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Summary of the development of a signature for detection of residual dust from collapse of the World Trade Center buildings

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Abstract

The collapse of the World Trade Center (WTC) towers on September 11, 2001, caused lower Manhattan and adjacent areas to be covered in millimeters to centimeters of dust. WTC dust penetrated into indoor spaces, and public health concerns remain regarding exposure to possible residual dust in the affected areas. The goal of the studies outlined in this review was to determine which, if any, components of the bulk WTC dust are sufficiently above typical background dust levels in New York City to develop an analytical method to screen for the component(s). Components of the <150-μm-size fraction of the dust are gypsum, phases compatible with crushed concrete, man-made vitreous fibers (MMVFs), silica, lead, chrysotile asbestos, and other materials. Slag wool was the most common WTC MMVF, whereas soda-lime glass and rock wool were minor to trace constituents. Most background samples also contained gypsum, phases compatible with concrete, and MMVF. However, the proportions of the various MMVF in background samples are typically unlike those characteristic of bulk WTC dust. Results indicate that slag wool can be used as a signature marker to identify areas that contain potential residual WTC dust contamination at concentrations that are less than average background levels for the material.

Keywords

World Trade Center; dust; slag wool; scanning electron microscope

Introduction

The dust generated by collapse of the WTC towers on September 11, 2001, covered much of lower Manhattan in millimeters to centimeters of powdered material. Concerns remain about

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the possible presence of residual WTC dust in indoor and outdoor environments in lower Manhattan and surrounding areas. Concerns have also arisen because of recognized medical effects of exposure to this dust, including WTC cough (Prezant et al., 2002; Gavett et al., 2003), and more recently the observations made by the Mt. Sinai consortium for WTC Medical Screening and Monitoring of non-FDNY (Fire Department of New York) WTC rescue workers and volunteers. This study found that among over 8000 screened subjects, ~70% reported new or worsening respiratory symptoms after September 11, 2001, and that those symptoms have persisted in most of the subjects for several years (Herbert et al., 2006). Further, many subjects experienced pulmonary function losses that are greater than those expected in either normal or cigarette smoking populations. These findings corroborate the initial studies published by the FDNY and the WTC health registry (Banauch et al., 2005; Brackbill et al., 2006; CDCP, 2004). There also remains concern about the potential for continued exposure to lead, asbestos, and other contaminants of potential concern (COPCs) present in residual WTC dust.

In March 2004, the US Environmental Protection Agency (EPA) established the World Trade Center Expert Technical Review Panel (WTCETRP) to evaluate health and environmental issues following collapse of the WTC buildings. The WTCETRP was asked to evaluate methods for detecting residual dust in residences, public buildings, and workplaces potentially impacted by collapse of the WTC buildings. Three authors (G.P.M., P.J.L., and M.L.) were members of the WTCETRP and constituted its subcommittee that worked with EPA scientists on the development of a WTC dust signature presented herein.

Identification of residual WTC dust in indoor spaces years after the collapse of the WTC buildings is complicated by dilution with other materials and possible variations in relative dust component abundances arising from factors such as dust's exposure to moisture; fractionation of components with distance from the WTC site; human activity; and building elevation. In addition, determining abundances of COPCs, such as asbestos, lead, and man-made vitreous fibers (MMVFs), originating from WTC dust, is complicated by possible contribution of these same materials from a variety of other historic and contemporary sources unrelated to collapse of the WTC buildings, including construction materials, asbestos-containing insulation, and lead-based paint.

A comparison of bulk WTC dust to local background dust (not impacted by WTC dust) was therefore initiated to determine which components, if any, are unique to, or have significantly elevated abundances in, WTC dust. Initial comparison of background samples to bulk WTC dust (Lowers et al., 2005), presented below, showed potential, and at the recommendation of the WTCETRP, EPA conducted an inter-laboratory study to evaluate a method for analysis of indoor dust samples and to evaluate the potential of using slag wool, a type of MMVF, as a signature for the identification of residual WTC dust in indoor spaces. The goals of that study were to determine if laboratories could (1) identify slag wool and other potential signature components in prepared background dust samples spiked with WTC dust; and (2) distinguish typical background samples from spiked samples. The results presented here summarize work reported by several government agencies and research groups, including EPA, United States Geological Survey (USGS), Environmental and

Occupational Health Sciences Institute (EOHSI), New York University School of Medicine, and others.

Methods

Bulk WTC Dust Samples

Dust generated by the WTC collapse was collected from outdoor and indoor locations at various distances from the WTC site by USGS scientists (Clark et al., 2001; Swayze et al., 2005). Samples USGS 4, 6, and 12 were collected at ground level between September 16 and 17, 2001, at distances of 0.80, 0.60, and 0.55 km, respectively, from the center of the WTC site (Figure 1). Dust collected at these sites was exposed to a rainstorm before collection. Sample USGS 36, collected on September 12, 2001, was obtained from inside a 30th-floor apartment 0.40 km from the WTC site.

Environmental and Occupational Health Sciences Institute sample LM2 is an outdoor sample collected on September 16–17, 2001, ~0.70 km east of the WTC site (Lioy et al., 2002). EOHSI sample L18-2 was collected indoors on November 19, 2001, from an area adjacent to the WTC site that was affected directly by the material released during the collapse (0.25 km west) (Yiin et al., 2004).

Representative aliquots of the WTC bulk dust samples were sieved to <150 μm (100 mesh) using an ultrasonic sieve shaker. Following the sieving procedure, half of each sieved sample was ashed at 480°C using a high temperature muffle furnace to remove the organic fraction. The upper temperature limit of 480°C was chosen to prevent potential decomposition of chrysotile. Melting temperatures of MMVF, particularly slag wool and rock wool, range from 1149 to 1260°C (TIMA, 1991), so it is unlikely that these materials were modified by the ashing procedure. Gypsum converts to anhydrite at these temperatures; however, by energy dispersive X-ray spectrometry (EDS) with data normalized to 100% totals, gypsum and anhydrite are indistinguishable. Most constituents of concrete are not significantly affected by heating to 480°C.

