Final Report: Chromium Exposure and Health Effects in Hudson County: Phase I

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A. **Introduction**

During the first half of the twentieth century, northern New Jersey was the chromite-chromate production capital of the world. Approximately 2 to 3 millions tons of chromite ore processing residue (COPR) were produced in Hudson County alone (Burke et al., 1991). This resulted in a legacy of industrial waste that was distributed gratis to many Hudson County communities (Gochfeld 1991). Over 200 chromium waste sites have been identified in Hudson County, NJ. Figure 1 displays the waste sites documented by New Jersey Department of Environmental Protection in Jersey City. The risks of exposure to chromium have been difficult to assess because the health effects of chromium differ greatly between trivalent chromium (Cr^{3+}), an essential nutrient, and hexavalent chromium (Cr^{6+}), a human carcinogen. The exposure issues are further complicated by the substantial analytic challenges in accurately measuring $Cr^{3+}$and Cr^{6+} partly because of the tendency for interconversion during analytical procedures.

Although the chromium species in house dust could not be distinguished in previous studies, studies that were conducted by EOHSI in the 1990s demonstrated that exposure to total chromium in house dust was occurring from waste sites located in Jersey City and Bayonne (Lioy et al., 1992; Fagliano et al., 1997; Freeman et al., 1997; Stern et al., 1998). Furthermore, the studies demonstrated that the removal of chromium waste (excavation) from these sites reduced chromium levels in house dust in homes adjacent to waste sties to background levels (Freeman et al., 1995, 1997, 2000).

Despite extensive remediation and evidence that remediation was effective in reducing or eliminating exposure, questions and concerns remained regarding the adequacy and efficacy of interim remediation efforts at industrial locations. In addition, concerns about the possibility of hitherto unidentified sources or pathways of chromium exposure remained. While virtually all the residential sites have been excavated, other remediation methods, including capping and interim coverings, have been used on other sites, particularly the industrial and commercial sites. Additionally some of the chromium-contaminated sites are still awaiting permanent remediation. The presence of un-remediated sites results in the continued presence of chromium in the community and the lingering potential for human exposure.

In contrast to the earlier studies that could only measure total chromium, the samples collected in this study were speciated to accurately measure hexavalent chromium with the new analytical methods developed by EOHSI. This project was the first to measure Cr^{6+} concentrations in the house dust in residential homes in general and specifically in house dust. This permits a more direct and accurate assessment of exposure and risk to Cr^{6+}, the toxicant of concern in COPR.

B. Study Design

B.1. Site selection and subject recruitment

In conjunction with NJDEP and the community, we identified a subset of the known chromium sites for detailed inspection and investigation (See Figure 1). The NJDEP Site Remediation Program has recently posted a status report of the known chromium waste sites in Hudson County (http://www.state.nj.us/dep/srp/siteinfo/chrome/statusrpt2007.pdf).

Initially, two residential locations were targeted for sampling, the Droyers Point development, and the Garfield Avenue neighborhood. These sites were selected due to their size and proximity to capped chromium sites (Sites 119 and 114 respectively). Participants were recruited largely through public meetings (Table 1) and direct mailings. The study protocol, consent forms and recruitment materials were reviewed and approved by the UMDNJ-Robert Wood Johnson Medical School Institutional Review Board.

The Droyers Point waste site was a large site (28 acres) located adjacent to Route 440. During remediation in the early 1990s, a portion of the site was permanently capped. The site was subsequently developed as the third phase of the Society Hill town homes in Jersey City. This phase, commonly known as Droyers Point, has 380 units and is directly adjacent to the first two phases bringing the total number of housing units to over 1,400 in the combined Society Hill developments. These developments are also near several other chromium waste sites along Kellogg Drive and Route 440 (Sites 73, 115, 124, 125, 134, 140, 163, and 187). During sampling, residents also expressed concern about chromium exposure due to the ongoing remediation at Site #115 (Roosevelt Drive-In). To recruit from this area, a total of 354 letters were mailed to residents of the Droyers Point development. Additionally the study brochure was posted, by residents, on the Society Hill website.

The Garfield Avenue Site (Site 114) is another large chromium site (15 acres) located on Garfield Avenue between Carteret Avenue and Union Street. A temporary cap has been in place on the site for many years. Several other sites are also located nearby (Sites 121, 132, 133, 135, 143, 199, and 207). Two separate mailings were made to the Garfield Avenue area. In the first mailing, 92 letters were mailed to residents of Randolph Avenue from Carteret Avenue to Union Street (residents of the side streets from Randolph to Garfield were included in the mailing). In the second mailing, the area of interest was expanded one block in either direction (Claremont Avenue to Bramhall Avenue) and an additional 120 letters were mailed.

Three other areas of Jersey City were considered for recruitment based on the presence of chromium sites and/or community concern. First, the area around Freedom Place (from Skyline Drive to Bayside Park Terrace) was selected because of community concern expressed at a public meeting on 9/26/06. Only one known chromium waste site (Site 100) appears to be located in this area. Approximately 170 letters were sent to homes in this area. Second, the area bordered by Rt. 78, Grand Street, Garfield Avenue and Carteret Avenue (Lafayette Area) was also selected. This area is largely residential and had several sites (Sites 6, 13, 18, 39, 127, 128, 142, 151, 159, 160, 161, and 202), including those that have been excavated as well as those under remedial investigation. Almost 500 letters were sent to homes on Halladay Street and Pacific Avenue. Third, an area roughly bordered by Stegman Street, Bergen Avenue, Woodlawn Avenue and Garfield Avenue was considered. Although many of the suspected sites in this area were previously determined by the NJDEP not have excess chromium (Sites 25, 26, 27, 30, 31, 32, 33, 34, 35, 36, 122) several residents identified the area around the Whitney Young, Jr. School (School P.S.15) as an area of concern. However, due to the poor response (approximately 1%) to recruitment letters sent to the Lafayette area, the mailings were discontinued and alternate recruitment methods (community meetings) were implemented..

Resident letters were successful in recruiting from the Droyers Point development with approximately 10% of the letters resulting in a study participant. The letters were less successful in other areas (approximately 5% around Garfield Avenue and only 1% in the Lafayette area). In an attempt to increase participation from other areas, several public meetings (Table 1) were held. Sign-up sheets were presented at each meeting. All residents who filled in the sign-up sheet were contacted by phone. At least three attempts were made to reach each interested person. If the person could not be reached during the day, attempts were made to reach them in the evening or on weekends.

Although formal presentations in the first two meetings yielded some participants, the public meeting held on December 1, 2007 greatly increased access to the community. Plans for this meeting were made with Councilwoman Viola Richardson. The councilwoman arranged for the use of the meeting space and the delivery of fliers to residents to advertise the meeting. The public support by Councilwoman Richardson and Deputy Mayor Kabili Tayari at the meeting reassured potential participants. An informal, interactive approach during the meeting also encouraged residents to ask questions and, ultimately, to participate in the study. Residents who attended this meeting then invited researchers to speak about the study at subsequent community meetings. An article about the meeting appeared in the Jersey City Reporter on December 9, 2007. The article prompted additional residents, often those outside targeted areas, to participate in the study.

B.2. House Dust Sample Collection

An appointment was made by phone with each participant for sample collection. During the appointment, the informed consent form was reviewed and all questions about the study were answered. A signed copy of the consent was obtained and an additional copy provided to each participant. A short questionnaire about the home, including questions about ventilation and renovations, was administered. Dust samples were collected from up to three areas in each home. If possible, a sample was collected from a window well, a surface in the basement, and a surface in a living area (living room, bedroom, dining room, etc.) in the home. Initially, in homes without a basement, only two samples were collected. Later, a second living area sample was collected to standardize all collections to three samples per home. Although at least one living area sample was collected in each home, window well and basement samples could not always be collected (participants had secured windows or did not have access to the basement). Initially two side-by-side samples were collected from each surface to serve as near-duplicate samples. A third side-by-side sample was later added to allow for both side-by-side hexavalent chromium and total chromium analyses. Within in these home areas (window well, basement and living area), surfaces were selected based on a visual assessment of an adequate dust loading, and, if possible, an adequate space to accommodate three side-by-side samples.

