at Wave Two (n=6,930)

Demographic Characteristics	n	%	Crude PR	(95% CI)	Adjusted* PR	(95% CI)
Gender						
Male	502	8.8	0.67	0.50-0.88	0.64	0.48-0.60
Female	46	14.4	Reference		Reference	
Age at Wave One						
55+	47	9.6	1.26	0.94-1.68	1.32	0.99-1.77
50-54	62	10.5	1.21	0.95-1.54	1.26	0.99-1.61
45-49	104	9.2	1.16	0.96-1.41	1.20	0.99-1.47
40-44	145	11.5	1.12	0.97-1.29	1.15	1.00-1.34
35-59	113	10.3	1.08	0.98-1.19	1.10	1.00-1.21
30-34	55	8.0	1.04	0.99-1.09	1.05	1.00-1.10
<30	22	5.6	Reference		Reference	
Race / Ethnicity						
Black, Non-Hispanic	24	9.6	1.13	0.71-1.82	1.18	0.72-1.93
Hispanic	59	11.3	1.11	0.75-1.65	1.15	0.76-1.73
Asian	6	8.7	1.09	0.79-1.49	1.12	0.81-1.55
Multiracial	5	7.0	1.06	0.84-1.35	1.09	0.85-1.39
Other	10	12.2	1.04	0.89-1.22	1.06	0.90-1.24
White, non-Hispanic	444	9.6	Reference		Reference	
Education						
non High School Graduate	15	8.9	1.04	0.95-1.14	1.02	0.93-1.13
High School Graduate	136	9.4	1.09	0.91-1.31	1.05	0.86-1.27
Some College	202	9.8	1.14	0.86-1.50	1.07	0.80-1.43
College grad / post Graduate	192	10.0	Reference		Reference	
Smoking Status at Wave Two						
Current	74	8.6	0.76	0.54-1.06	0.79	0.56-1.11
Former	150	9.3	0.83	0.67-1.04	0.85	0.68-1.07
Never	320	10.2	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment and mode characteristics.

Figure 4.3 Prevalence Ratios of Allergic Rhinitis at Wave Two



The effect of chronic WTC dust exposure on diagnosed allergic rhinitis was modified by PTSD status at Wave Two (interaction $p=0.022$) (Table D.5). The relationship between chronic dust exposure and allergic rhinitis was stronger among workers who did not screen positive for PTSD. The associations between chronic dust exposure and PTSD, however, remained statistically nonsignificant, regardless of PTSD status (Table 3.16).

Table 3.16 Prevalence Ratios of Allergic Rhinitis at Wave Two by PTSD Status at Wave Two

	Probable PTSD (n=1,455)		No PTSD (n=5,293)	
	Adjusted* PR (95% CI)		Adjusted *PR (95% CI)	
Chronic Dust Exposure				
High	0.63	0.38-1.06	1.26	0.82-1.94
Medium	0.74	0.52-1.04	1.17	0.88-1.56
Low	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment characteristics

Asthma (including RADS). Among WTC pile workers, there was a significant exposure-response relationship between WTC dust exposure and asthma (including RADS) (p trend <0.0001) (Table 3.17). Relative to the Low dust exposure group, the adjusted risk for reporting an asthma (or RADS) diagnosis was significantly higher for the High exposure ($PR_{adj} = 1.59$, 95% CI=1.28-1.99) and Medium exposure ($PR_{adj} = 1.36$, 95% CI=1.18-1.58) groups (Table 3.17) (Figure 4.4).

Table 3.17 Prevalence Ratios of Asthma (including RADS) at Wave Two (n=6,930)

Peri-Disaster Experiences						
	n	%	Crude PR	(95% CI)	Adjusted* PR	(95% CI)
Chronic Dust Exposure						
High	452	19.0	2.13	1.75-2.59	1.59	1.28-1.99
Medium	322	14.9	1.66	1.45-1.89	1.36	1.18-1.58
Low	298	12.5	Reference		Reference	
Dust Cloud on 9/11						
Intense	443	21.3	2.92	2.43-3.51	2.03	1.68-2.47
Some	94	15.1	2.04	1.81-2.31	1.60	1.41-1.83
None	463	12.1	Reference		Reference	
Respirator Use						
Yes	367	17.5	1.20	1.07-1.35	1.09	0.96-1.23
No	705	14.6	Reference		Reference	
Residence on 9/11						
Lower Manhattan	12	13.6	0.96	0.87-1.07	1.04	0.93-1.15
New York City	455	16.0	0.93	0.75-1.15	1.07	0.86-1.33
Outside New York City	605	15.2	Reference		Reference	
Enrollment and Mode Characteristics						
	n	%	Crude PR	(95% CI)	Adjusted PR	(95% CI)
Method of Enrollment						
Self	919	16.4	1.42	1.21-1.67	1.24	1.05-1.47
List	153	11.6	Reference		Reference	
Wave Two Survey Mode						
Web	420	15.4	0.93	0.79-1.09	0.97	0.83-1.15
Phone (CATI)	109	14.5	0.89	0.70-1.14	0.96	0.75-1.23
Mail	543	15.8	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment and mode characteristics.

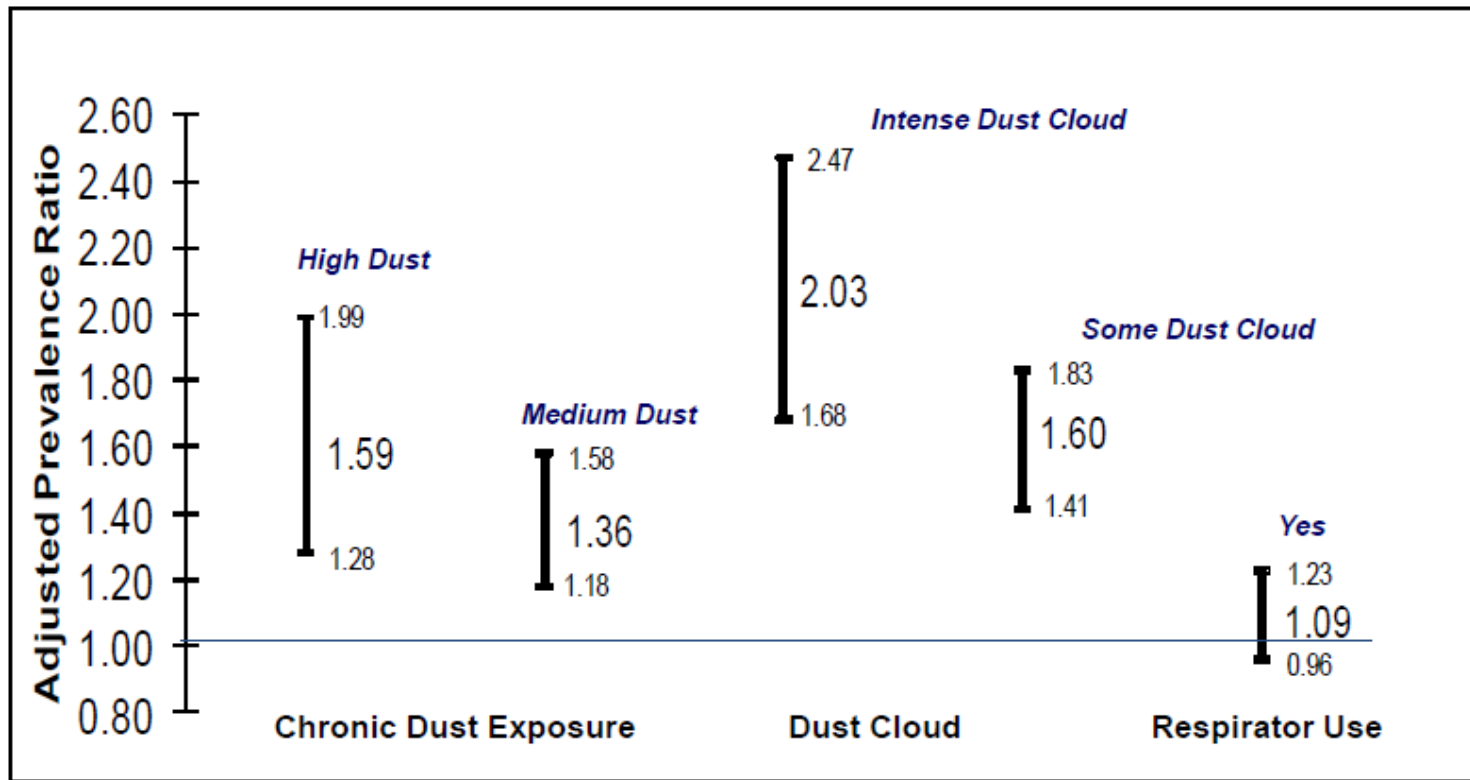
There was also a significant exposure-response relationship between dust could exposure and asthma (or RADS). The prevalence ratio for Asthma among workers in the Intense dust cloud was 2.03 (95% CI=1.68-2.47). The prevalence ratio among workers in the Some dust cloud group was 1.60 (95% CI=1.41-1.83) (Table 3.17).

Table 3.17 continued Prevalence Ratios of Asthma (including RADS) at Wave Two (n=6,930)

Demographic Characteristics	n	%	Crude PR	(95% CI)	Adjusted* PR	(95% CI)
Gender						
Male	979	21.7	0.70	0.58-0.84	0.61	0.51-0.74
Female	93	15.1	Reference		Reference	
Age at Wave One						
55+	82	13.5	1.14	0.93-1.39	1.24	1.01-1.52
50-54	120	16.0	1.12	0.94-1.32	1.20	1.01-1.42
45-49	249	18.2	1.09	0.95-1.25	1.16	1.01-1.33
40-44	238	15.0	1.07	0.97-1.18	1.12	1.01-1.24
35-59	207	15.6	1.04	0.98-1.17	1.08	1.01-1.15
30-34	116	14.1	1.02	0.99-1.06	1.04	1.00-1.07
<30	60	13.1	Reference		Reference	
Race / Ethnicity						
Black, Non-Hispanic	43	14.5	1.04	0.75-1.45	1.14	0.82-1.59
Hispanic	120	18.4	1.03	0.79-1.36	1.11	0.84-1.47
Asian	10	11.2	1.03	0.82-1.28	1.09	0.87-1.36
Multiracial	11	12.0	1.02	0.87-1.20	1.07	0.90-1.26
Other	16	15.0	1.01	0.91-1.13	1.04	0.93-1.17
White, non-Hispanic	872	15.4	Reference		Reference	
Education						
non High School Graduate	44	20.8	0.98	0.92-1.04	0.93	0.93-1.17
High School Graduate	240	13.9	0.96	0.85-1.09	0.87	0.88-1.00
Some College	423	16.8	0.94	0.78-1.14	0.82	0.77-1.00
College grad / post Graduate	361	14.9	Reference		Reference	
Smoking Status at Wave Two						
Current	638	16.6	0.62	0.49-0.79	0.63	0.50-0.81
Former	314	16.0	0.73	0.62-0.85	0.74	0.63-0.87
Never	113	10.9	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment and mode characteristics.

Figure 4.4 Prevalence Ratios of Asthma (including RADS) at Wave Two



Female gender (Male $PR_{adj} = 0.61$, 95% CI=0.51-0.74) and age were significant predictors of asthma at Wave Two. Current smokers ($PR_{adj} = 0.63$, 95% CI=0.50-0.81) and Former smokers ($PR_{adj} = 0.74$, 95% CI=0.63-0.87) were less likely to report asthma than Never smokers (Table 3.17).