A 0.2 g aliquot of each sieved and ashed sample was suspended in 125 ml of isopropanol. Using a micropipette with 1-mm diameter tip opening, six 20 μl drops of the suspension were filtered onto a 25mm diameter polycarbonate filter with a 0.4 μm pore size using a Millipore filter apparatus. The filter was placed on a conductive carbon tab adhered to an aluminum sample mount. After drying, the mounted sample was coated using a carbon evaporator before analysis in a scanning electron microscope (SEM). The amount of sample was adjusted to yield coverage of approximately 2–4% on the filter. Coverage greater than about 10% causes particles to overlap, which can cause analytical errors in the particle area estimation. Analyses were performed using a JEOL 5800LV SEM equipped with an Oxford ISIS EDS analysis system. Analytical conditions were 15KeV accelerating voltage, 0.5–5 nA beam current, 10mm sample working distance and zero-degree tilt. Data were processed using normalized standardless quantitative analysis.

Particles were binned by type (mineralogy and composition) based on extensive analysis of WTC dust by numerous studies using multiple analytical techniques (Table 1) (Clark et al.,

2001; Chatfield and Kominsky, 2002; Lioy et al., 2002; Millette et al., 2002; McGee et al., 2003; Offenberg et al., 2003; Badger et al., 2004; Yiin et al., 2004; Lowers and Meeker, 2005; Meeker et al., 2005a, b). The MMVFs were further subdivided into three distinct chemical groups based on Si, Ca, and Fe content as determined by quantitative electron probe microanalysis (EPMA) (Meeker et al., 2005b). The three groups are slag wool, rock wool, and soda-lime glass, based on chemical definitions and nomenclature of the Thermal Insulation Manufacturers Association (TIMA, 1991). The same fibers analyzed by EPMA were also analyzed by SEM/EDS and found to be distinguishable within the error of the EDS analysis based on the same criteria — that is, Si, Ca, and Fe.

Area percentage coverage of the sample on filters was determined using binary backscattered electron images. Dimensions of individual particles were determined manually by direct measurement using digital images. The maximum dimension of individual particles was recorded as the length and width defined as the mean diameter. The chemistry of each particle ≥3 μm in greatest dimension in the 500-times magnification field of view (FOV) was determined and binned according to particle type. This process was also performed at 2000-times magnification for all particles <3 μm in greatest dimension. Within each sample, 20 randomly selected FOVs, at each magnification, were analyzed. The number of particles analyzed within each sample ranged from 900 to over 3000, depending on the density of filter coverage.

The defined sample preparation method worked well for all components except MMVF. The abundance of MMVF particles in analytical filters was significantly less than their abundance in bulk dust, as determined by optical microscopy. Shadow patterns observed as uncoated portions on the polycarbonate filter with a fiber-like shape were visible, which suggests that the fibers were present during carbon coating but dislodged from the filter after coating because of particle overloading, charging effects in the SEM, or some other factor. To more accurately determine MMVF area percent coverage, three 5 μl aliquots of the suspension were directly pipetted onto conductive carbon tape. The area percentage of MMVF was determined separately for each bulk sample by analyzing one FOV at100 -times magnification. In addition, all particles were analyzed at 100-times magnification in five FOVs on two samples (USGS 4 and USGS 6). The area percent of particles by category (Table 1) collected on these two samples at 100-times magnification were comparable with those obtained by the filter preparation.

The number of MMVF per unit weight of sample was determined for separate preparations of USGS 6, 12, and 36. This was accomplished by placing a known weight of material into an isopropanol suspension, which was agitated in an ultrasonic bath. After sonification, the sample was shaken to resuspend the particles. A micropipette with the tip cut to produce an ~1 mm opening was used to extract six 5 μl aliquots from the top, middle, and bottom of the suspension. The suspension was not agitated between aliquot withdrawals, and aliquots were removed immediately after one another. The aliquots were placed onto a conductive carbon tab adhered to an aluminum sample mount. After drying, the mounted sample was coated using a carbon evaporator and analyzed using SEM/EDS conditions that were the same as those described above. Each entire sample mount was examined at 100-times magnification,

so the uneven distribution of particles did not affect the results. The number and type of MMVF were recorded in each FOV.

Background Samples

Initial bulk background dust samples from six locations were collected between November 2004 and January 2005 by the EPA from residential units at the approximate locations shown in Figure 1 (US EPA, 2005). The samples represent vacuumed surfaces, including windowsills, carpets, bathroom vents, and tops of storage units. It is assumed that, because of distance from the WTC, dust generated by the collapse of the WTC buildings did not contribute to these samples. It is also assumed that the asynchronous sampling of the background samples relative to the WTC bulk samples did not affect the results because no other major dust plume events affected the areas where background samples were collected since the WTC collapse. For more information concerning collection of these materials, see US EPA (2005) and Lowers et al. (2005).

The initial background samples, as provided to USGS by USEPA, were split using the cone-and-quarter technique. Half of each sample was ashed using the protocol described above. The ashed part of each sample was split again using the cone-and-quarter technique. Each split was prepared and analyzed in a similar way to the bulk WTC dust for the MMVF per unit weight determination described above. The number and type of MMVF in each FOV were recorded (Lowers et al., 2005).