Dust samples were collected by one of three methods. The preferred method was the LWW sampler using pre-weighed polyester filters to wipe the surface. Filter packets were prepared in the laboratory. A set of three filters was placed in a Petri dish and stored, opened, in the temperature and humidity controlled weighing room for at least 24 hours before weighing. The filters were weighed on the Mettler Toledo MT5 balance. Two calibration standards and a set of control filters (stored in the weighing room throughout the study) were weighed before and after

every 10 filter sets. All standards and filters were weighed twice and the mean of the weights was recorded on the Petri dish label, as well as the filter weighing form. The Petri dishes were then stored in 1-gallon Ziploc bags for transport to the field. The sampler consists of a 150 cm^2 template and a sampling block. Each filter was secured to the sampling block, wetted with distilled water, and slid across the surface in five passes. The dust sample was collected by wiping the outlined area sequentially with the set of three filters. The dish was labeled and stored in a cooler, with blue ice, for transport to the laboratory.

The second collection method was a free hand wipe. If the LWW sampler could not be used (the template did not fit on the surface or the rough texture of the surface tore the filter), the filters were held and the surface was wiped by hand. The LWW uses a rigid block to wipe the surface and is unable to conform to the surface irregularities (ridges & bumps); the free hand method could conform with pressure but not uniform pressure. Using gloves, the technician wetted each filter and wiped a pre-measured area in five passes. Three filters were used sequentially for each sample. After wipe sample collection, the filters were placed again in the Petri dish. The dish was labeled and stored in a cooler, with blue ice, for transport to the laboratory.

The third collection method was the sweep sample. Sweep samples were collected when the mass of dust on the selected surface appeared to be too great to collect using the wipe method. Packets of pre-weighed small (2 x 5-inch) Ziploc bags were prepared in the laboratory. The bags were weighed using the Mettler Toledo MT5 balance. Two standards were weighed before and after every 10 bags. All bags were weighed twice and the mean weight recorded on the bag label. The bags were then placed in a Petri dish for transport to the field. For sample collection, an area was selected and measured. A 1-inch disposable paint (chip) brush was used to sweep the mass into a disposable weighing tray. The dust was then transferred into the Ziploc bag. The bag was sealed and placed again in the Petri dish. The dish was labeled and stored in a cooler, with blue ice, for transport to the laboratory.

A chain of custody form was completed for all samples recording the location within the home and surface characteristics (material, paint, and condition) as well as the date, time, and method (standard wipe, free hand wipe, or sweep) of collection. After transport to EOHSI, the samples were stored with the chain of custody record in a $-15^{o}C$ freezer until analysis.

Repeat Dust Sampling

Based on discussions with the NJDEP project officer, repeat samples were collected if one or more samples within a home exceeded the NJDEP 20 μg/g residential hexavalent chromium site remediation soil criterion. There were six homes in this category, and the participant was notified by phone of the result and a repeat sampling was requested. During the repeat sampling, a sample was collected from each surface that had previously exceeded the site remediation soil criterion. At least two other surfaces, preferably in the same room, were sampled during the repeat visit.

B.3 Air Sample Collection

Air samples were collected on the Garfield Avenue site (Site 114) on September 26, 2007. Samples were collected using two stationary monitors and one mobile monitor over the same three hour period. Two stationary monitors were placed on the capped surface near the south corner (the intersection of Halladay St. and Carteret Ave.). Samples were collected using open face cassettes and SKC Leland Legacy pumps with a flow rate of 8.5 liters per minute. In the laboratory, pretreated cellulose filters were loaded into the cassette samplers. The cassettes were capped then transported under nitrogen in a sampling jar to the field. The sample cassettes were then connected to the pump in the field and initial flow rates were measured. The inlets were approximately 18 inches off the ground level. After sampling, the end flow rates were measured. The difference between the initial and end flow was less than 10%, and the average of the initial and end flow rates was used for air concentration calculation. The cassettes were removed, capped, and placed in the transport jar. All filters were stored in a cooler, with blue ice, for transport to the laboratory.

One air sample was collected using the mobile monitoring system called PIPER (Pre-toddler Inhalable Particulate Environmental Robotic sampler). The sample was collected using an AirLite sampling pump with a flow rate of 2.0 liters per minute. A pretreated cellulose filter was loaded into the IOM sampling head in the laboratory, sealed with a transport clip then transported, under nitrogen, to the field. The IOM sampling head was then installed on PIPER. The initial flow rate was checked and one air sample was collected as PIPER moved across the capped area. PIPER is designed to mimic activities of young children playing on a surface and incorporates stops and turns during the mobile sampling. Contact between the wheels and the ground provides opportunity for suspension of particles. For this preliminary testing, the sampling head was kept at a fixed height of approximately 18 inches off the ground. After sampling, the flow rate was checked; the IOM sampling head was removed and sealed with a transport clip. The assembly was placed in a Ziploc bag and stored in a cooler, with blue ice, for transport to the laboratory.

B.4 Sample Analysis

Analysis of hexavalent chromium

An ion chromatograph (IC) was used for the chromatographic separation of hexavalent and trivalent chromium, and an inductively coupled plasma mass spectrometer (ICP/MS) was used for the detection of the hexavalent and trivalent chromium in dust and air samples. Before sample analysis, dust sample weight was measured using a Mettler Toledo MT5 microbalance. No sample weight was taken for air samples because the cellulose filter was not suitable for weighing. Each wipe sample was removed from the freezer and placed in a temperature and humidity controlled weighing room for two to three hours before weighing. Based on the laboratory evaluation, an equilibrium time of 2-3 hours was sufficient for our dust sample to reach stable weight. Two calibration standards and a set of control filters (stored in the weighing room) were weighed before and after every 10 filter sets. All standards and filters were weighed twice and the mean weight was used to determine the sample mass. If the weight of the samples was not stable (% difference between two measures was greater than 5%), the sample was given additional drying time and re-weighed. For sweep samples, the total weight of the sweep samples

was first obtained and between 0.2 and 0.4 mg of the sweep sample was then weighed for analysis.

After weighing, samples were extracted using 5 mL of dilute nitric acid (pH = 4 HNO_3) and ultrasonication at 60°C for 40 minutes. After sonication, samples were first filtered for particles through a 45 µm syringe filter before analysis. One hundred µL of solution was injected into an ion chromatograph (IC) for the chromatographic separation of hexavalent and trivalent chromium, and an inductively coupled plasma mass spectrometer (ICPMS) was used for detection of the hexavalent and trivalent chromium. A CG5A guard column was used to separate the species. The elution scheme was 40% deionized water and 60% 1 M HNO_3 at a flow rate of 1.25 mL/min for 4 minutes. Before the sample was injected, a solvent blank (i.e. DI water blank) was injected. A calibration curve was constructed from six levels of Cr^{6+} and Cr^{3+} calibration standards (0.5, 1, 2, 5, 10, 25 ng/mL). The analytical detection limit (ADL) was calculated as 3 times of the standard deviation of seven replicate injections of the lowest level standard, which is 0.038 ng.

Total chromium

Eleven percent of samples were measured for total chromium, including one of the three side-by-side samples for all samples with Cr^{6+} concentration > 10 µg/g.

Total chromium was determined by microwave digestion followed by ICP/MS analysis. Sample filters were digested using 10 mL 100% HNO_3. The parameters of microwave digestion are listed below:

- 300 W power
- 300 psi pressure
- 200°C temperature
- 20 minute ramp time
- 10 minute hold time

Twelve samples were digested at once along with a solvent blank and a standard reference material (SRM, NIST 1648) certified values of total chromium. The certified particulate matter SRM (NIST 1648) was extracted concurrently with the samples to determine the recovery of total chromium. Recoveries of the SRM (mean±SD, n=4) were found to be 43±29%.

After digestion the samples were allowed to cool to room temperature before diluting. The extraction solution was then transferred to a 50 mL centrifuge tube and diluted to 50 mL with DI water. The diluted samples were then analyzed by ICPMS.