Effect Modification Analyses. There were no significant interactions between chronic WTC dust exposure and dust cloud, Gender, PTSD status, smoking status, or respirator use (Table D.1-D.5)

Reactive Airways Dysfunction Syndrome. The adjusted prevalence ratio for RADS for the High dust exposure group was 2.08 (95% CI, 1.39-3.09) compared to the Low exposure group (Table 3.18). Among the Medium exposure group, the prevalence ratio was 1.63 (95% CI, 1.25-2.12) compared to the Low exposure group, and there was a significant trend between WTC dust exposure and newly diagnosed RADS at Wave Two ($p \text{ trend} < 0.0001$) (Table 3.18).

Relative to the No dust cloud group, workers in the Intense ($PR_{adj} = 2.96$, 95% CI=2.08-4.21) and Some ($PR_{adj} = 2.06$, 95% CI=1.63-2.61) dust groups reported RADS diagnoses at higher prevalences. Female gender (Male $PR_{adj} = 0.65$, 95% CI=0.45-0.95) and Current ($PR_{adj} = 0.53$, 95% CI=0.35-0.83) or Former ($PR_{adj} = 0.66$, 95% CI=0.49-0.88) smoking status were also predictors of RADS at Wave Two.

Effect Modification Analyses. The effect of WTC dust exposure on newly diagnosed RADS was not modified by any of the following: dust cloud, gender, PTSD status, smoking status, or respirator use (Tables D.1-D.5).

Table 3.18 Prevalence Ratios of Reactive Airways Dysfunction Syndrome at Wave Two (n=6,930)

Peri-Disaster Experiences						
	n	%	Crude PR (95% CI)		Adjusted PR (95% CI)	
Chronic Dust Exposure						
High	180	7.6	3.12	2.17-4.49	2.08	1.39-3.09
Medium	123	5.7	2.14	1.68-2.72	1.63	1.25-2.12
Low	86	3.6	Reference		Reference	
Dust Cloud on 9/11						
Intense	190	9.2	5.76	4.08-8.13	2.96	2.08-4.21
Some	30	4.8	3.21	2.55-4.04	2.06	1.63-2.61
None	147	3.9	Reference		Reference	
Respirator Use						
Yes	140	6.7	1.3	1.06-1.58	1.12	0.91-1.38
No	249	5.2	Reference		Reference	
Residence on 9/11						
Lower Manhattan	2	2.3	0.99	0.83-1.19	1.07	0.88-1.29
New York City	167	5.9	0.99	0.68-1.43	1.14	0.78-1.67
Outside New York City	220	5.6	Reference		Reference	
Enrollment and Mode Characteristics						
	n	%	Crude PR (95% CI)		Adjusted PR (95% CI)	
Method of Enrollment						
Self	349	6.3	2.08	1.50-2.87	1.69	1.20-2.38
List	40	3.0	Reference		Reference	
Wave Two Survey Mode						
Web	174	6.4	0.85	0.64-1.14	0.93	0.70-1.25
Phone (CATI)	25	3.3	0.79	0.51-1.21	0.90	0.58-1.40
Mail	190	5.6	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment and mode characteristics.

Table 3.18 continued Prevalence Ratios of Reactive Airways Dysfunction Syndrome at Wave Two (n=6,930)

Demographic Characteristics	n	%	Crude PR	(95% CI)	Adjusted PR	(95% CI)
Gender						
Male	360	5.6	0.82	0.57-1.18	0.65	0.45-0.95
Female	29	6.8	Reference		Reference	
Age at Wave One						
55+	33	5.5	1.52	1.07-2.17	1.74	1.21-2.52
50-54	43	5.8	1.42	1.06-1.91	1.59	1.17-2.16
45-49	102	7.5	1.32	1.05-1.67	1.44	1.13-1.85
40-44	83	5.3	1.23	1.04-1.47	1.32	1.10-1.59
35-59	75	5.7	1.15	1.02-1.29	1.20	1.06-1.36
30-34	40	4.9	1.07	1.01-1.14	1.10	1.03-1.17
<30	13	2.9	Reference		Reference	
Race / Ethnicity						
Black, Non-Hispanic	7	2.4	0.68	0.36-1.30	0.86	0.45-1.66
Hispanic	35	5.4	0.73	0.43-1.25	0.88	0.51-1.52
Asian	3	3.4	0.78	0.50-1.19	0.90	0.59-1.40
Multiracial	2	2.2	0.83	0.60-1.14	0.93	0.67-1.29
Other	8	7.5	0.88	0.71-1.09	0.95	0.76-1.18
White, non-Hispanic	334	5.9	Reference		Reference	
Education						
non High School Graduate	16	7.7	1.00	0.90-1.12	0.94	0.84-1.06
High School Graduate	86	5.0	1.01	0.81-1.26	0.89	0.70-1.12
Some College	148	5.9	1.01	0.72-1.42	0.84	0.59-1.18
College grad / post Graduate	138	5.7	Reference		Reference	
Smoking Status at Wave Two						
Current	34	3.3	0.50	0.33-0.76	0.53	0.35-0.83
Former	115	5.9	0.63	0.47-0.84	0.66	0.49-0.88
Never	238	6.2	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment and mode characteristics.

Chronic Obstructive Pulmonary Disease. A total of 629 (9.1%) workers reported a post-September 11 diagnosis of emphysema or chronic bronchitis at Wave Two (Table 3.19). Compared to Low dust exposure workers, the adjusted prevalence ratio of COPD among High exposure workers was 1.67 (95% CI, 1.24-2.26). The risk among Medium exposure workers was 1.41 (95% CI, 1.15-1.72) relative to Low exposure workers (p trend <0.0001) (Table 3.19) (Figure 4.5).

Prevalence ratios were significant among workers who were in the dust cloud. Compared to the No dust cloud group, the prevalence ratio of COPD among workers who were in the Intense dust cloud was 2.09 (95% CI, 1.62-2.71). The prevalence ratio of COPD among workers in the Some dust cloud group was 1.64 (95% CI, 1.38-1.95) (Table 3.19).

Female gender (Male $PR_{adj} = 0.63$, 95% CI=0.48-0.82) and smoking status (Current $PR_{adj} = 1.49$, 95% CI=1.11-2.01; Former $PR_{adj} = 1.31$, 95% CI=1.07-1.59) were significant independent predictors of COPD at Wave Two. Self-identified enrollment and completing the Wave Two survey by mail were also significant predictors of COPD at Wave Two (Table 3.19).

Effect Modification Analyses. There was no evidence of interaction between chronic dust exposure and dust cloud, gender, PTSD status, smoking status, respirator use (Tables D.1-D.5).

Table 3.19 Prevalence Ratios of Chronic Obstructive Pulmonary Disease at Wave Two (n=6,930)

Peri-Disaster Experiences						
	n	%	Crude PR (95% CI)		Adjusted* PR (95% CI)	
Chronic Dust Exposure						
High	264	11.3	2.11	1.60-2.78	1.67	1.24-2.26
Medium	201	9.5	1.65	1.37-1.98	1.41	1.15-1.72
Low	164	7.1	Reference		Reference	
Dust Cloud on 9/11						
Intense	266	13.0	3.90	3.01-5.06	2.09	1.62-2.71
Some	58	9.5	2.48	2.09-2.95	1.64	1.38-1.95
None	269	7.2	Reference		Reference	
Respirator Use						
Yes	203	9.9	1.09	0.93-1.28	0.99	0.84-1.17
No	426	9.1	Reference		Reference	
Residence on 9/11						
Lower Manhattan	7	8.0	0.89	0.78-1.03	1.00	0.86-1.15
New York City	281	10.1	0.80	0.60-1.05	0.99	0.74-1.33
Outside New York City	341	8.8	Reference		Reference	
Enrollment and Mode Characteristics						
	n	%	Crude PR (95% CI)		Adjusted* PR (95% CI)	
Method of Enrollment						
Self	536	9.8	1.37	1.11-1.70	1.31	1.04-1.63
List	93	7.2	Reference		Reference	
Wave Two Survey Mode						
Web	277	10.5	0.60	0.47-0.75	0.63	0.50-0.80
Phone (CATI)	18	2.4	0.46	0.32-0.66	0.50	0.35-0.71
Mail	334	9.9	Reference		Reference	

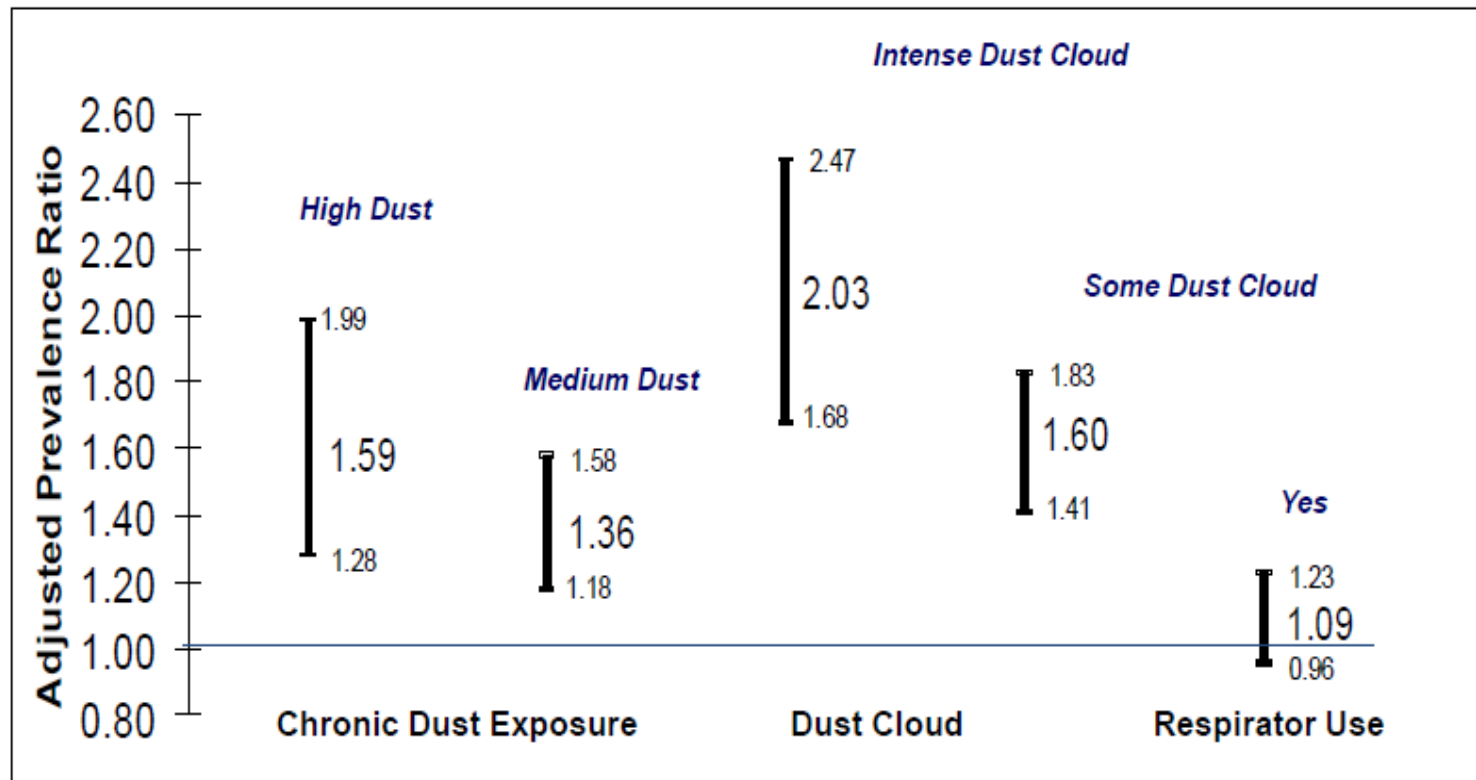
*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment and mode characteristics.