EPA Study Samples

For the EPA study, two sets of three spiked reference materials were prepared by USGS by adding bulk WTC dust to background samples to produce reference standards that contain WTC dust concentrations of 10%, 5%, and 1% by weight. The first set was spiked with a composite of several WTC dusts collected by USGS following the WTC collapse (USGS samples 7, 12, 16, 18, 20, 23, 31, 33, 35 (see Clark et al., 2001)). Approximately 30% of the dust contained in this composite material was collected from indoor areas not affected by rain. This spike (USGS) represents material that most closely approximates the dust that covered much of lower Manhattan immediately after the WTC collapse. The second spike (4 Albany) was composed of indoor dust collected by EPA in 2004 from a building located at 4 Albany Street. This material contained an order of magnitude less slag wool than any of the original bulk samples and appears to represent diluted WTC dust (US EPA, 2005). Additional background samples analyzed included samples collected from various locations in northern Manhattan by the EPA study; and a few samples collected in New Jersey and North Carolina. The background samples, by definition, are inferred t o contain no dust associated wit ht he WTC collapse.

Each of the six reference materials were blended for homogeneity at the USGS laboratories in Denver, CO, and then sent to EPA to be split into individual aliquots. The resulting aliquots and several additional background samples were sent for analysis to eight laboratories that were selected by EPA for participation in the study. The method protocol to prepare and analyze the samples was similar to that for the initial background samples and bulk WTC dust MMVF per unit weight determination described above.

Results

WTC Dust Samples

The major constituents of the six WTC bulk samples are gypsum, phases compatible with concrete, and MMVF (Table 2). In the outdoor samples, these components have variable relative abundances. In particular, the relative abundance of gypsum is variable when compared with the abundance of other major components. These variations are likely related to the fact that some samples were exposed to moisture and precipitation before sample collection, which caused variable amounts of gypsum dissolution. The two indoor samples (USGS36 and L18-2), which were unaffected by precipitation, have less variable compositions and more gypsum than the outdoor samples.

Regardless of sample location (indoor versus outdoor, or distance from the WTC site), the most consistent particle-type abundance ratios occur within the MMVF category (Table 2). In all samples, slag wool is the dominant MMVF component, whereas abundances of rock wool and soda-lime glass fibers are below ~10% to less than 1% of total MMVF (Table 2). The one exception to this was sample L18-2 that had 26% soda-lime glass, but the majority of MMVF were slag wool. The reason for this discrepancy may be the contribution of soda-lime glass from the sample location.

Separate preparations of USGS 6, 12, and 36 samples yielded similar relative slag wool fiber abundances (Table 3). Average abundance is 9.4×10^6 slag wool fibers per gram; 1 sigma deviation is 1.3×10^6 fibers per gram. Sample USGS 36, the indoor sample from the 30th floor, contains the lowest slag wool abundance but is still comparable with values for the outdoor samples.

Particle size distributions for the non-MMVF major dust components are summarized in Figure 2. The outdoor samples all have similar particle-size distributions (expressed as the maximum dimension of the particle as measured on SEM images) with the majority of the particles ranging from 0.3 to 3 μm^2. Indoor samples L18-2 and USGS 36 clearly deviate from the other samples with respect to size distribution. Sample L18-2, the closest sample to the WTC site, shows a higher abundance of larger particles, and sample USGS 36, collected on the 30th floor of a nearby building, shows a higher abundance of smaller particles.

Background Samples

All six background samples contain gypsum, silicon dioxide (probably quartz), talc, calcium–magnesium carbonate, calcium carbonate, and Fe-rich phases (Lowers et al., 2005). MMVFs are a minor to trace component of the six background samples. Slag wool particles were not observed in two of the six background samples analyzed by USGS (Table 3) (Lowers et al., 2005). The other four samples contain very low concentrations of slag wool, between 1,800 and 25,300 fibers per gram (Table 3) (Lowers et al., 2005). Additional background samples analyzed by US EPA (2005) contained less than detectable to 6.7×10^4 slag wool fibers per gram; most samples contain less than 1×10^4 slag wool fibers per gram (Table 3). Soda-lime glass particles (a type identified in WTC dust) and Ca–Al–Si glass fibers (a type not identified in WTC dust) are the dominant MMVF particle types in the background samples, and slag wool, a significant component of the MMVF in WTC dust

samples, is the least common MMVF particle type identified in the background samples. The presence of gypsum and phases compatible with concrete in the background samples indicates that the presence of slag wool and relative abundance of MMVF particle types holds the most promise for identification of a possible WTC dust signature.

EPA Interlaboratory Study

The results of the EPA (2005) interlaboratory slag wool detection study are summarized in Figure 3. Data used to construct Figure 3 are listed in Appendix E Tables 4 and 5 of the EPA study (2005). Error bars for slag wool analyses are based on the 95% Poisson distribution, as described in the International Standard Organization (ISO) Method 14966 (2002) for the analysis of asbestos. Data from each participating laboratory were plotted separately to highlight any interlaboratory difference. The data indicate large interlaboratory variations, which may result from variations in sample preparation and counting criteria. Regardless, all the laboratories' data depict similar patterns, such that slag wool fibers per gram values increase with increasing amount of spiking material. Slag wool abundances determined in all background samples counted by the various laboratories are at or below the 10% 4 Albany-spiked and the 1% USGS-spiked samples. In addition, all laboratories determined that the 10% 4 Albany-spiked sample contains a slag wool content that is similar to the 1% USGS-spiked sample. The 5% and 10% USGS samples are clearly distinguishable from the remaining samples in all cases. Finally, it is evident that detectability and quantification limits for slag wool are well below average background levels when sufficient numbers of fibers are counted.