The ICP/MS was run in continuous mode. A water blank was analyzed first. After a calibration curve with 7 levels (0.1, 0.3, 0.5, 0.7, 1, 3 and 5 ng/mL) was generated, a 10 ng/mL standard (NIST AB, Calibrant A and B, 1811-001, 1811-005, High Purity Standards, Charleston, SC) was analyzed. If the NIST AB concentration was not within 20% for chromium, the instrument was tuned and a calibration curve was regenerated before sample analysis. Analyses only proceeded after the calibration achieved this target value for precision and accuracy. After each sample was

analyzed, a 2% nitric acid rinse solution was used to clean the probe. After analyzing ten to twelve samples, a solvent blank and the NIST AB were run again to check the instrumentation status. If the variation of response was greater than 20%, a new calibration curve was established.

Quantification

The concentration of Cr^{6+} in solution (ng/mL) was determined based on the peak area of the most natural abundant species $^{52}Cr^{6+}$and the calibration curve. The concentrations were then multiplied by the volume of extracting solution and divided by the dust mass in milligrams to get concentration in μg/g. The Cr^{6+} loading was determined by dividing the mass, in nanograms, by the sample area in m^2 to obtain a final concentration of ng/m^2.

QA/QC

All the solvents used for sample preparation and analysis were checked before use for field sample processing. Twenty-two field blanks (7.5% of the total dust samples) were collected throughout the study; this met the QA/QC goal of 5% field blank samples. One laboratory blank and one field blank were analyzed for the air samples. The laboratory and field blank samples were analyzed using the same procedures as those for field samples. No hexavalent chromium was detected in any of the field or lab blanks.

Fifty house dust samples (17% of the total dust samples), collected side-by-side, were analyzed to examine the method variability. The mean±SD and median % difference between the side-by-side samples is 36% ±33% and 25%, respectively, with a range of 0 to 117%. It is worth noting that the spatial distribution of chromium species in house dust samples may not be homogeneous, i.e. the side-by-side collected house dust samples are not equivalent to duplicate samples. The variability measured represents the method variation as well as the variability of chromium deposition on the same surface. The variability of chromium deposition was investigated by comparing samples within the home. In 55 homes, two or more samples were collected from different surfaces within the living area. An analysis of these paired samples within the living area found much greater variability than observed for the side-by-side samples. The mean±SD and median % difference between the living area samples is 72% ±58% and 51%, respectively, with a range of 1 to 195%.

B.5 Data Analysis

Statistical analyses were conducted to examine whether there were differences in Cr^{6+} concentrations and loadings measured in different locations within Jersey City. Since the concentration was not normal distributed, non-parametric analyses (Kruskal Wallis; Mann Whitney U) were performed using SPSS 16.0. For the location comparison, the sampled homes were grouped based on proximity to target waste sites. Six separate sampling locations were created. Five groups corresponded to the recruitment areas (Droyers Point - DP and Society Hill - SH, Garfield Avenue Area, Freedom Place Area, and Lafayette Area). The sixth group (Other) represented 25 homes outside the targeted recruitment areas but within Jersey City. Comparisons were made for both the mean and the maximum concentrations of Cr^{6+} (μg/g) and loadings

(ng/m^2). Only one sample was below the analytical detection limit (non-detect). The value was replaced with one half the MDL for statistical analysis. Statistical were also conducted to investigate the potential contribution of the sampled surface, housing characteristics and landscaping characteristics to the Cr^{6+} levels in the dust samples.

C. Results

C.1 Cr^{6+} Concentration in Dust Samples

Dust samples were collected from 100 homes between 11/15/06 and 4/18/08. A total of 289 dust samples were collected on the primary visit to each home. Although window well samples had not been collected in the first 10 homes, repeat visits were made to three of these homes and window well samples were collected and included in the data set for a total of 292 samples. Of these 292 samples, 71% were collected using the standard wipe method (LWW), 26% were collected using the free hand wipe method, and 3% were collected by sweep sample. Hexavalent chromium was detected in all homes; only one sample with a low dust mass (less than 1 mg) was below the limit of detection (0.09 µg/g). In most homes (94%) all samples were below the 20 µg/g site remediation soil criterion. Only six homes had a single sample (2% of all samples) that exceeded this guideline.

For the summary data, if more than one sample was collected from the same area within the home (e.g., in homes without a basement, two Living Area samples may have been collected), the mean of the samples was used for comparison. The mean (±SD) hexavalent chromium concentrations measured in all samples was 3.7 +/-7.5 µg/g, with a range of non-detect to 90.4 µg/g (Table 2). The mean ±SD hexavalent chromium loading measured in all samples was 6,408±17,276 ng/m^2, with a range of non-detect to 196,432 ng/m^2.

Total chromium concentration was measured in 11% of all samples (31 samples) and the summary statistical data are present in Table 4. These values were not corrected for the recovery determined by the SRM so they represent the nitric acid extractable total chromium rather than the total recoverable chromium. One sample was found very high for total Cr, with a concentration value of 4054 µg/g. This sample was considered as an outlier (> 3 times of the standard deviation of the concentrations measured for the 31 samples) and was not included in the summary statistical analysis results. The average concentration of total chromium for the rest of samples was 285±403 µg/g, with a median value of 128 µg/g (Table 4). The mean ratio of hexavalent chromium to total chromium was 12% with a range of 0.3 to 51%. It is worth noting that this ratio may overestimate the underlying ratio for all the samples collected because only the samples with Cr^{6+} concentrations larger than 10 µg/g, i.e. the top ~10^{th} percentile of the samples collected, were preferentially selected for the analysis of total chromium.

Repeat samples were collected in Homes 6, 49, 52, 69, 80, and 82 due to elevated concentrations (>20 µg/g) of hexavalent chromium measured in the initial sample (Table 5). Only one surface in each home had an elevated level of chromium. During the repeat visit, an attempt was made to collect samples from the surface that yielded the elevated level and two to four additional surfaces in the home. However, in Home 80, the elevated surface (scrap wood in the basement) had been discarded by the participant; an alternate surface was selected. Only the elevated

surfaces in Homes 6 and 52 still exceeded the 20 μg/g site remediation soil criterion; samples collected from the previously elevated surfaces in the other four homes were found to be lower than 20 μg/g the site remediation soil criterion during the repeat visit. Additionally, no other surface in any of these six homes was found to be elevated on either the initial or repeat visits (Table 6). These results suggest that the contamination seemed limited to a single surface. All these surfaces were wood. Chromium was reported to be commonly used in wood stains between 1910 and 1970 (http://cat.inist.fr/?aModele=afficheN&cpsidt=4092777). However, the presence or absence of stain was not routinely recorded during sample collection.

Participants were sent the analytical results from the samples collected in their homes, including those collected during a repeat visit. Each sample was identified by date collected, room and surface sampled. The reported hexavalent chromium concentration was compared to the 20 μg/g site remediation soil criterion. An interpretation of the results was included in each report. For Homes 6 and 52, besides the letter, participants were instructed to use damp cleaning methods to clean the furniture but reassured that the results did not show a pattern of chromium contamination within the home.

C.2 Statistical Analysis: Location Comparison

Three factors were analyzed to determine their impact on chromium levels: sample method, area within the home, and material sampled. The raw data set was used to examine the impact of each factor on chromium concentration (Cr^{6+} μg/g) and loading (Cr^{6+} ng/m^2).

Three different methods were used to collect dust samples: LWW Wipe, Free Hand Wipe and Sweep. The three sampling methods recovered significantly different dust loadings and chromium concentrations (Kruskal Wallis; $p<0.001$ for both metrics); the difference in chromium loading was not significant (Table 7). The median chromium concentration recovered by the LWW (3.3 μg/g) was over tenfold the median recovered by either the free hand wipe (0.3 μg/g) or the sweep (0.1 μg/g).

