Determination of Airborne Hexavalent Chromium in Meadowland District-A Pilot Study

FINAL REPORT

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Submitted to:

Meadowlands Environmental Research Institute
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1. Background

Hexavalent chromium (Cr-VI), one of the main forms of chromium in environment, is highly toxic and carcinogenic (Barceloux, 1999, Kimbrough et al., 1999). Exposure to airborne Cr-VI at occupational settings has been associated with an increased risk of lung and nasal cancer (Barceloux, 1999; Kotas and Stasicka, 2000; Kimbrough et al., 1999). Given its toxicity, Cr-VI has been enlisted as one of the 188 hazardous air pollutants (HAPs), the 33 urban air toxics, and the 18 core HAPs by the U.S. EPA. However, we are still lack of understanding exposure to Cr-VI in ambient air that may lead to health effects because the data on ambient Cr-VI is scarce. Current air quality monitoring programs have measured only total chromium (Cr) in ambient particles, including the ongoing EPA-MERI (Meadowlands Environmental Research Institute) Near Road Air Toxic Particulate Pollutants Monitoring project. It is well known that there are two major forms of Cr in environment: trivalent chromium (Cr-III) and Cr-VI. Cr-III is an essential nutrient for human health; in contrast, Cr-VI is a human carcinogen (Barceloux, 1999; Kimbrough et al., 1999). Thus, accurately determination of Cr-VI concentration in ambient air is essential for accurately characterizing exposure and health effects.

Atmospheric chromium is emitted from anthropogenic sources, which account for 60-70%, as well as from natural sources, which account for the remaining 30-40% (ATSDR; Barceloux, 1999; Kotas and Stasicka., 2000). The major sources of environmental Cr-VI include metal processing, coal burning, and fossil fuel emission (ATSDR; Barceloux, 1999; Kotas and Stasicka., 2000). It was reported that chromium is among the top five most abundant metals in diesel particles (Wang et al., 2003). Thus, Meadowlands district, which is located close to NJ Turnpike (NJTPK) with high truck traffic volume, may have elevated atmospheric Cr-VI concentration. Further, Meadowlands district is only ~ 5 miles from Kearny and ~ 10 miles from Jersey City, areas with more than 200 historic chromium waste sites (Gochfeld, 1991). A recent study conducted at Environmental and Occupational Health Science Institute (EOHSI) found that Cr-VI is enriched in 2.5 μm size soil particles (Lioy et al., 2008). Wind erosion of the soil could make contaminated soil particles airborne, and the Cr-VI contaminated fine particles may be transported to Meadowlands area and contribute to Cr-VI pollution. Also, some studies reported that

total Cr and Cr-VI were associated with fine particles (Hughes et al., 1998; Kimbrough et al., 1999). However, the detailed particle size distribution of Cr-VI in ambient particles has not been characterized. Therefore, it is important to determine Cr-VI concentration as well as its particle size distribution in ambient air.

One of the main reasons for the knowledge gap in Cr-VI concentration in ambient air has been due to the lack of reliable measurement method. It is a great challenge in measuring Cr-VI in ambient air because Cr-VI and Cr-III can easily interconvert under different environmental conditions. With the joint effort from EOHSI and NJ Department of Environmental Protection (NJDEP), we have developed a reliable and sensitive sampling and analytical method for the measurement of Cr-VI in ambient air (Meng et al., 2010). The method includes collection of airborne Cr-VI particulate matter on a sodium bicarbonate pre-treated cellulose filter, extraction with nitric acid (pH=4), separation by ion chromatography (IC), and detection by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Isotope spike method is used to monitor potential interconversions between Cr-III and Cr-VI. Based on our evaluation of the method, Cr-VI is very stable on the sodium bicarbonate pre-treated cellulose filter stored at -15ºC. This method has been successfully applied to measure Cr-VI in ambient particles in our previous community exposure study conducted in Paterson, NJ (Yu et al., 2008).

2. Objectives

The objective of the proposed study is to measure hexavalent chromium air pollution in Meadowlands district. The specific aims are to: 1) determine the Cr-VI concentration in $PM_{2.5}$ at two sites (i.e., MERI site and William site) which are located at different distances to the NJ Turnpike (NJTPK) during different seasons (winter and summer), 2) determine Cr-VI distribution as a function of particle size at the site that is close to the NJTPK (i.e. William site) using a MOUDI (Microorifice Uniform Deposit Impactor) sampler, 3) evaluate the potential impact of gasoline/diesel traffic on Cr-VI levels in Meadowlands area by examining the association of the Cr-VI concentrations measured at the two sites with the traffic counts of the NJTPK, and 4) examine the impact of temperature and humidity on Cr-VI concentrations.

3. Methods

3.1. Sampling

In this study, we utilized the existing sampling sites and the sampling equipment of the MERI PM project to collect PM samples for the measurement of Cr-VI concentration. One site is located 50 m from the median strip of the NJTPK (Figure 1), and another site is located at the rooftop of MERI building, which is distance (> 700 m) from the main roads. The concentrations of Cr-VI in $PM_{2.5}$ as well as in different particle size fractions were determined. The Partisol 2000 Air sampler (Thermal Fisher Scientific) was used to collect $PM_{2.5}$ and the Micro-Orifice Uniform Deposition Impactor (MOUDI, MSP) was used to collect PM from size ranging from 0.18 to 18 μm. The total of 24-hour running was used to collect $PM_{2.5}$ samples, i.e., from 8 am to 8 am next day. For the Cr-VI concentration in different particle sizes, sampling time was 72 and 168 consecutive hours for summer and winter sampling, respectively. A pilot study was conducted at the two sites for three days, i.e., 6/15/2009 ~ 6/17/2009. Intensive summer sampling was conducted for the period of 8/4/2009 ~ 9/10/2009. The winter intensive sampling was conducted between 1/12/2010 and 3/2/2010. The Cr-VI concentration as a function of particle size was measured by 3 sets for the duration of summer sampling and 4 sets for the period of winter sampling. For QA/QC purpose, 9% lab blank, 9% field blank, and 6% duplicates were concurrently collected at William site. The filters for the Cr-VI sample collection, i.e. the 47-mm sodium bicarbonate pre-treated cellulose filter (VWR, NJ) was prepared by Dr. Fan's group at EOHSI.

