Understanding Dioxin-Like Compounds in Indoor Dust

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Final Technical Report

Protect Gainesville's Citizens, Inc.

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ABSTRACT

In 2011, the United States Environmental Protection Agency (EPA) Environmental Justice Small Grants (EJSG) Program supported Protect Gainesville's Citizens (PGC) project to study exposures to dioxins and dioxin-like compounds that are present in all house dust samples. Two specific sources of these compounds – a former wood treating Superfund site and flame retardant materials present in foam furniture or electronics – are specifically investigated in this research project to better understand variability and patterns of these compounds so that decisions may consider the potential cumulative exposures and risk reduction options.

Dust from thirty homes were sampled by EPA in 2012 and analyzed for chlorinated and brominated dioxin and furan compounds. Seventeen of these homes were adjacent to a former wood treating site where chlorinated dioxin/furans in soils were to be remediated under Superfund. PGC resampled dust from five homes near the site in 2014 after the soil remediation was completed. These were analyzed for chlorinated dioxins/furans, with dust from two homes also tested for the brominated congeners.

Prior to remediation, the average chlorinated dioxin/furan soil concentration near the superfund site was ~15 parts per trillion (ppt)[1]. Bioassay results had been reported suggesting dust concentrations were in the hundreds, in some cases over 1000 ppt – inferring these levels were Superfund contamination. A review of the literature suggested that these high levels are likely from various in-home sources, including flame retardants.

The chlorinated dioxin/furan data in dust samples showed an average background concentration of 25 ppt, with dust from homes near the Superfund site approximately 14 ppt higher. Congener patterns in dust from homes near the site were consistent with contributions from soil. No dust sample had a concentration above 100 ppt, and three homes with dust concentrations above 60 ppt had patterns suggesting contribution from an in-home source. After soil replacement was completed, dust concentrations were comparable to average background levels for four of the homes. The fifth home had a pattern suggesting an in-home source. Dust concentrations at this location increased from 60 to 75 ppt. The use of a wood burning stove was identified as a likely contributor to these elevated concentrations.

Brominated dioxins and furans are contaminants in, and formed from, brominated flame retardant chemicals. Concentrations in dust samples from the 30 homes analyzed in 2012 showed variable levels and patterns. These are among the compounds that contributed to the historically high bioassay results, and are not Superfund related. The use of these flame retardants have been phased out, and dust samples collected in 2014 showed significantly reduced concentrations of the brominated dioxin/furan compounds.

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[1] Concentrations as measured by 2,3,7,8-tetrchlorodibenzo-p-dioxin toxic equivalents or TCDD-TEQ.

[2] http://en.wikipedia.org/wiki/Aryl_hydrocarbon_receptor

ACKNOWLEDGEMENTS

As the principal investigator, Dr. Cline was the technical lead on behalf of Protect Gainesville's Citizens (PGC) and the author of this research report. Kim Popejoy and Kate Ellison, PGC board members, were key in the development of the proposal and support needed for completion of this project. However, this project could not have been completed without the support of EPA and other collaborators.

Our deepest thanks go to Scott Miller, US EPA Regional Project Manager for the Koppers Superfund Site. He incorporated PGC recommendations for expanding the scope of the 2012 dust investigation to support a more in depth understanding of bioassays, potential contributions from flame retardant materials, and sample collection protocols. He encouraged our participation in sample collection and data validation, including working with Phil Campagna, EPA Environmental Response Team manager and the Lockheed Martin/Scientific, Engineering, Response and Analytical Services staff who were generous in sharing their expertise. Mr. Miller also supported participation by Josh Hayes, JM Waller & Associates, who was instrumental in working with PGC collection of dust samples in 2014.

John Mousa, Alachua County Environmental Protection Department (ACEPD), has been integral in the initial dust study, working with EPA and PGC to identify and get participation in the 2012 dust investigation. His ongoing support, report review and input was important in the delivery of this report.

Randy Merchant, Florida Department of Health (FDOH) lead the preparation of the 2012 dust study work plan and subsequent health consultation reports that provided technical information and references integrated into our report. He has remained available for discussion and communication of the findings of our work, and his insights and expertise were important in the development of our evaluation.

We would also like to thank researchers who have taken the time to discuss their research findings with us, answer questions and provide suggestions. We would like to particularly thank Michael S. Denison, Ph.D. University of California Davis for extended discussions on the CALUX bioassay and additional insights/updates on his currently ongoing research on dioxin-like compounds.

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Finally, we would like to recognize the support of Daphne Wilson/EPA as the EJSG project manager for her flexibility and ongoing support that helped us to complete this challenging project.

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Acronyms

ACEPD	Alachua County Environmental Protection Department
AhR	Aryl Hydrocarbon Receptor
ATSDR	Agency for Toxic Substances and Disease Registry
BEQ	Biological Equivalent
CALUX	Chemical-Activated Luciferase Expression
DLCs	Dioxin-Like Compounds
DR-CALUX	Dioxin Responsive CALUX
EJSG	Environmental Justice Small Grant
EPA	Environmental Protection Agency
ERT	Environmental Response Team
FDEP	Florida Department of Environmental Protection
FDOH	Florida Department of Health
HRGC/HRMS	High Resolution Gas Chromatography/High Resolution Mass Spectrometry
PBDD/F	Polybrominated dibenzo-p-dioxins/furans
PBDE	Polybrominated diphenyl ethers
PCDD/F	Polychlorinated dibenzo-p-dioxins/furans
PCP	Pentachlorophenol
PGC	Protect Gainesville's Citizens
pg/m^2	Picogram per square meter
ppt	Parts per trillion
QAPP	Quality Assurance Project Plan
QC	Quality Control
REP	Relative Potency
RL	Reporting Limit
SCTL	Soil Cleanup Target Level
SERAS	Scientific, Engineering, Response and Analytical Services
SOP	Standard Operating Procedure
TAG	Technical Assistance Grant
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
TEF	toxicity equivalence factor
TEQ	toxicity equivalence
TSCA	Toxic Substances Control Act
WHO	World Health Organization
XDS	Xenobiotic Detection Systems

1 INTRODUCTION

Many of us are exposed to a variety of chemicals present in the house dust in our homes, including dioxins or dioxin-like compounds (DLCs). These include compounds associated with brominated flame-retardants found in furniture, carpeting, and electronics within most residential homes; these compounds are currently being reviewed by the United States Environmental Protection Agency (EPA) under the Toxic Substances Control Act (TSCA) with the goals to better understand and reduce risks associated with exposures to these compounds. This issue becomes more complex when residents adjacent to a site being addressed under the Comprehensive Environmental Response and Liability Action, also known as "Superfund," have an additional involuntary exposure to dioxins in their homes resulting from contaminated soils.

Understanding of the community's exposure to multiple environmental risks associated with the potential ongoing contributions of exposures to Superfund and non-Superfund related DLCs in residents' homes is a critical objective of this research project. In 2011, Protect Gainesville's Citizens (PGC) was awarded funding for a two-year research project funded by the Environmental Justice Small Grants (EJSG) Program to focus on community questions regarding exposure to DLCs in house dust, specifically:

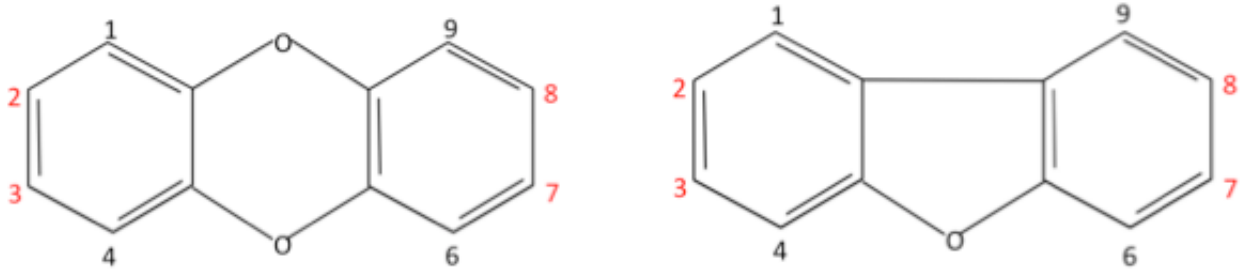
- Superfund Site related polychlorinated dibenzo-p-dioxins/furans (PCDD/Fs)
- Polybrominated dibenzo-p-dioxins/furans (PBDD/Fs) associated with flame retardants currently under evaluation under TSCA.

1.1 OVERVIEW OF DIOXINS/FURANS

Dioxins and furans are two classes of chemicals. They are structurally similar in that they both contain two carbon ring structures (Figure 1-1) with eight possible positions where substitution by a halogen (e.g. chlorine or bromine) can occur. There are 210 unique ways halogens could be placed on these rings. For this report, we are focused on dioxins or furans that contain either all chlorines or all bromines, chlorines used in illustrating homologue and congener configurations.

Homologues. Dioxin/furan homologues refer to compounds with the same number of chlorine (or bromine) atoms, regardless of position. For example, there are 22 possible tetrachlorodibenzo-p-dioxin (TCDD) congeners within the TCDD homologue class (Table 1-1). However, only one of these, 2,3,7,8-TCDD is considered toxic.

Congeners. Each of the 210 compounds are called a "congener" (75 dioxin and 135 furan congeners). These differ from each other in the number and position of chlorine (or bromine) atoms on the carbon rings. Seventeen of these configurations, with chlorine in the 2,3,7, and 8 positions are considered the most toxic and typically reported by laboratories and evaluated for risk assessment. These are listed on Table 1-2.



Chlorodibenzo-p-dioxin (CDD)
Bromodibenzo-p-dioxin (BDD)

Chlorodibenzofuran (CDF)
Bromodibenzofuran (BDF)

Figure 1-1 Dioxin and furan structures and numbering.