Discussion

Bulk WTC dust contains an average of 1×10^7 slag wool fibers per gram. Laboratories that contributed to the EPA study determined that the 10% USGS-spiked samples had ~1×10^6 fibers per gram, which is consistent with the amount of WTC dust add ed to background dust to make this reference material. The 10% 4 Albany-spiked samples contain ~1×10^5 slag wool fibers per gram, which is an abundance similar to that of the 1% USGS-spiked sample. The data depicted in Figure 3 indicate that the practical detection limit for residual WTC dust in indoor dust is on the order of 0.1 weight percent . This conclusion is derived from the data that show that the background samples are similar in concentration to the 1% 4 Albany-spiked material, which has one-tenth the slag wool abundance of the 1% USGS-spiked material. The cause of the dilution in the 4 Albany sample is unclear. Regardless, slag wool in the 1% 4 Albany sample was easily detectable despite the samples having been collected 3 years after the WTC collapse. The WTCETRP Signature Subgroup recognized that some false-positive determinations are unavoidable, as is made evident by determinations that show a small number of the background samples contain high slag wool levels. However, if it can be demonstrated that other components of the WTC dust, such as gypsum and phases compatible with concrete, are not present in these samples, in roughly the same proportions as shown in Table 2, then WTC can be eliminated as a possible source of the slag wool. As determined by all laboratories, the background samples with the highest slag wool abundances were from a North Carolina office building. This building had visible

insulation, fireproofing, or ceiling tiles that most likely contained slag wool (Rosati et al. 2008).

Consideration of the unashed weights (not reported in the final EPA report (2005)) of the original samples suggests that greater distinction between the background and bulk WTC dust samples can readily be made. During the ashing process, the background samples lost an average of 70%, the 4 Albany-spiked dust30%, and the USGS-spiked dust 10% of original weights. The weight loss differences between the 4 Albany- and USGS-spiked materials is further evidence that the 4 Albany material is diluted relative to the USGS-spiked material and pure WTC dust. Table 3 compares the slag wool abundances in the ashed samples with those corrected back to the unashed weights for samples in which the weight loss from ashing was available.

Because the dust component ratios of the bulk WTC dust are relatively consistent from sample to sample, it may also be possible to determine the maximum contribution of COPC from dust attributable to the WTC collapse. A conservative approach for an unknown sample containing slag wool would be to assume that all of the slag wool was derived from WTC dust. Therefore, the maximum amount of COPCs, such as chrysotile, crystalline silica, or lead derived from WTC dust could be calculated by using the relative proportions of phases found in WTC dust(Table 2). For example, the highest area percent ratio of chrysotile to slag wool is 1.8–30 (sample USGS 12), and the highest area percent ratio of silica to slag wool was 3.4–30 (sample USGS 12).Maximum potential abundances of other WTC dust-derived COPCs could be approximated in a similar manner. If slag wool fiber abundances in settled dust samples do not exceed a predetermined critical level, then it is unlikely that a bun dances of COPCs derived from WTC dust in settled dust samples will exceed levels of concern.

The usefulness of this method to delineate the extent of dust contamination associated with the WTC collapse is unknown due, at least in part, to the passage of considerable time since the event. Data summarized here suggest, however, that the slag wool signature could be detected at relatively low abundances in places where undisturbed dust might persist. These locations may include elevator shafts, utility sheds on roof tops, or other similar areas. Information gained from additional study of WTC dust distribution could provide valuable insights that might be applicable to ongoing health risks associated with new exposures to WTC dust, and to be prepared to respond to the need for risk analyses and risk management decisions associated with any type of similar catastrophic event.

A comparison of bulk WTC dust with a limited set of background samples strongly suggests that slag wool is the best primary indicator of WTC dust contribution because (1) slag wool is a major component(10–60%) of all pure bulk WTC dust samples collected shortly after the WTC collapse in studies conducted by numerous research groups; (2) slag wool is stable in the ambient environment, and likely to be persistent in undisturbed spaces for many years; and (3) slag wool is easily identifiable at low concentrations by available analytical techniques.

The results of the EPA interlaboratory study have provided several important insights into the feasibility of using slag wool as an indicator of residual WTC dust contamination. These are as follows: (1) data from all of the analytical laboratories involved in the method development and summarized in this article indicate that the background samples spiked with 10 and 5 weight percent pure USGS WTC dust can be clearly distinguished from average background dust at the 95% confidence level; (2) average background abundances of slag wool appear to correspond to levels equivalent to a WTC dust contamination of approximately 0.1–0.5 weight percent; (3) analytical uncertainties appear to be directly related to the total number of fibers counted; and (4) in settled dust samples, it should be possible to estimate an upper limit for other contaminants, such as asbestos and lead, due to an inferred WTC dust contribution.

A statistical evaluation of the interlaboratory data for detection of slag wool abundances in the spiked samples presented above was conducted by US EPA (2006) and presented by Rosati et al. (2008). Their findings also show that the slag wool abundances in the majority of the background samples analyzed by the participating laboratories were below the 95% lower confidence interval of the 10% 4 Albany spike (slag wool abundance equivalent to ~1% undiluted WTC dust), and that interlaboratory variability was related to the amount of dust analyzed and the number of observed fibers. In light of this evidence, and of the decision of EPA to proceed with a test and clean offer for occupied residential units in Lower Manhattan based solely on benchmarks for COPCs, rather than investigating extent of contamination based on elevated levels of COPCs in the presence of slag wool, we felt that it was important that the lessons learned in the process of developing and validating the slag wool signature method be made available to our scientific colleagues and appropriate public authorities should a similar emergency arise again.