3.2. Sample Analysis

Cr-VI concentrations were determined by Dr. Fan's group at EOHSI. Briefly, the filter samples were extracted with 5 mL pH=4 nitric acid (Optima grade, Fisher, MA), sonicated for 40 min at warm bath (60ºC), and the extract was filtered by membrane syringe filters (GHP Acrodisc with 0.45 μm, Gellman laboratory) and injected onto IC (Dionex) equipped with a CG5A column for separation of Cr-III and Cr-VI. The concentration of chromium species were determined by ICPMS, a VG PlasmaQuad PQIII system (VG Instruments, Winsford, Cheshire, UK). Stable isotope-enriched ^{50}Cr-III and

^{53}Cr-VI standard solutions (10 ng/μL) (AIT, CA) were spiked onto the filter samples before sampling to monitor any potential interconversion between Cr-III and Cr-VI during travelling, sampling, and sample processing. High purity natural abundance Cr-VI and Cr-III standards (High Purity Standards, Charleston, SC) were used for quantification. The final Cr-VI concentrations were determined by the US EPA-approved SIDMS (Speciated Dilution Isotope Mass Spectrometry) method (EPA 6800 method) provided by the AIT (Applied Isotope Technologies). Briefly, this method utilizes the ratios of ^{50}Cr, ^{52}Cr and ^{53}Cr isotopes to accurately estimate the ambient Cr-VI concentrations collected in the filter by reflecting the interconversions between Cr-VI and Cr-III in the sampling, extraction and analysis processes.

Both environmental conditions (temperature, RH, wind speed, and wind direction) and air pollutants concentrations (e.g. elements, O_3, CO_2, NOx, etc.) was obtained from the ongoing MERI PM project.

3.3. Data Collection

Meteorological data

The meteorological data, except solar ration data, during the concurrent sampling periods were collected from the sampling instrument deployed at each sampling site. The solar radiation data were obtained through MERI's GIS website (http://merigis.meadowlands.gov). The 15-minute recorded temperature, pressure, relative humidity, solar radiation, wind speed and wind direction data were averaged over the samplers' 24-h operation time (8:30 AM to 8:30 AM next date). Precipitation was accumulated over 24-h sampler's operation time. Descriptive statistics for meteorological data used in this study were provided in Table 1.

Ambient air pollutants

The ambient air concentrations of the co-pollutants were acquired from the continuous monitors placed at the MERI building for the MERI air quality monitoring project. O_3, NOx and CO_2 concentrations were averaged for the same sampling duration of 24 hours and used to examine the relationship between Cr-VI concentrations with

other pollutants existing in the ambient air. In Table 1, descriptive statistics for ambient co-air pollutants concentrations were displayed.

Traffic counts

The information of daily traffic flows passing the sampling sites (between 15W-16W exists for MERI site and between 16W-18W exits for William site) was obtained from the New Jersey Turnpike Authority during the sampling period. The 24-hour averaged traffic count was calculated for each sampling period. Since traffic was routinely counted separately on both directions of the highway, north and south bound traffic were combined to calculate the total numbers of the passing vehicles. Traffic counts were classified into two categories; diesel powered trucks and gasoline powered vehicles. During the sampling periods, an average traffic flow was 112,390/day (MERI site) and 78,278/day (William site) for gasoline powered cars and 16,493/day (MERI site) and 13,321/day (William site) for diesel powered trucks. Descriptive statistics for daily gasoline/diesel-powered vehicle counts at MERI (15W-16W) and William (16W-18W) sites were reported in Table 1.

3.4.Data Analysis

Descriptive statistics were performed to characterize the distributions of the measured Cr-VI ambient concentrations by sampling site and season in Meadowlands area. Due to the non-normal of Cr-VI concentrations, log-transformation was conducted prior to any data analysis and the log-transformed Cr-VI concentrations were normally distributed (Shapiro-Wilk test; $p = 0.6735$). Pooled t-test was conducted to compare the mean differences between the two monitoring sites (William site vs. MERI site) as well as two seasons (summer vs. winter).

Spearman correlations (r_s) were calculated to examine the association between Cr-VI concentrations and environmental conditions (temperature, humidity and wind speed/direction) and co-pollutants (i.e., O_3 and NOx) in the ambient air in the district of Meadowlands.

Multiple linear regression models were developed to estimate the contribution of diesel/gasoline-powered vehicles as well as other meteorological factors (i.e. temperature,

humidity, precipitation, solar radiation and wind speed/direction) and co-located ambient air pollutants (O_3, NOx, $PM_{2.5}$) measured in the district of Meadowlands. For the wind direction data (continuous variable as degrees), categorical variables of upwind, downwind and parallel to NJTPK were assigned as follows: upwind (<30 degrees and >240 degrees), parallel (between 30~60 degrees and between 210~240 degrees), and downwind (between 60 and 210 degrees). The categorical variables were replaced with numeric dummy variables and used in SAS REG procedure. Among 13 potential predicting variables, total of eight variables (precipitation, diesel traffic count, downwind direction, ozone, temperature, relative humidity, CO_2 and NOx) were selected by SAS's forward selection method (a significance level of below 0.15). The model was finalized with six variables, without CO_2 and NOx. Multi-colinearity for predicting variables was examined for the regression model to check the effect of correlation of variables. No significant correlations were observed among predicting variables in final regression models. Tests on equal variance, independence and normality for residuals were employed to check the assumptions of linear regression model.

All statistical analyses were conducted with the SAS program ver 9.2 (Cary, NC).

3.5. QA/QC

The 9% field (N=6) and lab blanks (N=6) and 6% co-located duplicate samples (N=4 pairs) were collected and analyzed. All blank results indicated there was no significant Cr contamination for the sampling in the field, analysis in the lab and transportation between EOHSI and field sites in Meadowlands district. The RPD (relative percent difference) for paired Cr-VI concentrations at William site was ranged from 28.2±21.3% with a range of 12.5 and 59.3 %. The method detection limit (MDL), defined as three times of the estimated standard deviation from seven filters spiked with a lowest calibration standard of 0.2 ng/mL and analyzed by the IC-ICP/MS, is 0.032 ng/m^3. Since there were no observable Cr-VI concentrations in field blanks, field blank subtraction was not conducted for all field samples in the report.

4. Results and Discussions

4.1. Descriptive statistics

Cr-VI was detected in all of the field samples (Table 2). The ambient Cr-VI concentration mean±SD, (median) was 0.52±0.32 (0.47) ng/m^3 at the MERI site and 0.40±0.20 (0.35) ng/m^3 at the William site. The ML Cr-VI concentrations were compared to Cr-VI concentrations measured in an urban location (Rahway) in New Jersey in the period of 2008 ~ 2009. Rahway is located close to US Routes 1, 9 and 27 and distant two miles away from NJ Garden State Parkway and NJTPK, representing the urban level of ambient Cr-VI concentrations in New Jersey. The ambient Cr-VI concentration in Rahway (N=29) was 0.35±0.13 (0.34) ng/m^3. The difference in Cr-VI concentrations was not significant between this study and Rahway measurements (t-test, p=0.0735).