Most of the surfaces sampled were wood (43%), vinyl (30%), and laminate (15%). The remaining surfaces (12%) included a variety of materials, i.e. concrete, plaster, brick, and ceramic tile. Significant differences were found in both chromium concentration (Kruskal Wallis; $p<0.001$) and chromium loading (Kruskal Wallis; $p=0.021$) by surface material (Table 8). Wood and laminate surfaces had the highest median chromium concentrations (4.1 μg/g and 3.5 μg/g, respectively). Only 13 of the 126 samples collected from wood surfaces were collected from floors but no significant differences were found in chromium levels (concentration and loading) between wood floors (median levels of 2.7 μg/g and 764 ng/m^2) and other wood surfaces (median levels of 4.4 μg/g and 2901 ng/m^2). No significant differences were found between painted (median levels of 1.9 μg/g and 1952 ng/m^2) and unpainted (median levels of 2.2 μg/g and 1982 ng/m^2) surfaces in chromium concentration or loading. If only wood surfaces were compared, the chromium concentration of unpainted surfaces (median of 4.5 μg/g) was marginally greater than those of painted surfaces (median of 3.0 μg/g; Mann-Whitney; $p=0.090$).

Within each home, three different areas were sampled: Living Areas (LA), Basements (BA), and Window Wells (WW). Not all areas were sampled in each home (many homes did not have

basements and window wells were sometimes inaccessible). Significant differences were found in both chromium concentration and chromium loading among the three areas (Table 9). Window wells had the lowest chromium concentrations and basements had the highest chromium loadings.

The sample method and surface material varied by area of the home. Window well samples were collected from predominantly vinyl surfaces (87%) and by the free hand wipe (64%). Basement samples were collected from predominantly wood (44%) and "other" surfaces (42%) by the LWW method (67%). Living area samples were also predominantly collected from wood surfaces (63%), followed by laminate surfaces (25%) using the LWW method (95%). To control the effects of sample collection method, material, and area within the home, the comparison between locations within Jersey City was restricted to samples collected by the most used method (LWW) and the most frequently sampled surface (wood). The area within the home was restricted to living area; in contrast to basement and window wells since samples were collected from living areas in every home. Since chromium concentration and loading on laminate surfaces were not significantly different from those measured on wood surfaces (see Table 8 for median values; Mann-Whitney U; n.s.), laminate surfaces were also included. If two or more samples meeting these criteria (in the living area, using the LWW wipe, from wood or laminate surfaces) were collected within one home, the mean of the samples was used. Based on this approach, chromium concentrations and loadings were significantly different among the six locations in Jersey City (Tables 10 and 11, respectively). Droyers Point has the lowest median values of all six areas; The Other location had the highest median concentration and the Freedom Place area had the highest median loading. An additional comparison was made for window well samples collected by the free hand wipe method from vinyl surfaces. Only two locations had at least 10 samples fitting these criteria (Droyers Point: n=23; Other: n=10). Both chromium concentration (median 0.1 μg/g v. 0.5 μg/g) and loading (median 563.1 ng/m^2 v. 3621.2 ng/m^2) were significantly lower in Droyers Point (Mann-Whitney; $p=0.003$, $p<0.001$, respectively).

The maximum values from each home were also used to compare locations. Significant differences in both concentration (Table 12) and loading (Table 13) were observed among the six locations. Again, Droyers Point had the lowest median concentrations and loadings of all six developments and the Freedom Place area had the highest median values.

C.3 Effect of Housing Characteristics on Cr^{6+} Concentration

Data on housing characteristics were collected by questionnaires, and only one participant failed to complete the questionnaire. Preliminary tests were conducted to examine the effect of the selected housing characteristics (Table 14) on both hexavalent chromium concentration and loading (mean and maximum values). Those housing characteristics selected for analysis included age of home, type of material around the outside of the house, presence of a basement, and presence of a garden. These characteristics were selected for analysis because they had some reasonable likelihood of being related to Cr^{6+} dust concentration and had sufficient variability to make an analysis meaningful. These analyses were stratified by area and nonparametric tests (Mann-Whitney) were used for the tests, and.

Associations between housing characteristics and chromium levels were observed in two locations, Lafayette and Other. In the Lafayette area, the outer surfaces around the home had an impact on chromium levels in the home. Mean and maximum concentrations were significantly higher in homes without grass in the yard ($p=0.045$ and $p=0.02$, respectively). Grass in the yard had the same effect for maximum loading (higher maximum loadings in homes without grass; $p=0.04$) but an opposite effect for mean loadings (higher mean loadings in homes with grass; $p=0.04$). Having a dirt area in the yard also had an effect on chromium loadings in the Lafayette area. Homes with a dirt area had higher mean and maximum loadings than homes with no dirt area ($p=0.04$ for both). Homes that did not have a basement in the Lafayette area had higher mean and maximum loadings than those with a basement ($p=0.04$ for both). In the Other area, homes with a garden had higher mean and maximum concentrations of hexavalent chromium ($p=0.02$ and $p=0.04$, respectively). Homes with a garden also had higher mean loadings ($p=0.04$) but the difference was not significant for maximum loadings. In the Other location, homes having grass in the yard had higher mean and maximum loadings ($p=0.01$ for both). Using linear regression, the age of the home had no significant relationship with chromium concentrations within the home. These findings may point toward the presence of hexavalent chromium in specific soil types and/or soil additives used in turf, top soil and gardening.

C.4 Air Samples

The two filters collected by the stationary monitors were combined for analysis. The resulting air concentration was 2.14 ng/m^3 on the Garfield Avenue waste site. No hexavalent chromium was detected in the single sample collected using PIPER. The lack of detection of hexavalent chromium may result from the low sampling air volume and mass.

C.5 Summary and Recommendations

The results showed low but detectable levels of hexavalent chromium throughout the areas targeted for sampling in Jersey City. Only 2% of the samples collected exceeded the 20 μg/g site remediation soil criterion. Although 6 homes had one sample above the site remediation soil criterion, repeat sampling did not find evidence of a generalized contamination throughout any of those homes. Several factors (sampling method, surface material, area within the home) were found to impact both chromium concentration and loading. When these factors were controlled, hexavalent chromium levels within homes in Jersey City were found to vary by the home's location. Based on the results obtained from samples collected from window wells and living areas, levels (both concentration and loading) of hexavalent chromium in Droyers Point were consistently lower than elsewhere in Jersey City. Comparisons of maximum values (with no control for sample method, surface material, or area within the home) also found lowest levels in Droyers Point. The analyses of housing characteristics show some significant associations between exterior ground covering (gardens, grass, and dirt) and levels of chromium in the home. Positive associations were restricted to just two locations, Lafayette and Other. In some locations (Droyers Point and Society Hill), the uniformity of ground covering precluded analysis of these variables. This suggests that soil levels in the areas immediately around the home may influence chromium levels in the home and that some soils, and/or soil additives may contain hexavalent chromium. From these data, it cannot be determined whether the influence of soils around

homes on levels of hexavalent chromium in house dust reflects chromium waste material in these soils.

The significance of the levels of hexavalent chromium found throughout Jersey City is difficult to determine. The concentration of hexavalent chromium found in nearly all of the samples in this study was below the current NJDEP site remediation soil criterion of 20 μg/g. No data exist on levels of hexavalent chromium in household dust in uncontaminated areas. Hexavalent chromium is generally considered to be anthropogenic. Although small amounts of hexavalent chromium are known to be present in cement, pigments and dyes and in CCA-treated wood, it was not *a priori* anticipated that hexavalent chromium would be detected in house dust at the levels found in this study. These findings may reflect a ubiquitous background of hexavalent chromium in urban areas or perhaps even beyond to suburban or rural areas. Alternatively, these findings may represent residual chromium waste that is specific to the historic waste sites in Jersey City. A preliminary investigation of hexavalent chromium levels found in other urban areas of New Jersey is currently being conducted. The results of that investigation will be compared to those found in Jersey City. This comparison will allow investigators to determine if the hexavalent chromium levels observed in Jersey City are greater than that observed in other communities without a history of chromium waste sites.

The levels of hexavalent chromium may represent a potential for exposure. Further study, outlined in the original proposal, is needed to investigate the impact of the hexavalent chromium contamination on personal exposure. Previous studies (Stern et al., 1998) found that high levels of total chromium in household dust were associated with higher levels of chromium in urine for young children. A biomonitoring (Phase II) study has been initiated to measure the relationship between hexavalent chromium concentration in house dust samples and total chromium level in children's urine samples. Data collected will be used to determine if levels of hexavalent chromium in household dust are associated with higher exposure. The results of this Phase I study will be incorporated in the design of the Phase II study. Since window well samples were significantly lower than basement and living area samples, no window well samples will be collected. Sample collection will focus on the child's play area, the main entry within the home, and, if available, the basement. In homes without a basement, another location within the living area of the home will be selected. Since concentrations in samples from Droyers Point were frequently lower than other areas of Jersey City, recruitment for the Phase II study will focus on the other areas of Jersey City, including the Freedom Place, Garfield Avenue and Lafayette Areas outlined in this study.