Table 3.19 continued Prevalence Ratios of Chronic Obstructive Pulmonary Disease at Wave Two (n=6,930)

Demographic Characteristics	n	%	Crude PR	(95% CI)	Adjusted* PR	(95% CI)
Gender						
Male	574	9.1	0.68	0.52-0.88	0.63	0.48-0.82
Female	55	13.3	Reference		Reference	
Age at Wave One						
55+	59	10.1	1.21	0.93-1.59	1.26	0.95-1.66
50-54	68	9.3	1.18	0.94-1.47	1.21	0.96-1.53
45-49	113	8.5	1.14	0.95-1.36	1.17	0.97-1.40
40-44	166	10.7	1.10	0.96-1.26	1.12	0.98-1.29
35-59	123	9.4	1.07	0.97-1.17	1.08	0.98-1.18
30-34	76	9.4	1.03	0.99-1.08	1.04	0.99-1.09
<30	24	5.4	Reference		Reference	
Race / Ethnicity						
Black, Non-Hispanic	22	7.5	1.45	0.96-2.18	1.44	0.94-2.22
Hispanic	74	11.6	1.36	0.97-1.92	1.36	0.95-1.95
Asian	8	9.2	1.28	0.97-1.68	1.28	0.96-1.70
Multiracial	11	12.5	1.20	0.98-1.48	1.20	0.97-1.49
Other	11	10.6	1.13	0.99-1.30	1.13	0.98-1.31
White, non-Hispanic	503	9.1	Reference		Reference	
Education						
non High School Graduate	18	8.7	0.92	0.84-1.00	0.92	0.84-1.00
High School Graduate	167	9.9	0.84	0.71-1.00	0.84	0.70-1.00
Some College	252	10.3	0.78	0.60-1.00	0.77	0.59-1.00
College grad / post Graduate	188	8.0	Reference		Reference	
Smoking Status at Wave Two						
Current	113	11.3	1.49	1.11-2.00	1.49	1.11-2.01
Former	186	9.7	1.30	1.07-1.58	1.31	1.07-1.59
Never	325	8.6	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment and mode characteristics.

Figure 4.6 Prevalence Ratios of Chronic Obstructive Pulmonary Disease at Wave Two



Chronic Bronchitis. Approximately 11% of the High dust exposure group, 9% of the Medium dust exposure group, and 7% of the Low dust exposure group reported at chronic bronchitis diagnosis (Table 3.20). There was a significant exposure-response trend in chronic bronchitis risk with High exposure ($PR_{adj} = 1.74$, 95% CI=1.28-2.39) and Medium exposure ($PR_{adj} = 1.45$, 95% CI=1.18-1.79) workers more likely to report newly diagnosed chronic bronchitis than Low exposure workers.

Dust cloud was a stronger independent predictor of chronic bronchitis than chronic dust exposure. Workers in the Intense dust cloud ($PR_{adj} = 2.04$, 95% CI=1.55-2.67) and Some dust cloud ($PR_{adj} = 1.61$, 95% CI=1.34-1.92) groups were more likely to report a diagnosis of chronic bronchitis than workers in the No dust cloud group (Table 3.20).

Female gender, Self-identified enrollment, and Wave Two survey mode were predictors of chronic bronchitis (Table 3.20). Unlike COPD diagnoses, smoking status was not significantly associated with chronic bronchitis diagnoses (Table 3.19 versus Table 3.20).

Effect Modification. There was no evidence of a modified relationship between chronic dust exposure and chronic bronchitis by dust cloud, gender, smoking status, PTSD status, or respirator use (Tables D.1-D.5).

Table 3.20 Prevalence Ratios of Chronic Bronchitis at Wave Two (n=6,930)

Peri-Disaster Experiences						
	n	%	Crude PR	(95% CI)	Adjusted* PR	(95% CI)
Chronic Dust Exposure						
High	246	10.5	2.19	1.64-2.92	1.81	1.30-2.51
Medium	186	8.8	1.68	1.39-2.04	1.48	1.19-1.84
Low	149	6.5	Reference		Reference	
Dust Cloud on 9/11						
Intense	246	12.0	3.84	2.93-5.03	2.04	1.55-2.67
Some	53	8.7	2.45	2.04-2.93	1.61	1.34-1.92
None	250	6.7	Reference		Reference	
Respirator Use						
Yes	188	9.1	1.09	0.93-1.29	0.99	0.83-1.17
No	393	8.4	Reference		Reference	
Residence on 9/11						
Lower Manhattan	7	8.0	0.90	0.78-1.04	1.00	0.86-1.10
New York City	257	9.2	0.81	0.60-1.09	1.01	0.74-1.37
Outside New York City	317	8.2	Reference		Reference	
Enrollment and Mode Characteristics						
	n	%	Crude PR	(95% CI)	Adjusted* PR	(95% CI)
Method of Enrollment						
Self	498	9.1	1.43	1.14-1.79	1.32	1.05-1.68
List	83	6.4	Reference		Reference	
Wave Two Survey Mode						
Web	262	9.9	0.63	0.50-0.81	0.66	0.52-0.84
Phone (CATI)	17	2.3	0.50	0.35-0.72	0.54	0.37-0.77
Mail	302	9.0	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment and mode characteristics.

Table 3.20 continued Prevalence Ratios of Chronic Bronchitis at Wave Two (n=6,930)

Demographic Characteristics	n	%	Crude PR	(95% CI)	Adjusted PR	(95% CI)
Gender						
Male	529	8.3	0.66	0.51-0.86	0.62	0.47-0.82
Female	52	12.6	Reference		Reference	
Age at Wave One						
55+	50	8.6	1.07	0.80-1.42	1.10	0.83-1.49
50-54	58	8.0	1.05	0.83-1.34	1.09	0.86-1.39
45-49	103	7.8	1.04	0.86-1.26	1.07	0.88-1.30
40-44	158	10.2	1.03	0.90-1.19	1.05	0.91-1.22
35-59	116	8.9	1.02	0.93-1.12	1.03	0.94-1.14
30-34	74	9.1	1.01	0.96-1.06	1.02	0.97-1.07
<30	22	4.9	Reference		Reference	
Race / Ethnicity						
Black, Non-Hispanic	21	7.2	1.50	0.98-2.30	1.51	0.96-2.35
Hispanic	70	11.0	1.40	0.99-2.00	1.41	0.97-2.04
Asian	8	9.1	1.31	0.98-1.74	1.31	0.98-1.77
Multiracial	10	11.4	1.23	0.99-1.52	1.23	0.98-1.53
Other	10	9.6	1.15	0.99-1.32	1.15	0.99-1.33
White, non-Hispanic	462	8.3	Reference		Reference	
Education						
non High School Graduate	16	7.7	0.95	0.87-1.04	0.94	0.85-1.02
High School Graduate	147	8.7	0.90	0.75-1.08	0.88	0.72-1.05
Some College	234	9.5	0.85	0.65-1.12	0.82	0.62-1.08
College grad / post Graduate	181	7.7	Reference		Reference	
Smoking Status at Wave Two						
Current	98	9.8	1.24	0.91-1.69	1.27	0.93-1.74
Former	164	8.6	1.15	0.94-1.42	1.17	0.95-1.45
Never	314	8.3	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment and mode characteristics.

Analyses excluding Missing Responses to Disease Questions. Enrollees with missing respiratory disease outcome data were assigned a negative response to disease questions. Sensitivity analyses to were conducted by determining the prevalence ratios for outcomes excluding missing outcome data. Prevalence ratios did not significantly differ by method of handling missing data (Table 3.21).

Table 3.21 Prevalence Ratios of Respiratory Diseases excluding Missing Outcome Data

	Adjusted PR* missing coded as 0	Adjusted PR* excluding missing
Allergic Rhinitis		
Chronic Dust Exposure		
High	1.11 (0.80-1.52)	1.24 (0.88-1.72)
Medium	1.07 (0.86-1.32)	1.15 (0.92-1.44)
Low	Reference	Reference
Asthma		
Chronic Dust Exposure		
High	1.59 (1.28-1.99)	1.59 (1.25-2.00)
Medium	1.36 (1.18-1.58)	1.36 (1.17-1.59)
Low	Reference	Reference
RADS		
Chronic Dust Exposure		
High	2.08 (1.39-3.09)	1.99 (1.29-3.04)
Medium	1.63 (1.25-2.12)	1.58 (1.19-2.10)
Low	Reference	Reference
COPD		
Chronic Dust Exposure		
High	1.81 (1.30-2.51)	1.83 (1.35-2.50)
Medium	1.48 (1.19-1.84)	1.50 (1.22-1.84)
Low	Reference	Reference
Chronic Bronchitis		
Chronic Dust Exposure		
High	1.74 (1.28-2.39)	1.87 (1.42-2.73)
Medium	1.45 (1.18-1.79)	1.57 (1.26-1.95)
Low	Reference	Reference

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment and mode characteristics.

3.5 Sensitivity Analyses

Response Bias. To assess response bias, newly diagnosed diabetes, a disease that has not been associated with WTC dust exposure, was examined among the chronic dust exposure groups. There was no association between chronic WTC dust exposure and newly diagnosed diabetes after September 11, 2001 among workers in this study population (Table 3.22).

Table 3.22 Prevalence Ratios of Diabetes at Wave Two (n=6,930)

	n	%	Crude PR (95% CI)		Adjusted *PR (95% CI)	
Chronic Dust Exposure						
High	54	2.4	0.77	0.45-1.30	0.82	0.45-1.50
Medium	58	2.8	0.84	0.59-1.19	0.88	0.59-1.31
Low	65	2.8	Reference		Reference	

*Adjusted for all demographic characteristics, peri-disaster experiences, and enrollment and mode characteristics.

Enrollment Bias. Results may have differed based on method of enrollment in the Registry. Table 3.23 presents prevalence ratios of respiratory outcomes stratified by method of enrollment in the Registry. Outcomes among list-enrolled workers were more likely to demonstrate exposure-response associations for Lower respiratory symptoms than outcomes among self-enrolled workers. In contrast, for Upper respiratory symptoms, exposure-response associations were significant among self-enrolled workers and not significant among List-enrolled workers (Table 3.23).

Among the disease outcomes, chronic dust exposure was associated with Asthma and

RADS outcomes only among self-enrolled workers. Chronic dust exposure-response associations with COPD and Chronic Bronchitis were significant, regardless of type of enrollment. Associations were much stronger, however, among List-enrolled workers.

