Final Report: Contribution of Particle Emissions from a Cement Facility to Outdoor Dust in Surrounding Community

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October 6, 2008

1. Summary

The St. Lawrence Cement Facility is located near the neighborhood of Waterfront South (WFS), Camden, New Jersey. The residents in the vicinity of the facility have had concerns about the impact of the fugitive particulate emissions from the material stored and/or used at the facility on the neighborhood as outdoor dust air pollution. To address their concern, this study collected deposited particles and surface dust samples near the facility and the raw cement material (RCM) from the pile of the dust outside of the facility, analyzed morphological characteristics and elemental concentrations in the samples, and assessed the contribution of particles emitted from the cement facility to the dust pollution in local community. Specifically, we

a) developed deposition samplers to collect outdoor dust;
b) conducted two field sampling studies to collect deposited dust samples from 10-12 locations within the radial distance of 800 m northeastern bound of the cement facility for a duration of 21 and 31 days, respectively;
c) collected two surface dust samples from 15 locations in the areas surrounding the facility;
d) analyzed the elemental compositions (cement-enriched elements including Ca, Fe, Al and Mg) of the deposited dust and surface dust samples;
e) analyzed morphological characteristics of the deposited dusts in subset of the samples and the RCM acquired from the facility; and
f) estimated the contribution of the cement facility to outdoor dust by 1) comparing the elemental concentrations measured in the RCM with the deposited particle and surface dust samples, and 2) conducting a source-receptor model (CMB v. 8.2, US EPA) using the elemental composition data obtained from this study.

The detailed study approach, results and discussion are presented below.

2. Methods

2.1 Site selection for deposited and surface dust collection

The raw cement material is stored outside of the cement plant without a cover. The pile of the material is about 9 m high. The pile is known to be replenished with a cycle of 3 days and frequently transported to the production line by a wheel loader. Since the prevailing wind directions are southwest or northwest in the Camden area, the fugitive emissions from the cement material pile can be transported to the WFS neighborhood, which is located ~200 m downwind (i.e. northeast) of the facility (Figure 1).

To determine the impact of fugitive emissions from the cement facility on the WFS, we decided to collect deposition particle and surface dust samples in different locations in WFS. Before dust sample collection, we made two trips to Camden for site selection. The ideal sites for sampling would be locations that are easily accessed by field technicians, protected from inclement weather, and secure. Based on the site visits, the most appropriate sampling sites for collecting re-suspended dusts emitted from the cement facility were located between the outer fence of the cement facility to Jackson Street, South 8th Street, and Morgan Street. The area is bounded by Route 676, Jackson Street, and Chelton Avenue, i.e. the main residential area of

sampler. The sampler is plastic with a funnel hood to protect the filter from rain during field sampling. The sampler is painted dark green or black to minimize attention. The sampler can house up to four co-located quartz fiber filters 37 mm in diameter (Pall Life Sciences, Ann Arbor, MI). During sampling, the samplers were placed in open spaces to collect particles. Examples are: balcony, terrace, porch of resident's house; or a tree, or fence/electric pole. A photo of a field deposition sampler placed at a resident's home is shown in Figure 3.

The first deposition field sampling covered the period from July 5 to 26, 2007. Four samplers, including the one at the control site, were lost during the 21-day of sampling period. The samplers at these sites were relatively more visible and accessible than other locations. During the second field sampling which was conducted from August 17 to September 17, 2007, the samplers were placed at less visible locations. All samplers were recovered after the 31-day sampling period.

2.3 Collection of the surface dust

Based on previous experiences for undisturbed attic dust study (Ilacqua et al., 2003) and lead carpet dust intervention study (Yu et al., 2006), we decided to collect dust samples from flat surfaces using a wipe sampling method. The moistened wipe sample, Cliniguard Dry Washcloths, with size of 13×17.5 cm^2 (TENA, Waukegan, WI) were used in the study. Our previous studies showed that the moistened wipe could collect sufficient mass of dust for analysis on any flat surface reliably (Ilacqua et al., 2003; Yu et al., 2006).

Surfaces selected for sampling were tops of air conditioners, outdoor ledges/sills, and electrical boxes that are located close to the cement piles. These surfaces are better protected from the scavenging by the wind, but can be influenced by fugitive emissions. Also, they are flat and can be easily sampled by the wipe sampler. A visual inspection of a selected designated surface was completed prior to wipe sampling. Two wipe samples were collected from each 15 different sampling locations, and a total of 30 wipes were collected. The surface dust sampling locations are presented in Figure 5. It is worth to note that the particles deposited on surfaces with electrostatic force could be higher than those without electrical charges (Fews et al., 1999; Jeffers, 2006).

2.4 Collection of the raw cement material from the cement facility

The large pile of raw cement material (RCM) placed outside of the cement plant was considered to be the most important source of fugitive dust in the area. Thus, the bulk cement samples were collected from three upper locations where we could approach (~ 2 m high) of the cement pile. Each sample was collected from the top layer of each sampling location with a wide-mouth bottle (~ 150 g for each sample), and the three samples were combined as one sample to minimize the variability in the bulk cement material. Only one composite RCM sample was collected because the particle characteristics of the RCM did not expect to vary significantly over time. The RCM sample was stored in a temperature-controlled (4±1 °C) cold room at EOHSI prior to analysis.

2.5 Sample analyses

Analysis of elemental concentrations

After obtaining the weight of the dust mass, the deposited dust samples, surface dust samples and the raw material obtained from the piles at the facility were analyzed for elements by a VG Elemental Plasma Quad 3 (PQ3) inductively coupled plasma mass spectrometry (ICPMS) at EOHSI.

For elemental analysis, the dust samples were digested by the microwave oven-assisted digestion method with concentrated high purity nitric acid (EPA methods TO-3050a and 3052). The RCM was sieved and the particles < 38 μm in diameter were used for analysis. The size selection for RCM was based on the considerations of particles that would possibly transport to the target areas (see Table 1). The sieved RCM particles below 38 μm in diameter was weighed, and were 0.06% (by weight) of the whole bulk RCM. After digestion, the extract was analyzed for element by ICPMS. The ICPMS analysis conditions were similar to EPA method 200.8.

Field and lab blanks were concurrently analyzed with the samples. Sample concentrations were field blank subtracted before data analysis.

Microscopic analyses

Five settled dust samples collected from the 2nd deposition sampling study and one sample of the RCM were analyzed for morphology, size distribution, and elemental composition by the MVA Scientific Consultants (Duluth, GA). The five settled dust deposition samples were selected from the locations nearest to the facility (Location 1, 2, 3, 4 and 8) (see Figure 4). The RCM was sieved and particles < 38 μm were submitted for analysis. The particle size and elemental composition were obtained using a JEOL Model JSM-6500F field emission scanning electron microscope (SEM), operating in automated mode under the control of a Thermo Noran System SIX x-ray analysis system. The morphological examination was conducted by polarized light microscopy (PLM) analysis using an Olympus SZ-40 stereomicroscope at magnifications from 7 to 40X.

2.6 Data analyses

Descriptive Statistics

First, descriptive statistics was conducted to summarize the dust mass, loading, and elemental concentrations for the samples collected. Sampling method precision was also examined by calculating the difference in dust mass collected by 1) the four filters placed in one sampler and 2) %Diff (percent difference) between the mass collected by two co-located deposition samplers.

Association of the mass and elemental concentrations with the distance to the facility

Spearman correlation analysis was conducted to examine the association between the distance from each sampling site to the facility and the mass and element concentration in the dust collected at each site. The results were used to assess whether the dust mass would decrease as the distance to the facility increased.

Enrichment factors for elements

To explore the possibility of a contribution to dust deposition and surface dust by a possible source of raw cement material in the sampling area, a ratio for elements in given environmental sample to reference soil or rock was calculated for all elements that were quantified. This ratio,

called the enrichment factor (EF), is an indicator for a source(s) contributing to a background sample on the basis of elevated elemental concentrations (Adejumo et al., 1994). The enrichment factors defined in equation (1.2) were calculated using titanium (Ti) as a reference element. Titanium was chosen from a variety of elements analyzed in the study as a reference element based on the following requirements: 1) generally higher concentrations in reference rock or soil, 2) very low levels in pollution sources, 3) ease of determination by a number of analytical techniques, and 4) freedom from contamination during sampling.

$$EF = \frac{E_s / Ti_s}{E_r / Ti_r} \qquad (1.2)$$

where, EF is the calculated enrichment factor for a given element,
E_s is an elemental concentration or loading in the examined sample,
Ti_s is a titanium concentration or loading in the examined sample,
E_r is an elemental concentration in reference crustal rock, and
Ti_r is a reference titanium concentration in crustal rock (= 4,400 ppm)

In the above equation, the reference material concentration was obtained from Mason's crustal rock composition values (Rahn, 1976). An EF > 5 indicates the presence of a source of the element in question that is causing it to be enriched in the sample material relative to the background soil (Adejumo et al., 1994).

Ca/Fe concentration ratios

The ratios of two elements, calcium and iron, were obtained to test the contribution of the cement material to outdoor dust. Calcium is a marker for cement-related activities and iron is a typical fingerprinting element for soil dust. Therefore, if the ratios are inversely proportional to proximity to the cement facility, the results indicate there are relative contributions of RCM to outdoor dust.