Table 1-1 Homologue Classes, number of congeners in each class, and order as shown in figures.

Figure Order*	Homologue Class	Prefix	Number of Chlorines	Number of Congeners
1	Total TCDD	Tetra-	4	22
2	Total PeCDD	Penta-	5	14
3	Total HxCDD	Hexa-	6	10
4	Total HpCDD	Hepta-	7	2
5	OCDD	Octa-	8	1
6	Total TCDF	Tetra-	4	38
7	Total PeCDF	Penta-	5	28
8	Total HxCDF	Hexa-	6	16
9	Total HpCDF	Hepta-	7	4
10	OCDF	Octa-	8	1

*Order of homologues as shown in figures in this report.

Table 1-2 Congeners with halogens in the 2,3,7,8- substituted positions, and order as presented in figures.

Figure Order*	Congener	2005 WHO TEF**
1	2,3,7,8-TCDD	1
2	1,2,3,7,8-PeCDD	1
3	1,2,3,4,7,8-HxCDD	0.1
4	1,2,3,6,7,8-HxCDD	0.1
5	1,2,3,7,8,9-HxCDD	0.1
6	1,2,3,4,6,7,8-HpCDD	0.01
7	OCDD	0.0003
8	2,3,7,8-TCDF	0.1
9	1,2,3,7,8-PeCDF	0.03
10	2,3,4,7,8-PeCDF	0.3
11	1,2,3,4,7,8-HxCDF	0.1
12	1,2,3,6,7,8-HxCDF	0.1
13	1,2,3,7,8,9-HxCDF	0.1
14	2,3,4,6,7,8-HxCDF	0.1
15	1,2,3,4,6,7,8-HpCDF	0.01
16	1,2,3,4,7,8,9-HpCDF	0.01
17	OCDF	0.0003

*Order of congeners as shown in figures in this report.
World Health Organization consensus Toxicity Equivalence
Factor for chlorinated dioxins/furans

Properties. Dioxins/furans are typically found as a complex mixture of congeners, with similar physical and chemical properties. They have a very low water solubility and are primarily associated with organic matter and particles like soil or dust. Once sorbed to soil, these show limited potential for leaching or volatilization. These are stable under most conditions, with the exception of photolysis in the atmosphere, or at the soil or water-air interface. These are therefore persistent, and can bioaccumulate in people and animals.

Toxicity. Our study is focused on the presence and patterns of brominated and chlorinated dioxin/furans and estimates of the toxicity of a mixture of these compounds using accepted regulatory protocols. Chlorinated dioxin/furans have been extensively studied, and a consensus approach to estimating the toxicity of a mixture of these compounds has been established. This includes identifying a TEF for each of the seventeen 2,3,7,8-substituted compounds and summing the toxicity of each resulting in a single value for the mixture:

> <u>TEF (Toxicity Equivalence Factor).</u> The most toxic and most studied of the PCDD/Fs is 2,3,7,8-TCDD (TCDD). The toxicity of other dioxins/furans are measured in relation to this TCDD congener. On this scale, TCDD is giving a TEF value of 1. EPA

guidance (USEPA, 2010b) recommends the 2005 World Health Organization (WHO) consensus TEFs (Van den Berg et al., 2006) for PCDD/Fs (Table 1-2).

TEQ (Toxic Equivalence). The TCDD-TEQ is calculated by multiplying the concentration of each of the 17 congeners by its respective TEF. The TCDD-TEQ of the mixture is calculated by summing the TEQs of each of these 17 congeners.

TEFs are an *order-of-magnitude consensus estimate* of the toxicity of a compound relative to the toxicity of TCDD that is derived using scientific judgment of all available toxicity studies. These include short and long term studies in whole animals (*in vivo* tests) and bioassay using tissues or cells (*in vitro* assays). The studies reviewed have been completed by various laboratories, each measuring a range of possible toxic endpoints that provide a numerical value for a chemical that can be compared to TCDD. The numerical value developed for a chemical by a single laboratory for a single endpoint is designated "relative potency" (REP). The database of REPs that meet WHO criteria were reviewed to assign a single scaling factor, the TEF.

Brominated analogues of these dioxins/furans were reviewed and similar interim TEF values for both chlorinated and brominated congeners were recommended for human health risk assessment. (van den Berg et al., 2013) However, fewer REPs have been completed on these compounds and many of these are in vitro assays that may not incorporate other potential differences that may be measured in whole animal toxicity studies. Therefore, the use of a single TEQ for a mixture of these compounds has much greater uncertainty.

Bioassays (*in vitro* tests) have been developed that measure "dioxin-like" activity. One of these is the Chemical-Activated Luciferase Expression bioassay test (CALUX®). These assays are based on the measurement of a compound or mixture binding to a protein (the aryl hydrocarbon receptor or AhR)[2] in a cell culture. According to EPA (2010) and van den Berg et al., (2013) and others, the AhR mediates most if not all of the biologic and toxic effects of TCDD and other dioxin-like compounds in vertebrates, and is the underlying basis for this test.

Any single measurement by a laboratory using this assay would be considered a REP. There are CALUX assays that use different cell lines and are completed by different laboratories. Each of these are "REPs" and results vary, and no single result should be considered equivalent to a TEF.

> *The measurement of the response of a mixture in the CALUX assay is should not be designated as a TCDD-TEQ, but more accurately a TCDD-BEQ – or "biological equivalent".*

While there are advantages to the use of screening bioassays, in vitro studies may not always predict responses in living organisms. Evaluation of potential toxic effects is complex. In February 2012 EPA finalized its most recent reassessment of dioxin toxicity. Numerous documents are provided on their website [3], including numerous health

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[2] http://en.wikipedia.org/wiki/Aryl_hydrocarbon_receptor

[3] http://cfpub.epa.gov/ncea/CFM/nceaQFind.cfm?keyword=Dioxin

assessments published by EPA since 1985. Hundreds of in vivo mammalian dose-response and epidemiological studies have been completed on 2,3,7,8-TCDD, the most studied and toxic of the dioxins.

Calibrating a bioassay using TCDD may provide information on relative activation of the AhR and link to the measured response based on the numerous in vivo tests. However, brominated dioxin/furans may potentially vary in absorption, tissue distribution, metabolism, and/or excretion. Van den Berg et al. (2013) considered this, and although based on the limited number of brominated congeners that have been studied, results were similar to their chlorinated analogues.

1.2 SUPERFUND SITE BACKGROUND

The Superfund related source of dioxins are attributed to the former Koppers wood treating operations – referred in this report as the "Site". This is part of the Cabot Carbon-Koppers Superfund Site in Gainesville, Florida (Figure 1-2) listed on the Superfund National Priorities List in September 1984.

Koppers wood treating operations continued for approximately 95 years at this 90 acre property (between the years of 1916 and 2010). Soil on the site is contaminated with dioxins and other chemicals. Onsite surface soil dioxin concentrations, expressed as 2,3,7,8-tetrachlorodibenzo dioxin toxicity equivalents or TCDD-TEQ, frequently exceeded the Florida commercial/ industrial soil cleanup target level (SCTL)[4] of 30 parts per trillion (ppt) with hot spots exceeding 1000 ppt. PCDD/Fs are contaminants in pentachlorophenol (PCP) which was used as a wood preservative at the site for approximately 20 years (1969-1990).

Since 2009, consultants for the responsible party have investigated levels of dioxins in offsite soils. This has included background areas as well as soils in the residential area to the west of the Site, referred to "near site" locations in this report. These data are presented and discussed in Section 3.

EPA Region 4 has the primary responsibility for coordinating response actions for the Site.[5] The 2011 Record of Decision for the Koppers site required remediation of residential properties adjacent to the Site with dioxin concentrations in soil exceeding the state residential SCTL of 7 ppt as TCDD-TEQ. Approximately 80 parcels have TCDD-TEQ concentrations in surface soil (0-6 inch sample interval) that exceeded the residential SCTL. Surface soils near site homes above this criteria were remediated between February and November 2014.

Residents raised concerns that these soil data may underestimate their level of exposure to Site related dioxins and provided XDS-CALUX bioassay screening data showing levels of total TCDD-TEQ in indoor dust samples exceeding 1000 ppt at some locations. These concentrations were much higher than levels previously measured in soils. Therefore, residents advocated for further study of levels of dioxins in their homes.