Table 3.23 Prevalence Ratios at Wave Two by Method of Enrollment in the Registry (n=6,930)

	All Workers (n=6,930)	Self -Enrolled* (n=5,603)	List-Enrolled** (n=1,327)
Lower Respiratory Symptoms			
Chronic Dust Exposure			
High	1.20 (1.06-1.36)	1.12 (0.97-1.30)	1.37 (1.03-1.81)
Medium	1.13 (1.04-1.22)	1.08 (0.98-1.19)	1.23 (1.02-1.48)
Low	Reference	Reference	Reference
Upper Respiratory Symptoms			
Chronic Dust Exposure			
High	1.15 (1.07-1.24)	1.14 (1.05-1.24)	1.11 (0.93-1.32)
Medium	1.10 (1.05-1.14)	1.09 (1.03-1.16)	1.07 (0.95-1.21)
Low	Reference	Reference	Reference
Asthma			
Chronic Dust Exposure			
High	1.59 (1.28-1.99)	1.62 (1.26-2.09)	1.39 (0.78-2.47)
Medium	1.36 (1.18-1.58)	1.38 (1.17-1.63)	1.24 (0.85-1.83)
Low	Reference	Reference	Reference
RADS			
Chronic Dust Exposure			
High	2.08 (1.39-3.09)	1.92 (1.22-3.02)	3.01 (0.84-10.83)
Medium	1.63 (1.25-2.12)	1.54 (1.14-2.09)	2.09 (0.89-4.89)
Low	Reference	Reference	Reference
COPD			
Chronic Dust Exposure			
High	1.81 (1.30-2.51)	1.58 (1.12-2.22)	3.61 (1.63-8.03)
Medium	1.48 (1.19-1.84)	1.35 (1.08-1.71)	2.36 (1.39-4.01)
Low	Reference	Reference	Reference
Chronic Bronchitis			
Chronic Dust Exposure			
High	1.74 (1.28-2.39)	1.69 (1.18-2.41)	3.63 (1.57-8.39)
Medium	1.45 (1.18-1.79)	1.42 (1.12-1.80)	2.36 (1.35-4.13)
Low	Reference	Reference	Reference

*Adjusted PR among self-identified workers

**Adjusted PR among list-identified workers

Exposure Assessment. The sensitivity of the initial job-exposure matrix dust estimates was evaluated using alternative dust estimates. Exposure Misclassification Scenario 3 substituted dust estimates for Periods 2 and 3 that were an order of magnitude higher (1.70 mg/m^3) than OSHA respirable dust concentrations (0.17 mg/m^3). Under Scenario 3, prevalence ratios for respiratory symptoms, asthma, and COPD remained significant and were comparable to prevalence ratios associated with the initial exposure group assignments (Table 3.23).

Exposure Misclassification Scenario 6 excluded workers who arrived at the pile prior to September 12, 2001. Under Scenario 6, prevalence ratios for lower respiratory symptoms, asthma, and COPD were comparable to prevalence ratios associated with the initial exposure group assignments (Table 3.24).

Exposure Misclassification Scenario 8 excluded workers who arrived at the pile prior to September 18, 2001. A total of 508 workers remained in the analytical dataset. Prevalence ratios for were elevated respiratory symptoms, asthma, and COPD. However, these associations were not significant for all outcomes except COPD (Table 3.24).

Table 3.24 Prevalence Ratios at Wave Two by Exposure Misclassification Scenario

	All Workers (n=6,930)	Scenario 3* (n=6,930)	Scenario 6** (n=4,834)	Scenario 8*** (n=508)
Lower Respiratory Symptoms				
Chronic Dust Exposure				
High	1.20 (1.06-1.36)	1.29 (1.12-1.47)	1.15 (1.01-1.33)	1.54 (0.92-2.55)
Medium	1.13 (1.04-1.22)	1.18 (1.08-1.30)	1.10 (1.00-1.21)	1.33 (0.95-1.87)
Low	Reference	Reference	Reference	Reference
Upper Respiratory Symptoms				
Chronic Dust Exposure				
High	1.15 (1.07-1.24)	1.32 (1.06-1.39)	1.09 (0.95-1.25)	1.18 (0.72-1.93)
Medium	1.10 (1.05-1.14)	1.14 (1.04-1.25)	1.06 (0.97-1.16)	1.12 (0.81-1.55)
Low	Reference	Reference	Reference	Reference
Asthma				
Chronic Dust Exposure				
High	1.59 (1.28-1.99)	1.71 (1.30-2.27)	1.54 (1.18-2.03)	3.03 (0.94-9.78)
Medium	1.36 (1.18-1.58)	1.44 (1.19-1.73)	1.34 (1.11-1.60)	2.09 (0.96-4.57)
Low	Reference	Reference	Reference	Reference
COPD				
Chronic Dust Exposure				
High	1.81 (1.30-2.51)	1.62 (1.33-2.33)	1.95 (1.37-2.77)	4.89 (1.23-19.49)
Medium	1.48 (1.19-1.84)	1.38 (1.09-1.76)	1.56 (1.23-1.97)	2.88 (1.15-7.24)
Low	Reference	Reference	Reference	Reference

* Adjusted PR for Scenario 3: Assigning Periods 2 and 3 estimates a magnitude than reference strata in job-exposure matrix

** Adjusted PR for Scenario 6: Excluding workers who worked on the pile prior to September 12, 2011

*** Adjusted PR for Scenario 8: Excluding workers who worked on the pile prior to September 18, 2011

DISCUSSION

This study established a semi-quantitative method for assessing exposure to World Trade Center (WTC) dust among a cohort of rescue, recovery, and cleanup workers who worked on the pile after the September 11, 2001 WTC disaster. This was the first WTC Health Registry study to use environmental monitoring data and task-specific work histories as data sources for dust exposure assessment among workers.

The unforeseen nature of the September 11, 2001 World Trade Center disaster and the resulting disaster-related work activities presented noteworthy epidemiologic challenges. One of the most significant challenges was assessing occupational exposures among WTC workers with limited environmental monitoring measurements. Dust exposure was the primary inhalation toxicant in this study of respiratory health outcomes among WTC workers. Exposure to other respiratory irritants such as diesel exhaust constituents, organic gases, and heavy metals were not accounted for.

Respirable dust was the preferred surrogate for exposure in this study because of the substantial amount of sampling data available relative to other toxicants, and its biological relevance to respiratory health outcomes. Moreover, the wide range of dust concentrations in this cohort of WTC pile workers allowed for a more detailed analysis of the exposure-response relationship between WTC dust and respiratory outcomes. Additional theoretical and methodological issues are as follows:

Strengths

Cohort. The WTC Health Registry included a large, heterogeneous cohort of WTC disaster workers. The detailed work histories collected from the Wave One survey allowed for the development of an exposure assessment method for chronic occupational exposure to WTC dust. Through two surveys of workers exposed to the WTC disaster, Registry data was available to provided valuable insight into the sequelae of respiratory conditions five-to-seven years after the September 11, 2001 World Trade Center disaster.

Exposure Assessment. Dust exposure at the WTC site during rescue, recovery, and cleanup activities was characterized by particulates from a variety of sources, including building materials and vehicle emissions. Direct measures of individual exposures to WTC dust did not exist within this cohort of WTC workers. A retrospective exposure assessment approach was necessary for epidemiologic analyses of respiratory outcomes.

Previous Registry studies of WTC rescue, recovery, and cleanup workers had employed measures of exposure such as 1) their presence in the dust and debris cloud on September 11, 2001, 2) their location of WTC-related work, 3) their date of arrival at WTC-related work location, 4) their number of days of work at WTC-related work location, 5) WTC-work related organizational affiliation, and 6) WTC-related work tasks [54, 56, 58, 87]. These measures of exposures were all self-reported, and the

interpretation of individual predictors (i.e. date of arrival versus number of days worked) were subject to multicollinearity [78].

There are several methodological approaches to reduce multicollinearity among predictor variables in epidemiologic analyses. One approach is to increase the sample size of the study population [78]. Another method is to transform continuous variables into categorical variables. Multicollinearity can also be limited in the multivariable model by reducing the number of covariates using factor analysis or hierarchical models [77, 78]. In this study of WTC disaster workers, multicollinearity was reduced by incorporating several measures of exposure (location of WTC-related work, date of arrival at WTC-related work location, number of days of work at WTC-related work location, and WTC-related work tasks) with environmental monitoring data (respirable dust) from the Occupational Safety and Health Administration (OSHA) to create a single chronic WTC dust exposure variable.

Strengths of this exposure assessment method include a large set of environmental monitoring measurement samples (n=751) and a large and diverse cohort of WTC rescue, recovery, and cleanup workers (n=9,258). Misclassification of dust exposure was possible, especially when combining dust estimates from multiple sources or when exposure data are sparse. However, the reliability of the WTC dust exposure index was verified by comparing its exposure classifications to those modeled through various

misclassification scenarios. These sensitivity analyses indicated good correlation between the bias scenarios and the dust exposure index categories.

Respiratory Symptoms. The second aim of this study was to examine the exposure-response relationships between chronic WTC dust exposure and reported respiratory symptoms among rescue, recovery, and cleanup workers five-to-seven years after September 11, 2001. At Wave One, significant exposure-response relationships were observed for both upper and lower respiratory symptoms. Prevalence ratios of respiratory symptoms at Wave Two (five-to-seven years after 9/11) were weaker than prevalence ratios of respiratory symptoms at Wave One (2-3 years after 9/11). This weakened association could be due to the resolution of symptoms naturally or through treatment seeking behaviors of workers. Nevertheless, the associations between chronic exposure to WTC dust after September 11 and respiratory symptoms at Wave Two remained significant. In these analyses of respiratory health outcomes among WTC rescue, recovery, and cleanup workers, significant exposure-response associations persisted five-to-seven years after the WTC disaster.

Effect Modification. Several factors modified the relationship between chronic WTC dust exposure and upper respiratory symptoms at Wave One. Stratification by dust cloud exposure indicated that the exposure-response relationship between chronic WTC dust exposure and upper respiratory symptoms was stronger among workers who

reported that they were in the dust and debris cloud on the morning of September 11, 2001. Approximately 47% of workers in this study were present in the dust cloud. Exposure to the dust cloud may have sensitized workers to the impact of chronic dust exposure on the upper airways after September 11, 2001. At Wave Two, however, dust cloud was not an effect modifier, indicating that the effect of dust cloud on the relationship between chronic dust cloud exposure and upper respiratory symptoms had waned by Wave Two.

Stratification also revealed different exposure-response associations for upper respiratory symptoms by gender. Among male workers, there was a significant association between chronic WTC dust exposure and upper respiratory symptoms. The associations observed among female workers were much weaker, and could have been the result of the small size (6% of total sample) of the female population. The association between chronic WTC dust exposure and respiratory symptoms was not modified by gender at Wave Two.

Longitudinal Course of Respiratory Symptoms. The course of respiratory symptoms through two survey waves of the Registry was classified as Recurrent, Early-Onset/Resolved, Late-Onset, and Asymptomatic. Almost half of the study population reported recurrent lower (48.3%) and upper (47.4%) respiratory symptoms five-to-seven years after September 11, 2001. Positive exposure-response associations were observed

between chronic WTC dust exposure and Recurrent and Early-Onset/Resolved presentations of respiratory symptoms.