4.2. Site comparison (MERI vs. William)

The ambient Cr-VI concentrations measured at William site where is parallel and close to NJTPK (within 50 m from the road) as well as at the rooftop of MERI building (distant ~ 700 m from the NJTPK) were provided in Table 3. The site difference i.e., William vs. MERI, was not significant either in pooled data (t-test, p=0.1272) or season-specific datasets (p=0.4604 for summer and p=0.0785 for winter). The ambient Cr-VI concentrations at MERI site were generally higher than the levels at William site; however, the difference was not significant (p>0.05). This suggests there may be other Cr-VI sources besides vehicular emissions near the ML district. One of the wetland sites in Kearny in the Meadowlands received COPR (Chromate Ore Processing Residue) deposits in the past, but was not completely filled in and remained a brackish marsh that is submerged and weathered for over 40 years (Elzinga and Cirmo, 2010). This Kearny Brackish Marsh is distant approximately 2.1 miles SW from the MERI building. Therefore, Cr-VI derived from COPR in the marsh in ML district could be additional sources for the Cr-VI measured at the MERI site. However, the current study was limited to monitor the Cr-VI concentration in ambient air in the district, future study such as source identification will be necessary to identify the COPR in the marsh contributes to the increase of Cr-VI concentrations in the area.

The co-located $PM_{2.5}$ mass concentrations, provided in Table 3, were significantly higher at William site than MERI site (t-test, p=0.0032). This trend remained the same for the summer (p=0.0143) and winter (p=0.0353) datasets. The higher $PM_{2.5}$

concentrations measured at the William site was resulted from heavy traffic emissions on the NJTPK. In contrast, the MERI site was located at the rooftop of MERI building (~ 10 m above the ground), > 700 m from the main roads. Thus, low $PM_{2.5}$ is expected for the MERI site. It was frequently observed that PM concentrations decreased with distance to major roads (Janssen et al., 1997; Hitchins et al., 2000; Cyrys et al., 2003). However, the trend was not significant or weak in other studies (Roorda-Knape et al., 1998; Wu et al., 2002).

4.3. Seasonal difference (Summer vs. Winter)

Generally the summer concentrations were found to be higher than the winter measurements at both monitoring sites; however, the differences were not significant ($P>0.05$). The stronger photooxidation of Cr-III to Cr-VI in hot summer season was expected to increase Cr-VI concentrations significantly (Nusko and Heumann, 1997). We suspect that the limited data collected in the pilot study may not have enough power to detect seasonal difference. More data should be collected in order to confirm the seasonal variation.

$PM_{2.5}$ mass concentrations were significantly higher in summer than in winter (t-test, $p=0.0015$), although higher $PM_{2.5}$ emission from vehicular exhaust is reported on winter season (Etyemezian et al., 2003; Parrish, 2006). The same trend was observed at both monitoring sites ($p=0.0126$ for the William site and $p=0.0156$ for the MERI site). These results suggest the stronger impact of photochemical reactions toward increasing the Cr-VI concentrations on $PM_{2.5}$ in the summer, despite of the influence of higher vehicular emission from the NJTPK in winter than in summer.

4.4. Ambient Cr-VI concentrations by particle size fractions

The MOUDI (Microorifice Uniform Deposit Impactor) can collect the ambient particles by specific particle size ranges (Marple et al., 1991). We employed the MOUDI (model 100, MSP Corp, Minneapolis, MN) to collect the ambient particles with particle size range of 0.18 ~ 18 μm in diameter. The eight size fractions are: 18-10, 10-5.6, 5.6-3.2, 3.2-1.8, 1.8-1.0, 1.0-0.56, 0.56-0.32, and 0.32-0.18 μm, respectively. The particle size distributions of Cr-VI concentrations were obtained and provided in Table 4. The

Figure 2 and 3 illustrates the ambient Cr-VI concentrations measured at the William site for summer and winter seasons, respectively. Except the data collected from 8/12-14, the Cr-VI concentrations were concentrated in the particles for the diameter less than 2.5 μm. The Cr-VI particle size distribution for the sampling period of 8/12-14 (Figure 2-b) were different: particle size ranges, between 18 ~ 10 μm and between 10 ~ 5.6 μm, were higher than the other 6 fractions. We suspected that the particle size distribution pattern may be affected by the large analytical variability due to the very low concentrations of Cr-VI measured during this sampling period. We conducted paired t-test by examining whether the Cr-VI concentration measured in small particles (total Cr-VI concentration for particles with diameters # 1.8 μm) was significantly greater than that in big particles (diameter between 1.8 μm and 18 μm). The results showed that the difference was significant (N=5; p=0.001). We like to note that the measurements obtained from the first and second rounds were excluded from analysis due to missing data in the first round and suspected higher concentrations in the second round. The elevated Cr-VI concentration in fine particle size (e.g., diameter < 2.5 μm) poses higher health risks, due to greater penetration of smaller particles (generally mass median diameter of 0.2 ~ 2.0 μm) into the lower lung airways (Hinds, 1998; Kimbrough et al., 1999). Thus, further study with more particle size-fractioned data should be conducted to confirm the observations obtained from this study.

4.5. The effects of NJTPK gasoline/diesel traffics and environmental factors

The effects of vehicular emissions on adjacent NJTPK as well as environmental factors such as co-existing ambient air pollutants of ozone (oxidizing agent) and NOx (reducing agent) and meteorological data of temperature, humidity, precipitation, pressure, solar radiation, wind speed/direction were examined using a multiple linear regression analysis for ML site. There was no significant difference in Cr-VI concentrations between MERI vs. William sites ($p>0.05$); thus, ambient Cr-VI concentrations obtained from the MERI and William sites were combined for the regression analysis . The selected predicting variables were precipitation, diesel traffic counts, downwind direction, ozone, temperature and relative humidity in the model. The final model was provided in Table 5.

In the ML site, the regression model explained approximately 48% of the variability in Cr-VI concentrations. All of six variables were significant in the model ($p<0.05$). The variable of precipitation was the most significant contributing factor (approximately 16%) to explain the variability of Cr-VI concentrations measured at the ML site. However, when compared with the standardized estimates, ozone was the most important factor for the predicted Cr-VI concentrations. A one standard deviation increase in ozone concentration would yield a 0.7 standard deviation increase in the predicted Cr-VI concentration, assuming that all other variables in the model are held constant. The results are consistent with the knowledge of Cr-VI chemistry. Ozone was suggested as an oxidizing agent to be likely increasing Cr-VI concentration by oxidizing Cr-III to Cr-VI (Kimbrough et al., 1999). Meteorological factors of temperature and relative humidity explained approximately 8% and 4%, respectively, in the variability of Cr-VI concentrations. Traffic related factors, diesel traffic counts and downwind direction, are additional explanatory variables (approximately 7% each) for the Cr-VI concentrations. These results suggested that Cr-VI concentration in the study area was affected by emissions from diesel-powered vehicles on nearby NJTPK as well as metrological factors.