Chemical Mass Balance (CMB) model

A source apportionment was completed to estimate the contribution of particles emitted from the facility to the dust pollution in surrounding area. The Chemical Mass Balance (CMB) model (EPA version 8.2) was used for analysis. This source-receptor model involved the solution of linear equations that expresses each receptor chemical concentration as a linear sum of products of source fingerprint abundances and contributions (EPA, 2004). The CMB model requires detailed source profiles of each potential source located in the study area or profiles of similar sources in order to estimate the contribution of each source to the pollutant concentrations at each receptor. However, this study measured only the chemical composition of the raw cement material, one of the many potential sources for the outdoor dust in the study area. To utilize the CMB model, we employed source profiles from a well characterized published dataset, Portland Aerosol Characterization Study (PACS), which investigated the source-receptor relationship for $PM_{2.5}$, PM_{10} trace elements, ionic species and carbon in Portland, Oregon (Watson, 1979). The PACS source profiles included typical urban dust sources such as natural (e.g., marine aerosol and urban dust) and anthropogenic sources (e.g., automobile exhausts, oil combustions, and industrial emissions like paper mills and furnaces) in both fine-sized (< 2.5 μm) and coarse-sized (< 10 μm) fractions. The concentrations of 19 elements, elemental and organic carbon, and

sulfates/nitrates were quantified for all PACS sources. Also elemental concentrations in average rock and soil were added when building up the CMB source profile. The elemental abundances in reference rock (Mason 1966) and soil (Bowen 1966) were obtained from the report for chemical composition of the atmospheric aerosol study (Rahn, 1976).

Thus, the construction of CMB source profile was finalized with three sub-sets: 1) an elemental composition for the RCM sample analyzed in this study, 2) elemental concentrations in both reference rock and soil, and 3) six potential urban dust sources (marine aerosol, urban dust, automobile exhausts, residual oil combustion, aluminum production, and ferromanganese furnace). The contributions estimated from additional urban dust sources in the PACS study indicated that other potential dust sources, besides RCM and reference rock and soil, exist in the studied area and, as a whole, contribute to the increase of outdoor dust in the surrounding communities. However, each potential source can not be directly linked with the specific source, and detailed source specific information would be needed beyond the levels estimated by CMB model to characterize individual source contributions. Due to the high variability of elemental concentrations in surface dust samples (e.g., %Diff = 65 ± 37 % for 3 collocated duplicates), only dust deposition samples (N = 28) were used in the CMB model. The source elimination option was applied in running the CMB model to eliminate any negative source contribution estimate out of total nine source candidates. The contribution of RCM to outdoor dust was obtained from the estimated RCM contribution dividing by the sum of all source contribution estimates. The percentage calculated indicates the cement source contribution to each dust deposition sample examined by the CMB.

In the CMB model application default values were used to set up model options, and the performance of regression model was examined by investigating R^2, χ^2 and %Mass of the fitted models. The R-square (R^2) is the fraction of the variance in the measured concentrations that is explained by the variance in the calculated species concentrations. The reduced chi-square (χ^2) is the weighted sum of squares of the differences between the calculated and measured fitting species concentrations, and the percent mass (%Mass) is the percent ratio of the sum of the model-calculated source contribution estimates to the measured mass concentration (EPA, 2004). The CMB manual suggests that an $R^2 > 0.8$, $\chi^2 < 4.0$, and %Mass of 80 ~ 120 % provides an acceptable fit of the regression model (EPA, 2004). The CMB results showed 93 %, 89 %, and 64 % of the fitted receptors were found to be within the acceptable range of R^2, χ^2, and %Mass, respectively.

3 Results and Discussion

3.1 Particle mass and spatial distribution

The dust mass (mg) for the samples collected from the first and second deposition sampling studies is summarized in Tables 2 and 3, respectively. The mass ranged from 0.54 to 2.26 mg for a three-week sampling duration and 0.16 to 1.98 mg for a sampling duration of 31 days. The deposition sampling rate for the collected dust ranged from 2.39 to 10.01 $\mu g/cm^2$-day and between 0.48 ~ 5.94 $\mu g/cm^2$-day under the first and second samplings, respectively.

The deposition dust samples located close to the cement facility had higher measured dust mass for collected deposition samples. This inverse relationship between the dust mass collected

and proximity to the cement facility was tested by a Spearman correlation. The analysis showed that the mass of dust collected generally decreased with distances from the cement piles (r_s = -0.7697; p = 0.0069), indicating the impact of the dust emitted from the Cement Facility to outdoor dust pollution.

Surface dust samples showed a larger variability in mass as well as loading (see Table 4). The collected mass and calculated loading for surface dust samples ranged from 1.71 to 227 mg and from 8.5 to 379.4 $\mu g/cm^2$, respectively. No spatial distribution of the surface dust mass was observed. This was probably because many factors can affect the retention of the dust on the flat surfaces, such as the previous dust loading of the surface and scavenging of dust by rain and wind.

3.2 Particle size distribution

The particle size analysis (Table 5) revealed that the deposited dust was composed of mostly fine particles (< 2.5 μm), ranging from 78 to 88%. The fraction of coarse particles (2.5-10 μm) ranged from 11 to 19%. The similar size distribution was observed for the sample sieved from the RCM (with particle size of 38 μm and below in diameter). These results indicated that cement dust contains significant numbers of inhalable particles, which can be of health concern. RCM contained 7.1% particles > 5 μm in diameter, relatively higher than the percentage of those particles found in the deposition samples (0.1, 3.7 and 4.3% for the 3 deposition samples respectively). This could be caused by the dry deposition collection substrate not holding all particles collected during the sampling duration due to the possible loss of particles by bouncing or blow-off by wind. This is especially the case for coarse particles, which can be scavenged by strong winds blowing over the filters in the field. The actual mechanism is unknown, but it should be noted that large particles may be under-estimated by the dry deposition sampler. However, we should also note that larger particles normally will not deposit deep in the lung.

3.3 Elemental concentrations/loadings and spatial distribution

The elemental concentrations (ng/mg) for both deposited dust samples and RCM are presented in Tables 5 and 6 for 1st and 2nd deposition samplings, respectively. The elemental loadings (ng/cm^2) for surface dust samples are provided in Table 7. We found that Al (0.6 ~ 2.0 %), Ca (2.9 ~ 7.2 %), Fe (1.7 ~ 5.2 %), Mg (0.6 ~ 1.7 %), and Zn (0.1 ~ 2.0 %) were the most abundant elements in the dust deposition samples. Cu, Mn, Pb and Ti were the second abundant elemental group in the deposited dusts, ranging mostly from 100 to 1,000 ng/mg in concentrations. The reported Cd, Cr, Si and V concentrations were primarily below 100 ng/mg. For surface dust samples, the loadings of each element were similar to the concentration order for the deposited dust samples. However, some wipes (for example Zn in both S007 and S020 and Cd in S020) had exceptionally higher levels compared to wipe samples collected at the other locations. An urban dust characterization study in Oslo, Norway found higher concentrations of Zn and Cd in the street dust collected from under the metal ledges and balconies of old buildings or around buildings undergoing renovations (Miguel et al., 1997). The elevated Cd and Zn concentrations may be linked with the corrosive action of urban rainwater (with pH of below 4.0 in many cases) by urban atmosphere, especially for coastal cities. The wipe sample (S020) was collected very close to the worn metal electric box mounted on a building wall, and another wipe sample (S007) was also collected on the top of painted electric box. Thus, the elevated metal

loadings might be related with the metals deteriorated from the electric boxes by corrosive actions under urban atmosphere; however calcium loadings in two wipes were not significantly different from the loadings at other locations, suggesting the local source was limited to the increase of cadmium, iron and zinc in wiped samples.

The contribution of the facility's particle emissions to the dust deposition sample was examined by comparing the elemental concentrations/loadings in the dust samples and surface dust samples collected from each sampling locations to those derived from the RCM. Calcium concentrations measured in dust deposition samples are the most representative element showing the trend of exponentially decreasing with increasing of the distance to the facility, as shown in the plot (Figure 6) of calcium concentrations in deposited dusts vs. the radial distances below 800 m downwind from the facility in Figure 6. An exponentially decreasing relationship was established between calcium concentrations (%) and the radial distances to the RCM (R^2 = 0.7228; p = 0.0037). However, the calcium concentration (30%) measured at the distance of 0 km was much higher than the rest points (Figure 6), which may bias the observed relationship. Therefore, a regression analysis without the suspecting data was also conducted, and the results remained statistically significant (R^2 = 0.5683; p = 0.0307), confirming that there is a statistically significant decrease in Ca concentration in the dust with increasing distance from St. Lawrence.

The Spearman correlation showed that only calcium (r_s = -0.7727; p = 0.0037) had a statistically significant negative association between the concentration and the radial distance to the facility. This observation was consistent to the results reported in a previous atmospheric deposition study (Adejumo et al. 1994), i.e. calcium concentrations in deposited particles decreased exponentially along with the distance to three cement factories in Nigeria. Thus, our results showed that the presence of raw cement material piled inside the cement facility contributed to the increase of calcium concentration in outdoor dust in the neighborhood around the facility.

However, the same relationship was not observed for the surface dust loadings ($p > 0.05$ for all elements). We suspected that the dust, which was re-suspended from the cement piles in the facility and settled on the open flat surface, were easily scavenged by rain and wind, thus the dust mass collected by the surface wipe samples were not associated with the distance to the facility. Or, as will be discussed below, other sources contributed to the actual total dust loading.