The results of these longitudinal analyses suggest that WTC workers continue to present with pulmonary difficulties years after their WTC-related work activities. These findings are consistent with studies of FDNY rescue workers who experienced significant persistent declines in lung function after exposure to WTC dust [53, 55]. Long-term follow-up, information about access to quality treatment, and more objective measurements of pulmonary function will be necessary to fully understand the scope of respiratory morbidity among this cohort of WTC workers.

Allergic Rhinitis. Occupational rhinitis can present after an acute exposure to high concentrations of an irritant material [88]. WTC dust contained a highly alkaline mix of pollutants that, in theory, could have irritated upper airways [89]. Although, chronic rhinosinusitis has been classified as a WTC-covered condition by NIOSH and the WTC Medical Monitoring and Treatment Program [86], few studies of WTC workers, to date, have reported on the prevalence of allergic rhinitis. In a NIOSH study of illnesses among WTC workers immediately after the disaster, the incidence of allergic rhinitis among workers reported in the two weeks following the WTC disaster was relatively low compared to other respiratory ailments and illnesses [90]. This study is the first to examine the relationship between WTC dust exposure and newly diagnosed allergic rhinitis among workers in the WTC Health Registry. Among the three chronic dust

exposure categories, there were no significant differences in the reporting of newly diagnosed allergic rhinitis five-to-seven years after September 11, 2001. Presence in the dust cloud, however, was a significant independent risk factor for allergic rhinitis after September 11, 2001. An important aim of future studies should be to define the mechanisms and relationships between dust cloud exposure and newly diagnosed allergic rhinitis after September 11, 2001.

Asthma. Respiratory disease outcomes were assessed using validated, standardized survey questions. The Registry's asthma question, specific to new diagnoses after September 11, for example, was modeled after validated asthma questions used by the CDC's National Health and Nutrition Examination Survey [91].

Results of this study expanded on previous Registry studies of newly diagnosed asthma among WTC rescue and recovery workers [54, 58]. There was a significant exposure-response relationship between WTC dust exposure and newly diagnosed asthma among this population of WTC pile workers. The strongest peri-disaster predictor among worker in this study was exposure to the dust cloud (Intense $PR_{adj} = 2.03$, 95% CI 1.68-2.47). After controlling for dust cloud exposure, chronic occupational exposure to WTC dust was also a significant risk factor as High dust exposure workers were 1.59 times (95% CI, 1.28-1.98) and Medium exposure workers were 1.36 times (95% CI, 1.18-1.58) more likely to report newly diagnosed asthma than Low exposure workers. The

development of chronic dust exposure categories allowed for the examination of the impact of occupational exposure to dust on asthma, regardless of dust cloud exposure on the morning September 11, 2001.

Enrollment of List-Identified Workers. Sensitivity analyses allowed for examination of potential biases in study results. Approximately 30% of Registry workers were recruited from employment lists. In analyses restricted to this group of "List-enrolled" workers, exposure-respiratory outcome associations remained significant for COPD and chronic bronchitis, indicating that the associations observed between exposure and these disease outcomes could not be attributed to selection bias alone.

Assessment of Psychological Distress. Psychological distress may have had an impact on the reporting of respiratory conditions among this population of trauma-exposed disaster workers. Registry survey at both Waves One and Two included a psychometrically validated screen of posttraumatic stress disorder, the PCL-CV [92]. This study examined PTSD as a potential effect modifier. Psychological distress specific to September 11, 2001 traumas did not significantly modify the association between chronic exposure to WTC dust and reported respiratory outcomes.

Limitations

Exposure Assessment. There are limitations in using this semi-quantitative method to characterize WTC dust exposure among WTC workers. First, information on exposure

determinants such as sampling flow rates, meteorological conditions during sampling, and type of work being performed during sampling was not incorporated into this index. It is not known whether predictors other than job tasks and location may have had an impact on dust exposure. Second, it is unknown whether the workers selected and sampled by OSHA were representative of workers in the Registry. Third, the accuracy of OSHA sampling of dust exposure among WTC workers is unknown, and OSHA sampling may not have accurately represented working conditions. Fourth, OSHA monitoring data was not available for all exposure time periods. For sampling periods prior to September 18, 2001, assumptions about dust exposure were made based on estimates from other sources of monitoring data. Finally, the exposure index could not be validated by another independent sample of environmental monitoring data.

The WTC dust exposure index is a combination of several exposure indicators that have already been identified as risk factors for asthma in previous Registry studies [54, 58]. This composite exposure variable cannot be used to make generalizations about the relationships between specific sources of dust exposure (such as metals or silica) and respiratory outcomes. The principle utility of this approach to exposure assessment, however, is the ability to identify an exposed population for future tracking and medical monitoring. Also, in epidemiologic analyses where the primary predictor of interest is not WTC dust exposure, this WTC dust exposure variable reduced the potential for spurious associations, and allowed for the evaluation of potential modifiable risk factors.

A semi-quantitative WTC dust exposure method has been developed for use in epidemiologic studies of New York State employees who responded to the World Trade Center Disaster after September 11, 2001 [39]. This exposure algorithm assigned an overall exposure score to selected participants in New York State Department of Health epidemiologic studies. The New York State exposure algorithm was similar to the exposure assessment method used in this current study of Registry workers in that the algorithm accounted for location at the site, amount of time at the site, and environmental monitoring results.

The differences between this semi-quantitative exposure assessment and the methods used by the New York State Department of Health should be noted. The surrogate for dust exposure in the New York State algorithm was calcium [39]. The surrogate for dust in this study of Registry workers was respirable dust. While the New York State exposure algorithm used ambient air monitoring results to estimate dust exposure, the current study used personal monitoring data to estimate dust exposure.

The most notable difference between the two semi-quantitative exposure assessment methods was in the accounting for mask and respirator use. The New York State algorithm accounted for mask and respirator use through assigned attenuation factors [39]. In this study of Registry workers, mask and respirator use was not accounted for during exposure assessment. The impact respirator use was evaluated as a covariate during epidemiologic analyses.

The differences between the two approaches in assessing mask and respirator use are the result of important discrepancies in data collection. The Registry did not collect data on mask and respirator types during the Wave One survey. The New York State Department of Health, however, asked study participants about six different types of respiratory protection at their baseline survey. Although information on masks and respirators were collected from workers during the Registry's Wave Two survey, only 75% of the Registry workers participated in the Wave Two survey.

As a result of the limited data about mask use, the impact of respirator use on respiratory outcomes was evaluated by introducing an "exposure group^xrespirator use" interaction term into the multivariable model. For each respiratory outcome examined in these analyses, there was no statistical evidence of effect modification by respirator use. In addition to interaction terms, results were also stratified by respirator use. Results indicated that the relationship between WTC dust exposure categories and respiratory outcomes were not significantly different among workers who did wear a respirator compared to workers who did not wear a respirator. These respirator-only subset analyses, however, may have been compromised by the variability in use and effectiveness among respirators in addition to a reduced sample size (Respirator users = 2,096, 30% of the study population).

Respiratory Symptoms. Lower respiratory symptoms were reported in 71.2% of the study population at Wave One and 57.0% of the study population at Wave Two. The prevalence of upper respiratory symptoms among workers was 66.5% at Wave One and 61.9% at Wave Two. It should be noted that the time periods of symptom assessment differed between the two Registry survey waves. Reported symptom prevalence at Wave One was a period prevalence between September 11, 2001 and the date of the Wave One survey. In contrast to the time period reported at Wave One, the time period at Wave Two reflected the 30 days prior to the Wave Two survey. A weakness of this study is that the two measures of symptom prevalence at Waves One and Two were not comparable. A better indication of long-term respiratory morbidity was accomplished by examining symptoms at two points in time after 9/11. This study was the first to examine the patterns of respiratory symptoms through the two survey waves of the Registry.

Categorization of Symptoms. At both survey waves, associations between WTC dust exposure and respiratory symptoms were stronger for lower respiratory symptoms compared to upper respiratory symptoms (Wave One: lower respiratory High $PR_{adj} = 1.44$, 95% CI 1.29-1.61 versus upper respiratory High $PR_{adj} = 1.40$, 95% CI 1.31-1.49; Wave Two lower respiratory High $PR_{adj} = 1.20$, 95% CI 1.06-1.36 versus upper respiratory High $PR_{adj} = 1.15$, 95% CI 1.07-1.24). Points estimates were different between the two symptom groups, and there were small risk differences between the two groups. Although respiratory symptoms were classified into upper and lower symptom

categories based on a review of the WTC respiratory outcome literature [89, 93], symptom questions were nonspecific, and could have been subject to misclassification resulting in similar risk estimates between the two symptom categories.

Cross-Sectional Study Design. Cross-sectional observational studies measure exposures and outcomes at one point in time. In this study, the prevalence of respiratory symptoms was determined through cross-sectional surveys at Wave One and Wave Two. Period prevalence measures reflected both the incidence and the duration of each reported respiratory symptom [77].

At Wave Two, prevalence ratios of respiratory symptoms may have been subjected to prevalence-incidence bias [94]. Chronic exposure to WTC dust could have affected the duration of the symptom instead of symptom incidence. Symptoms with long durations may have been overrepresented. Alternatively, symptoms with short durations may have been underestimated. A limitation in this study is the interpretation of the prevalence ratio as the measure of effect of chronic dust exposure on respiratory symptom outcomes [79].

Another limitation of the cross-sectional design is that the 30-day symptom prevalence at Wave Two could have been mitigated by therapeutic treatments. If there was a difference in the way symptoms were treated among the high or medium exposure

groups compared the low exposure group, the prevalence ratios of respiratory symptoms at Wave Two may have been biased.

Reactive Airways Dysfunction Syndrome. Workers participating in rescue, recovery, and cleanup activities after the WTC disaster were exposed to variety of environmental and occupational exposures at the WTC site. Of particular concern have been the effects of exposure to WTC dust from collapsed and burning. Animal toxicity studies have revealed that exposure to World Trade Center particulates resulted in respiratory tract hyperresponsiveness in mice [22]. In humans, inhalation exposures to high concentrations of WTC dust may have contributed to the development of bronchiolar inflammation and airway hyperresponsiveness [52].

Among World Trade Center rescue, recovery, and cleanup workers, newly diagnosed asthma after 9/11 has been well documented [54]. Few studies have examined the spectrum of newly diagnosed asthma after 9/11 among WTC rescue and recovery workers diagnosed with asthma after 9/11. Reactive Airways Dysfunction Syndrome (RADS), a phenotype of new-onset asthma characterized by asthma symptoms within 24 hours of a single or multiple high level occupational exposures, has been documented in WTC rescue and recovery worker populations [52].

In this study, asthma outcomes included RADS. With over 500 reported diagnoses, the WTC Health Registry contains one of the largest cohorts of self-reported RADS cases to

date [95]. A strength of this study was the ability to separate RADS for asthma outcomes among a cohort of WTC workers. Approximately 7.6% of workers in the High chronic dust exposure group were diagnosed with RADS after September 11, 2001, and chronic exposure to WTC dust was significantly associated with RADS among workers in this study population. After adjusting for confounders, the strongest predictor of RADS, however, was exposure to the Intense dust cloud on the morning of September 11, 2001 ($PR_{adj} = 2.96$, 95% CI 2.08-4.21).

Although, these results lend support to a plausible role for the dust cloud in the development of RADS among WTC workers, limitations should be noted.