D. References

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Table 1. Public Meetings for Recruitment

Date	Group	Location
9/12/06	Public Meeting (with NJDEP)	City Hall
9/26/06	NAACP	Calvary CME Church
12/1/07	Residents of Wards E and F	Monumental Baptist Church
1/25/08	Randolph Avenue Block Association	Mount Olive Baptist Church
2/7/08	Morris Canal Redevelopment Area Community Development	St. John's AME Church
2/10/08	Congregation of Mount Olive Baptist Church	Mount Olive Baptist Church

Table 2. Cr^{6+} Concentration (µg/g) by Location

Location	N*	Mean	Std Dev	CV	Median	5th Ptcl	95th Pctl	Min	Max
DP	58	1.9	3.4	177.4	0.6	0.03	8.5	0.02	19.3
Freedom	19	6.2	8.6	137.1	2.8	0.36	36.7	0.36	36.7
Garfield	40	3.1	4.5	146.8	1.5	0.04	14.9	0.03	19.7
Lafayette	31	2.9	3.1	104.7	2.0	0.14	9.7	0.14	11.5
SH	16	2.9	2.5	86.0	2.7	0.06	8.1	0.06	8.1
Other	61	5.6	12.1	215.8	2.9	0.11	11.5	0.05	90.4
All samples	225	3.7	7.5	202.5	1.8	0.05	11.5	0.02	90.4

*No duplicate or blank samples. Same for all tables below.

Table 3. Cr^{6+} Loading (ng/m^2) by Location

Location	N	Mean	Std Dev	CV	Median	5th Ptcl	95th Pctl	Min	Max
DP	58	1620	2876	177	812	212	5148	40	20747
Freedom	19	8831	6867	78	8724	1118	25676	1118	25676
Garfield	40	6554	16460	251	3027	203	15734	143	104664
Lafayette	31	7846	17108	218	2713	477	37813	413	91291
SH	16	4690	7016	150	1975	194	28216	194	28216
Other	61	9829	26828	273	4002	679	23524	328	196432
All samples	225	6408	17276	270	2279	261	18289	40	196432

Table 4. Total Cr Concentration and % Cr^{6+} in Total Cr*

Analyte	Mean	STD	CV	Median	0.05	0.95	Min	Max
Total Cr (n=30)	285	403	141%	128	75	1076	66	1952
$\%Cr^{6+}$ of the total Cr	12%	11%	94%	9%	1%	33%	0.3%	51%

*The recovery determined by the SRM is 43±29% (n=4). No correction for the recovery. One sample with 4054 μg/g was not included in the analysis.

Table 5. Repeat Sampling – Same Surface

HID	Location	Initial Date	Initial Cr^{6+} (μg/g)	Repeat Date	Repeat Cr^{6+} (μg/g)
HCC006	Other	12/9/06	90.4	3/10/07	64.7
HCC049	Freedom	8/18/07	32.1	10/20/07	10.6
HCC052	Freedom	9/13/07	36.7	10/20/07	30.3
HCC069	Other	1/26/07	24.6	3/8/08	15.3
HCC082	Lafayette	2/21/08	21.6	4/18/08	15.3

Table 6. Repeat Sampling – All Samples

HID	Location	Initial Date	Area within Home	Initial Cr^{6+} (µg/g)	Repeat Date	Area within Home	Repeat Cr^{6+} (µg/g)
HCC006	Other	12/09/06	LA	2.5	03/10/07	BA	64.7
			LA	3.2		BA	5.6
			BA	90.4		BA	2.4
						BA	2.0
HCC049	Freedom	08/18/07	LA	6.3	10/20/07	LA	10.6
			LA	32.1		LA	3.9
			LA	4.8		LA	4.5
HCC052	Freedom	09/13/07	LA	2.3	10/20/07	BA	30.3
			LA	1.6		BA	10.6
			BA	36.7		BA	4.9
						BA	4.0
						BA	6.4
HCC069	Other	01/26/08	LA	24.6	03/08/08	LA	15.3
			LA	0.3		LA	2.0
			LA	6.9		LA	4.6
HCC080	Other	02/18/08	LA	5.9	04/18/08	BA	7.9
			LA	0.6		BA	4.5
			BA	27.3		BA	0.3
HCC082	Lafayette	02/21/08	LA	1.4	04/18/08	LA	15.3
			LA	21.6		LA	3.8
			BA	4.1		LA	3.5

Table 7. Median Levels by Method

	LWW Wipe	Free Hand Wipe	Sweep	Kruskal Wallis (p-value)
N	208	76	8	
Cr^{6+} µg/g	3.34.8	0.31.6	0.11.0	<0.001
Cr^{6+} ng/m^2	2067.74745.2	1733.27570.6	4811.716659.6	0.104
Dust mg/m^2	698.31995.5	5156.78583.7	34712.636378.3	<0.001

Table 8. Median Levels by Surface Material

	Wood	Vinyl	Laminate	Other	Kruskal Wallis (p-value)
N	126	87	43	36	
Cr^{6+} µg/g	4.16.5	0.28	3.54.2	1.22.1	<0.001
Cr^{6+} ng/m^2	2400.58311.7	1412.43973.8	2425.93894.1	1586.73755.5	0.021

Table 9. Median Levels by Area within the Home

	Living Area	Basement	Window Well	Kruskal Wallis (p-value)
N	166	36	90	
Cr^{6+} µg/g	3.94.9	2.17.3	0.27	<0.001
Cr^{6+} ng/m^2	1981.84104.8	3554.016593.9	1545.24631.7	0.002

Table 10. Comparison of Cr^{6+} Concentration (µg/g) by Location: LWW Wipe Samples from Wood and Laminate Surfaces in Living Areas*

Location	N	Mean	Std Dev	CV	Median	5th Ptcl	95th Pctl	Min	Max
DP	29	3.7	4.1	112.5	2.3	0.39	16.2	0.23	19.3
Freedom	7	7.7	6.6	85.6	4.8	1.22	19.2	1.22	19.2
Garfield	16	5.1	4.5	89.1	3.6	0.33	15.4	0.33	15.4
Lafayette	11	5.1	2.4	47.5	5.1	1.41	9.7	1.41	9.7
SH	10	3.9	2.1	54.0	4.0	0.58	7.20	0.58	7.20
Other	25	6.6	4.7	71.5	5.2	2.02	20.7	1.97	24.6
All samples	98	5.1	4.4	85.1	4.0	0.60	14.5	0.23	24.6

* Kruskal Wallis p=0.011

Table 11. Comparison of Cr^{6+} Loading (ng/m^2) by Location: LWW Wipe Samples from Wood and Laminate Surfaces in Living Areas*

Location	N	Mean	Std Dev	CV	Median	5th Ptcl	95th Pctl	Min	Max
DP	29	1594	1879	118	907	179	7591	100	9055
Freedom	7	9137	6444	71	10836	1559	20136	1559	20136
Garfield	16	4128	3772	91	3440	225	12342	225	12342
Lafayette	11	9711	20046	206	2894	522	69360	522	69360
SH	10	2928	2502	85	1975	363	7798	362	7798
Other	25	5815	4132	71	5157	652	16401	402	18288
All samples	98	4671	7738	166	2404	319	12345	100	69360

*Kruskal Wallis p<0.001

Table 12. Maximum Cr^{6+} Concentration (µg/g) by Location*

Location	N	Mean	Std Dev	CV	Median	5^{th} Ptcl	95^{th} Pctl	Min	Max
DP	29	4.2	4.1	98.9	2.9	0.6	13.1	0.4	19.3
Freedom	8	14.4	12.9	89.9	11.3	2.8	36.7	2.8	36.7
Garfield	16	6.3	5.3	84.5	4.1	0.3	19.7	0.3	19.7
Lafayette	12	6.9	5.2	75.7	5.7	2.5	21.6	2.5	21.6
SH	10	5.2	2.7	52.2	4.9	0.8	9.8	0.8	9.8
Other	25	12.3	17.4	141.2	7.1	2.5	27.3	2.1	90.4