We like to note that precipitation was identified as dominant explanatory variable in the model. Actually, there were only 7 raining days out of 34 sampling days and only 3 days with rain above 0.03 inches, i.e. there were no heavy raining days. We speculate that precipitation may represent the effect of humidity on the Cr-VI concentration/chemical reactions in ambient air; however, the specific effects of humidity on Cr-VI chemistry and thus concentrations are not clear to us at this moment and warrant further research.

5. Summary and Conclusions

This pilot study provided preliminary data of airborne Cr-VI concentration at two locations in ML area in two seasons (i.e., summer and winter). The concentrations measured at MERI site (0.53 ± 0.32 ng/m^3), away from NJTPK above 700 meters, were higher than the William site (0.39 ± 0.21 ng/m^3), distant only 50 meters from NJTPK; however, the difference was not significant ($p>0.05$). This result indicates that there are other potential Cr-VI sources in the ML district, considering emissions from passing vehicles on NJTPK did not make any difference as a function of proximity to the NJTPK

main roads. One potential source for airborne Cr-VI in the ML district is historically deposited COPR in the area. The historical COPR waste sites uncapped and unattended in the district may provide continuing source for airborne Cr-VI in the area by extracted with water and aerosolized with winds.

The particle size distributions of Cr-VI concentration measured were obtained from the William site. The function of particle size distribution data indicated that Cr-VI was more concentrated in fine particles (e.g., $PM_{2.5}$) than in coarse particles (e.g., $PM_{2.5-10}$). This finding is important in perspectives of human health risks, due to fine particles penetrate deeply in human lung airways. Also it is known that Cr-VI is human carcinogen through the pathway of inhalation exposure.

The multiple linear regression models developed in this study based on traffic counts near the NJTPK, meteorological factors and co-air pollutant concentrations provided preliminary data to examine the potential impact of each factor on Cr-VI air pollution in ML district. Among the predicting variables, precipitation and ozone were the most contributing variables in explaining the variations of Cr-VI concentrations in ambient air. The oxidation of Cr-III to Cr-VI is considered to be the major process to increase the ambient Cr-VI concentrations by oxidizing agent of ozone. However, gasoline/diesel-powered vehicle counts on NJTPK didn't significantly impact on the Cr-VI concentration in the area.

This pilot study provides valuable baseline data to understand the Cr-VI air pollution in ML area. However, to verify the findings obtained from the pilot study and fully characterize Cr-VI seasonal variation, particle size distribution, and investigate the sources of Cr-VI in the ML areas, further studies are needed.

Acknowledgements

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Appendix

Table 1. Descriptive statistics for meteorological data and ambient air pollutants concentrations concurrently monitored in Meadowlands district.

Variables	Unit	N	Avg.	SD	Min	Q1	Med	Q3	Max
Temperature	℃	34	12.7	11.9	-2.73	0.68	17.3	23.8	28.8
Relative humidity	%	34	64.0	9.96	43.7	56.8	64.5	71.8	83.3
Solar radiation	W/m^2	34	56.3	42.1	0.03	34.8	50.4	69.9	185
Precipitation	in	34	0.03	0.09	0.00	0.00	0.00	0.00	0.38
Wind speed	m/sec	34	2.95	1.44	1.34	1.82	2.44	3.86	6.23
Wind direction	degrees	34	205	76.6	41	149	236	260	312
Pressure	mmHg	34	762	4.68	749	758	763	765	769
Ozone	ppb	34	18.6	8.89	2.50	12.0	19.8	22.0	39.2
CO2	ppb	34	393	24.8	346	378	389	403	461
NOx	ppb	34	30.4	29.1	9.50	13.7	20.0	34.4	139
Gasoline-MERI	#/day	34	112390	9589	98273	104218	112042	119104	134809
Gasoline-William	#/day	30	78278	7749	67974	71178	78425	83292	95752
Diesel-MERI	#/day	34	16493	1060	13083	16220	16618	17084	18294
Diesel-William	#/day	30	13321	1063	10089	12998	13487	13938	15002

Table 2. The ambient Cr-VI (ng/m^3) and $PM_{2.5}$ ($\mu g/m^3$) concentrations measured at MERI and William sites for summer and winter seasons in Meadowlands district.

Season	Date	Site	Cr-VI Conc. (ng/m^3)	$PM_{2.5}$ Conc. ($\mu g/m^3$)
Summer	6/15/2009	MERI	1.071	NA*
Summer	6/15/2009	William	0.827	.NA*
Summer	6/16/2009	MERI	1.183	NA*
Summer	6/16/2009	William	0.826	NA*
Summer	6/17/2009	MERI	1.388	NA*
Summer	6/17/2009	William	0.936	NA*
Summer	8/4/2009	MERI	1.086	25.39
Summer	8/4/2009	William	0.616	32.31
Summer	8/5/2009	MERI	0.486	27.45
Summer	8/5/2009	William	0.273	14.92
Summer	8/6/2009	MERI	0.164	5.72
Summer	8/6/2009	William	0.146	14.18
Summer	8/7/2009	MERI	0.066	9.03
Summer	8/7/2009	William	0.162	16.46
Summer	8/10/2009	MERI	0.511	14.38
Summer	8/10/2009	William	0.345	20.45
Summer	8/11/2009	MERI	0.166	9.83
Summer	8/11/2009	William	0.273	15.39
Summer	8/12/2009	MERI	0.379	11.21
Summer	8/12/2009	William	0.183	16.58
Summer	8/13/2009	MERI	0.279	6.57
Summer	8/13/2009	William	0.388	14.72
Summer	8/14/2009	MERI	0.470	14.79
Summer	8/14/2009	William	0.455	20.38
Summer	8/17/2009	MERI	0.431	26.32
Summer	8/17/2009	William	0.546	37.21
Summer	8/18/2009	MERI	0.680	14.76
Summer	8/19/2009	William	0.558	17.52
Summer	9/8/2009	MERI	0.652	12.25
Summer	9/8/2009	William	0.366	NA*
Summer	9/9/2009	MERI	0.288	7.52
Summer	9/9/2009	William	0.198	24.58
Summer	9/10/2009	MERI	0.387	8.36
Summer	9/10/2009	William	0.469	17.43
Winter	1/12/2010	MERI	0.785	6.88
Winter	1/13/2010	MERI	0.285	15.21
Winter	1/13/2010	William	0.673	NA*
Winter	1/14/2010	MERI	0.579	NA*
Winter	1/21/2010	MERI	0.245	20.49
Winter	1/21/2010	William	0.333	13.67
Winter	1/26/2010	MERI	0.557	3.55
Winter	1/26/2010	William	0.275	11.17
Winter	1/27/2010	MERI	0.337	11.26
Winter	1/27/2010	William	0.480	NA*
Winter	1/28/2010	MERI	0.493	6.49
Winter	1/28/2010	William	0.294	9.37
Winter	2/1/2010	MERI	0.255	13.94
Winter	2/1/2010	William	0.228	23.52
Winter	2/2/2010	MERI	0.231	15.86
Winter	2/2/2010	William	0.221	27.46