Pulmonologists disagree on the association between WTC dust and debris exposure and RADS [96]. Prior to the WTC disaster, dust had never been documented as a cause of RADS, and Brooks' definition of RADS was limited to an irritant, gas, fume, or vapor exposure [96, 97]. Also, the high prevalence of RADS among WTC disaster workers may be a reflection of heightened awareness among physicians who treat WTC-exposed workers. Other subtypes of irritant-induced asthma may be misclassified as RADS by WTC physicians, or RADS may be misclassified as another subtype of irritant-induced asthma among non-WTC physicians. Currently, the Registry lacks the data to account for diagnostic differences among physicians. A validation study examining the manner in which physicians evaluate and diagnose RADS may clarify the results presented in this study.

COPD and Chronic Bronchitis. Chronic bronchitis is defined by the presence of cough with sputum production for at least three months a year for two consecutive years [98]. Chronic bronchitis is often difficult to properly diagnose because of its overlap with COPD, emphysema, and asthma [99]. This lack of a common and precise definition often leads to bias in epidemiological studies of chronic bronchitis. If the definition is too strict, chronic bronchitis is under-diagnosed by health professionals, and true outcomes are underestimated. If a liberal definition of chronic bronchitis, one that includes COPD and Emphysema, is used, cases of chronic bronchitis in a study population could be overestimated biasing study results.

In these analyses, chronic bronchitis was defined as an affirmative response to a question about a diagnosis of chronic bronchitis by a doctor or other health professional. Epidemiologic studies have identified airborne pollutants, smoking, and bacterial pathogens as risk factors for chronic bronchitis [98]. In this study, although the associations were stronger among never smokers, the risk of chronic bronchitis in relation to WTC dust exposure was not significantly affected by smoking status ($p=0.10$). These results, however, should be interpreted with caution as Registry surveys did not include questions about sputum production, an indicator of airway obstruction commonly associated with chronic bronchitis.

Persistent coughing and shortness of breath are symptoms associated Chronic Obstructive Pulmonary Disorder (COPD). Along with emphysema, chronic bronchitis

is the most prevalent form of COPD. In order to study the full scope of COPD among this population of WTC disaster workers, future survey waves of the World Trade Center Health Registry should include questions about symptoms such as a productive cough and chest tightness in addition to shortness of breath and wheezing. Continued follow-up will be necessary to determine whether the recurrent respiratory symptoms observed in this study will devolve into COPD. Also, because COPD is a debilitating respiratory condition that has been shown to result in long-term disability and death, future studies should examine the progression of COPD among WTC disaster workers, particularly among smokers and older workers.

Enrollment Bias. As with many voluntary cohorts, asymptomatic and low-exposed workers may not have been inclined to participate in epidemiologic studies [100, 101]. In an examination of Registry participation rates, Murphy and colleagues estimated that approximately 34% of the eligible exposed rescue and recovery workers enrolled in the Registry at Wave One [100]. Exposure information and symptom outcomes among workers who did not enroll in the Registry are unknown. Although the risk for chronic respiratory problems was a documented concern among workers after the collapse of the twin towers [102], there is no data available to assess whether workers who were both symptomatic and highly exposed were more likely to enroll in the Registry. Assuming non-differential enrollment by symptomatic workers, exposure enrollment bias at Wave One was minimized by the use of an internal exposure reference group, the Low dust exposure group.

Wave Two Participation Bias. Participation bias was a source of concern for the Wave Two survey. Exposure-disease relationships among those who participated in the Wave Two survey could have differed from exposure-disease relationships among those did not participate [77]. Participation at Wave Two was examined jointly by exposure group assignment and Wave One respiratory symptom status. Workers in the Low chronic exposure group who reported at least one symptom at Wave One were less likely to participate in the Wave Two survey than all other exposure-symptom groups. This differential participation could have biased results away from the null. Sensitivity analyses, however, indicated that prevalence ratios would not have been overestimated by more than eight percent.

There were significant demographic differences between participants and non-participants as Wave Two participants were more likely to be non-Hispanic white, older, wealthier, and more educated. Non-New York City residents and workers who were in the Dust cloud on the morning of September 11 were also more likely to participate in the Wave Two survey. These demographic and peri-disaster participation factors were controlled for during data analyses. Nevertheless, there could have been other determinants of participation that were not included in Registry surveys, and therefore this study was unable to control for during statistical analyses.

Information Bias. WTC exposures, health outcomes, and employment outcomes were all self-reported. There is the potential for differential recall bias and over-reporting of

exposures and outcomes among rescue and recovery workers. For example, workers with one or more respiratory outcomes and have recalled their exposures differently from workers who did not report any respiratory outcomes during Registry surveys. Exposure recall bias was minimized by the use of a semi-quantitative exposure assessment method and an internal exposure reference group. Also, to assess reporting bias, the relationship between WTC dust exposure and self-reported Diabetes diagnoses was examined. There were no significant differences among the exposure groups in reporting Diabetes. This result could suggest that information bias due to self-reporting was limited in this study. However, an alternate explanation could be that enrollees may have been less likely to over-reporting a condition they think is not related to 9/11, diabetes, than respiratory symptoms and diseases.

Diagnostic Bias. Unlike respiratory symptoms, respiratory disease outcomes were self-reported as diagnosed by a doctor or healthcare professional. Respiratory disease outcomes may have been more likely to be diagnosed among high dust exposed workers because physicians and medical professionals may have been more likely to screen for and diagnose these outcomes. High exposed workers could have also had more contact with physicians than low dust exposed workers. The result of this misclassification bias would have been the overestimation of prevalence ratio comparing the high to the low dust exposed groups. This study of Registry workers was unable to account for differences among physicians in evaluating and diagnosing new-onset respiratory

diseases after 9/11. Verification through medical records is recommended to validate respiratory outcomes among WTC disaster workers after September 11, 2001.

SUMMARY AND CONCLUSIONS

The World Trade Center attacks on September 11, 2001 resulted one of the worst environmental disasters in United States history. During the nine month cleanup, tens of thousands of workers and volunteers were exposed to dust and debris through their WTC-related activities. This study was the first to develop a semi-quantitative WTC dust exposure estimation method for use in epidemiological studies of respiratory health outcomes among WTC Health Registry workers who worked on the pile.

The results of this study support the *a priori* hypotheses that chronic occupational exposure to WTC dust was associated with respiratory health outcomes among WTC pile workers. Five-to-Seven years after the World Trade Center disaster, almost half of Registry WTC pile workers reported Recurrent lower and upper respiratory symptoms, and there were significant dust exposure-response associations between WTC dust exposure and lower and upper respiratory symptoms. These findings present a unique contribution to the Registry as the exposure index method developed in this dissertation can be used to identify a highly dust-exposed group of WTC disaster workers that may be at higher risk for adverse respiratory outcomes than other WTC disaster workers. Comprehensive follow up should continue to document the progression of respiratory symptoms among this group of WTC disaster workers in addition to their pulmonary responses to treatment and medications.

This study has identified older workers as a group of disaster responders that may have been more susceptible to the effects of chronic WTC dust exposure on respiratory health. Older workers were more likely to report lower respiratory symptoms, asthma, and RADS than younger workers. These results could have substantial public health implications for disease prevention and surveillance. In terms of prevention, older workers could be identified as a population group that requires targeted interventions and early medical monitoring during disaster response. Surveillance could provide information on occupational histories, differences in the utilization of medical services, and the long-term sequelae of respiratory illnesses. Furthermore, as evidenced by the persistence of lower respiratory symptoms five-to-seven years after the disaster, accelerated declines in pulmonary function may be a concern as the study population ages.

These results also have significant implications for population health. The findings of this study are biologically plausible for the adverse respiratory outcomes observed among WTC exposed workers. Respiratory outcomes observed among WTC disaster workers are consistent with the results of animal studies that reported pulmonary inflammation and significant increases in airway hyper-responsiveness in mice exposed to high levels of WTC dust. In addition to disaster workers, Lower Manhattan residents also experienced chronic exposure to WTC dust. The exposure-response associations observed in this epidemiologic study provide support for healthcare services for WTC

dust exposed residents as well other populations chronically exposed to dust such as construction and remediation workers.

The retrospective exposure assessment method developed in this study can provide methodological guidance for the use of monitoring data in epidemiologic studies of health outcomes among disaster workers. Environmental monitoring in the days immediately after the World Trade Center disaster was limited. Future disaster response research should anticipate these limitations, and strategically sample workers from a variety of work locations, job titles and tasks, work shifts, and time periods.

Disaster work presents a unique challenge to respiratory protection as masks and respirators can only be effective when they are properly used. In the disaster setting, workers perform their activities for long hours and are often under high stress. Many WTC disaster workers did not use their masks and respirators effectively as they abandoned proper respiratory protection in favor of their commitment to the disaster rescue, recovery, and cleanup process. WTC workers noted serious problems communicating and multitasking while wearing masks and respirators. In addition to educating disaster workers on proper fit-testing and maintenance techniques, more research attention should be focused on effectiveness of masks and respirators in disaster settings for extended periods of time. In this study, respirator use did not modify the relationship between chronic dust exposure and respiratory symptoms and diseases. The role of masks and respirators during chronic exposure to particulates is a necessary area

for future research and policy development as it may be relevant to develop protective equipment that is specific to the needs of protecting workers during an extended, multifaceted disaster recovery and cleanup process.

The results of this study emphasize the need to monitor the long-term respiratory health of WTC-exposed disaster workers. An estimated 91,694 workers were exposed to the WTC disaster and, to date, World Trade Center health programs in New York City and nationwide have treated 52,978 workers and volunteers [100, 103]. Epidemiologic studies along with continued surveillance will to be vital in understanding the respiratory health burden associated with occupational exposures after the September 11, 2001 World Trade Center disaster.