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Appendix E

Table 4

SEM – Slag wool fiber count/gram of sample. Reproduced in part from Appendix E: Report from the U.S. EPA Contractor on the Screening Method Study (USEPA, 2005). Samples spiked with WTC dust, at 1%, 5% and 10% levels are shaded. DB samples represent those spiked with the 4 Albany material. All others are background samples

Sample Designations	Laboratory Letter Codes							
	A	B	C	D	E	F	G	H
AP5(1)	non-det.[a]	3,663		non-det.	<249 [b]	<500	2,470	<7386
AP5(2)		<3636		6,980	<667	500	13,910	<7698
CMC(1)	non-det.	3,448		11,800	<282	<4500	5,780	<7241
CMC(2)		<3875		9,620	309	667	6,100	<6289
HS3(1)	16,393	7,299		19,000	<286	2,750	<6320	<7576
HS3(2)		7,692		18,600	<667	5,060	7,370	34,813
WGS(1)	5,900	34,221		26,400	<256	1,630	9,480	16,077
WGS(2)		10,753		18,100	6,990	<30500	3,520	18,399
MW(1)	12,232	18,939		18,700	1,320	1,000	13,630	17,301
MW(2)		3,717		31,800	893	<45500	18,080	<9497
DB1%(1)	5,747	10,909	5,451	29,900	<2000	1,920	7,650	15,924
DB1%(2)	34,826	17,422	9,133	27,300	3,770	12,500	1,320	16,038
DB5%(1)	72,562	29,197	32,385	50,800	31,000	1,700	6,230	107,143
DB5%(2)	67,797	25,271	33,646	35,800	6,900	14,700	13,040	70,472
DB10%(1)	104,575	66,421	74,837	113,000	108,000	7,000	12,900	114,638
DB10%(2)	84,746	77,778	57,644	95,100	20,400	34,100	25,210	96,696
C1-RTP(1)	246,914	159,011		269,000	168,000	38,000	84,650	188,088
C1-RTP(2)		173,585		165,000	21,900	160,000	39,930	318,143
USGS1%(1)	98,039	109,091	50,293	119,000	366,000	79,800	9,200	90,992
USGS1%(2)		83,032	50,160	104,000	18,700	79,500	25,370	137,363
USGS5%(1)	600,000	404,332		681,000	227,900	433,000	66,450	672,926
USGS5%(2)		343,284	364,813	146,000	191,000	197,000	73,330	347,904
USGS10%(1)	1,218,855	840,231	531,277	1,620,000	1,410,000	629,000	144,120	734,767
USGS10%(2)		1,366,470	521,212	238,000	271,000	372,000	33,040	413,153
USC(1)	73,394	56,025		91,800	33,700	15,600	<3230	29,268
USC(2)		41,199		40,700	7,890	48,400	3,540	74,212

Sample Designations	Laboratory Letter Codes							
	A	B	C	D	E	F	G	H
FedPlaza(1)	18,519	18,051		16,300	1,100	12,400	11,920	28,249
FedPlaza(2)		16,470		31,800	3,920	30,500	<1181	25,489
MUNYC1(1)	10,840	7,220		14,400	14,900	13,100	<2545	6,803
MUNYC1(2)		3,745		20,200	1,960	<22300	<1228	41,118
MUNYC2(1)	41,298	28,777		66,500	1,390	17,800	<12453	123,106
MUNYC2(2)		48,507		45,500	24,200	30,500	2,330	59,473

[a] Non-det = Non-detect – zero slag wool fibers were noted in the sample.

[b] < indicates that the value was less than the detection limit of the respective laboratory. When this result was reached, the value was divided by the square root of 2.

Table 5

SEM – Slag wool fiber count. Reproduced in part from Appendix E: Report from the U.S. EPA Contractor on the Screening Method Study (USEPA, 2005). Samples spiked with WTC dust, at 1%, 5% and 10% levels are shaded. DB samples represent those spiked with the 4 Albany material. All others are background samples

Sample Designations	Laboratory Letter Codes							
	A	B	C	D	E	F	G	H
AP5(1)	0	1		0	0	0	2	0
AP5(2)		0		3	0	1	6	0
CMC(1)	0	1		5	0	0	4	0
CMC(2)		0		4	1	0	5	0
HS3(1)	3	2		8	0	1	0	0
HS3(2)		2		8	0	3	4	4
WGS(1)	1	9		11	1	1	6	2
WGS(2)		3		8	7	0	3	2
MW(1)	2	5		8	6	1	6	2
MW(2)		6		14	2	0	22	0
DB1%(1)	1	3	1	13	0	1	7	2
DB1%(2)	7	5	2	12	4	2	1	2
DB5%(1)	8	8	7	22	7	1	6	6
DB5%(2)	12	7	7	16	8	2	11	10
DB10%(1)	16	18	12	48	13	2	10	13
DB10%(2)	15	21	12	42	9	3	25	12
C1-RTP(1)	20	45		116	16	4	22	24
C1-RTP(2)		46		72	30	4	17	37
USGS1%(1)	15	30	9	54	27	11	11	10
USGS1%(2)		23	11	47	23	4	22	15
USGS5%(1)	99	112		194	25	20	64	43
USGS5%(2)		92	62	65	21	19	27	39
USGS10%(1)	181	45	124	450	38	19	18	41

Sample Designations	Laboratory Letter Codes							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
USGS10%(2)		45	129	105	19	16	9	49
USC(1)	6	13		39	6	13	0	3
USC(2)		11		18	6	4	2	8
FedPlaza(1)	3	5		7	3	2	2	3
FedPlaza(2)		5		14	4	1	0	3
MUNYC1(1)	1	2		6	4	3	0	1
MUNYC1(2)		1		9	2	0	0	5
MUNYC2(1)	7	8		28	3	3	0	13
MUNYC2(2)		13		20	24	3	1	7