3.4 RCM contributions to outdoor dust enrichment factor analyses and Ca/Fe ratios

The enrichment factors (EF) for all elements analyzed in this study and Ca/Fe ratios are provided in Table 9. The EF of calcium was greater than 5 for the samples examined, indicating a significant cement dust source, i.e. fugitive particulate emissions from RCM pile inside the facility associated with the sampling sites. Spearman correlation showed calcium's enrichment factors for deposited dusts were decreasing with the radial distances from the facility; however, the relationship was not significant (r_s = -0.1273; p = 0.6932). Similar results were also observed for surface dusts (r_s = -0.3351; p = 0.1981). Except for calcium, other elements did not show an inverse relationship between enrichment factors and radial distance from the facility. The Ca/Fe ratios were tested with the radial distances, too. A strong negative correlation was found for dust deposition samples (r_s = -0.9000; $p < 0.0001$; Spearman correlation), indicating the contribution

of RCM to outdoor dust in the sampling area. However, the inverse relationship was not significant for surface dust samples (r_s = -0.3410; p = 0.1900). A previous study (Adejumo et al., 1994) reported significant contribution (approximately 21~30 %) of cement dust emitted from the cement production factories to neighborhood dust loadings located within 5 km in radial distance from the facilities.

The enrichment factors for Pb (ranged from 101 to 375 and from 68 to 2,860) and Zn (between 135 ~ 733 and 22 ~ 13,935) in both deposited dust and surface dust samples, respectively, were exceptionally higher than EFs for RCM (3.31 for Pb and 9.91 for Zn). These results suggested that there are local source(s) of Pb and Zn in these areas. Based on the local source information by the site visit, we found a metal treating facility, distant approximately 0.6 km from the cement facility and providing services of abrasive blasting and painting processes, and an iron workshop located ~0.15 km from the Gloucester City Park, the background site, respectively. The radial distances from the nearest metal processing facility were obtained and the proximities were tested by a Spearman correlation for both Pb and Zn enrichment factors. The significant associations between EFs and radial distances were found for Pb (r_s = -0.8061; p = 0.0026) and Zn (r_s = -0.7818; p = 0.0052) in deposited dust samples; however, the associations were not significant for surface dusts (p > 0.05). This suggests the metal treating facility in Camden and an iron workshop in Gloucester City may attribute to the increase of lead and zinc concentrations in the ambient air locally; however, the proximity effect of these metal processing facilities was not conclusive for surface dusts, and other sources may be in the area including street dust for the lead.

3.5 CMB-model estimated RCM contributions to outdoor dust

The CMB model was completed for all dust deposition samples, and the source contributions (%) of RCM in the cement facility to outdoor deposited dusts are summarized in Table 9. The CMB modeling results for the deposition sample of D001-B collected from the closest site to the cement facility (within a radial distance < 0.2 km), are provided in Figure 7 as an example. The contributions of the RCM to outdoor dust at Site 1 (see Figure 4) and the control site, Gloucester City Park, which represented the closest and the farthest location to the facility, were estimated and are shown in Figure 8-a and Figure 8-b, respectively.

The estimated contributions of the cement dust to outdoor dust measured by deposition dust samplers ranged from 4.9 to 18.2 % (9.8 ± 3.7 %) and 5.6 to 21.8 % (13.1 ± 4.9 %) for 1st and 2nd deposition sampling studies, respectively. We observed that the RCM contributions to outdoor dusts were lower as the radial distances are further from the cement facility (see Table 9). For example, the averaged at RCM contributions were estimated to be 16.2 %, 8.5 %, and 8.9 % for dusts within the radial distance of 0-0.4 km, 0.4-0.66 km, and above 2.0 km from the cement facility, respectively.

Two sensitivity factors that affect the CMB model estimable code (estimable vs. inestimable) are maximum source uncertainty (default = 20%) and maximum source projection (default of 95%) in CMB options window. We conducted the CMB modeling with the suggested default values, and in most cases, the sources tested were significantly estimable by the CMB model, except marine aerosols. Another significant factor for quantitative uncertainty in the model is the

precision of the ambient and source profile data. We assumed an uncertainty approximately 10% for the mean of each element and put this value in input ambient and source data, if the uncertainty could not otherwise be estimated. For the study objectives, calcium in RCM was examined in detail to show the reliability of the source contribution estimates reported by the CMB model. The RCM was consistently selected as a significant source contributor (> 50% in Contribution by Species) and an influencing source (> 0.9 in MPIN Matrix) for all modeled dust deposition samples. Considering the overall model performance diagnostics and additional model performance measures in the above, the CMB model result was robust and reliable to estimate the RCM contributions to outdoor dust pollution in the neighborhood around the cement facility. The lack of emissions data for other sources in the studied area, will provide some level of uncertainty in the results since the source emissions estimates used in the CMB modeling were from other areas. However, this technique has been applied widely in source apportionment analyses completed by the US EPA and other organizations (Chow et al., 1992; Watson et al., 1994; Schauer et al., 1996).

4 Conclusions

We conducted a study to investigate the contribution of fugitive particulate emissions from the St. Lawrence Cement Facility to outdoor dust from Jan 1, 2007 to June 30, 2008. One-month dust deposition samples and instantaneous area surface dusts were concurrently collected within the radial distance of 800 m from the facility as well as outside the radial distance above 2.0 km upwind from the facility. The elemental concentrations and morphological characteristics showed that the re-suspended dusts from the raw cement piles in the cement facility did have some impact the residential areas surrounding the cement facility. The cement facility's contribution to outdoor dust was estimated to ranges from 4.9 % to 22 % when calculated by an EPA approved source-receptor model (CMB v8.2). We did conclude that the spatial impact of particulate emissions from the Cement Facility to outdoor dust occurred during the study; however, the contribution is limited to Camden residents living immediately around the facility, and the analyses determined that other sources contributed at least 75 % of total outdoor dust. The highest percent contributions were found to occur at locations with 0-0.4 km of the facility piles. A cover over the piles would be a reasonable and well tested way to control these fugitive emissions. Daily monitoring of the pile could be used to demonstrate the effectiveness of such an approach to the reduction in current fugitive releases.

References

Adejumo J. A., Obioh I. B., Ogunsola O.J., Akeredolu F. A., Olaniyi H. B., Asubiojo O. I., Oluwole A. F., Akanle O. A., and Spyrou N. M. The atmospheric deposition of major, minor and trace elements within and around three cement factories. Journal of Radioanalytical and Nuclear Chemistry (1994) Vol. 179, No. 2, 195-204.

Cheng M. D., Gao N., and Hopke P. K. Source apportionment study of nitrogen species measured in southern California in 1987. Journal of Environmental Engineering (1996), Vol. 122, 183-190.

Chow J. C., Watson J. G. Lowenthal D. H., Solomon P. A., Magliano K. L., Ziman S. D., and Richards L. W. PM_{10} source apportionment in California's San Joaquin Valley. Atmospheric Environment (1992) Vol. 26 (A), 3335-3354.

Dockery D. W., Pope C. A., Xu X., Spengler J. D., Ware J. H., Fay M. E., Ferris B. G., and Speizer F. E. An association between air pollution and mortality in six U.S. cities. New England Journal of Medicine (1993) Vol. 329, 1753-1759.

Edwards R. D., Yukrow E. J., and Lioy P. J. Seasonal deposition of housedusts onto household surfaces. The Science of the Total Environment (1998) Vol. 224, 69-80.

Ekinci E., Munlafalioglu I., Tiris M., and Pekin A. V. Characterization of cement plant emissions in Turkey. Water, Air, and Soil Pollution (1998) Vol. 106, 83-95.

Fews A. P., Henshaw D. L. Keitch P. A. Close J. J., and Wilding R. J. Increased exposure to pollutant aerosols under high voltage power lines. International Journal of Radiation Biology (1999) Vol. 75, 1505-1521.

Franssens M., Flament P., Deboudt K., Weis D., and Pedrix E. Evidence lead deposition at the urban scale using "short-lived" isotopic signatures of the source term (Pb-Zn refinery). Atmospheric Environment (2004) Vol. 38, 5157-5168.

Garland J. A. On the size dependence of particle deposition. Water, Air, and Soil Pollution: Focus (2001) Vol. 1, 323-331.

Hinds W. C. Aerosol Technology: properties, behavior, and measurement of airborne particles, Second Edition. (1999), John Wiley & Sons, Inc.

Ilacqua V., Freeman N. C. G., and Lioy P. J. The historical record of air pollution as defined by attic dust. Atmospheric Environment (2003) Vol. 37, 2379-2389.

Jeffers D. E. AC electric fields and particle deposition on a sphere. Radiation Protection Dosimetry (2006) Vol. 118, 56-60.

Table 1. The traveling distance for different size particles that may be emitted from the cement pile at the median wind speed (3.5 m/s)[a] in the WFS neighborhood (Hinds, 1999)

Particle diameter (μm)	Settling velocity (cm/sec)	Particle travelling distance (m) for a settling height of 4.5 m[b]	Particle travelling distance (m) for a settling height of 9.0 m[c]
10	0.3	5,297	10,595
20	1.2	1,324	2,649
38	4.3	367	734
53	8.4	189	377
75	17	94	188
125	36	44	89
1000	386	4	8
2000	694	2	5

[a]The median wind speed during June and September, 2006 was obtained from the Philadelphia International Airport Weather Station located 12 km west of the cement facility.
[b]Assuming each sized aerodynamic particle traveled from the middle height of the cement pile (4.5 m) to a deposition sampler on the ground level.
[c]Assuming each sized aerodynamic particle traveled from the top of the cement pile (9 m) to a deposition sampler which was placed on the ground level.