Winter	2/3/2010	MERI	0.315	10.99
Winter	2/3/2010	William	0.286	18.29
Winter	2/4/2010	MERI	0.307	6.91
Winter	2/4/2010	William	0.256	NA*
Winter	2/8/2010	MERI	0.585	3.44
Winter	2/8/2010	William	0.245	10.62
Winter	2/17/2010	MERI	0.549	4.07
Winter	2/17/2010	William	0.368	8.79
Winter	2/18/2010	MERI	0.984	2.20
Winter	2/18/2010	William	0.454	5.54
Winter	3/1/2010	MERI	0.782	2.31
Winter	3/1/2010	William	0.431	7.63
Winter	3/2/2010	MERI	0.327	7.29
Winter	3/2/2010	William	0.293	13.75

*11 $PM_{2.5}$ samples were not recovered in the field or not sampled during the pilot study.

Table 3. Descriptive statistics for ambient Cr-VI (ng/m^3) and $PM_{2.5}$ ($\mu g/m^3$) concentrations at William site and rooftop of MERI building in Meadowlands district.

Site	Season	Cr-VI (ng/m^3)							
		N	Mean	SD	Min	Q1	Med	Q3	Max
MERI	Summer	18	0.57	0.38	0.07	0.29	0.48	0.68	1.39
William		16	0.44	0.25	0.15	0.24	0.38	0.58	0.94
MERI	Winter	16	0.48	0.23	0.23	0.30	0.42	0.58	0.98
William		14	0.35	0.13	0.22	0.26	0.29	0.43	0.67
Site	Season	$PM_{2.5}$ ($\mu g/m^3$)							
		N	Mean	SD	Min	Q1	Med	Q3	Max
MERI	Summer	15	14.1	7.20	5.72	8.36	12.3	17.5	27.5
William		12	20.4	7.43	14.2	15.2	17.0	22.5	37.2
MERI	Winter	15	8.73	5.63	2.20	3.55	6.91	13.9	20.5
William		11	13.6	6.85	5.54	8.79	11.2	18.3	27.5

Table 4. The ambient Cr-VI concentrations (ng/m^3) with particle size fractions measured by MOUDI at William site for summer and winter seasons in ML district.

Round	Sampling period	Particle size range (μm)	Cr-VI Conc. (ng/m^3)
I	8/4/2009 ~ 8/6/2009	18 ~ 10	0.075
		10 ~ 5.6	0.086
		5.6 ~ 3.2	0.101
		3.2 ~ 1.8	0.095
		1.8 ~ 1.0	0.095
		1.0 ~ 0.56	0.096
		0.56 ~ 0.32	0.068
		0.32 ~ 0.18	NA*
II	8/12/2009 ~ 8/14/2009	18 ~ 10	0.200
		10 ~ 5.6	0.187
		5.6 ~ 3.2	0.099
		3.2 ~ 1.8	0.125
		1.8 ~ 1.0	0.104
		1.0 ~ 0.56	0.106
		0.56 ~ 0.32	0.073
		0.32 ~ 0.18	0.052
III	9/14/2009 ~ 9/16/2009	18 ~ 10	0.077
		10 ~ 5.6	0.093
		5.6 ~ 3.2	0.102
		3.2 ~ 1.8	0.121
		1.8 ~ 1.0	0.114
		1.0 ~ 0.56	0.089
		0.56 ~ 0.32	0.089
		0.32 ~ 0.18	0.133
IV	1/13/2010 ~ 1/19/2010	18 ~ 10	0.034
		10 ~ 5.6	0.045
		5.6 ~ 3.2	0.047
		3.2 ~ 1.8	0.047
		1.8 ~ 1.0	0.063
		1.0 ~ 0.56	0.057
		0.56 ~ 0.32	0.047
		0.32 ~ 0.18	0.050
V	1/19/2010 ~ 1/26/2010	18 ~ 10	0.034
		10 ~ 5.6	0.044
		5.6 ~ 3.2	0.042
		3.2 ~ 1.8	0.046
		1.8 ~ 1.0	0.047
		1.0 ~ 0.56	0.051
		0.56 ~ 0.32	0.053
		0.32 ~ 0.18	0.040

VI	1/27/2010 ~ 2/2/2010	18 ~ 10	0.025
		10 ~ 5.6	0.023
		5.6 ~ 3.2	0.020
		3.2 ~ 1.8	0.020
		1.8 ~ 1.0	0.028
		1.0 ~ 0.56	0.037
		0.56 ~ 0.32	0.031
		0.32 ~ 0.18	0.021
VII	2/3/2010 ~ 2/9/2010	18 ~ 10	0.022
		10 ~ 5.6	0.014
		5.6 ~ 3.2	0.013
		3.2 ~ 1.8	0.015
		1.8 ~ 1.0	0.018
		1.0 ~ 0.56	0.025
		0.56 ~ 0.32	0.028
		0.32 ~ 0.18	0.017

*The concentration of Cr-VI was not available due to sampling/analysis errors.

Table 5. The final multiple linear regression models to predict Cr-VI concentrations measured in this study.