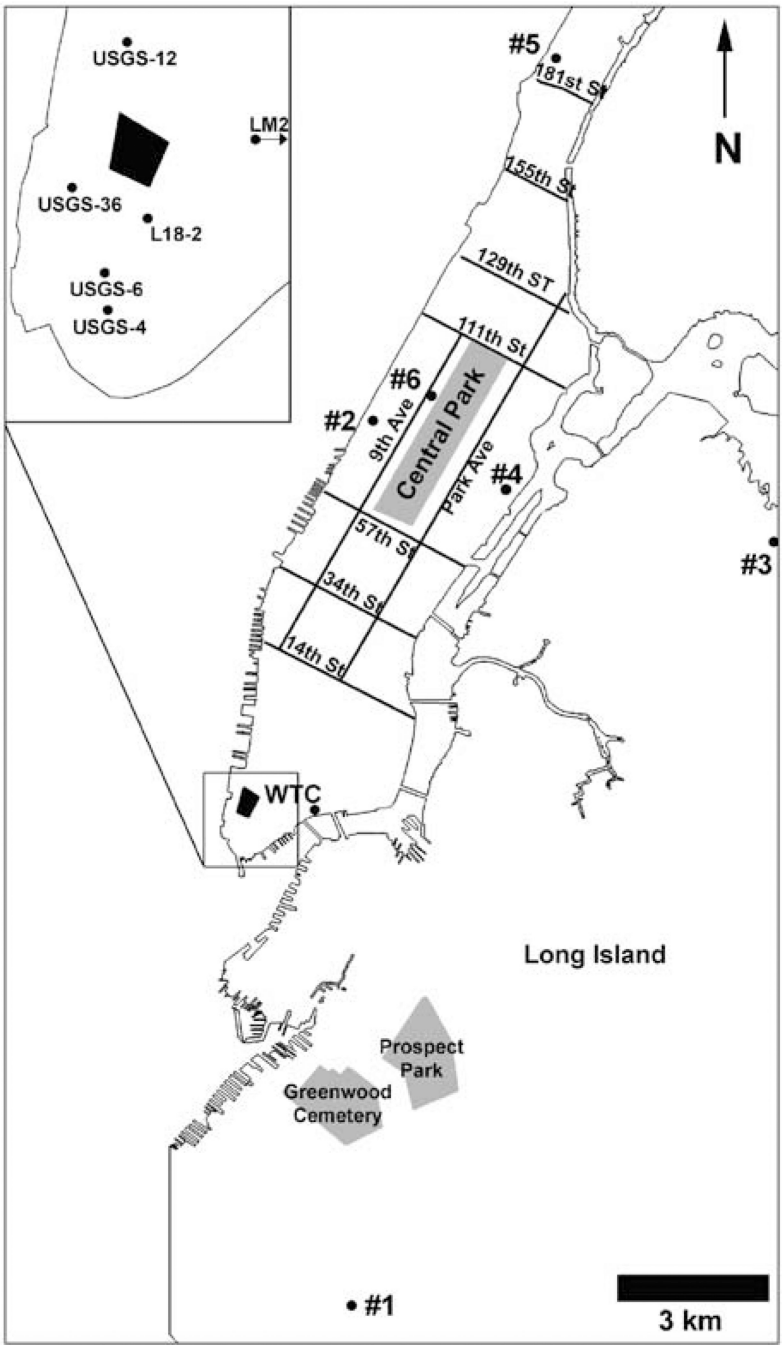

Figure 1.

Map of New York City showing approximate locations of indoor residential units where background samples were collected (#1 to #6). Approximate locations of bulk WTC dust samples are shown in the inset. All bulk WTC samples were collected outdoors with the exception of USGS-36 and L18-2, which were collected from indoor locations.