Table 2. Summary of dust deposition samples collected for 3-week at Camden sampling sites (1st deposition dust field sampling)

Location	Sampler	Collected dust (N=4)		Co-located samplers		Comments
		Average (mg)	RSD (%)	Difference (mg)	%Diff[a]	
No. 1	001	1.523	5.5	0.037	2.4	Open space (fence)
	002	1.560	5.0			
No. 2	003	1.600	9.4	0.560	30	Open space (tree)
	004	2.160	7.9			
No. 3	005[b]	NA	NA	NA	NA	Residence (front porch)
	006[b]					
No. 4	007	1.422	4.5	NA	NA	Residence (front porch)
No. 5	010	0.912	9.5	NA	NA	Residence (front porch)
No. 6	011	1.103	13	0.010	0.9	Parking lot (tree)
	012	1.093	11			
No. 7	013	1.558	7.1	0.263	19	Open space (road sign)
	014	1.295	6.6			
No. 8	015[b]	NA	NA	NA	NA	Residence (front porch)
	016[b]					
No. 9	017	0.692	18	0.152	20	Parking lot (tree)
	018	0.844	19			
No. 10	019[b]	NA	NA	NA	NA	Open space (sunshade)
	020[b]					
No. 11	021[b]	NA	NA	NA	NA	Control site (tree)
	022[b]					
No. 12[c]	023	0.966	18	NA	NA	Residence (back yard)
				Ave. %Diff	14	
				SD	12	

[a]Relative mean difference (%Diff) reported as percentage between two co-located samplers at the same location
[b]The deposition samplers were not recovered in the field

Table 3. Summary of dust deposition samples collected for 1-month at Camden sampling sites (2nd deposition dust field sampling)

Location	Sampler	Collected dust (N=4)		Co-located samplers		Comments
		Average (mg)	RSD (%)	Difference (mg)	%Diff[a]	
No. 1	001	1.730	14	0.253	16	Open space (tree)
	002	1.477	18			
No. 2	003	1.439	7.0	0.419	34	Open space (fence)
	004	1.020	29			
No. 3	005	1.202	14	0.029	2.3	Open space (tree)
	006	1.230	7.2			
No. 4[b]	007	0.796	9.4	NA	NA	Residence (front porch)
No. 5	008	1.586	8.0	0.028	1.7	Residence (back yard)
	009	1.614	8.7			
No. 6	010	1.042	9.6	0.040	3.7	Church (tree)
	011	1.082	10			
No. 7	012	0.990	4.2	0.164	15	Residence (back yard)
	013	1.154	1.7			
No. 8[b]	014	0.904	14	NA	NA	Residence (front porch)
No. 9	015	0.427	45	0.038	8.6	Control site (tree)
	016	0.466	44			
No. 10	019	0.550	15	0.010	1.8	Control site (tree)
	020	0.560	9.3			
				Ave. %Diff	10	
				SD	10	

[a]Relative mean difference (%Diff) reported as percentage between two co-located samplers at the same location
[b]The sampling location deployed with two deposition samplers (covered vs. un-covered) only reported the result from the hooded type

Table 4. Summary of surface dust samples obtained at vicinities of St. Lawrence Cement Facility

Sample	Collected weight (mg)	Loading ($\mu g/cm^2$)	Location	Sample	Collected weight (mg)	Loading ($\mu g/cm^2$)	Location
001-003	2.17±0.58[a]	NA	Field blank	021	31.54	70.7	Window sills
004-006	2.45±0.65[a]	NA	Lab blank	022	30.57	68.6	
007	80.99	38.7	Electrical box	023	29.49	52.0	Electrical box
008	19.12	42.0		024	35.37	41.8	
009	15.81	8.5	Outdoor table	025	21.03	38.4	Air conditioner
010	56.35	30.2		026	15.57	28.4	
011	44.77	73.0	Collecting box	027	7.17	10.6	Telephone booth
012	52.61	85.8		028	57.63	248.1	
013	15.38	47.3	Deserted boat	029	7.45	24.3	Electrical box
014	18.80	19.8		030	23.59	43.8	
015	158.89	259.1	Metal drum bin	031	12.56	23.7	Window sills
016	65.31	106.5		032	39.79	97.3	
017	99.31	296.9	Outside air duct	033	22.13	12.7	Air conditioner
018	59.55	178.1		034	3.61	14.4	
019	20.57	47.1	Electrical box	035	227.44	244.8	Vending machine
020	123.35	379.4		036	110.10	130.2	

[a]The number stands for average ± standard deviation from each three samples

Table 5. The result of particle size distribution (percent) for the RCM (RCM; sieved below 38-μm in diameter) and the deposited filters obtained from the St. Lawrence Cement Facility

Diameter Range (μm)	RCM	D001-A	D003-B	D005-A
0.5-1.0	56.0	36.5	4.4	26.8
1.0-2.5	30.4	51.6	79.6	58.4
2.5-5.0	6.5	8.3	15.9	10.7
5.0-7.5	2.4	1.5	0.0	2.1
7.5-10.0	1.6	0.7	0.1	0.7
>10.0	3.1	1.5	0.0	1.4
Particle Number Counted	950	1206	889	2000

Table 6. The result of elemental analyses[a] for deposited dust on filters by 1st deposition sampling around St. Lawrence Cement Facility in Camden, New Jersey

L.	Sample	Mass (mg)	Distance[b] (km)	Al	Ca	Cd	Cr	Cu	Fe	Mg	Mn	Pb	Si	Ti	V	Zn
-	RCM	NA	0.00	18,991	301,988	DL[c]	34	58	7,801	14,595	877	10	17	1,006	10	148
1	D001A	1.401	0.23	12,133	60,585	3.1	56	166	22,270	12,114	662	294	254	679	51	2,413
	D001B	1.538		10,635	51,287	3.0	58	284	22,003	10,553	564	308	216	609	40	1,456
	D002A	1.560		13,697	56,875	5.8	84	192	26,635	11,809	653	355	159	874	52	2,562
2	D003A	1.683	0.37	10,172	42,163	4.3	92	394	28,568	10,598	511	582	141	627	48	2,699
	D004A	2.258		6,828	41,311	3.2	45	312	20,177	9,725	412	523	46	368	37	14,225
	D004B	2.238		6,253	37,033	3.2	48	279	19,964	8,671	355	458	124	323	39	20,080
4	D007A	1.441	0.36	8,854	35,961	3.2	74	260	26,232	9,049	422	420	132	545	33	1,820
5	D010A	1.037	0.50	6,378	29,449	6.5	50	185	16,816	5,871	296	282	215	410	29	1,439
6	D011A	0.971	0.66	7,675	37,672	15	94	329	34,480	8,198	444	501	199	471	41	3,265
	D012A	1.082		7,076	37,634	4.7	167	279	33,549	8,135	524	523	148	402	39	3,039
7	D013A	1.625	0.65	8,261	32,246	3.8	65	186	21,698	7,946	370	402	95	465	38	2,837
	D013B	1.648		9,538	37,573	5.8	70	344	26,893	9,305	478	600	88	502	49	8,011
	D014A	1.247		9,995	33,569	5.9	106	296	23,785	7,803	437	428	164	768	43	2,513
9	D017A	0.543	0.55	20,158	56,685	8.8	290	450	51,565	16,482	856	926	297	1,059	98	12,847
	D018A	1.034		16,194	41,344	5.4	336	261	41,248	11,922	662	618	88	1,070	71	4,504
12	D023A	0.751	0.45	14,684	61,438	11	177	335	43,196	14,876	787	730	151	780	66	4,421

[a]Concentration unit is ng/mg
[b]Distance means a radial distance from the center of cement piles in the facility
[c]DL means the concentration is below the method detection limit

Table 7. The result of elemental analyses[a] for deposited dust on filters by 2nd deposition sampling around St. Lawrence Cement Facility in Camden, New Jersey

L.	Sample	Mass (mg)	Distance[b] (km)	Al	Ca	Cd	Cr	Cu	Fe	Mg	Mn	Pb	Si	Ti	V	Zn
-	RCM	NA	0.00	18,991	301,988	DL[c]	34	58	7,801	14,595	877	10	17	1,006	10	148
1	D001-B	1.976	0.19	14,231	71,478	2.6	80	183	25,212	13,006	742	331	29	1,099	55	2,444
	D001-C	1.862		13,652	72,234	2.0	77	155	24,092	13,222	734	307	26	1,030	52	2,211
2	D003-C	1.512	0.29	10,918	51,138	2.8	97	172	24,034	10,918	589	347	26	877	53	2,411
	D003-D	1.482		9,761	46,221	2.4	172	174	24,777	10,363	582	661	34	760	53	2,383
3	D006-C	1.137	0.27	11,351	61,266	DL[c]	80	220	24,996	11,796	624	336	28	824	55	2,517
4	D007-D	0.800	0.35	11,910	67,100	3.7	104	349	38,475	14,795	660	615	51	826	65	2,990
5	D008-B	1.519	0.38	11,814	45,126	6.9	112	327	29,939	11,098	681	620	46	663	63	3,576
6	D011-B	1.151	0.61	12,598	45,770	11.0	710	251	51,364	14,189	813	550	47	497	65	5,797
7	D012-D	1.026	0.55	11,844	57,500	6.1	216	296	33,578	14,213	684	565	52	572	73	4,328
8	D014-C	0.872	0.45	11,954	50,493	4.9	106	307	29,661	16,773	621	359	69	690	138	5,105
9[d]	D016-C	0.608	2.38	7,284	33,202	5.7	124	186	20,249	8,404	392	330	26	427	40	2,118
10[d]	D020-C	0.594	2.20	11,121	47,845	5.0	140	238	28,185	17,027	522	265	70	808	123	4,848

[a]Concentration unit is ng/mg

[b]Distance means a radial distance from the center of cement piles in the facility

[c]DL means the concentration is below the method detection limit

[d]Location 9 and 10 are representing typical elemental concentrations in deposited particles in the vicinity area of Camden, New Jersey.