	Parameter estimate	Standardized estimate	P-value	Model/Partial R^2
ML (N=64)			<.0001	0.4836 (0.4292)
Intercept	-4.05891	0	<.0001	-
Precipitation	2.23342	0.36550	0.0008	0.1565
Diesel	0.00008	0.24901	0.0159	0.0680
Downwind	0.30958	0.26489	0.0573	0.0663
Ozone	0.04732	0.69785	<.0001	0.0645
Temperature	-0.03141	-0.62993	0.0004	0.0845
Relative humidity	0.02068	0.36157	0.0319	0.0438

*R^2 value in parenthesis means the adjusted R^2 in the model

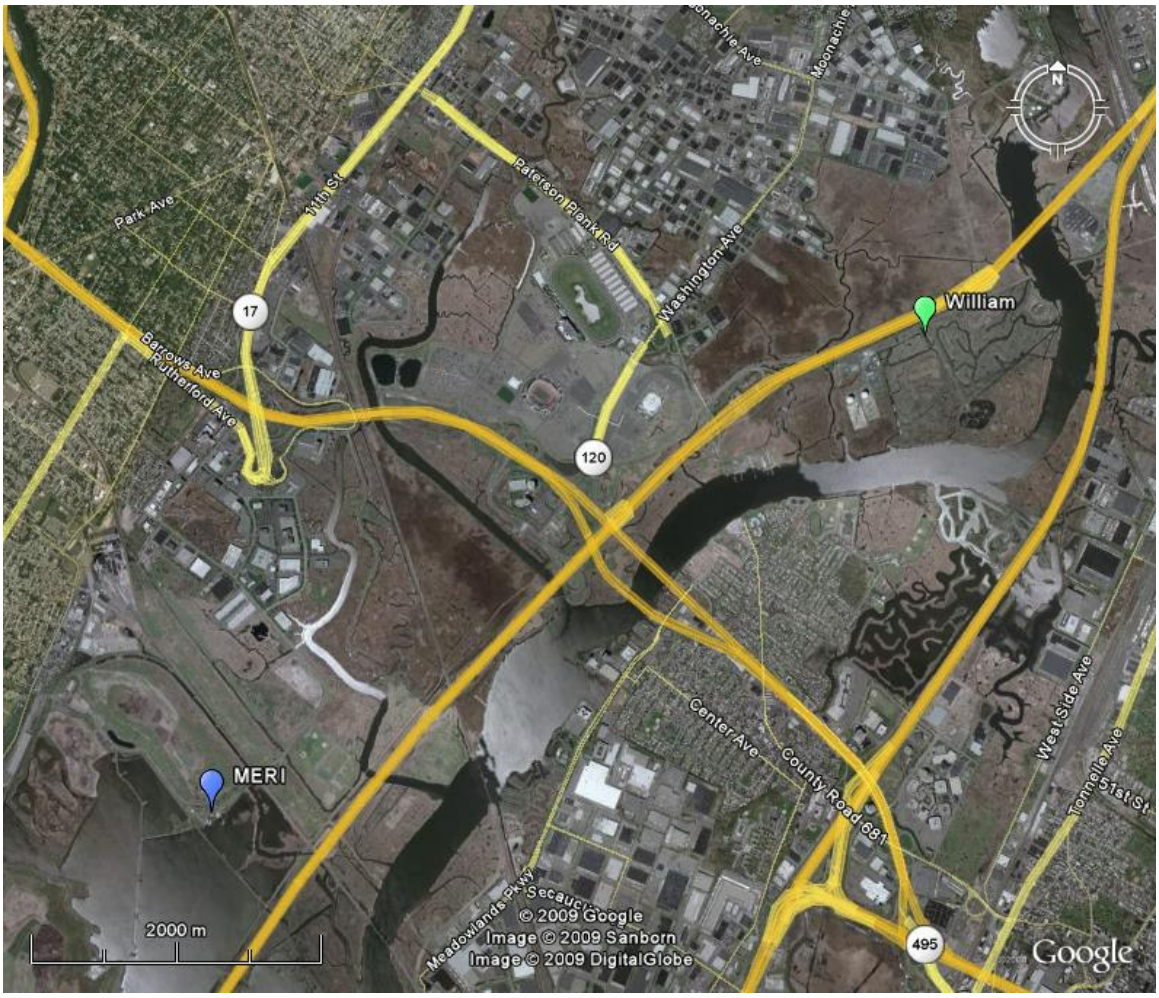
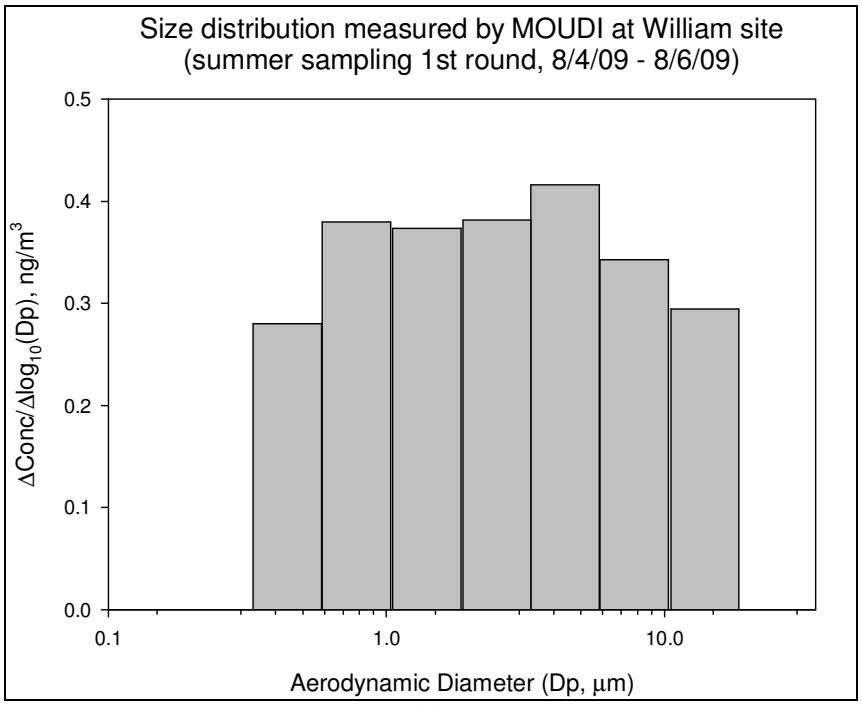
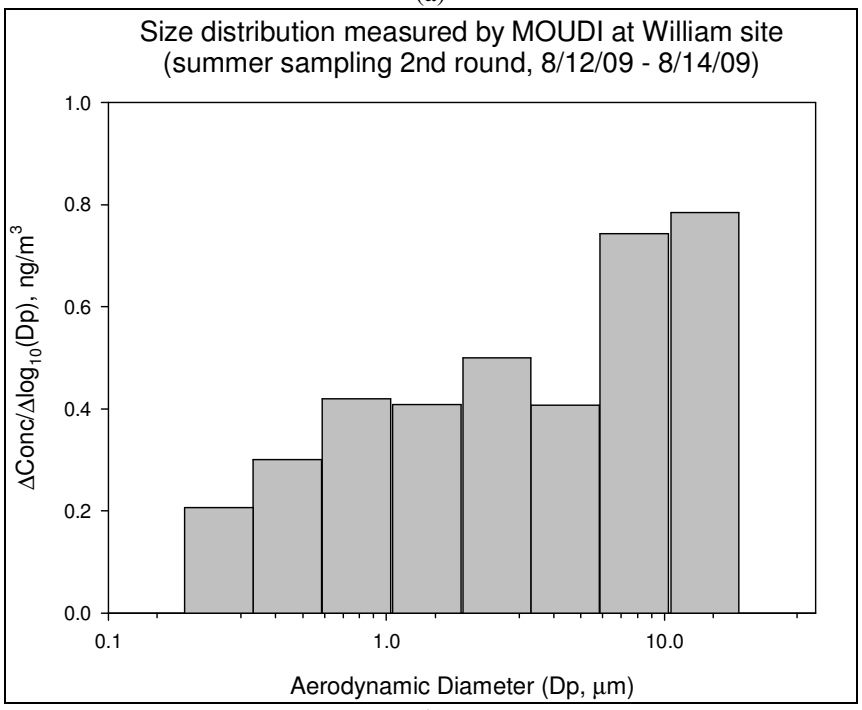