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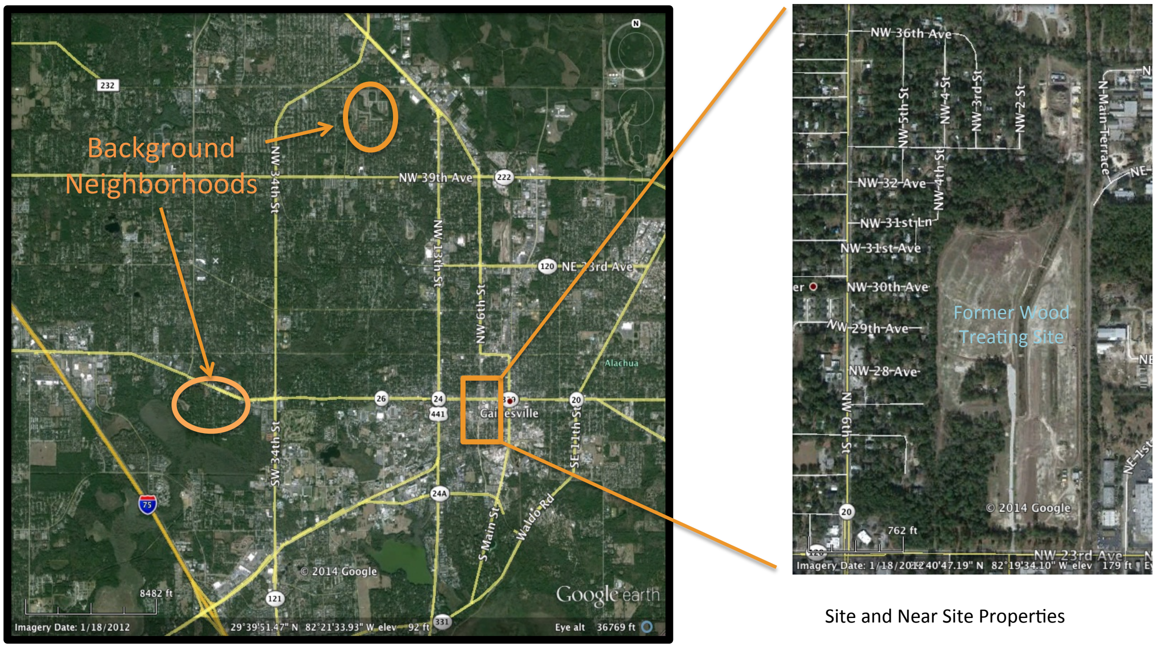
[4] The SCTLs for TCDD-TEQ are based on a target cancer risk level of 1×10^{-6}

[5] Site documents: http://www.epa.gov/region4/superfund/sites/npl/florida/ckopfl.html



Gainesville, Florida

Site and Near Site Properties

Figure 1-2 Location of the former wood treating site and background areas included in this study.

The XDS-CALUX screening test is based on the ability of dioxin and related chemicals to activate the AhR, which provides a measure to estimate the relative toxic potential of individual chemicals or the total TCDD-TEQ for a mixture of these chemicals. It was recognized that this test responds to a range of dioxin-like compounds that may be present in home indoor dust that are not related to contamination from the Koppers Superfund Site. Several published studies have shown that brominated furans associated with flame retardants found in residential house dust respond in this assay.

1.3 SUPERFUND DECISION PROBLEM FORMULATION

EPA Region 4 has the lead in making decisions regarding potential Site related remedial actions, including potential remediation of dust inside homes. Data Quality Objectives (DQOs) to support this decision required the following:

- Sufficient samples collected from near site homes, as well as background areas.
- Samples collected using a standard protocol used at other sites
- Analysis of PCDD/Fs using the definitive EPA Standard Method (1613B).

An Indoor Dust Workgroup chaired by Randy Merchant of the Florida Department of Health (FDOH) helped EPA develop the overall protocols for sampling and analysis of dust samples to support these decisions. This work plan (FDOH 2012) also provided background information on dioxins in dust and the approach for interpretation of the results. Members of the workgroup included:

- U.S. Environmental Protection Agency (EPA) Kevin Koporec
- U.S. Agency for Toxic Substances and Disease Registry (ATSDR) Lynn Wilder
- Florida Department of Environmental Protection (FDEP) Kelsey Helton, Nancy Murchinson
- Alachua County Health Department Anthony Dennis
- Alachua County Environmental Protection Department John Mousa, Robin Hallbourg
- Alachua County Environmental Protection Advisory Committee Bob Palmer
- Protect Gainesville's Citizens, Inc. Technical Advisor Pat Cline
- University of Florida, Center for Environmental & Human Toxicology (UF CEHT) Steve Roberts, Leah Stuchal
- ARCADIS-US Paul Anderson

In 2012, thirty samples were collected to support this decision. (Details of the sampling and analysis approach are provided in Section 2.) Seventeen dust samples were from homes near the site and thirteen were from background neighborhoods (See Figure 1-2). The TCDD-TEQs from these samples were used by the EPA to determine if potential additional remediation is required for inside homes. These data were also used by Florida Department of Health (FDOH) in their health consultation (FDOH, 2014)regarding dioxins present in indoor dust. Site documents can be found at the Alachua County Environmental Protection Department (ACEPD) website focused on the Cabot Koppers Superfund site. [6] EPA reported that chlorinated dioxin compounds are somewhat higher in the near site dust samples as compared to background, but generally within the concentration range measured in these samples. The maximum chlorinated TCDD-TEQ concentration detected was 90.9 ppt. The highest increased cancer risk from lifetime exposure was estimated at 1 in 100,000 or 1×10^{-5}. In addition, the concentrations of these chlorinated dioxin/furans is not likely to cause non-cancer illness in adults or children. Based on these findings, EPA Region 4 determined no additional remedial actions were needed to address indoor dust. (USEPA, 2013)

1.4 DIOXIN/FURANS IN HOUSE DUST – RESEARCH

In 2012, PGC collaborated with the Indoor Dust Workgroup and EPA to design and implement a program that can expand understanding of exposures to DLCs in homes, as well as the science of sample collection and data interpretation. To support research on these issues, brominated dioxins/furans (PBDD/Fs) were analyzed by modified Method 1613B in the 30 samples. Where sufficient sample was obtained, the CALUX assay was also analyzed. In addition, six dust samples obtained from home vacuums were analyzed.

Review of congener/ homologue and bioassay results provided an opportunity to better understand sources, patterns and potential exposures. For example:

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[6] http://www.alachuacounty.us/Depts/EPD/Pollution/Pages/CabotKoppersSuperfund.aspx

  - How do DLC concentrations compare with background?
  - What is the contribution from soils?
  - What is measured in the CALUX assay?
  - What types of sources within homes contribute to DLC concentrations?
  - Congener/homologue patterns:
    - How do dust patterns compare to those in soils?
    - How do near site and background patterns compare?
    - Can these patterns provide information on sources within homes?
  - How do DLC concentrations in dust samples obtained from home vacuums compare with results from samples collected using the EPA protocol?

Sections 2-4 of this report focus on the 2012 investigation results for dust samples collected prior to soil remediation to address these questions. All data are included in Appendix A.

Section 5 of this report documents results of five dust samples collected from near site homes in July 2014, after completion of the soil remediation. Residents have been concerned that soil remediation will not address the perceived elevated levels of dioxins in their homes. These additional were collected to better understand the impact of soil replacement and/or other approaches that may reduce exposures these compounds.

2 SAMPLE COLLECTION AND ANALYSIS

This section summarizes the sample collection and analysis of dust samples in collected in May of 2012. This includes documentation of:

- Sample Locations
- Sample Collection
- Analytical Methods
- Data Quality Review

The overall strategy for the 2012 dust investigation was based on the Indoor Dust Investigation/Interpretation Plan prepared by the Indoor Dust Dioxin Workgroup chaired by the Florida Department of Health (FDOH, 2011)The data required to support Health Consultation by FDOH (2014) and EPA risk based decisions were collection of dust samples using standard operating procedures and analysis of PCDD/Fs using the definitive analytical method.

The 2012 dust study sampling and data validation was implemented by EPA Scientific, Engineering, Response and Analytical Services (SERAS) supporting the EPA Environmental Response Team (ERT). This study was performed consistent with the protocols in the Quality Assurance Project Plan (QAPP) finalized May 2, 2012. The approved QAPP followed the “Uniform Federal Policy for Quality Assurance Project Plans” (UFP--QAPP). The plan was designed and implemented to meet the Quality Control (QC) requirements to support decisions related to PCDD/Fs that may be associated with historical activities at the Site.

PGC collaborated on the investigation to provide support and collect data for a more comprehensive understanding of dioxins in our homes. Specifically

- Developed the strategy for selection of homes to be sampled.
- Recommended analysis of samples for dioxin/furans associated with flame retardants and CALUX assay to better interpret the presence of dioxin-like compounds in our homes.
- Recommended collection and analysis of home vacuum dust samples at a subset of the locations. This provides information on reproducibility of data, sampling protocols and context for comparison with results reported in the literature.
- Documented information on the homes and residents during sample collection.
- Reviewed the data and the data validation protocols

After soil remediation was completed in 2014, dust from five near site homes were resampled. The protocols and results of that sampling is presented in Section 5.

2.1 SAMPLE LOCATIONS

PGC developed the strategy for identification of homes to be sampled, and collaborated with ACEPD and EPA in finalizing these locations.

To evaluate the presence of dioxins in homes that may be a result of the former wood treating operations, it was necessary to also determine concentrations in background samples. In February 2009, soil samples were collected from four background areas and analyzed for PCDD/Fs. Two of these areas (Figure 1-2) had more consistent low concentrations of PCDD/Fs, and were about 2 or more miles from the site. The nine soil samples analyzed from two background residential areas west of the Site had dioxin concentrations ranging from 0.2 to 1.7 ppt, with a median concentration of 0.4 pg/g. Calls were made and ACEPD sent letters to residents in these two neighborhoods requesting interest in participating in the dust study. From these, 13 participants were identified and included in the dust study.

For near site locations, letters were sent to homes within the area previously identified as having dioxin soil above 7 ppt. Seventeen access agreements were obtained and these homes were included in the study.

The specific locations of the homes remain confidential. Each was assigned a “House ID”. A total of 30 locations were included in the study. General information on these locations are summarized in Table 2-1.

2.2 SAMPLE COLLECTION AND PROCESSING

The dust samples were collected by SERAS at the 30 homes between May 5, 2012 and May 15, 2012. Dust samples collected for decision making followed the EPA standard operating procedure (SOP) #2040, Collection of Indoor Dust Samples from Carpeted Surfaces for Chemical Analysis Using a Nilfisk GS-80 Vacuum Cleaner. The sampling consisted of one composite dust sample per household. Each dust sample was collected from high traffic floor areas that were easily accessible including carpets, rugs, tile, and wood floors. The area sampled was documented allowing expression of results in both weight per surface area (picograms per square meter (pg/m^2) and concentration parts per trillion (ppt or pg/g).