Table 8. The result of elemental loadings[a] for surface dust wipes collected by the surface dust sampling around St. Lawrence Cement Facility in Camden, NJ

L.	Sample	Mass (mg)	Area (cm^2)	Dist. (km)	Al	Ca	Cd	Cr	Cu	Fe	Mg	Mn	Pb	Sb	Si	V	Zn
1	S007	80.99	2,090	0.24	3,908	1,022	0.2	34	20	2,274	184	23	40	33.6	<0[c]	4.1	5,882
2	S009	15.81	1,867	0.24	361	361	0.3	1	3	561	94	7	5	0.5	1	1.1	26
3	S011	44.77	613	0.27	1,304	2,688	0.1	26	11	4,198	1,484	29	31	DL[b]	<0[c]	3.3	155
	S012	52.61	613		570	1,220	0.1	22	8	3,010	1,802	32	23	1.3	7	4.7	87
4	S013	15.38	325	0.29	1,137	1,130	DL[b]	14	9	2,725	2,234	21	32	DL[b]	38	4.9	51
	S014	18.80	948		<0[c]	203	0.4	2	2	586	124	6	6	1.6	<0[c]	0.8	10
5	S016	65.31	613	0.27	1,083	3,565	0.1	16	14	3,575	399	26	9	0.9	<0[c]	2.9	60
6	S017	99.31	334	0.31	2,499	23,251	0.5	22	32	12,275	2,602	113	80	DL[b]	<0[c]	8.6	716
7	S020	123.4	325	0.32	7,708	10,067	656.8	78	224	96,808	2,611	271	1,142	15.9	3	83.6	10,299
8	S021	31.54	446	0.34	1,398	4,255	0.3	23	26	10,452	872	71	53	0.7	<0[c]	7.4	95
9	S023	29.49	567	0.32	<0[c]	579	4.4	4	12	2,824	333	19	317	13.1	<0[c]	4.6	86
	S024	35.37	845		1,005	1,840	1.4	9	16	4,477	419	26	149	93.4	<0[c]	5.0	110
10	S025	21.03	548	0.50	1,302	2,021	0.5	8	16	4,109	616	37	44	1.9	<0[c]	5.0	100
11	S028	57.63	232	0.43	5,451	14,474	1.1	58	131	24,297	4,234	176	296	7.2	<0[c]	24.1	700
12	S030	23.59	539	0.43	1,386	2,547	0.3	23	24	5,731	806	45	44	2.4	<0[c]	6.4	258
13	S032	39.79	409	0.37	1,832	5,596	0.1	15	20	7,086	1,451	38	104	DL[b]	<0[c]	8.7	489
14[d]	S033	22.13	1,747	2.01	236	344	0.0	4	3	605	121	6	6	DL[b]	<0[c]	2.2	37
15[d]	S036	110.1	845	2.01	2,828	2,230	0.1	29	42	7,063	837	51	45	8.7	<0[c]	15.1	80

[a]Loading unit is ng/cm^2

[b]DL means the concentration is below the method detection limit

[c]<0 means negative value after blank subtraction

[d]Location 14 and 15 are at background site, Gloucester City Park

Table 9. Enrichment factors and Ca/Fe ratios for the deposited dust, surface dust, and RCM samples

Element	RCM	Deposited Dust				Surface Dust			
		Sampling Sites (< 0.66 km)		Background (> 2.0 km)		Sampling Sites (< 0.5 km)		Background (> 2.0 km)	
	Mean	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Al	1.02	0.86	0.67 – 1.37	0.84	0.75 – 0.94	1.62	0.43 – 7.97	1.21	0.69 – 1.72
Ba	5.10	7.24	4.27 – 10.5	5.56	4.63 – 6.48	28.0	1.43 – 143	4.02	3.48 – 4.57
Ca	36.4	9.23	7.07 – 12.2	8.02	7.18 – 8.86	5.76	0.95 – 21.2	1.18	0.09 – 2.26
Co	0.17	2.71	1.00 – 6.32	2.73	2.57 – 2.89	4.76	2.35 – 25.3	2.37	1.83 – 2.91
Cr	1.47	12.3	3.21 – 62.9	7.19	6.74 – 7.63	13.5	4.29 – 56.6	11.6	8.82 – 14.3
Cu	4.63	26.5	12.0 – 41.4	29.6	23.6 – 35.5	27.3	4.79 – 62.0	26.2	14.7 – 37.6
Fe	0.68	3.86	2.02 – 9.09	3.43	3.07 – 3.78	8.30	1.66 – 29.5	4.94	2.88 – 7.00
Ga	4.43	4.22	2.28 – 7.43	4.62	3.86 – 5.38	29.1	2.08 – 145	4.96	3.82 – 6.09
Li	3.35	3.77	2.45 – 6.05	3.94	3.80 – 4.08	5.15	1.16 – 16.0	3.98	2.42 – 5.53
Mg	3.06	3.64	2.49 – 6.01	4.78	4.44 – 5.11	2.96	1.46 – 6.45	1.68	1.37 – 1.98
Mn	4.04	4.20	3.11 – 7.57	3.58	2.99 – 4.17	2.97	0.67 – 4.34	2.09	1.51 – 2.67
Ni	0.34	7.48	3.28 – 18.8	6.93	6.35 – 7.52	6.33	1.27 – 17.8	6.09	4.60 – 7.59
Pb	3.31	224	101 – 375	144	111 – 176	538	67.8 – 2,860	143	114 – 173
Rb	0.15	0.90	0.57 – 1.37	1.42	1.39 – 1.46	1.03	0.28 – 2.21	1.38	0.80 – 1.95
Si	0.00	0.00	NA	0.00	NA	0.00	NA	0.00	NA
Sr	6.87	2.80	2.10 – 3.70	2.30	1.83 – 2.77	1.68	0.27 – 3.79	0.87	0.84 – 0.90
Ti	1.00	1.00	NA	1.00	NA	1.00	NA	1.00	NA
V	0.34	2.66	1.63 – 4.29	5.74	4.97 – 6.51	3.37	1.10 – 9.43	4.70	3.85 – 5.54
Zn	9.25	287	135 – 733	421	377 – 465	1145	22.1 – 13,935	91.4	56.7 – 126
Ca/Fe	38.7	2.00	0.89 – 3.00	1.70	1.70 – 1.70	0.58	0.10 – 1.89	0.44	0.32 – 0.57

Table 10. The percent estimation of RCM contribution to outdoor dusts by using an EPA CMB model based on elemental concentration compositions of RCM and other potential dust sources

Sampling	Sampling site (< 0.4 km)			Sampling Site (0.4-0.66 km)			Background Site (> 2.0 km)		
	N	Mean	Range	N	Mean	Range	N	Mean	Range
1st	7	12.2 %	8.8–18.2 %	9	7.9 %	4.9–11.8 %	NA	NA	NA
2nd	7	16.2 %	12.4–21.8 %	3	8.5 %	5.6–10.9 %	2	8.9 %	8.89–8.94 %