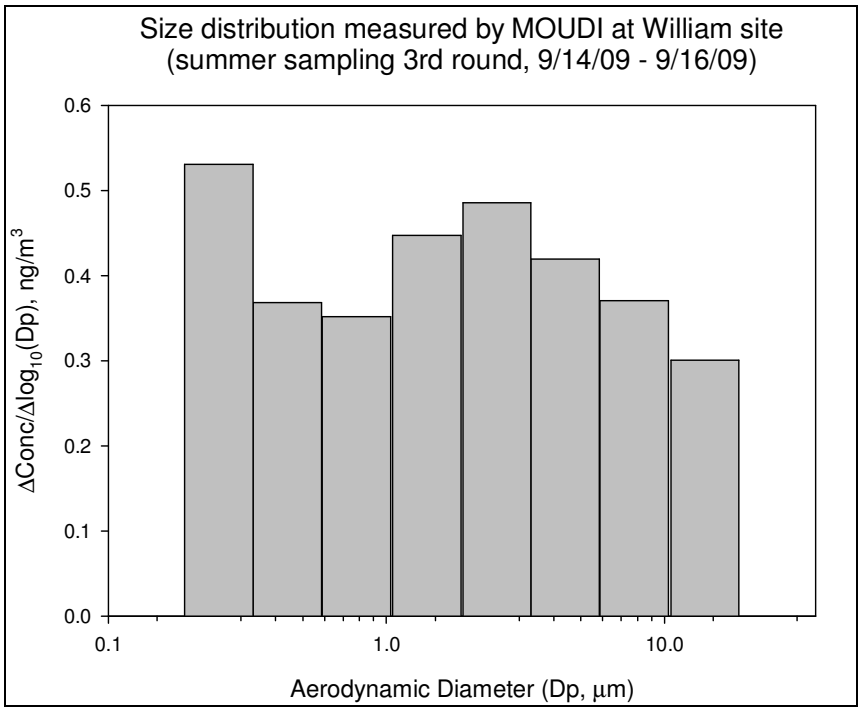
Figure 1. The two sampling locations of William site, distant < 50 m from the NJTPK and roof top of MERI building, distant > 700 m from the NJTPK (obtained from Google Earth).


Size distribution measured by MOUDI at William site
(summer sampling 1st round, 8/4/09 - 8/6/09)
0.5
0.4
0.3
0.2
0.1
0.0
ΔConc/Δlog10(Dp), ng/m3
0.1
1.0
10.0
Aerodynamic Diameter (Dp, μm)

(a)

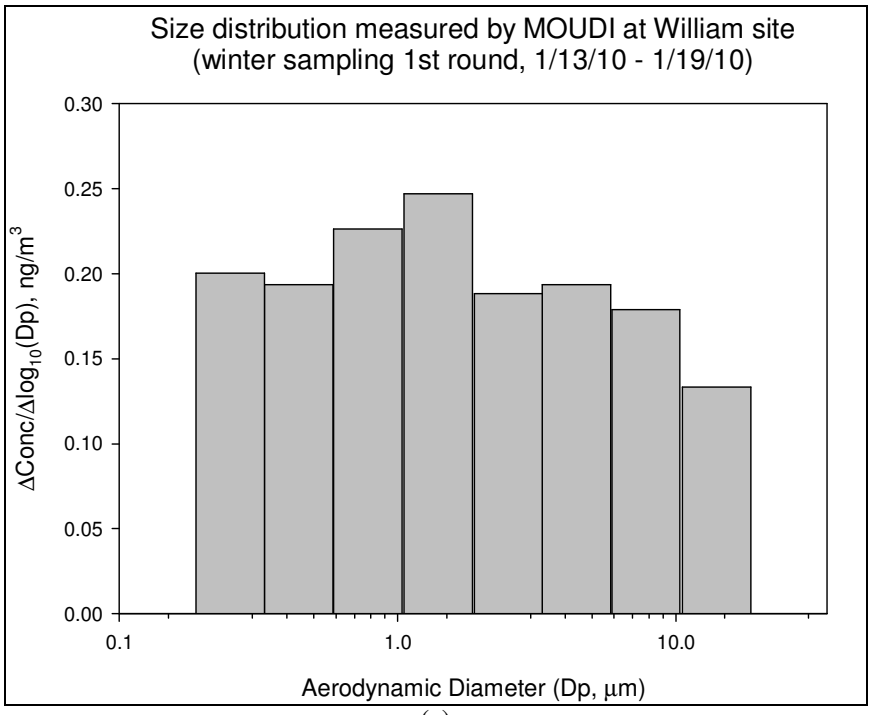

Size distribution measured by MOUDI at William site
(summer sampling 2nd round, 8/12/09 - 8/14/09)
1.0
0.8
0.6
0.4
0.2
0.0
ΔConc/Δlog10(Dp), ng/m3
0.1
1.0
10.0
Aerodynamic Diameter (Dp, μm)

(b)