In addition to the 30 samples collected following the SOP, dust samples obtained from resident's vacuum bags from six of these homes were processed and analyzed. The residents vacuum samples were included to understand the impact of the sampling protocol on dioxin concentrations in support of this EJSG research study, and to provide context for comparison with results from samples collected from home vacuums reported in the literature.

All 36 samples were sieved with an automated system with 100-mesh sieve and weighed following the protocol in SOP #2040. This processing was completed in the SERAS lab in Edison, New Jersey (NJ). Only the fine dust which passed the 100-mesh sieve was weighed and portioned to the laboratories for analysis. For each location, Table 2-2 summarizes the accessible area sampled using EPA SOP 2040, the total mass of the sample collected, and the mass of sieved sample sent to each laboratory for analysis. The total and sieved mass of sample obtained from 6 of the home vacuums are also included.

Table 2-1 General characteristics of homes included in the dust study.

House ID	Year Built	Square Feet	# of Residents	# of Pets	Fireplace	Computers
Background Homes						
A	1958	1860	1	1	No	2
B	1963	2257	5	2	No	5
C	1967	2365	1	0	Yes	2
D	1986	1530	4	1	Yes	3
E	1997	1952	4	1	Yes	2
F	1986	1612	1	2	Yes	1
G	1956	1492	2	0	No	1
H	1960	1413	2	0	No	1
I	1958	1860	3	0	No	3
J	1979	2000	2	0	Yes	5
K	1982	1561	3	1	Yes	3
L	1959	1860	1	0	No	1
M	1964	2362	2	2	Yes	2
Near Site Homes						
A	1981	896	1	12	No	1
B	1935	1400	1	0	No	
C	1948	1172	1	1	No	1
D	1950	780	2	2	No	
E	1978	768	1	0	No	0
F	1960	796	2	0	No	1
G	1960	682	2	5	No	
H	1950	924	2	1	No	
I	1936	891	1	9	No	1
J	1940	672	2	4	Yes	2
K	2008	1152	3	2	No	1
L	1950	1199	2	3	No	
M	1950	1989	2	0	No	2
N	1950	1272	2	0	No	1
O	1951	1576	2	0	No	1
P	1954	1120	1	1	No	
Q	1950	1158	1	2	Yes	1

Table 2-2 Total mass of sieved dust sample, and mass submitted for analysis by Method 1613B and 4435 (CALUX assay).

HouseID	Sieved Mass (gms)			Square Feet Sampled
	Total	1613B	4435	
Background Homes				
A	3.6 (61)	1.8 (51)	1.8 (10)	908
B	5.6	2.3	2.3	1038
C	7.5	3.8	3.8	1452
D	5.6	2.2	2.2	1074
E	52 (60)	42 (47)	10 (10)	1373
F	11.5	5.7	5.7	453
G	15.2	7.6	7.6	868
H	0.6 (117)	0.5 (107)	NA (10)	693
I	4.5	2.2	2.2	927
J	4.5	2.2	2.2	730
K	4.2	2.1	2.1	947
L	2.1	2.1	NA	1030
M	8.0	3.9	3.9	1337
Near Site Homes				
A	35.6	25.4	10	382
B	5.6	2.6	2.6	777
C	1.9	1.3	0.5	607
D	29.5	19.4	10	429
E	1.8	1.3	0.5	603
F	12.3	6.5	6.5	501
G	14.6	7.2	7.2	192
H	32.4	22.3	10.0	315
I	8.1 (33)	4.1 (24)	4.1 (10)	480
J	2.4	2.2	NA	234
K	27 (74)	17 (64)	10 (10)	594
L	42 (32)	32 (22)	10 (10)	504
M	66.7	56.6	10	579
N	26.9	16.6	10	298
O	2.0	1.3	0.5	854
P	10.5	5.3	5.3	721
Q	4.3	2.1	2.1	544

NA - not analyzed, insufficient sample.

Number in () is the sample mass from the home vacuum bag.

2.3 ANALYTICAL METHODS

All dust samples collected were analyzed using the definitive High Resolution Gas Chromatography/ High Resolution Mass Spectrometry or HRGC/HRMS by Vista Analytical Laboratory, El Dorado Hills, California (CA). Vista is National Environmental Laboratory Accreditation Program (NELAP) certified for analysis of PCDD/Fs in solid matrices using EPA Method 1613B. This was the priority method of analysis for all dust samples, reporting results for all seventeen 2,3,7,8- substituted PCDD/Fs, eight total homologue concentrations, and the minimum sample TEQ (TEQ min) based on the detected congeners.

There is no standard method for analysis of brominated dioxins and furans (BDD/Fs), but these can be detected by a modification of EPA method 1613B as developed by Vista. Analytical standards are not available for all of the brominated congeners, so all seventeen possible 2,3,7,8-substituted congeners were not quantified.

Table 2-3 summarizes the analytes reported and the method detection limits for the PCDD/Fs and PBDD/F 2,3,7,8-congeners. Due to limited amount of sample received, the laboratory did not determine percent moisture content of the samples. Results are reported on an “as received” basis.

Xenobiotic Detection Systems (XDS)-CALUX® EPA Method 4435 is a relatively new bio-analytical screening procedure for dioxin-like compounds in soils/sediments. EPA has not validated this method for dust samples. This method is based on the ability of dioxin and related chemicals to activate the aryl hydrocarbon receptor (AhR), a chemical-responsive DNA binding protein that mediates the toxic and biological effects of these chemicals. The CALUX® method compares the bioluminescence response from dioxin-like chemicals in a sample extract to a standard response from different concentrations of 2,3,7,8-TCDD to report a CALUX® TCDD Bio-TEQ concentration in a sample. This screening method has been demonstrated to estimate total PCDD/Fs in soils samples by comparing results with split samples analyzed by the required confirmatory analysis by EPA 8290 (HRGC/HRMS). Confirmatory samples are required because the correlations may vary with different sites/media.

The optimal sample size to achieve the lowest detection limits was 10 grams of sieved sample for each of these methods. If the total mass of sieved sample was less than 20 grams, the mass sent to the laboratories was decreased, and in some cases sufficient sample was collected only for analysis by the definitive method, 1613B, as a priority for decision making.

A total of 36 samples were sent to Vista Analytical Laboratory, El Dorado Hills, California (CA) for analysis following Method 1613B. A total of 33 samples were sent to XDS, Durham, North Carolina (NC) for analysis following Method 4435. XDS received three fewer samples due to insufficient sample volume.

Table 2-3 Brominated and chlorinated 2,3,7,8-congeners reported, number of detected concentrations, and range of detection and reporting limits (ppt).

Congener Order	Analyte	# of Detects	Detection Limit		Reporting Limit	
			Min	Max	Min	Max
1	2,3,7,8-TBDD	2	0.678	1540	5.32	348
2	1,2,3,7,8-PeBDD	0	5.89	784	21.3	1390
3	1,2,3,4,7,8/1,2,3,6,7,8-HxBDD	1	3.72	516	36.2	6960
4	1,2,3,7,8,9-HxBDD	1	4.35	490	53.2	3480
5	1,2,3,4,6,7,8-HpBDD	11	12.7	923	250	13900
6	OBDD	9	13.1	3580	1060	69600
7	2,3,7,8-TBDF	0	4.53	1060	5.32	348
8	1,2,3,7,8-PeBDF	6	24.1	4500	21.3	1390
9	2,3,4,7,8-PeBDF	0	12.2	1820	21.3	1390
10	1,2,3,4,7,8-HxBDF	10	3.86	1260	71	3480
11	1,2,3,4,6,7,8-HpBDF	34	132*	4950	758	3080
12	OBDF	35	403*	5990	3250	3250
1	2,3,7,8-TCDD	10	0.0816	6.59	0.313	43.5
2	1,2,3,7,8-PeCDD	21	1.21	6.78	1.57	217
3	1,2,3,4,7,8-HxCDD	25	0.142	8.84	1.96	217
4	1,2,3,6,7,8-HxCDD	34	2.54	9.27	45.5	217
5	1,2,3,7,8,9-HxCDD	33	3.07	10.8	45.5	217
6	1,2,3,4,6,7,8-HpCDD	36	149*			
7	OCDD	36	1620*			
8	2,3,7,8-TCDF	21	1.3	9.12	3.1	43.5
9	1,2,3,7,8-PeCDF	22	0.253	4.46	1.96	217
10	2,3,4,7,8-PeCDF	27	0.826	4.38	44.8	217
11	1,2,3,4,7,8-HxCDF	32	1.01	4.8	46.7	217
12	1,2,3,6,7,8-HxCDF	30	0.726	4.77	44.8	217
13	1,2,3,7,8,9-HxCDF	9	0.0708	7.53	1.96	217
14	2,3,4,6,7,8-HxCDF	32	1.19	5.28	45.5	217
15	1,2,3,4,6,7,8-HpCDF	35	5.37*	19.7	25.3	25.3
16	1,2,3,4,7,8,9-HpCDF	26	0.602	11.5	17.7	217
17	OCDF	36	21.9*			

Includes 30 homes sampled using the EPA protocol, and 6 home vacuum samples analyzed in this study.
* minimum detected concentration

2.4 DATA REVIEW AND VALIDATION

2.4.1 Dioxin and Furans

SERAS data validation group reviewed the data packages produced by the analytical laboratories for completeness for EPA Method 1613B. A qualitative review was completed on the Method 1613B data package from Vista Analytical Laboratory including the review of mass resolution checks, window defining mixtures, lock mass channels, initial calibrations, continuing calibrations, internal standards and column performance checks as to their acceptability to method criteria. A review of QC samples (method blanks, laboratory control samples and Matrix spikes/duplicates as to their acceptability to method criteria.