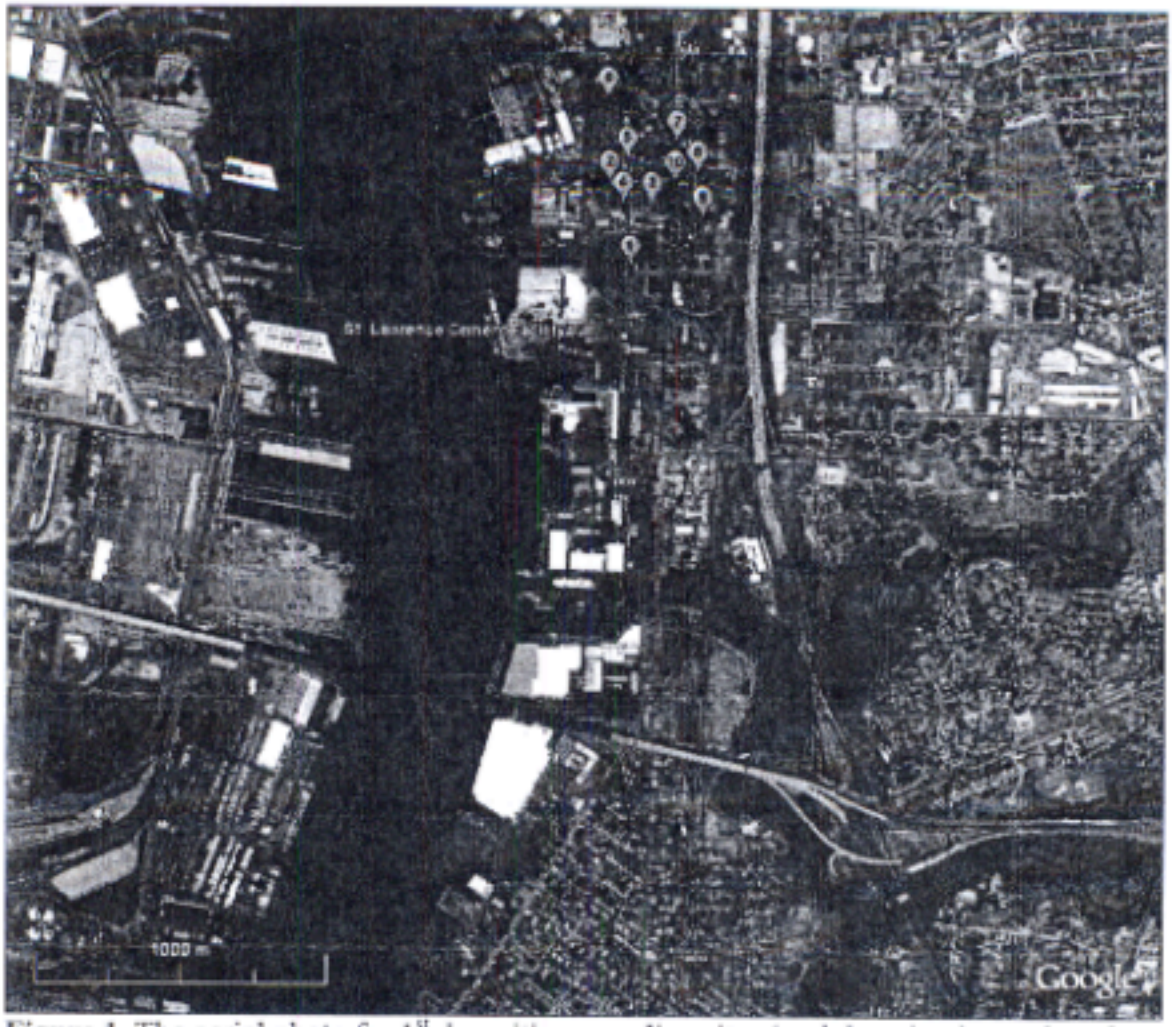

Figure 1. The aerial photo for 1st deposition sampling sites (each location is numbered 1~12 in the picture) to collect dusts from St. Lawrence Cement Facility, in Camden, New Jersey (obtained from Google Earth)

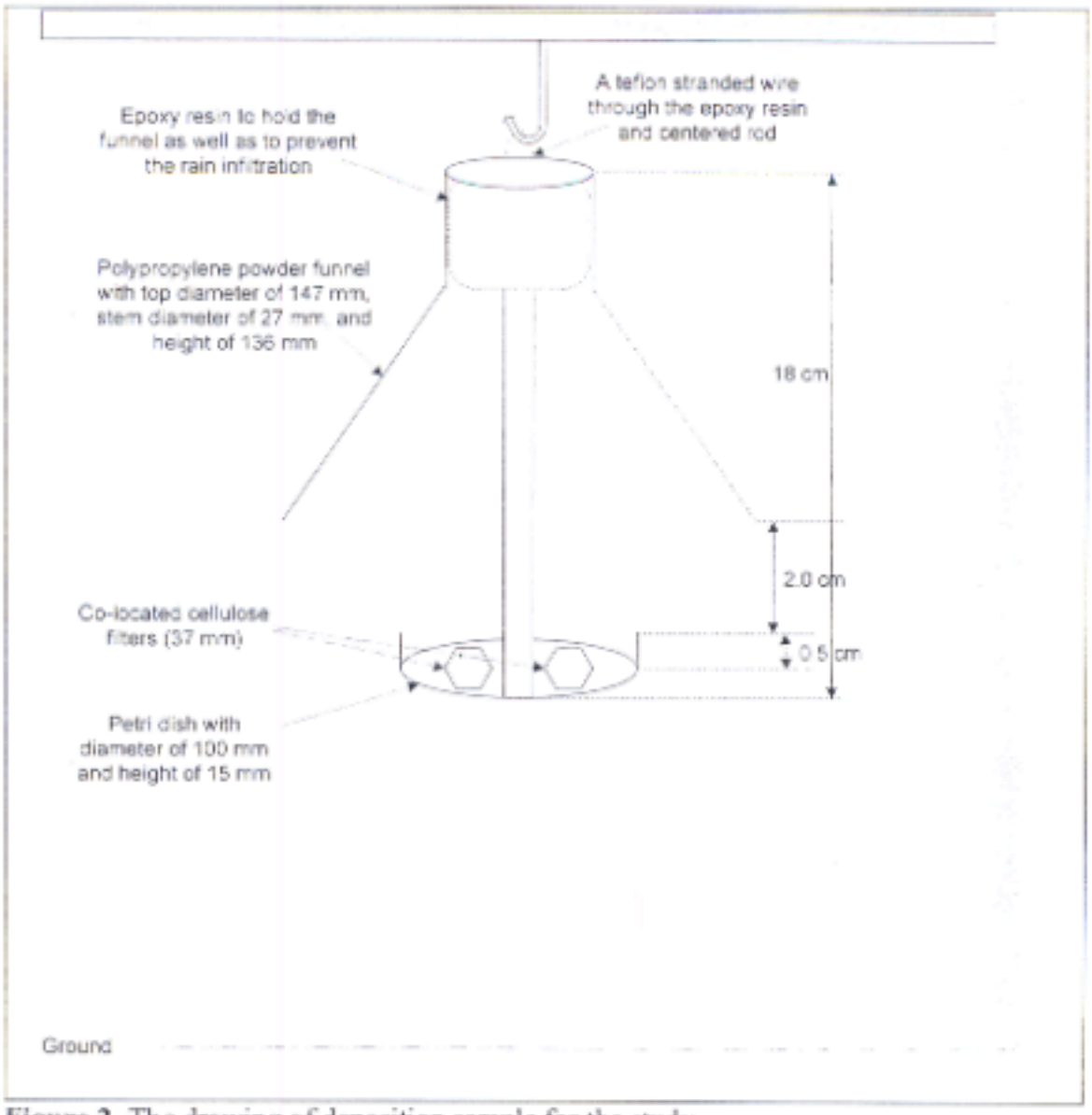

Figure 2. The drawing of deposition sample for the study

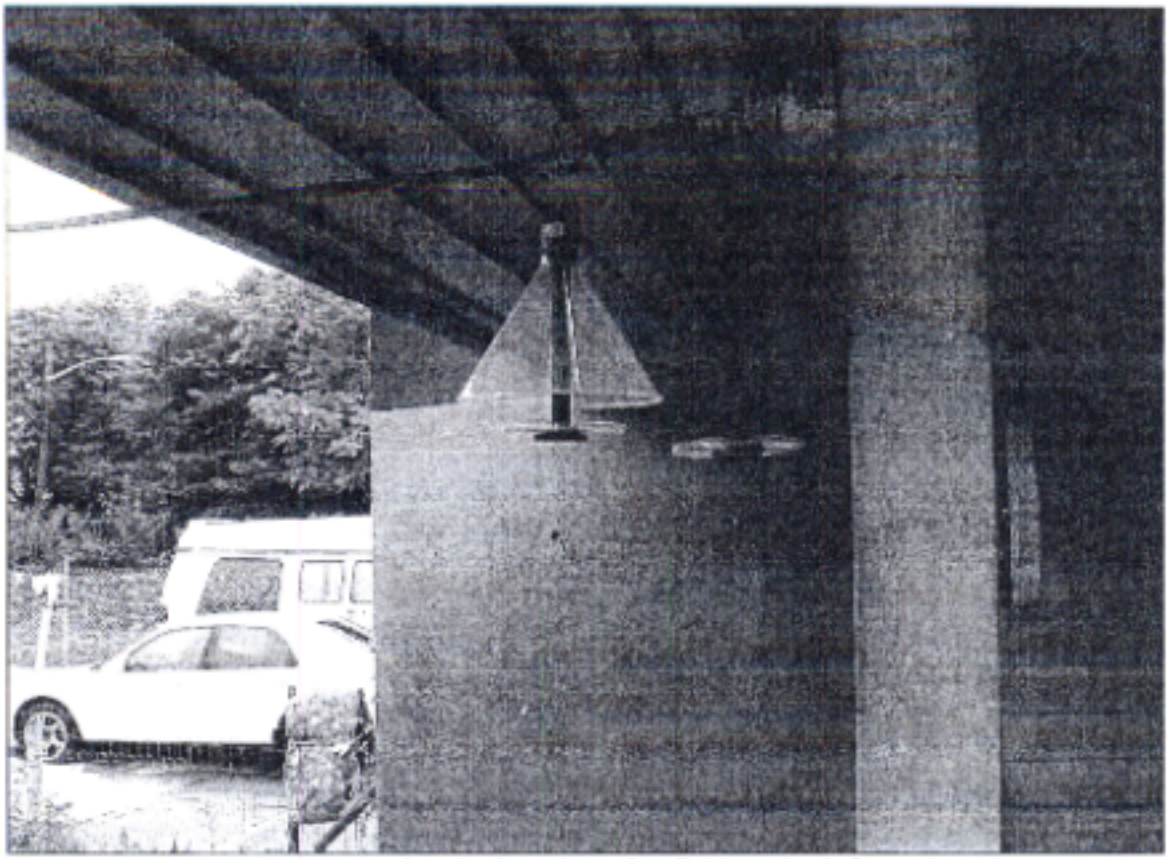

Figure 3. A deposition sampler deployed in the field with (left) and without a cover (right)