* Kruskal Wallis p=0.001

Table 13. Maximum Cr^{6+} Loading (ng/m^2) By Location*

Location	N	Mean	Std Dev	CV	Median	5th Ptcl	95th Pctl	Min	Max
DP	29	2866	3932	137	1896	310	9055	278	20747
Freedom	8	13515	8207	61	12219	2137	25676	2137	25676
Garfield	16	13253	24862	188	6647	438	104664	438	104664
Lafayette	12	19036	29559	155	5244	1061	91291	1061	91291
SH	10	8326	8560	103	6819	550	28216	550	28216
Other	25	19773	40240	204	7651	2279	83388	1823	196432

*Kruskal Wallis p<0.001

Table 14. Housing Characteristics by Location

Location	Droyers Point (DP)	Society Hill (SH)	Garfield	Freedom	Lafayette	Other	All Homes
N	29	10	17	8	11	25	100
House Type							
Single Family/Duplex	0	0	16	5	3	12	36
Townhouse/ Row House	29	10	0	3	8	7	57
Mult-unit	0	0	1	0	0	6	7
Reported Age* (Years)							
Age (Min)	1	14	10	40	14	1	1
Age (25th percent)	1	15	50	40	100	29	2
Median Age	2	17	77	44	110	60	25
Age (75th percent)	2	18	100	94	125	100	98
Age (Max)	3	20	130	100	200	150	200
Yard Material							
Grass	27	10	10	7	6	16	76
Dirt	3	0	5	3	7	8	26
Mulch	16	4	3	0	1	2	26
Have A Garden	4	2	9	6	6	10	37
Have A Basement	0	0	15	6	7	16	44
Home with inside smoker	2	1	2	3	1	1	10
Any Renovation	11	3	10	3	2	15	44
Add a room	0	0	1	0	0	0	1
Put up/ Take down wall	1	0	3	0	0	3	7
Replace Window	0	0	3	0	1	0	4
Refinish floor	6	0	2	1	0	2	11
Ext. paint	0	0	0	2	0	3	5
Int. Paint	10	3	8	1	1	12	35
Children							
Home with child <18	7	1	5	1	4	7	25
Home with child ≤6	6	1	2	0	3	5	17
Heating System							
Hot water	0	0	15	5	8	15	43
Forced air	29	10	2	3	2	9	54
Electric	0	0	0	0	1	1	2
Air conditioning	29	10	17	8	10	24	98
Central	29	10	1	3	2	4	49
Window	0	0	16	5	8	20	49
Open Windows During Year	20	5	12	8	9	19	73

* The number of homes with a reported age were: Droyer's Point – 28; Society Hill - 10; Garfield – 15; Freedom – 6; Lafayette – 9; Other – 20.

Figure 1. Sample Areas with Current Chromium Waste Sites. The boxes show the areas of participants recruited for this study.

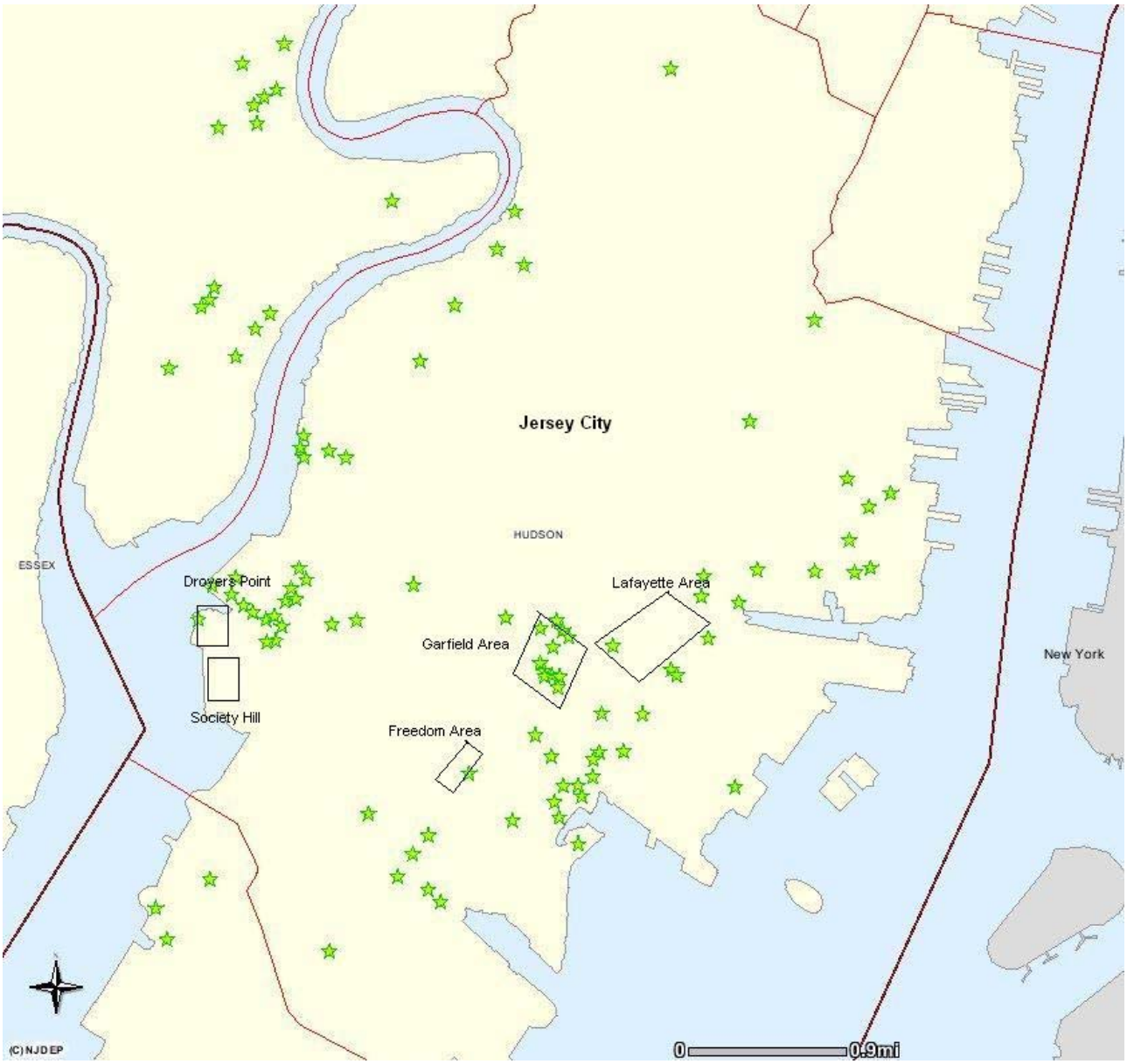

Figure 2. Boxplot of Cr^{6+} Concentration (µg/g) by Location – All Samples Included