The PCDD/Fs data review followed the functional guidelines for validation. A similar approach was used for the PBDD/Fs, however, because these are less routine, greater uncertainty was possible.

- In some cases, the higher molecular weight PBDD/Fs were detected in the method blank. Where the sample concentrations in these data packages were less than five times the method blank concentration, results were qualified non-detect (U).
- In several cases the percent recovery of the standards were not within the QC limits and the results were qualified as estimated (J). In many cases %R were below the QC limits indicating the concentration in the sample may be biased low.
- OCDD results were above the linear range for several samples and were qualified as estimated (J). OCDD was reported at the highest concentration in all samples. Although its concentration may be somewhat uncertain, lower detection limits and confidence in those congeners with lower concentrations may be improved.
- Of the total of over 1800 results for dioxins and furans, four results were qualified as unusable based on not being recovered in the matrix spike. These included two samples where 2,3,7,8-TBDD was not recovered, and one sample where the HxBDD congeners were not recovered. Furans are the dominant constituents associated with flame retardants, so these findings did not impact the analysis of the results.

There is a contract required reporting limit (RL) for these compounds. This is a concentration above which there is confidence in the quantitation of the result. For instrument signals a certain minimum level above the background signal, the compound is considered detected, but the concentration is less certain. These results are qualified as estimated (J). For each result not detected, an estimated sample specific detection limit is calculated by the laboratory associated with this minimum signal. This value is below the reporting limit, and may vary for each sample and analyte. Because of the significance of the toxicity of these compounds, the lower value – the laboratory sample specific estimated detection limit – is used to represent non-detected concentrations rather than the RL provided during validation.

2.4.2 CALUX ® Assay

The CALUX assay is one of the *in vitro* bioassays that measure the activation of the AhR by dioxins and dioxin-like compounds. XDS is the only laboratory in the US who performs this assay, however, laboratories in Asia and Europe also perform this (or a comparable) assay. The use of this assay on dust samples in 2009 as part of litigation, prompted interest in understanding exposure to multiple chemicals that may show dioxin-like responses.

No specific data validation protocols have been established by EPA for this assay. The results provided for the 36 dust samples collected in 2012 were reviewed, and it was concluded that confidence in these data are low and are not usable as part of our study. This is based on comparison of results with historical data and lack of response to brominated dioxins/furans. The response to these compounds have been demonstrated in the literature, including research published by XDS.

The CALUX and other similar assays can provide valuable information on the total dioxin-like response of various environmental mixtures, leading to additional studies that identify specific compounds and/or additional toxicity studies. The published information on this assay also contributes to our interpretation of the presence of PBDD/Fs as discussed in Section 4.

2.4.3 Sample Collection Method Discussion

Each of the 30 homes were sampled using the EPA/ERT SOP 2040 to have a supportable and consistent approach for collecting dust from within the accessible areas of the home to support the decision process. We were interested in better understanding the impact of the sampling protocol on the results for several reasons:

- Consistency and reliability of the data
- Potential impact of change in equipment for samples collected in 2014
- Placing these data in the context of results reported in the literature, and contributing to research on dust sampling methods.

Duplicate field samples cannot be collected from within a home during a sampling event, since the sample is a composite of all the accessible floor surfaces. Home vacuum samples from 6 homes were analyzed and the results were compared with samples collected following the SOP.

The dust samples for these six locations generally show comparable TCDD-TEQs for the PCDD/Fs. The most significant TEQ difference was shown for background dust samples from home A (Table 2-4). The difference in the mass of sample provided to the laboratory using these two methods can also impact the achievable detection limits, and adds to the potential variability in the results.

The detected chlorinated congeners and homologue concentrations were also generally correlated (Figure 2-2) With the exception of background home A, the PCDD/F congener concentrations were highly correlated for the two samples. Results from home A are presented separately, showing a consistent bias with PCDD/F concentrations ~20% of the result for the EPA sample suggesting some overall dilution of the sample, possibly by some other use of the home vacuum.

Table 2-4 Chlorinated dioxin/furan sampling method evaluation: comparison of sample mass and TCDD-TEQ concentrations.

House ID	Mass of Sieved Sample (gms)		Chlorinated Dioxin/Furans TCDD-TEQ (ppt)	
	EPA Sampling Protocol (2040)	Home Vacuum Sample	EPA Sampling Protocol (2040)	Home Vacuum Sample
A	1.8	51	34	6.1
E	41	47	6.3	5.5
H	0.5	107	6.7	11.3
I	4.1	24	43	45
K	17	64	17.5	14.8
L	32	22	37.6	31.6

Samples A, E and H were from background homes; Samples I, K, and L were from near the site.

Greater variability was observed when comparing concentrations of PBDD/Fs. typically with concentrations higher in the home vacuum sample. Flame retardant materials may be more localized and variable within the homes, and the persistence and properties of the PBDEs and PBDD/Fs may differ.

Discussion The EPA SOP using the high volume surface sampler is considered the "gold standard" for collection of dust samples. Differences in sample collection can impact the measured concentrations, but systematic use of a particular standardized protocol provides better comparisons across studies and a basis for correlating with exposures.

Home vacuum samples are reported in many published studies because of the ease and cost as compared to researcher collected dust. Dust collected from home vacuums as compared to using a standard protocol are different. The home vacuum dust may represent contamination found in several rooms over periods of months or years. Dust collected by the standard protocol provides in formation about contamination present over a shorter time interval, and may focus on only selected rooms. (Whitehead, Metayer, Buffler, & Rappaport, 2011).

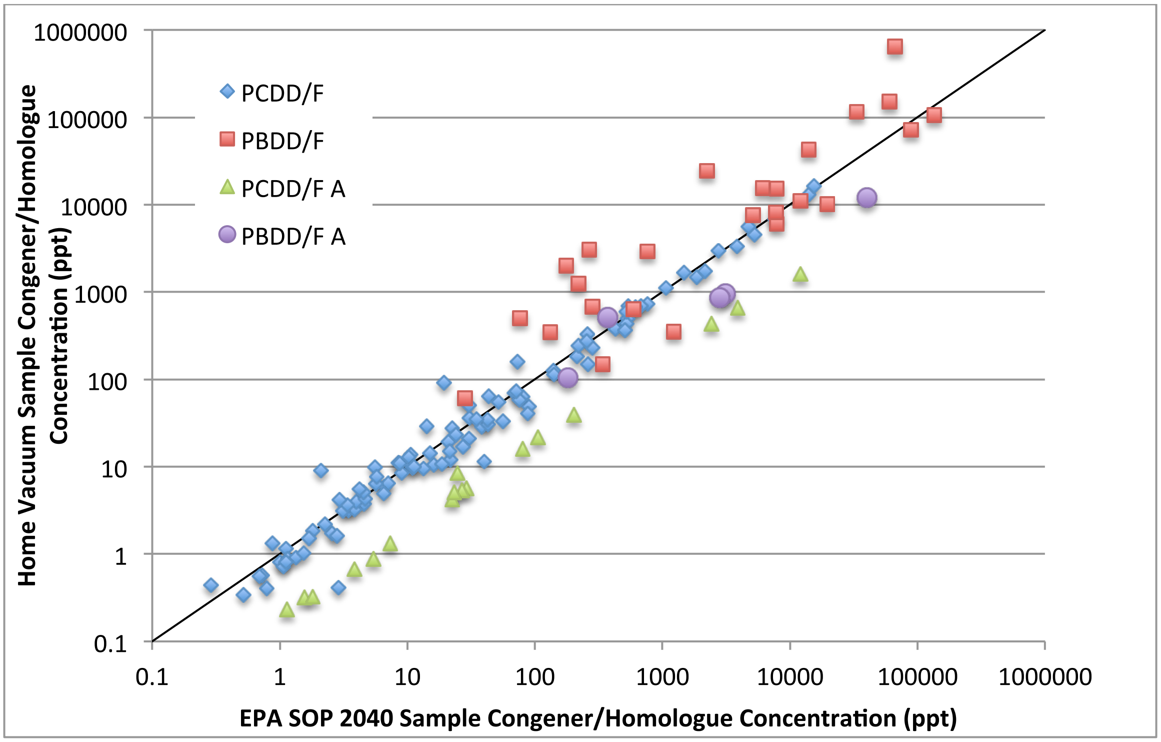


Figure 2-1 Comparison of detected congener and homologue concentrations (ppt) for dust samples collected by EPA method 2040 with results from analysis of contents of the home vacuum.

Studies that compared results from a home vacuum bag versus a standard protocol were reviewed. However these were not necessarily comparable to our study. For example:

> Allen et al. 2008. Samples from 20 homes compared PBDE concentrations measured in the home vacuum bag with a sample collected from the main living area, and another from the bedroom using a vacuuming method different from our SOP (dust captured by a cellulose extraction thimble). Penta- and decaBDE were higher in the main living area compared to the bedroom, and generally supports the idea that sources are localized and not a general home characteristic. PBDEs measured in match samples were not well correlated. Lower concentrations generally found in in the home vacuum bag sample ((Allen, McClean, Stapleton, & Webster, 2008)
>
> Bjorklund et al. 2011. Vacuum bag sample results were compared with those collected from surfaces above floor level. Results were correlated for decaBDE but not for pentaBDE. Higher concentrations were found in the researcher collected samples. (Björklund et al., 2011).
>
> Colt et al. 2008. Vacuum bag samples were compared to researcher collected dust using a high volume sampler, but focused on specific rooms (where children play or located on the side of the home facing agricultural crops) and specifically focused on carpeted areas. Dust concentrations for samples collected by the two methods were correlated for polycyclic aromatic hydrocarbons and polychlorinated biphenyls, with similar median concentrations. It was concluded household vacuum method is a reasonable alternative for detecting, ranking and quantifying the concentrations of

> pesticides and other compounds as long as dust loading is not a critical factor. (Colt et al., 2008)

A range of sampling approaches have been used to evaluate concentrations of indoor contaminants including collection of dust from air, surface wipes, attics, furnace filters, and floors. Each of these methods may produce a different estimate of the concentration of a contaminant, however, the goal of most studies are to ultimately estimate how the measured concentration predict exposures and potential associations between exposure and disease. The appropriate protocol depends on the specific contaminant being evaluated and the demonstrated correlation between the dust sample concentration with intake/exposures from measurements of the contaminant in biological samples (e.g. blood, urine, milk).