APPENDIX A

WORLD TRADE CENTER SAMPLING DATA

Table A.1 WTC Occupational Task Category Classifications [69]

OSHA Job Title	Occupational Task Category
BOBCAT	Heavy Equipment Operation
BOBCAT OPERATOR	Heavy Equipment Operation
BORING MACHINE OPER	Heavy Equipment Operation
CARPENTER	Heavy Equipment Operation
CAT 235C OPERATOR	Light Construction
CAT OPERATOR	Heavy Equipment Operation
CONCRETE DRILLER	Heavy Equipment Operation
CORE DRILLER	Heavy Equipment Operation
CORER	Heavy Equipment Operation
CRANE OPERATOR	Heavy Equipment Operation
CRANE OPERATOR/OPERATING ENGINEER	Heavy Equipment Operation
DOCK BUILDER	Heavy Equipment Operation
DRILLER	Welding / Steelcutting / Torch Operation
EXCAVATING ENGINEER	Heavy Equipment Operation
EXCAVATOR BOBCAT OPERATOR	Heavy Equipment Operation
EXCAVATOR OPERATOR	Heavy Equipment Operation
EXCAVATOR OPERATOR/OPERATOR ENGINEER	Heavy Equipment Operation
EXCAVATOR	Heavy Equipment Operation
FLAGGER	Heavy Equipment Operation
FOREMAN	Light Construction
FRONT END LOADER	Light Construction
GENERAL LABORER TOWER 2	Heavy Equipment Operation
GENERAL LABORER	Light Construction
GENERAL LABORER/SPOTTER	Light Construction
GRABBER/CLAW OPERATOR/OPERATING ENGINEER	Heavy Equipment Operation
GRAPPLER OPERATOR	Heavy Equipment Operation

Table A.1 WTC Occupational Task Category Classifications [69]

OSHA Job Title	Occupational Task Category
GRAPPLER	Heavy Equipment Operation
GRAPPLER/CLAW OPERATOR/OPERATING ENGINEER	Heavy Equipment Operation
GRAPPLERS AND DOZERS/TRUCKS. FOREMAN WORKING AREA BETWEEN WTC-1-2.	Heavy Equipment Operation
IRON WORKER-BURNER/CUTTER	Welding / Steelcutting / Torch Operation
IRONWORKER	Welding / Steelcutting / Torch Operation
IRONWORKER, RUBBLE SOUTH OF TOWER 2 AND NORTH OF 90 WEST.	Welding / Steelcutting / Torch Operation
IRONWORKER/TORCH CUTTER	Welding / Steelcutting / Torch Operation
IRONWORKER-BURNER/CUTTER	Welding / Steelcutting / Torch Operation
JACKHAMMER OPERATOR	Welding / Steelcutting / Torch Operation
KEEPING ROADWAY CLEAR ON NORTH SIDE OF #7 WTC.	Light Construction
LABORER	Light Construction
LABORER FOREMAN	Light Construction
LABORER-FLAGMAN	Light Construction
MACHINE OPERATOR, RUBBLE AND LOADING TRUCKS	Light Construction
NY FIRE DEPARTMENT	Firefighting
NY POLICE DEPARTMENT	Search Rescue
NY POLICE	Search Rescue
OPERATING ENGINEER	Heavy Equipment Operation
OPERATOR	Heavy Equipment Operation
OTHER RESCUER	Search Rescue
POLICE OFFICER	Search Rescue
SHOP STEWART/IRONWORKER	Welding / Steelcutting / Torch Operation
SUPERVISOR/FOREMAN	Light Construction
TORCH CUTTER	Welding / Steelcutting / Torch Operation

Table A.1 WTC Occupational Task Category Classifications [69]

OSHA Job Title	Occupational Task Category
TORCH CUTTING STEEL BEAMS WEST AREA OF PILE WTC-1	Welding / Steelcutting / Torch Operation
SUPERVISOR/FOREMAN	Light Construction
TORCH CUTTER	Welding / Steelcutting / Torch Operation
TORCH CUTTER/BURNING	Welding / Steelcutting / Torch Operation
TORCH CUTTING STEEL BEAMS WEST AREA OF PILE WTC-1	Welding / Steelcutting / Torch Operation
TORCHCUTTER	Welding / Steelcutting / Torch Operation
TRUCK DRIVER	Heavy Equipment Operation
WATER TRUCK OPERATOR/GENERAL LABORER	Heavy Equipment Operation

Table A.2 Respirable Dust Concentration (mg/m³) by Time Period, All Locations

Exposure Time Period: September 18, 2001 – December 31, 2001							
WTC Job Task	n	Arith. Mean	Geo. Mean	Median	Min	Max	# > PEL
Firefighting	1	0.34	0.34	0.34	0.34	0.34	0
Heavy Equipment Operation	104	0.35	0.14	0.19	0.00	5.70	1
Light Construction	41	0.55	0.25	0.26	0.00	4.20	0
Search and Rescue	26	0.80	0.51	0.76	0.04	2.30	0
Welding	31	0.46	0.18	0.16	0.03	3.90	0
All Tasks	203	0.47	0.19	0.21	0.00	5.70	1
Exposure Time Period: January 1, 2002 – June 30, 2002							
WTC Job Task	n	Arith. Mean	Geo. Mean	Median	Min	Max	# > PEL
Firefighting	28	0.12	0.10	0.11	0.00	0.28	0
Heavy Equipment Operation	83	0.30	0.14	0.17	0.00	2.50	0
Light Construction	49	0.62	0.15	0.17	0.00	13.00	1
Search and Rescue	55	0.63	0.30	0.24	0.03	9.30	1
Welding	333	0.50	0.17	0.16	0.00	9.90	7
All Tasks	548	0.48	0.17	0.16	0.00	13.00	9

*OSHA Permissible Exposure Limit = 5.0 mg/m³

Table A.3 Respirable Dust Concentration (mg/m³) by Time Period, East Location

Exposure Time Period: September 18, 2001 – December 31, 2001							
WTC Job Task	n	Arith. Mean	Geo. Mean	Median	Min	Max	# > PEL*
Firefighting	1	0.34	0.34	0.34	0.34	0.34	0
Heavy Equipment Operation	35	0.45	0.23	0.33	0.00	2.30	0
Light Construction	22	0.76	0.40	0.34	0.05	4.20	0
Search and Rescue	10	0.81	0.56	0.76	0.15	1.90	0
Welding	16	0.53	0.25	0.17	0.06	3.80	0
All Tasks	84	0.59	0.30	0.32	0.00	4.20	0
Exposure Time Period: January 1, 2002 – June 30, 2002							
WTC Job Task	n	Arith. Mean	Geo. Mean	Median	Min	Max	# > PEL*
Firefighting	14	0.13	0.10	0.13	0.00	0.25	0
Heavy Equipment Operation	68	0.30	0.16	0.22	0.00	2.50	0
Light Construction	33	0.75	0.17	0.17	0.00	13.00	1
Search and Rescue	37	0.67	0.29	0.24	0.03	9.30	1
Welding	253	0.58	0.19	0.18	0.00	9.90	7
All Tasks	405	0.54	0.19	0.19	0.00	13.00	9

*OSHA Permissible Exposure Limit = 5.0 mg/m³

Table A.4 Respirable Dust Concentration (mg/m³) by Date Period, Northwest Location

Exposure Time Period: September 18, 2001 – December 31, 2001							
WTC Job Task	n	Arith. Mean	Geo. Mean	Median	Min	Max	# > PEL*
Firefighting	0	N/A	N/A	N/A	N/A	N/A	N/A
Heavy Equipment Operation	36	0.11	0.07	0.06	0.00	0.29	0
Light Construction	13	0.38	0.15	0.12	0.00	1.20	0
Search and Rescue	12	0.74	0.48	0.66	0.04	2.30	0
Welding	8	0.56	0.12	0.08	0.03	3.90	0
All Tasks	69	0.32	0.12	0.12	0.00	3.90	0
Exposure Time Period: January 1, 2002 – June 30, 2002							
WTC Job Task	n	Arith. Mean	Geo. Mean	Median	Min	Max	# > PEL*
Firefighting	14	0.11	0.10	0.09	0.05	0.28	0
Heavy Equipment Operation	8	0.41	0.14	0.15	0.03	2.20	0
Light Construction	7	0.66	0.24	0.30	0.02	3.10	0
Search and Rescue	10	0.71	0.39	0.35	0.07	1.80	0
Welding	40	0.29	0.17	0.16	0.00	2.20	0
All Tasks	79	0.35	0.17	0.15	0.00	3.10	0

*OSHA Permissible Exposure Limit = 5.0 mg/m³

Table A.5 Respirable Dust Concentration (mg/m³) by Date Period, Southwest Location

Exposure Time Period: September 18, 2001 – December 31, 2001							
WTC Job Task	n	Arith. Mean	Geo. Mean	Median	Min	Max	# > PEL*
Firefighting	0	N/A	N/A	N/A	N/A	N/A	N/A
Heavy Equipment Operation	33	0.52	0.19	0.21	0.00	5.70	1
Light Construction	6	0.18	0.15	0.13	0.05	0.33	0
Search and Rescue	4	0.93	0.48	0.69	0.06	2.30	0
Welding	7	0.20	0.15	0.22	0.03	0.46	0
All Tasks	50	0.47	0.19	0.22	0.00	5.70	1
Exposure Time Period: January 1, 2002 – June 30, 2002							
WTC Job Task	n	Arith. Mean	Geo. Mean	Median	Min	Max	# > PEL*
Firefighting	0	N/A	N/A	N/A	N/A	N/A	N/A
Heavy Equipment Operation	7	0.18	0.10	0.09	0.01	0.62	0
Light Construction	9	0.14	0.06	0.08	0.00	0.50	0
Search and Rescue	8	0.37	0.26	0.23	0.09	1.30	0
Welding	40	0.22	0.08	0.09	0.00	3.50	0
All Tasks	64	0.22	0.09	0.11	0.00	3.50	0

*OSHA Permissible Exposure Limit = 5.0 mg/m³

APPENDIX B

WORLD TRADE CENTER HEALTH REGISTRY SURVEY QUESTIONS

WAVE ONE

Gender

What is your sex?

Age

What is your current age?

Race/Ethnicity

Which of the following would you say is your race? You may select more than one category.

Are you Hispanic or Latino/Latina?

Income

What was your total household income in 2002 before taxes?

Education

What is the highest grade or year of school you completed?

Marital Status

What is your current marital status?

Smoking Status

Have you smoked at least 100 cigarettes in your entire life?

Do you now smoke cigarettes?

Residence on September 11, 2001

Did you live in New York City on September 11th, 2001?

Dust Cloud

On September 11th, were you outdoors within a dust or debris cloud resulting from the collapse of the World Trade Center towers?

Occupational Group

What organization did you work for at the World Trade Center site?

Mask/Respirator Use

On September 11th, 2001, did you wear a mask?

On September 12th, 2001, did you wear a mask?

From September 13th to September 17th 2001, did you wear a mask?

From September 18th to December 31st 2001, did you wear a mask?

After December 31st, 2001, did you wear a mask?

WAVE TWO**Gender**

What is your gender?

Age

What is your current age?

Race/Ethnicity

Not Asked

Income

Not Asked

Education

Not Asked

Marital Status

What is your current marital status?

Smoking Status

Do you now smoke cigarettes every day, some days, or not at all?

About how many cigarettes on average do you smoke per day?

Residence on September 11, 2001

Did you live in New York City on September 11th, 2001?

Dust Cloud

On September 11, 2001, were you in the dust and debris cloud that resulted from the collapse of the WTC Towers?

Dust Cloud Experience

When you were in the dust and debris cloud on September 11, 2001, which of the following did you experience?

I could not see more than a couple of feet in front of me.

I had trouble walking or finding my way because the dust was so thick.

I had to find shelter like under a car or in a doorway.

I was covered from head to toe with dust and debris.