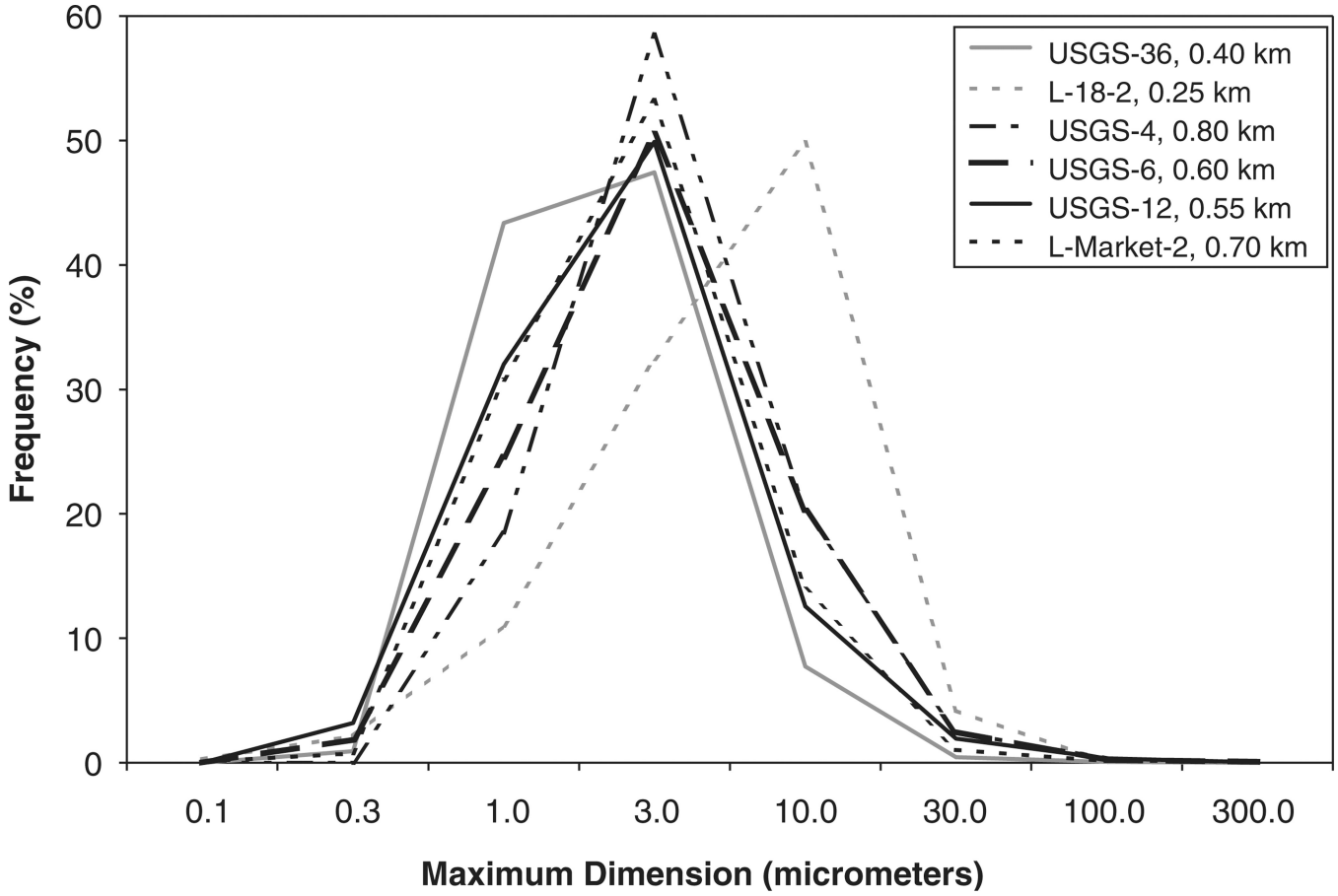

Figure 2.

Particle-size data for each sample presented as maximum dimension vs. frequency percent. Approximate distances from the center of WTC plaza are given. All outdoor samples have a similar size distribution, whereas the two indoor samples have different size distributions related to distance from the WTC site.

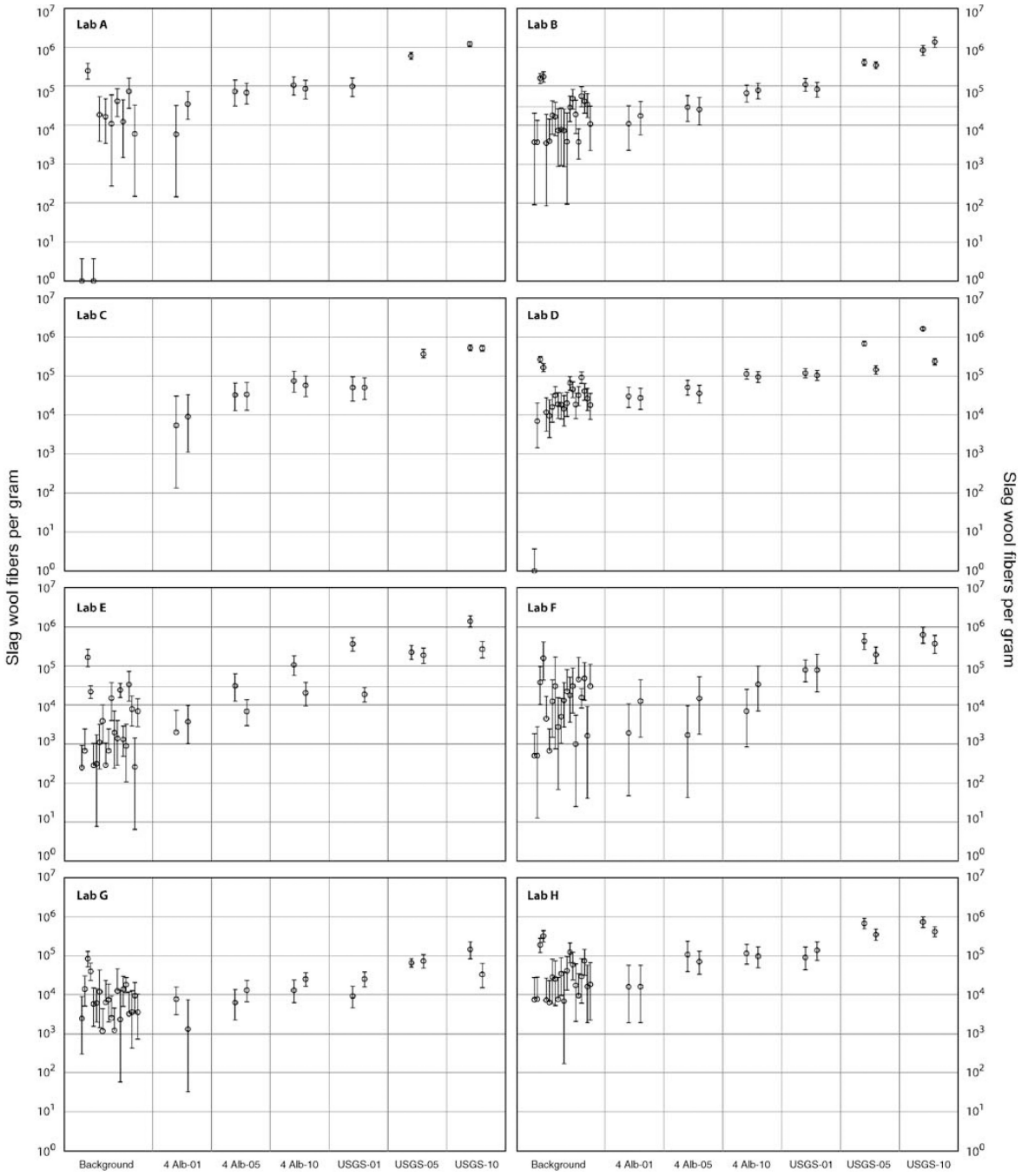

Figure 3.