For Superfund, with a focus of contaminants that may be tracked into the home, vacuum sampling is preferred. However, it is clear that specific sampling methods and locations within a home may show concentrations higher than obtained by vacuuming floors. Samples collected from attics, or wipe samples of fine settled dust particles may show higher concentrations. In evaluating this issue for sampling of homes for lead contamination, EPA emphasized that

> *..any household dust lead standard should be linked to the method by which dust is sampled, because the relationship between children's blood lead levels and dust lead levels varies significantly by method of dust collection. The relationship between blood lead levels and household dust lead is different for floors, window sills, and window troughs using the same dust collection method, indicating that different standards are needed for each surface*.

The critical factors are the assumptions relating the concentration to the possible exposure. Higher concentrations in light dust settled on high surfaces (fans, lights, etc) may be found, but the amount of intake or exposure to these surfaces may be limited. Sampling from floors was recommended because these areas best represent average long-term dust exposure for children. (USEPA, 2008)

Unlike several studies, we compared the “gold standard” high volume surface sampling of all accessible floor space, to samples from home vacuums which are likely to be used in these same areas. There is no bias with a preference with samples collected above floor level (likely finer particles), or focusing on specific rooms suspected of having higher concentrations. This increases the likelihood that the results of these paired samples may be more comparable.

For our results, PCDD/Fs in home vacuum samples serve as duplicates and demonstrate acceptable precision when interpreting the 30 samples collected by the standard protocol. Relative percent differences tend to be higher for results near detection limits, however, the average RPD for homes E, H, I, K, and L were 14 to 29%. For home A, the average of the RPDs between the home vacuum and 20% of the congener/ homologue concentration was 8%. The specific make or model of the vacuum does not appear critical. However, as shown by the sample at one of the homes, there may be artifacts in some home vacuum samples that may increase or dilute the contaminant concentration of interest.

Our PBDD/F results are more variable (overall average RPD of 85%) between samples collected by these two methods. Results were typically higher in the vacuum bag samples. Part of this variability may be related to greater uncertainty in this modified analytical method, since these compounds are not frequently analyzed. Allen et al. 2008 and Bjorkland et al. 2011 found higher concentrations of PBDEs in the researcher collected samples, however, they were not measuring levels in samples collected from all accessible floor areas of the homes. A relationship between PBDEs and PBDD/Fs is expected, however, the properties and persistence of these may differ.

3 CHLORINATED DIOXINS AND FURANS

This section discusses the PCDD/F results of the 30 dust samples collected in 2012 prior to soil remediation. These were collected using EPA SOP 2040 and analyzed by EPA Method 1613B. All analytical results are provided in Appendix A.

Key Findings

- The TEQ levels in home dust samples near the former wood treating site were statistically higher than background homes sampled in this study.
- The level of increase in the TEQ potentially associated with the former wood treating operations is estimated at ~14 ppt.
- Higher molecular weight dioxins/furans congeners/ homologues are at the highest concentrations at all locations.
- Concentrations of OCDF and HpCDF tend to proportionally higher in the near site samples, however, these do not have a significant contribution to the TEQ.
- There are outliers (TEQ concentrations > 60 ppt) that show different relative concentrations of homologues than observed in near site samples, and suggest contributions from in home sources.

3.1 PROBLEM FORMULATION

Current analytical methods allow characterization of PCDD/Fs at parts per trillion (ppt) levels. These are detectable at these levels in environmental media including soil, dust and food. Many regulations have been imposed in recent years that have significantly reduced emission of dioxins from industrial sources, regulated the use of pentachlorophenol (PCP) and taken other actions that have significantly reduced public exposures to PCDD/Fs.

Technical grade pentachlorophenol (PCP), historically used as a wood preservative, is the source of PCDD/Fs associated with the Superfund site. It was used at the former wood treating site from 1969 to 1990. Dust samples were collected from seventeen homes near the site where concentrations in soils were above the Florida Soil Cleanup Target Level (SCTL).

PCDD/Fs come from a variety of sources within homes. Background studies of dioxins in house dusts show detectable TCDD-TEQ concentrations at part per trillion levels in all homes tested (O'Connor and Sabrsula 2005). To evaluate the potential contribution from the former wood treating site, dust concentrations from background homes in this general vicinity that are not impacted by the site must be measured. Soil concentrations in the background area were low (median concentration 0.23 ppt as TCDD-TEQ).

The PCDD/F concentrations measured in the dust from the 30 homes were evaluated to better understand several questions of interest as highlighted below:

<u>TCDD-TEQ.</u> The sum of the toxicity equivalence (TEQ) of each of the seventeen 2,3,7,8-congeners provides a single concentration to represent the toxicity of the sample.

- How do the concentrations differ between background and near site samples?
- How do results from these 30 samples compare with other background levels or dust concentrations near other sites?
- What increase may be potentially attributed to the former wood treating site?
- Is there a relationship between the soil and dust concentrations near the site? Are these consistent with published information regarding tracking in of contaminated soils?

Congener/Homologue Concentrations. The PCDD/F results reported by Vista included the seventeen 2,3,7,8- congeners, and the additional total homologue concentrations for congeners containing 4-7 chlorines.

- What congeners are at the highest concentrations?
- How do near site concentrations congener/homologue concentrations compare with background?
- Which contribute most significantly to the total TCDD-TEQ?
- How do soil and dust concentrations compare for individual samples?
- How variable are individual background and near site samples?

Forensics. To understand potential sources, profiles of the relative concentrations of the seventeen 2,3,7,8- substituted congeners or the 10 homologue classes of the dust samples are compared to those published for different potential sources. Standardization is needed allowing comparisons of profiles from sources with reported concentrations differing by orders of magnitude or representing different environmental media.

- How do site soils compare with published profiles for technical grade PCP?
- What common materials may be a source of PCDD/Fs in our homes?
- Can we draw conclusions regarding specific source contributions?

3.2 TCDD-TEQ

The TCDD-TEQ concentrations (ppt) for the dust samples from the 30 homes collected using the EPA SOP are shown in Table 3-1. These TEQs were reported in the FDOH Health Consultation (2014) and the EPA Indoor Dust Study Data Report (EPA 2013).

3.2.1 Risks and EPA Decisions

FDOH concluded that the dioxin/furan concentrations in dust from the background and near site homes are not likely to cause non-cancer illness and the estimated cancer risk is very low. The highest increased cancer risk from lifetime exposure was estimated at $1x10^{-5}$.

Because of uncertainties, exposure was not estimated based on dust loading. The approach for calculating a benchmark dose for dioxin in settled dust used by the EPA (2003) was based on dust loading was 2000 pg/m^2, with a background concentration of 693 pg/m^2. An updated benchmark of 153 pg/m^2 for TCDD-TEQ loading was calculated using current toxicity values and a target risk level of 1 x 10^{-6}. None of the dust loading concentrations as shown on Table 3-1 exceeded even this more conservative benchmark.

Based on review of the TCDD-TEQ results by EPA, the decision was made that no intervention to reduce exposures to dioxins in house dust was required.

Table 3-1 TCDD-TEQ Concentration and load for dust from background and near site homes.

Background Homes			Near Site Homes		
House ID	TCDD-TEQ (ppt)	TCDD-TEQ Load (pg/m^2)	House ID	TCDD-TEQ (ppt)	TCDD-TEQ Load (pg/m^2)
A	34	1.46	A	11.4	11.43
B	5.37	0.31	B	72.3	5.64
C	35.1	1.93	C	29.2	0.99
D	2.66	0.15	D	38.1	28.23
E	6.34	2.61	E	8.92	0.29
F	6.45	1.77	F	13.4	3.55
G	47.6	8.95	G	27.6	22.52
H	6.69	0.06	H	50.6	56.06
I	18.3	0.95	I	42.9	7.81
J	6.52	0.43	J	60.3	6.63
K	77.3	3.63	K	17.5	8.7
L	18.2	0.4	L	37.6	33.88
M	15.3	0.98	M	44.9	55.68
			N	6.78	6.58
			O	27.7	0.69
			P	90.9	14.27
			Q	19	1.62
median	15.3	0.98	median	29.2	7.81
geometric mean	13.6	0.88	geometric mean	27.9	6.96

3.2.2 Comparisons of Background and Near Site Soil and Dust TCDD-TEQs

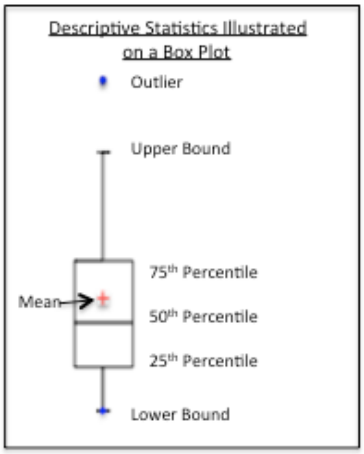
The descriptive statistics for TCDD-TEQs in soil and dust samples are summarized in Table 3-2 and illustrated in the box plot shown on Figure 3-1.