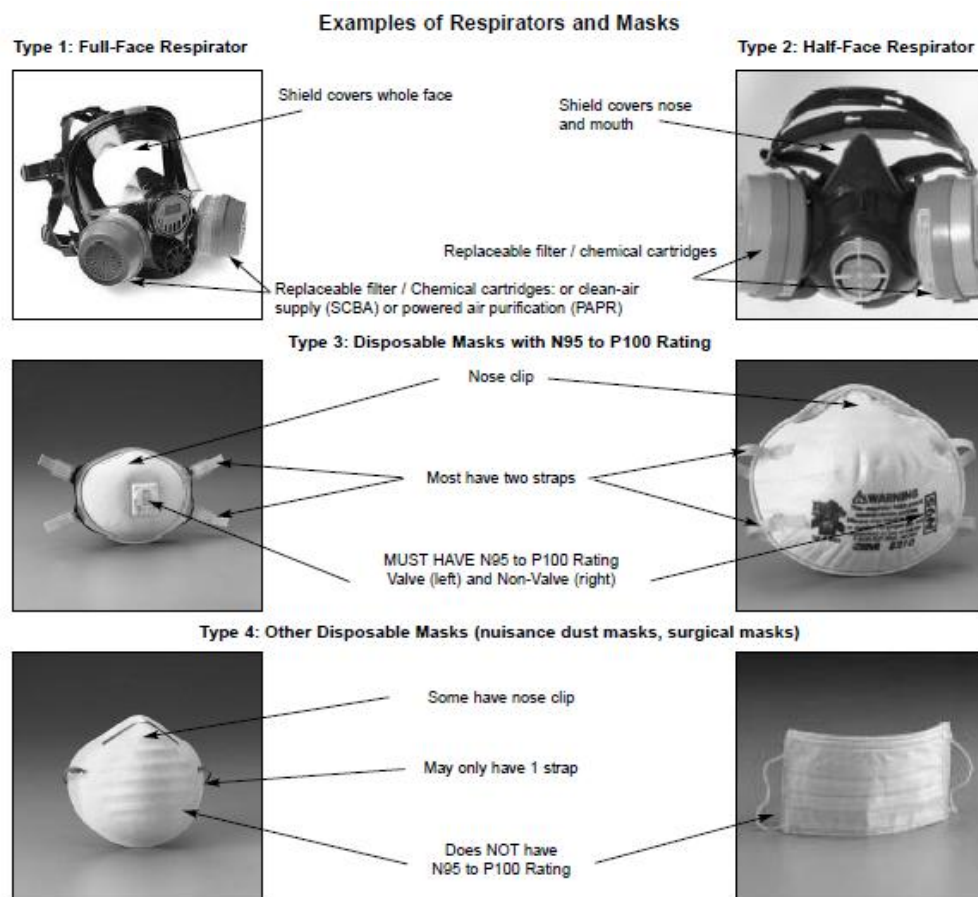
I could not hear anything.

Respirator Use

On September 11, 2001, which type of mask or respirator did you wear the most?

From September 12 to December 31, 2001, which type of mask or respirator did you wear the most?

From January 1, 2002 onward, which type of mask or respirator did you wear the most?



Respiratory Disease History

Have you ever been told by a doctor or other health professional that you had asthma? Were you told before 9/11/01?

Have you ever been told by a doctor or other health professional that you had hay fever or allergic rhinitis? Were you told before 9/11/01?

Have you ever been told by a doctor or other health professional that you had chronic bronchitis? Were you told before 9/11/01?

Have you ever been told by a doctor or other health professional that you had emphysema before 9/11? Were you told before 9/11/01?

Probable Posttraumatic Stress Disorder

The PTSD Checklist-Civilian Version was used to assess probable posttraumatic stress disorder. The PTSD Checklist is a self-reported scale of 17 symptoms that corresponds to the DSM-IV criteria. Each symptom was assessed as event-specific (“as a result of the World Trade Center disaster”) and current (“within the last 30 days”) on a 5-point scale. A score at or above 44 meeting the DSM-IV diagnostic criteria was indicative of probable PTSD [92, 104].

APPENDIX C

PARTICIPATION RATES BY REGISTRY SURVEY WAVE

Table C.1 Demographic Characteristics of Study Participants by Registry Survey Wave

	Wave One		Wave Two		Participation Rate	
	n	%	n	%	%	<i>p</i> value*
Gender						0.55
Male	8674	93.7	6499	93.8	73.8	
Female	584	6.3	431	6.2	74.9	
Age						<0.0001
< 30	717	7.7	458	6.6	63.9	
30 - 34	1240	13.4	824	11.9	66.5	
35 - 39	1831	19.8	1331	19.2	72.7	
40 - 44	2072	22.4	1586	22.9	76.5	
45 - 49	1709	18.5	1368	19.7	80.1	
50 - 54	962	10.4	754	10.9	78.4	
55+	727	7.9	609	8.8	83.8	
Race / Ethnicity						<0.0001
White, Non - Hispanic	7229	78.1	5686	82.1	78.7	
Black, Non - Hispanic	512	5.5	299	4.3	58.4	
Hispanic	1058	11.4	656	9.5	62.0	
Asian	128	1.4	89	1.3	69.5	
Multiracial	138	1.5	92	1.3	66.7	
Other	193	2.1	108	1.6	56.0	
Household Income						<0.0001
< \$25,000	325	3.5	207	3.0	63.7	
\$25,000 - < \$50,000	1109	12.0	742	10.7	66.9	
\$50,000 - < \$75,000	2229	24.1	1643	23.7	73.7	
\$75,000 - < \$150,000	4371	47.2	3482	50.3	79.7	
\$150,000+	518	5.6	418	6.0	80.7	
Missing	706	7.6	438	6.3	62.0	

*Chi – Square test comparing Wave Two participants to Wave Two nonparticipants

Table C.1 continued Demographic Characteristics of Study Participants by Registry Survey Wave

	Wave One		Wave Two		Participation Rate	
	n	%	n	%	%	<i>p</i> value*
Education						<0.0001
Non- High School Graduate	373	4.0	212	3.1	56.8	
High School Graduate	2416	26.1	1728	24.9	71.5	
Some College	3329	36.0	2520	36.4	75.7	
College grad / post Graduate	3027	32.7	2423	35.0	80.1	
Missing	113	1.2	47	0.7	41.6	
Marital Status						<0.0001
Married / Cohabiting	6821	74.5	5314	77.1	77.9	
Divorced / Widowed / Separated	977	10.7	675	9.8	69.1	
Never Married	1355	14.8	902	13.1	66.6	
Smoking Status						<0.0001
Never Smoker	5182	56.5	3924	56.9	75.7	
Former Smoker	2363	25.8	1842	26.7	78.0	
Current Smoker	1632	17.8	1133	16.4	69.4	

*Chi – Square test comparing Wave Two participants to Wave Two nonparticipants

Table C.2 Peri-disaster Characteristics of Study Participants by Registry Survey Wave

	Wave One		Wave Two		Participation Rate	
	n	%	n	%	%	<i>p</i> value*
Residence on 9/11						<0.0001
Lower Manhattan below Canal	134	1.5	88	1.3	65.7	
New York City	4046	43.7	2853	41.2	70.5	
Outside New York City	5078	54.9	3989	57.6	78.6	
Dust Cloud						0.005
Yes	4303	46.6	3281	47.4	76.3	
No	4934	53.4	3636	52.6	73.7	
Occupational Group						<0.0001
Fire and rescue	2817	30.6	2352	34.0	83.4	
EMS and medical, medical examiner	463	5.0	372	5.4	80.0	
Law Enforcement and military	1826	19.8	1379	19.9	75.4	
Construction, utilities, remediation	1554	16.9	983	14.2	63.1	
Sanitation	466	5.1	293	4.2	62.5	
Public Agency, not already specified	1025	11.1	786	11.4	76.5	
Volunteers and miscellaneous	1059	11.5	754	10.9	71.0	
Mask Use						0.127
Ever	8609	93.0	6461	93.3	75.1	
Never	648	7.0	465	6.7	72.3	

*Chi – Square test comparing Wave Two participants to Wave Two nonparticipants

Table C.3 Enrollment Characteristics of Study Participants by Registry Survey Wave

	Wave One		Wave Two		Participation Rate	
	n	%	n	%	%	<i>p</i> value*
Method of WTC Health Registry Enrollment						<0.0001
List - Identified	2103	22.7	1327	19.2	63.1	
Self - Identified	7155	77.3	5603	80.8	78.3	

*Chi – Square test comparing Wave Two participants to Wave Two nonparticipants

Table C.4 Wave Two participation rates by Exposure Group and Symptom Status at Wave One

	Any Respiratory Symptom		No Respiratory Symptoms	
	n	Participation Rate (%)	n	Participation Rate (%)
High Exposure	2097	75.7	281	76.4
Medium Exposure	1700	75.9	464	78.0
Low Exposure	1747	71.8*	641	75.3

* p = 0.003, Chi – Square test comparing participation jointly by exposure group and symptom status at Wave One

APPENDIX D

INTERACTION TESTS BETWEEN CHRONIC WTC DUST EXPOSURE

CATEGORIES AND SELECTED COVARIATES

Table D.1 Tests for Interaction between Chronic WTC Dust Exposure and Dust Cloud

Outcome	p value*
Lower Respiratory Symptoms at Wave One	0.125
Upper Respiratory Symptoms at Wave One	0.002*
Lower Respiratory Symptoms at Wave Two	0.985
Upper Respiratory Symptoms at Wave Two	0.510
Allergic Rhinitis at Wave Two	0.498
Asthma at Wave Two	0.940
RADS at Wave Two	0.144
COPD at Wave Two	0.621
Chronic Bronchitis at Wave Two	0.785

*Interaction p value between chronic WTC dust exposure group and dust cloud.

**Significant and $p < 0.05$ level

Table D.2 Tests for Interaction between Chronic WTC Dust Exposure and Gender

Outcome	p value*
Lower Respiratory Symptoms at Wave One	0.655
Upper Respiratory Symptoms at Wave One	0.027*
Lower Respiratory Symptoms at Wave Two	0.831
Upper Respiratory Symptoms at Wave Two	0.292
Allergic Rhinitis at Wave Two	0.382
Asthma at Wave Two	0.220
RADS at Wave Two	0.633
COPD at Wave Two	0.879
Chronic Bronchitis at Wave Two	0.629

*Interaction p value between chronic WTC dust exposure group and gender.

**Significant and $p < 0.05$ level

Table D.3 Tests for Interaction between Chronic WTC Dust Exposure and PTSD Status

Outcome	p value*
Lower Respiratory Symptoms at Wave One	0.061
Upper Respiratory Symptoms at Wave One	0.254
Lower Respiratory Symptoms at Wave Two	0.160
Upper Respiratory Symptoms at Wave Two	0.973
Allergic Rhinitis at Wave Two	0.022*
Asthma at Wave Two	0.368
RADS at Wave Two	0.993
COPD at Wave Two	0.376
Chronic Bronchitis at Wave Two	0.231

*Interaction p value between chronic WTC dust exposure group and PTSD status.

**Significant and $p < 0.05$ level

Table D.4 Tests for Interaction between Chronic WTC Dust Exposure and Smoking Status

Outcome	p value*
Lower Respiratory Symptoms at Wave One	0.054
Upper Respiratory Symptoms at Wave One	0.195
Lower Respiratory Symptoms at Wave Two	0.197
Upper Respiratory Symptoms at Wave Two	0.949
Allergic Rhinitis at Wave Two	0.056
Asthma at Wave Two	0.971
RADS at Wave Two	0.443
COPD at Wave Two	0.057
Chronic Bronchitis at Wave Two	0.096

*Interaction p value between chronic WTC dust exposure group and smoking status.

Table D.5 Tests for Interaction between Chronic WTC Dust Exposure and Respirator Use

Outcome	p value*
Lower Respiratory Symptoms at Wave One	0.900
Upper Respiratory Symptoms at Wave One	0.801
Lower Respiratory Symptoms at Wave Two	0.209
Upper Respiratory Symptoms at Wave Two	0.506
Allergic Rhinitis at Wave Two	0.069
Asthma at Wave Two	0.082
RADS at Wave Two	0.668
COPD at Wave Two	0.826
Chronic Bronchitis at Wave Two	0.777

*Interaction p value between chronic WTC dust exposure group and respirator use.

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