Slag wool fiber abundances in background and spiked reference materials. Data from US EPA (2005) study. Lab C did not analyze background samples. Error bars reflect the uncertainty of the total number of fibers counted (ISO, 2002). The horizontal lines mark the 95% confidence limits of slag wool abundance in background samples from the study of Lowers et al. (2005). All labs were able to statistically distinguish background, 1% USGS, and 10% 4 Albany-spiked material from 5% and 10% USGS-spiked material.

Table 1

Categories for binning WTC dust particles.

Particle Type	Comment
Gypsum	Includes all Ca sulfate particles
Concrete	All phases compatible with hydrated cement
Man-made vitreous fiber (MMVF)	
Slag wool[a]	TIMA (1991) nomenclature
Rock wool	TIMA (1991) nomenclature
Soda-lime glass	TIMA (1991) nomenclature
Chrysotile	Bundles and single fibers
Silica	Primarily crystalline
Ti-rich	Primarily Ti metal and Ti oxide
Zn-rich	Primarily Zn metal and Zn oxide
Pb-rich	Primarily Pb metal and Pb oxide
Fe-rich	Primarily Fe metal and Fe oxide
Other	Identified but not binned
Unidentified	Could not be classified based on bulk chemistry

[a] Some workers have used relative fiber dissolution rates in acid to distinguish slag wool from rock wool. However, the glass fiber industry classifies MMVF based on chemical composition, not dissolution rates (TIMA, 1991). The MMVF identified as slag wool by x-ray microanalysis (Meeker et al., 2005b) clearly fits in to the slag wool compositional space defined by TIMA (1991). Regardless of the name given to this glass fiber type, the chemical identification method described in Meeker et al. (2005b) clearly distinguishes this glass fiber type from other MMVF types identified in WTC dusts and background samples discussed herein.

Table 2

Area percent coverage of particles in the bulk WTC dust samples (ND = not detected).

Sample	**USGS 12**	**USGS 6**	**LM-2**	**USGS 4**	**L18-2**	**USGS 36**
Location	Outdoor	Outdoor	Outdoor	Outdoor	Indoor	Indoor
Elevation	Ground	Ground	Ground	Ground	Ground	30th floor
Distance from WTC site (km)	0.55	0.6	0.7	0.8	0.25	0.4
Gypsum	26.28	53.31	48.8	32.56	63.7	63.26
Concrete materials	30.83	20.29	21.79	19.26	13.99	21
MMVF	32.42	20.28	20.78	40.59	19.21	9.46
Slag wool	98	92	94	94	66	93
Soda-lime	2	2	6	ND	26	1
Rock wool	ND	6	0.5	6	8	6
Chrysotile	1.76	0.72	0.73	0.41	0.01	0.05
Quartz	3.42	0.97	0.76	1.15	0.69	0.45
Fe-rich	0.94	1.33	0.21	0.79	0.1	1.07
Ti + Zn-rich	0.32	0.32	0.44	0.22	0.06	1.27
Pb-rich	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Other	3.83	2.6	5.86	3.57	1.39	2.59
Unidentified	0.2	0.18	0.62	1.44	0.86	0.84

Table 3

Comparison of slag wool fiber abundances per gram of sample in the ashed versus unashed weight.

			Slag wool fibers per gram		Number of MMVF fibers counted			
Material	**Data**	**Sample**	**Of ashed material**	**Corrected for unashed weights**	**Slag wool**	**Soda-lime glass**	**Rock wool**	**Other**
WTC dust	USGS data	USGS6	1.1×10^7	1.1×10^7	1218	36	11	0
WTC dust	USGS data	USGS 12	9.3×10^6	9.3×10^6	520	12	9	0
WTC dust	USGS data	USGS 36	8.2×10^6	8.2×10^6	506	15	8	0
Background	US EPA (2005)	AP2-07-02	7.7×10^3	3.1×10^2	2	NA	NA	NA
Background	US EPA (2005)	AP3-08-01	1.3×10^5	$3.8 \times 10 \times 10^3$	2	NA	NA	NA
Background	US EPA (2005)	AP3-08-02	3.6×10^3	ND	0	NA	NA	NA
Background	US EPA (2005)	HS1-06-01	3.6×10^4	1.0×10^4	9	NA	NA	NA
Background	US EPA (2005)	HS1-06-02	2.3×10^5	6.7×10^4	15	NA	NA	NA
Background	US EPA (2005)	HS3-18-01	1.2×10^4	1.8×10^3	3	NA	NA	NA
Background	US EPA (2005)	MW924WEAve	8.1×10^3	1.3×10^3	2	NA	NA	NA
Background	US EPA (2005)	WGS6557	3.5×10^4	6.7×10^3	7	NA	NA	NA
Background	Lowers and Meeker (2005)	AP5-12-01S0.25	1.9×10^3	ND	0	2	0	0
Background	Lowers and Meeker (2005)	AP2-07-01S0.1	2.5×10^3	90	1	0	0	0
Background	Lowers and Meeker (2005)	AP7-14-01S0.25	1.9×10^3	1.1×10^3	1	3	2	0
Background	Lowers and Meeker (2005)	AP4-10-01S0.1	2.5×10^4	5.4×10^3	6	58	1	2
Background	Lowers and Meeker (2005)	HS2-09-01C0.1	4.3×10^3	ND	0	2	0	0
Background	Lowers and Meeker (2005)	AP3-08-01S0.1	8.1×10^3	2.5×10^2	1	3	0	39

Also tabulated is the number of man-made vitreous fiber (MMVF) types counted. NA = the data was not available in the US EPA (2005) study.