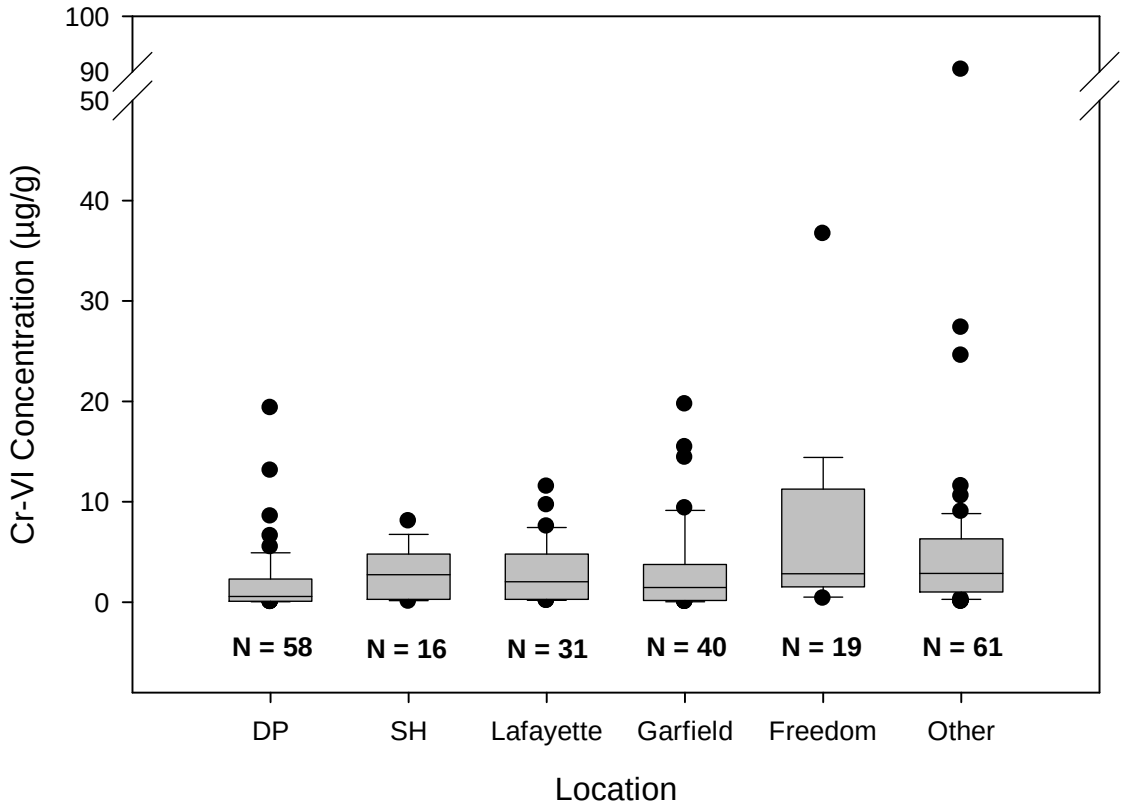

Figure 3. Boxplot of Cr^{6+} Concentration (μg/g) in Basement Samples by Location

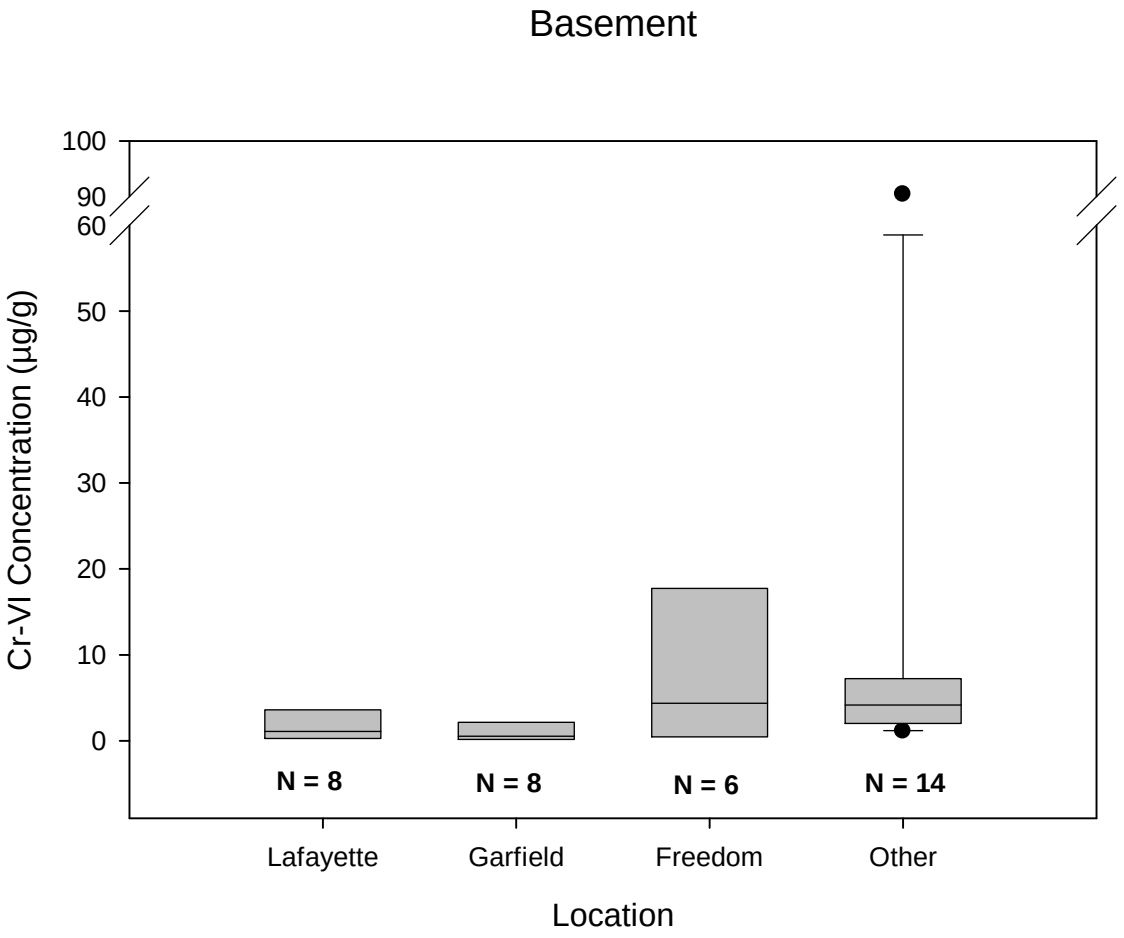

Figure 4. Boxplot of Cr^{6+} Concentration (µg/g) in Living-Area Samples by Location

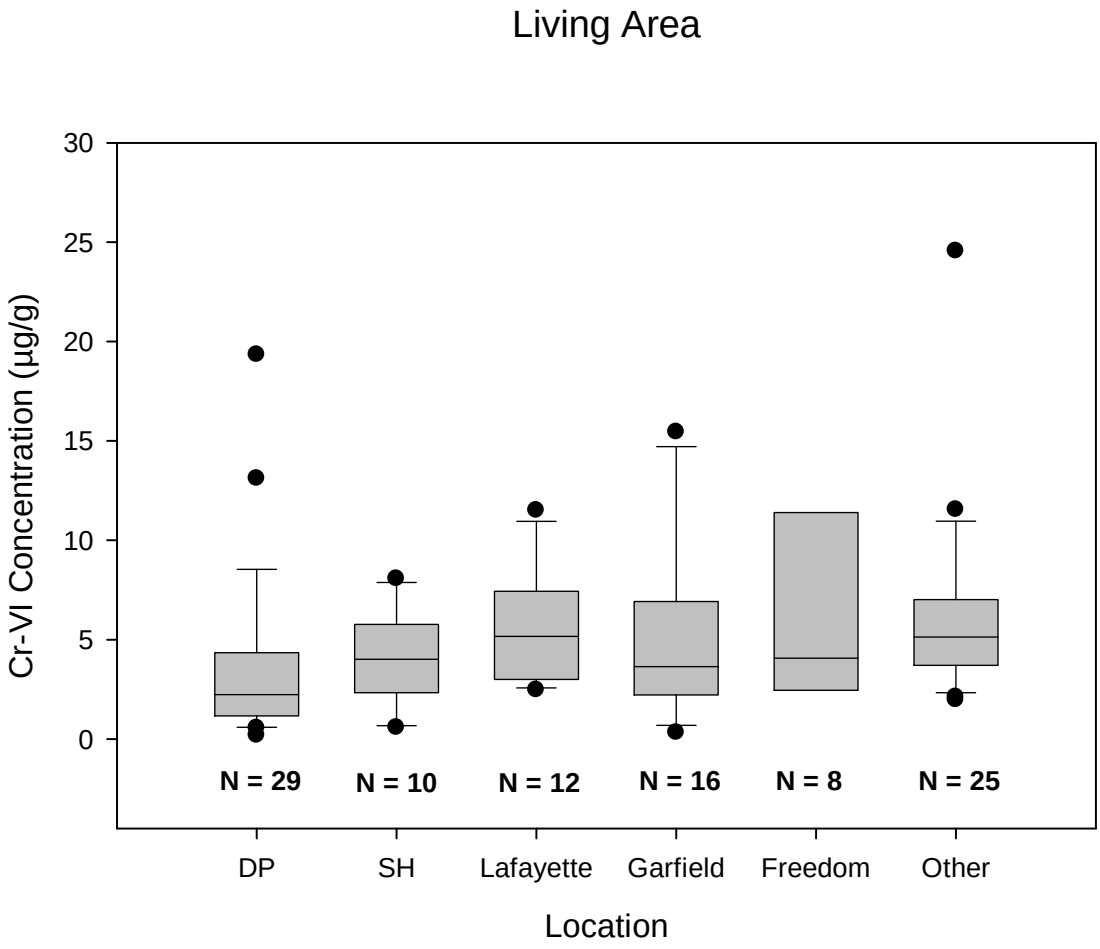

Figure 5. Boxplot of Cr^{6+} Concentration (µg/g) in Window Well Samples by Location