- There are chlorinated dioxins/furans in all dust samples.
- Background results show differences that may reflect variability within homes, as well as variability from analytical and/or sampling. Based on review of these data, these are not
    - Related to soil.
    - Related to Koppers.
    - Spatially correlated between adjacent homes or proximity to higher traffic roads.
- The median and average concentrations in dust samples from homes near the site are elevated above background, indicating contribution from Koppers.
- There are isolated homes with high concentrations that do not appear related to location. For example, this includes
    - A background outlier concentration of 77.3 ppt. Other nearby homes were below 7 ppt.
    - A near site concentration of 90.9 ppt was more than two standard deviations above the average of the near site dust concentrations. Soils at this property were below 7 ppt, and it was the located farther from the Superfund Site boundary than other near site samples.

Table 3-2 Descriptive statistics for soil and dust TCDD-TEQs (ppt) in near site and background areas.

Statistic	Soil		Dust		
	Background	Near Site	Background	Near Site	Difference
Minimum	0.05	2.4	2.7	6.8	4.1
25th Percentile	0.13	8.0	6.4	15.5	9.1
median	0.23	11.6	15.3	29.2	13.9
Average	0.53	15.4	21.5	35.2	13.7
75th Percentile	0.71	19.9	34.6	47.8	13.2
Maximum	1.57	69.7	77.3	90.9	13.6
Soils: 9 samples collected in the two background neighborhoods; 99 surface soil samples in the soil remediation zone.					
Dust - 17 near site samples, 13 background samples. The difference reflects the increased concentration in the dust concentration for each statistic.					

A box plot provides a graphic display of a data distribution as shown in the following illustration:



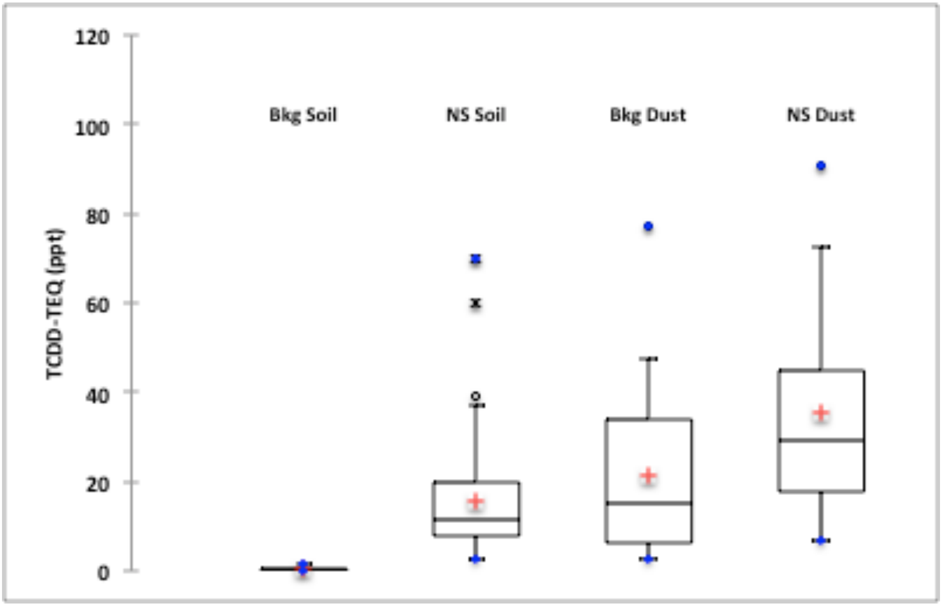


Figure 3-1 Illustration of the distribution of TCDD-TEQ concentrations for background and near site soil and dust samples.

3.2.3 How do these concentrations compare with other sites?

Background Soil. Nine soil samples were collected from the two background neighborhoods. The TCDD-TEQ concentrations ranged from 0.2 to 1.7 ppt, below the range reported by EPA (2006) of 2-21 ppt TCDD-TEQ for background urban soils.

Background Dust. Background dioxin concentrations in dust are defined as a range of levels that may be in homes that are not related to a specific industrial source, in this case the former wood treating site. Studies reviewed had several limitations, specifically, the complete data sets were not provided, protocols differed, TEQ calculations differed, etc. The average and ranges from these studies can be compared with the results shown on Table 3-2.

> O'Connor and Sabrsula (2005) reported house dust dioxin concentrations for "selected homes" in Mississippi in an area believed to be unpolluted. The average TEQ for 14 samples was 20.3 ppt, with a range of 1.3-53.7 ppt. This is similar, but somewhat lower, than results in our study. However, 20 of the 34 samples were discarded. Based on comments on this study (suggesting bias because of use of these data in litigation), some of these were analyzed and results discarded because concentrations were elevated.
>
> Deziel et al. (2012) reported results from 40 dust vacuum bag samples from four areas of the US. The median TEQ concentration was 20 ppt, with a range from 5.4 to 260 ppt, and interquartile range (25th to 75th percentiles) of 14 to 33 ppt. This study evaluated the results with respect to distance from a range of potential sources.

These results are similar and slightly higher than measured in our background samples, some were near known sources.

Near Site Dust. The median and maximum TCDD-TEQ concentrations in near site dust samples were compared to studies of dust from living spaces in homes near dioxin sources as summarized in the work plan for the indoor dust study (FDOH, 2011). As stated in this work plan, average dioxin TCDD-TEQ levels were between 50 and 300 ppt near these sources. Ten of the 12 studies summarized that used comparable protocols had maximum concentrations greater than 94 ppt, six of these with concentrations over 500 ppt (maximum was 3936 ppt). Nine of these studies had median dust concentrations ranging from 47 to 323 ppt, as compared to 29 ppt for our near site dust samples. These comparisons suggest dust concentrations near this Site are at lower levels than reported in homes near many other dioxin sources.

3.2.4 What incremental increase in concentration may be attributable to the Site?

Tracking in of contaminated soil in the near site properties appear to increase the TCDD-TEQ in house dust by approximately 14 ppt.

There are no direct measurements in soil for each of the properties, so the statistical comparisons from these two areas were used to better understand the relationship of soil to dust concentrations. It is clear from results shown on Table 3-2 that background soil concentrations are low, typically below 1 ppt, while the PCDD/F levels in dust generally reflect contributions from in home sources, which can be highly variable.

The difference in the background and near site dust concentrations for each of the summary statistics (e.g. quartiles, median, average) are also shown on Table 3-2. The TCDD-TEQ concentrations for the near site dust samples were higher than background at levels of approximately 14 ppt. These data suggest that while the near site homes have higher PCDD/F concentrations, much of this appears attributable to indoor sources.

3.2.5 How does incremental increase relate to soil concentrations?

The average TCDD-TEQ concentration in the near site soil (15.4 ppt) is near the estimated incremental increase in dust concentrations (~14 ppt) when near site homes are compared to background.

Initially, the goal was to attempt to correlate the individual home / soil combinations. However, soil samples were not collected at each of the homes where dust samples were also collected. Most TCDD-TEQ concentrations in background soils were below 1 ppt, with a median of 0.23 and average concentration of 0.53 ppt. Therefore, it is assumed that TCDD-TEQs were at or below 1 ppt at each of the homes where dust samples were obtained at these background neighborhoods, and any differences would not be significant when comparing to near site samples.

The TCDD-TEQ soil concentrations near the former wood treating site are higher than background, and more variable. The median soil concentrations near the site was 11.6 ppt, with an average concentration of 15.4 ppt. Significant variability was observed where multiple samples were collected from a specific property. No direct linking of a home with a single specific nearby soil concentration adequately characterize these differences.

3.2.6 How does this compare to reports of impacts from tracking in contaminated soil?

The ratio of the incremental increase in TCDD-TEQ in dust to the average soil concentration is near one, within the range of reported dust/soil ratios.

Models (Hunt, Johnson, & Griffith, 2006; Johnson, 2008; Layton & Beamer, 2009) identify some factors that impact the movement of soils to indoor areas. It was clear no single set of assumptions accurately predict the indoor concentrations of a soil contaminant at a specific home. Levels may be impacted by the number and ages of residents, pets, ground cover/gardens, climate, cleaning frequencies, carpeted surfaces, type of vacuum cleaning, use of air filters, fans, etc.

In addition, the relationship between soil and dust concentrations for any specific study can differ based on how samples are collected. For example:

- Soil Samples. Depth of the soil sample is frequently not specified in summaries of many studies, but may vary from upper few centimeters to a composite of 6 inches to 2 feet. For our study, soil samples were a 6 inch composite for a contaminant that is assumed to be localized to the upper few centimeters.
- Dust Samples. Samples may be collected by vacuuming floors in accessible areas (as done for this study), vacuuming specific areas, wipe samples etc.

Contaminant concentrations may be lower in house dust as compared to soils because of dilution of the soil with materials from within the home. Conversely, contaminant concentrations can be higher in house dust than soils because of enrichment (higher concentrations on finer particles that are tracked into the home), contribution from indoor sources and other processes.

To simplify and put things in a general range:

- Results from several studies suggest on average, house dust includes 30-70% soil material, and can range from 8 to over 80%. (Oomen & Lijzen, 2004)
- The dust/soil ratio for lead has been reported to range from 0.3 to 9.2 (Paustenbach, Finley, & Long, 1997).
- A default dust/soil ratio of 0.7 is used by EPA as an input for the their child lead risk model. (USEPA, 1998)

For our study, the incremental increase above background in the TCDD-TEQ in the dust samples is ~14 ppt, as compared to an area average for soils of 15.4 ppt suggesting a dust/soil ratio near one, within the range of reported dust/soil ratios.