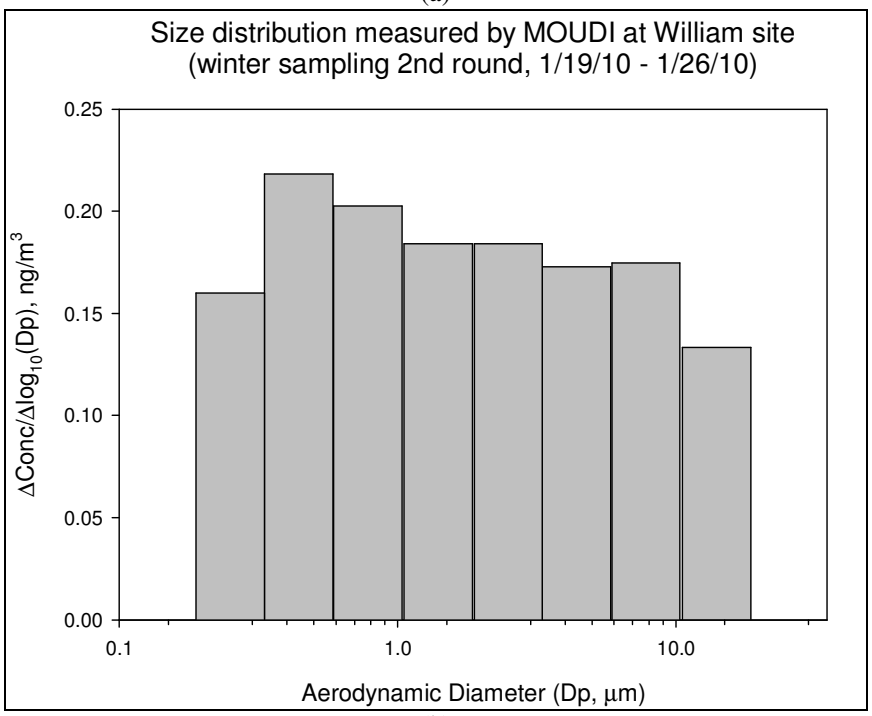


(c)

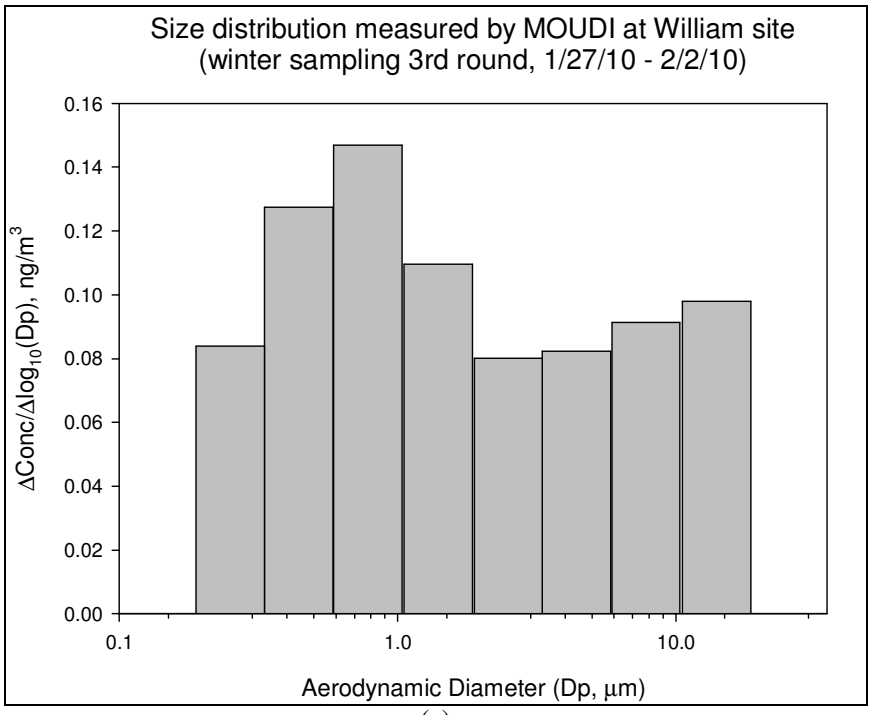
Figure 2. The ambient Cr-VI concentrations as a function of particle size by MOUDI sampling at William site within 50 m distant from the heavy trafficked NJTPK for the period of (a) 8/4/2009 ~ 8/6/2009, (b) 8/12/2009 ~ 8/14/2009, and (c) 9/14/2009 ~ 9/16/2009.


Size distribution measured by MOUDI at William site
(winter sampling 1st round, 1/13/10 - 1/19/10)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
ΔConc/Δlog10(Dp), ng/m3
0.1
1.0
10.0
Aerodynamic Diameter (Dp, μm)

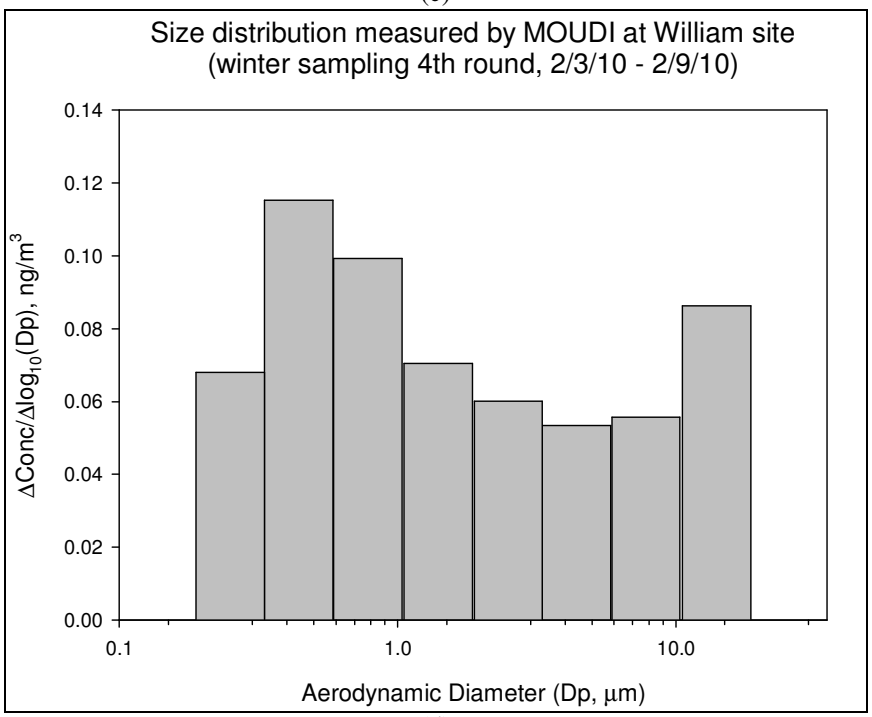
(a)


Size distribution measured by MOUDI at William site
(winter sampling 2nd round, 1/19/10 - 1/26/10)
0.25
0.20
0.15
0.10
0.05
0.00
ΔConc/Δlog10(Dp), ng/m3
0.1
1.0
10.0
Aerodynamic Diameter (Dp, μm)

(b)



(c)



(d)

Figure 3. The ambient Cr-VI concentrations as a function of particle size by MOUDI sampling at William site within 50 m distant from the heavy trafficked NJTPK for the period of (a) 1/13/10 ~ 1/19/2010, (b) 1/19/10 ~ 1/26/10, (c) 1/27/10 ~ 2/2/10 and (d) 2/3/10 ~ 2/9/10.