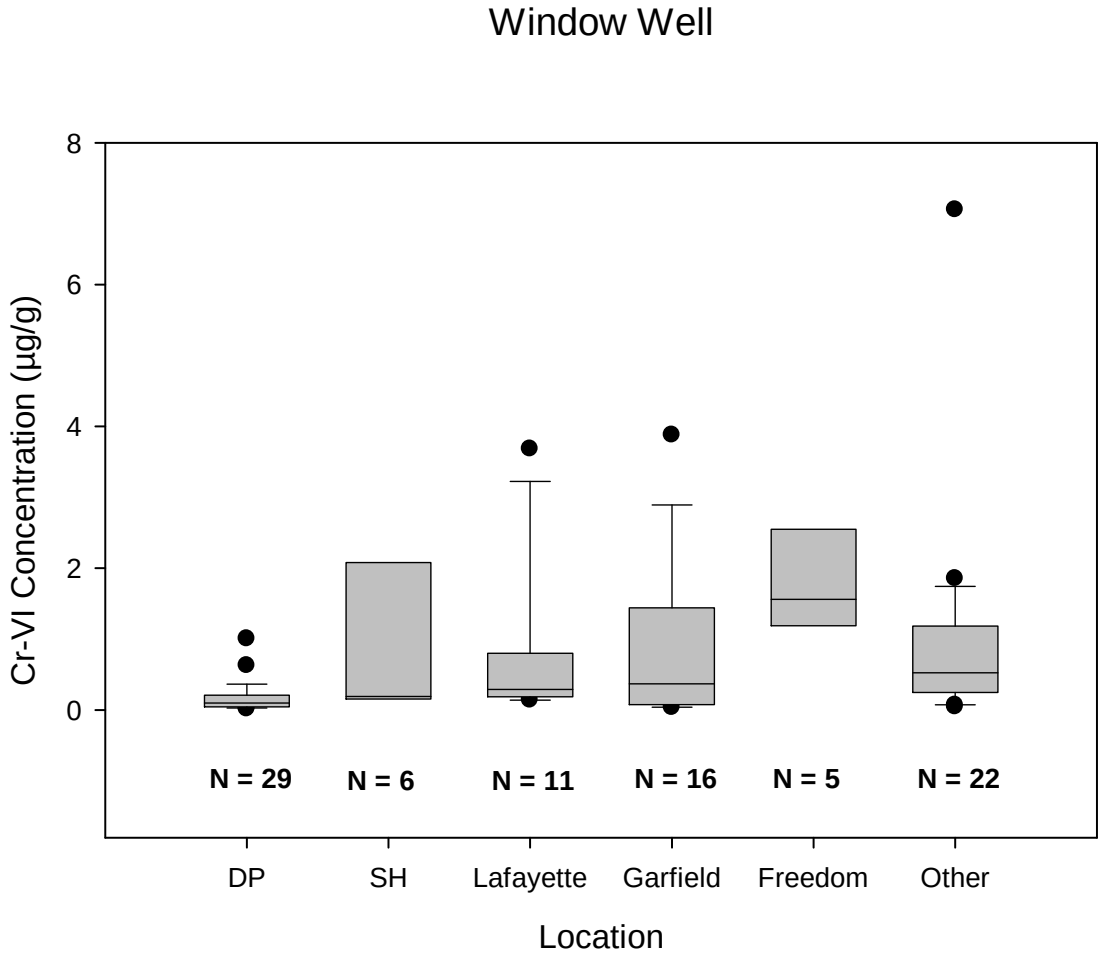

Figure 6. Boxplot of Maximum Cr^{6+} Concentration (µg/g) in Each Household by Location

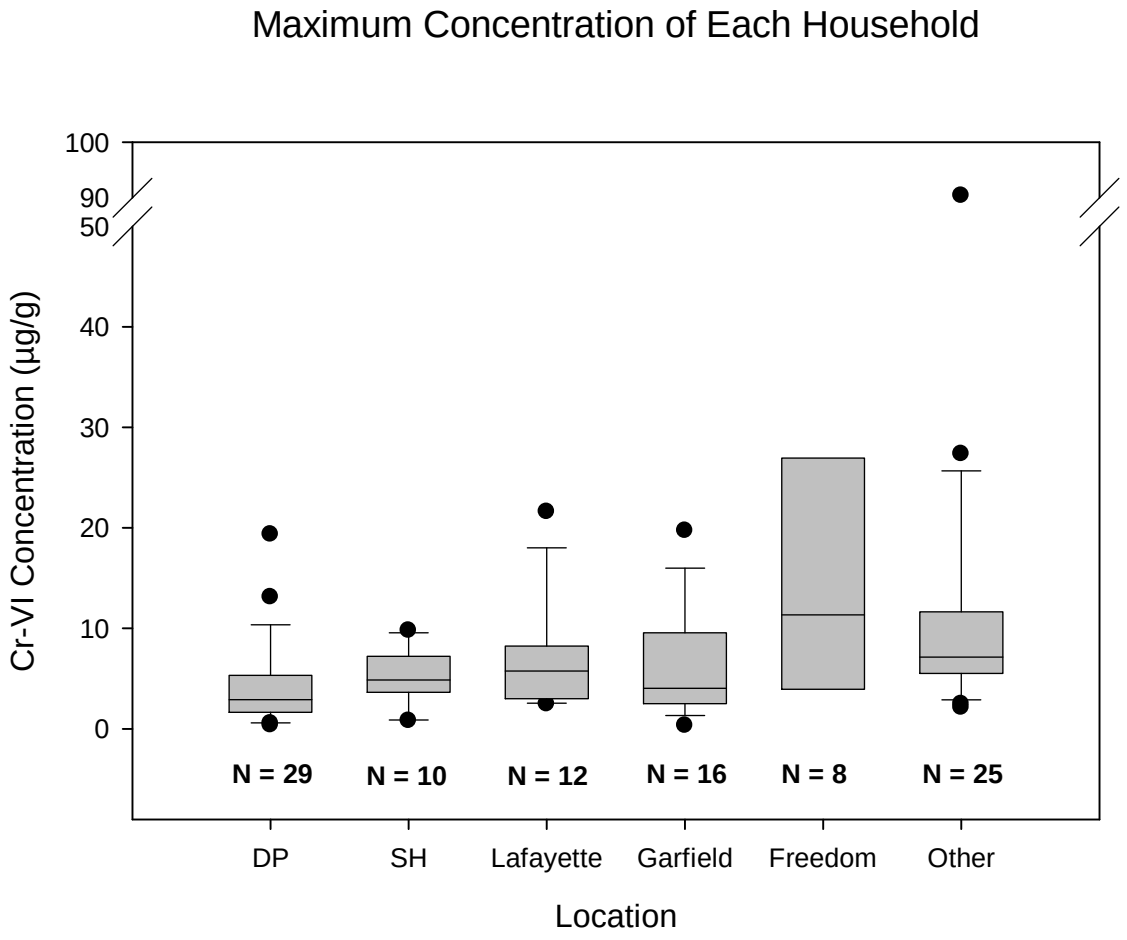

Figure 7. Boxplot of Cr^{6+} Loading (ng/m^2) by Location – All Samples Included