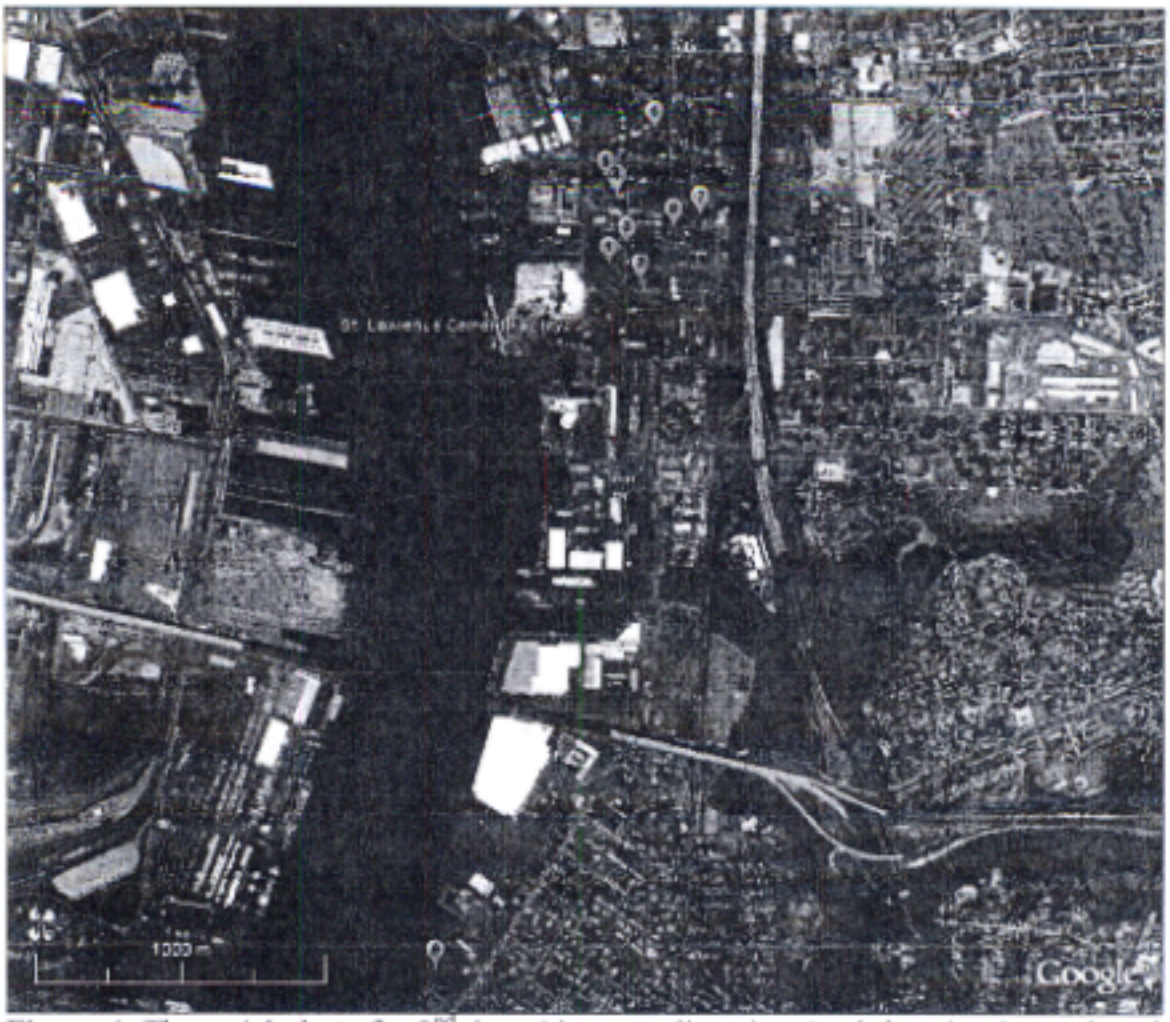

Figure 4. The aerial photo for 2nd deposition sampling sites (each location is numbered 1~10 in the picture) to collect dusts from St. Lawrence Cement Facility, in Camden, New Jersey (obtained from Google Earth)

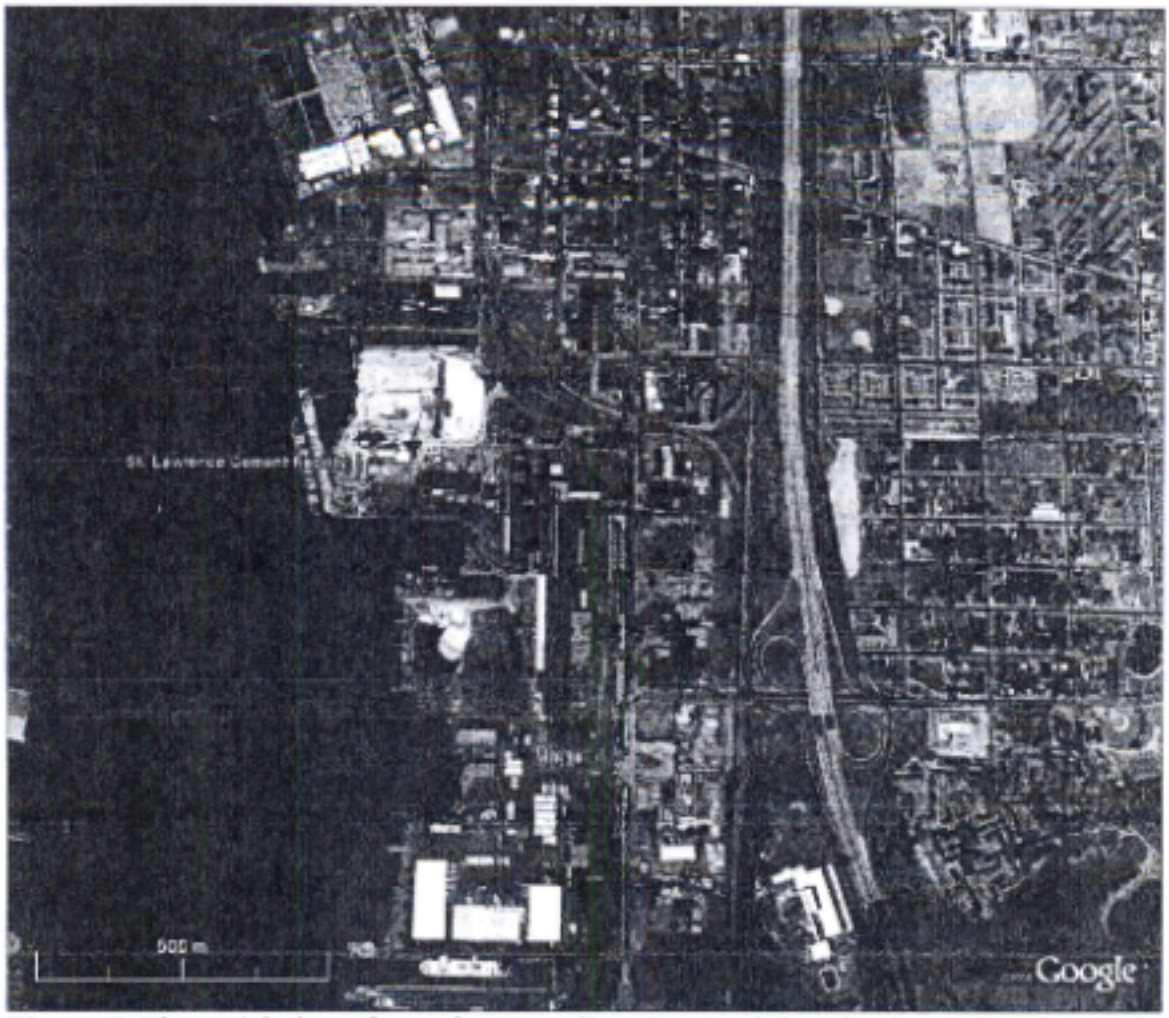

Figure 5. The aerial photo for surface sampling sites (each location is numbered 1~13 in the picture and background locations 14/15 are not displayed) to collect dusts from St. Lawrence Cement Facility, in Camden, New Jersey (obtained from Google Earth)

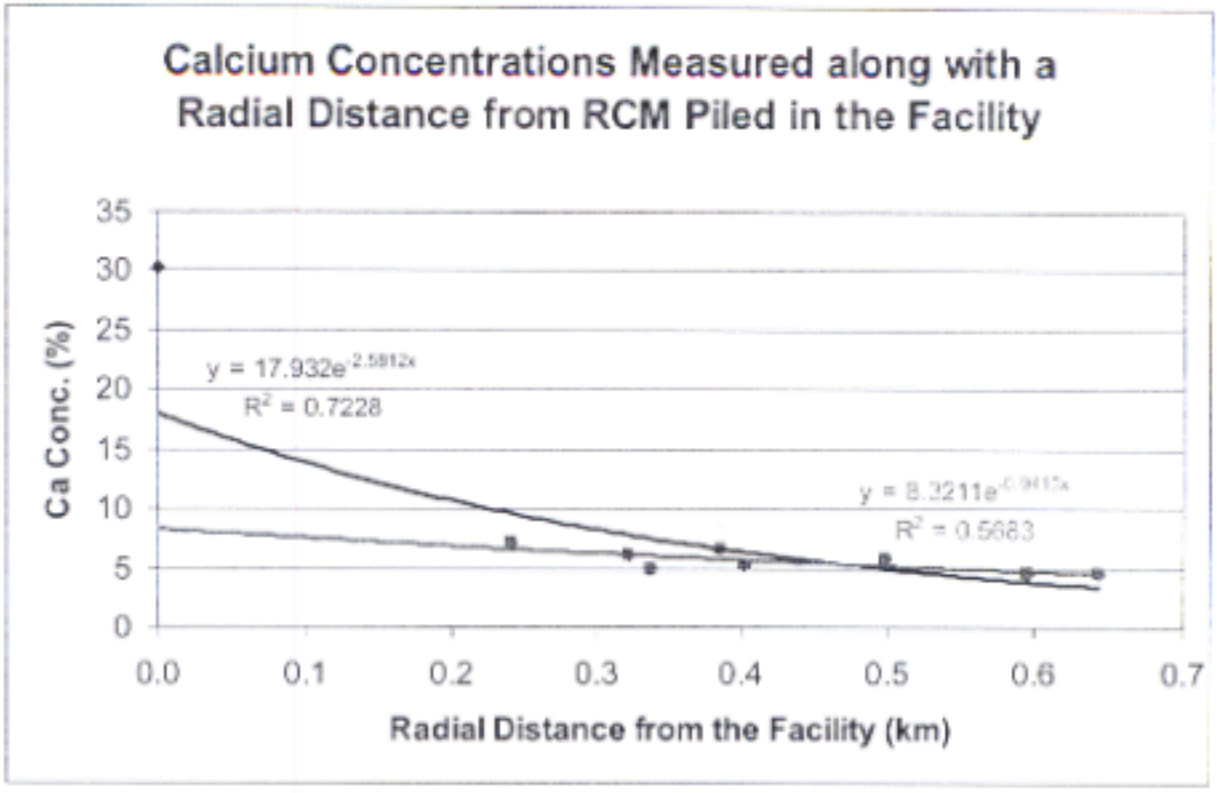

Figure 6. The Ca concentrations (percent) obtained from the deposited filters and RCM along with a radial distance (km) from the location of RCM piled inside of the cement facility.

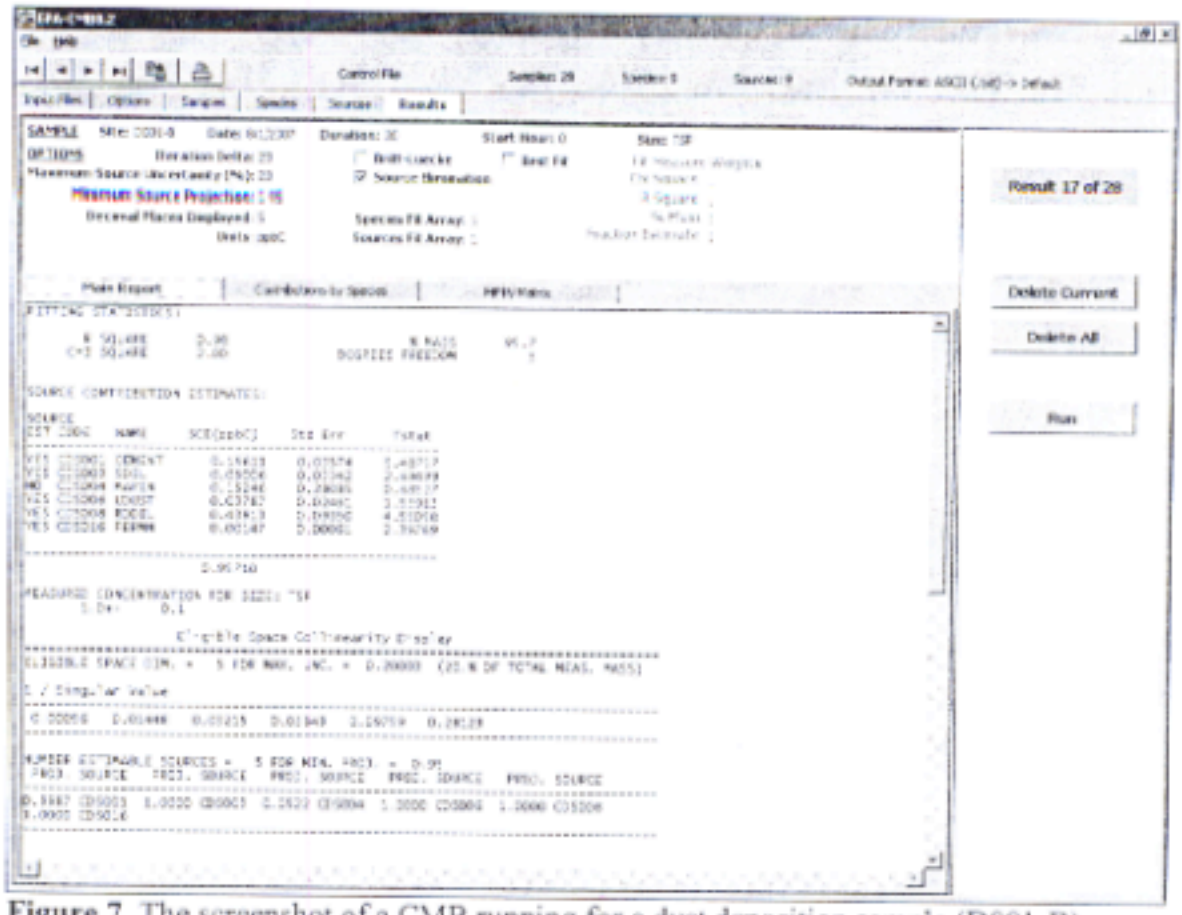

Figure 7. The screenshot of a CMB running for a dust deposition sample (D001-B)

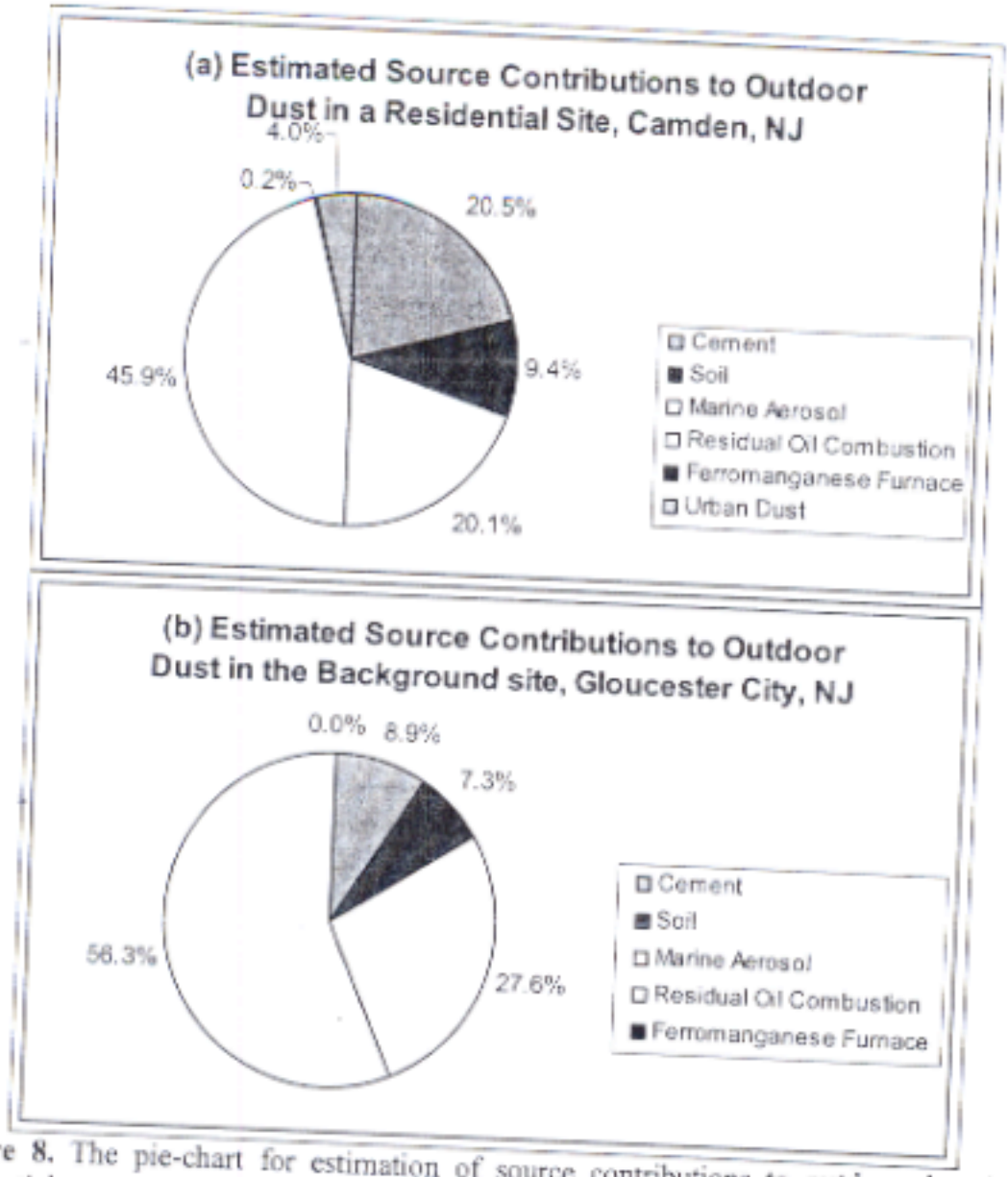

Figure 8. The pie-chart for estimation of source contributions to outdoor dust in a residential area near the cement facility (a) and in Gloucester City Park distant over 2 km upwind of the cement facility (b)