These comparable levels are not inconsistent with the concept that only a fraction of dust is comprised of soil material. It is likely that the actual TCDD-TEQ soil concentration tracked into the near site homes is higher than the average of the 6 inch composite samples. For example, if all the contaminant was in the upper two inches, the surface soil material tracked in would be three times higher, and subsequently diluted when mixing with other materials from within the home.

3.3 CONGENER/HOMOLOGUE CONCENTRATIONS

This section explores the concentrations and patterns of the congeners and homologue results for dust and soil. The TEQs discussed previously allow a comparison of total toxicity at various locations, but do not consider the relative contributions of the various 2,3,7,8-substituted congeners.

These data are explored to:

- Examine patterns related to potential site related contributions
- Gain insight into other congeners/homologues that are associated with sources within homes.

The frequency of detection of PCDD/F congeners is frequently higher in the near site dust samples (Table 3-3), particularly those with 4-6 chlorines. The arithmetic average was calculated using half the detection limit for non-detects. These are illustrated graphically on Figure 3-2.

Table 3-3 Summary of average concentrations (ppt) of PCDD/Fs in background dust, near site dust and near site soils.

	Bkg Dust (13 samples)			NS Dust (17 Samples)			NS Soils	
	No. Det.	Avg Conc	Avg TEQ	No. Det.	Avg Conc	Avg TEQ	Avg Conc	Avg TEQ
Congeners								
1	1	0.76	0.76	6	0.65	0.65	0.39	0.4
2	4	1.09	1.09	12	2.65	2.65	5.99	6.0
3	5	1.93	0.19	15	6.91	0.69	21.5	2.2
4	11	25.4	2.53	17	42.8	4.28	49.7	5.0
5	11	7.71	0.77	16	17.7	1.77	33.1	3.3
6	13	1354	13.54	17	1638	16.38	2046	20.5
7	13	6592	1.98	17	15565	4.67	15724	4.7
8	6	3.41	0.34	9	1.61	0.16	0.36	0.0
9	6	1.36	0.04	11	1.15	0.03	0.78	0.0
10	6	2.96	0.89	15	4.05	1.22	2.06	0.6
11	11	3.73	0.37	15	6.47	0.65	8.40	0.8
12	8	2.08	0.21	16	5.02	0.50	7.50	0.7
13	1	0.97	0.10	6	1.05	0.11	1.79	0.2
14	10	2.98	0.30	16	7.85	0.78	13.21	1.3
15	**12**	**31.4**	**0.31**	**17**	**165**	**1.65**	**303**	**3.0**
16	5	2.76	0.03	15	9.78	0.10	19	0.2
17	**13**	**90.4**	**0.03**	**17**	**531**	**0.16**	**1153**	**0.3**
Homologues								
TCDD	8	3.9		12	7.5		5	
PeCDD	13	40.6		17	59.7		50	
HxCDD	13	227		17	439		739	
HpCDD	13	2277		17	4275		8170	
OCDD	13	6592		17	15565		15724	
TCDF	8	35.6		14	29.6		10	
PeCDF	10	44.7		17	50.3		57	
HxCDF	13	43.7		17	157		339	
HpCDF	13	72.9		17	449		1125	
OCDF	13	90.4		17	531		1153	

Bkg - Background; NS - Near Site
No. Det. = number of detected concentrations..
Average concentrations using half the detection limit for non-detects.
Congeners in bold have concentrations in near site dust 3 or more times higher than background.

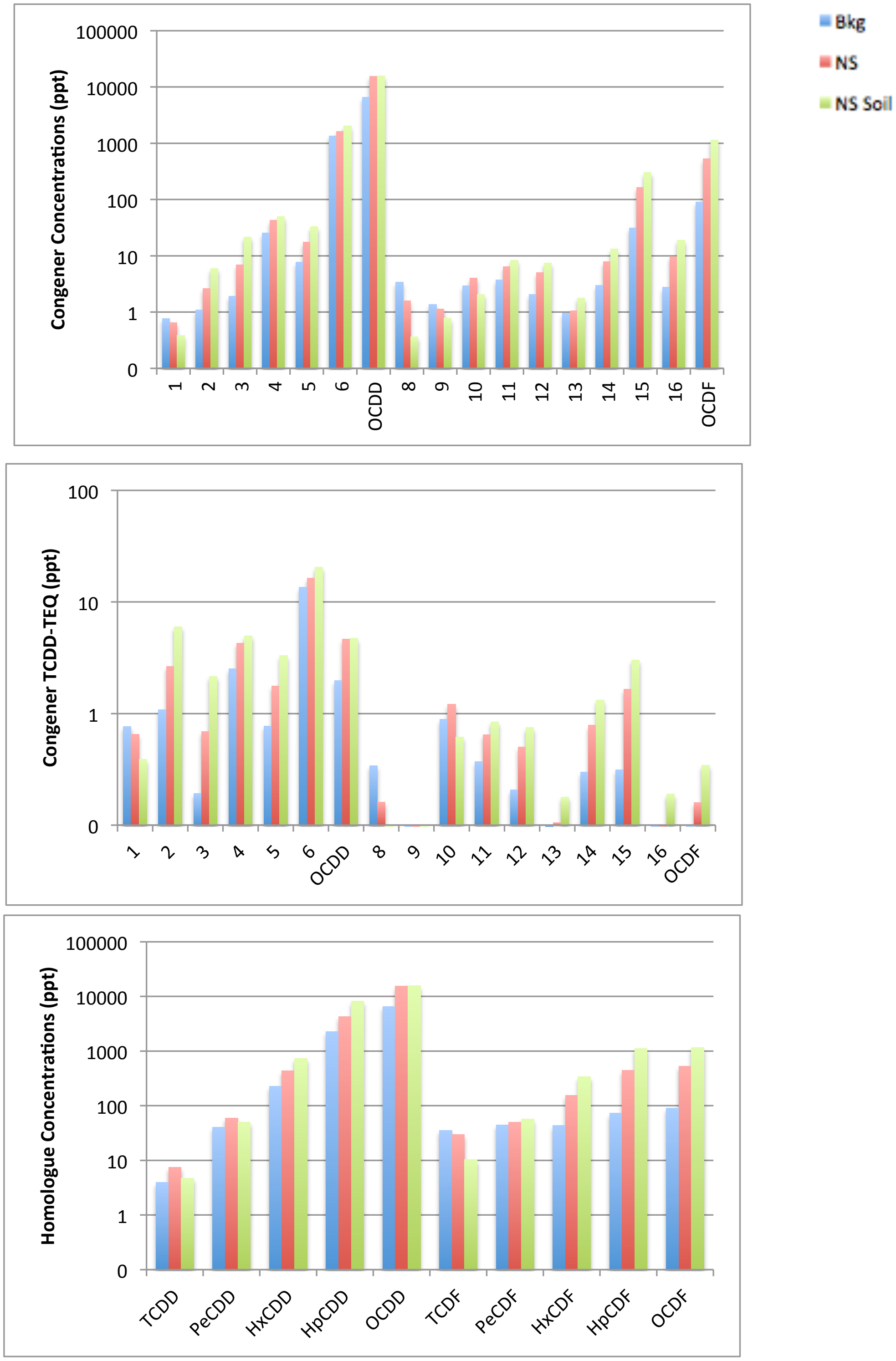


Figure 3-2 Comparison of average PCDD/F congener and homologue concentrations for background dust (bkg), near site dust (NS) and near site soil (NS soil) samples.

3.3.1 Which congeners and homologues are at the highest concentrations?

For both soil and dust samples, OCDD and HpCDD congener/homologues have the highest average concentration in both background and near site samples. These are prevalent in wood treating sites, but found in many other sources. The dioxins and furans with 4-5 chlorines and some of the HxCDD congeners had relatively low concentrations and were less frequently detected in soil and dust, however, these were detected more frequently in the dust samples near the site.

3.3.2 How do near site concentrations congener/homologue concentrations compare with background?

Several congeners shown in bold on Table 3-3 had near site dust concentrations 3 or more times higher than the average for background dust. OCDF and HpCDF had lower overall dust concentrations than the corresponding dioxins, but were about six times higher than background, providing a more unique difference between these sources. (These ratios remain the same when comparing concentrations and TEQs).

The differences in the lower molecular weight congener concentrations that include the nondetects in the averages (as on Table 3-3 and Figure 3-2) are more difficult to compare directly because of the variability and lower frequencies of detection. TCDF and PeCDF congener concentrations were higher in dust than in soils, with background dust concentrations slightly above the near site dust samples, however, the concentrations were low (near 1 ppt). The homologues of these compounds are more frequently detected in dust and suggest similar concentrations.

3.3.3 Which of the congeners contribute most significantly to the total TCDD-TEQ?

1,2,3,4,6,7,8-HpCDD had the highest average TCDD-TEQ of all congeners in each soil and dust. Although concentrations of OCDD were higher, the relative impact on the TEQ is less (~ 2 ppt for background and ~4.7 ppt for near site dust and soil). Other congeners typically contribute less than 5 ppt to the overall TCDD-TEQ. Compounds like OCDF that are clearly higher in the near site dust samples than those from background, have little impact on the total TEQ for the sample.

3.3.4 How do soil and dust concentrations compare for individual samples?

Because the dust concentration differences were more pronounce for the OCDF, other selected congeners were plotted to provide a better understanding of the correlation between this congener and OCDD, total HpCDD, total HpCDF and total HxCDF (Figure 3.3). Background soil concentrations of these are low, therefore, the dust concentrations appear related to indoor sources. Although both soil and dust concentrations are typically higher in the near site area than background, dust concentrations of OCDD and Total HpCDD are comparable in many of the samples.

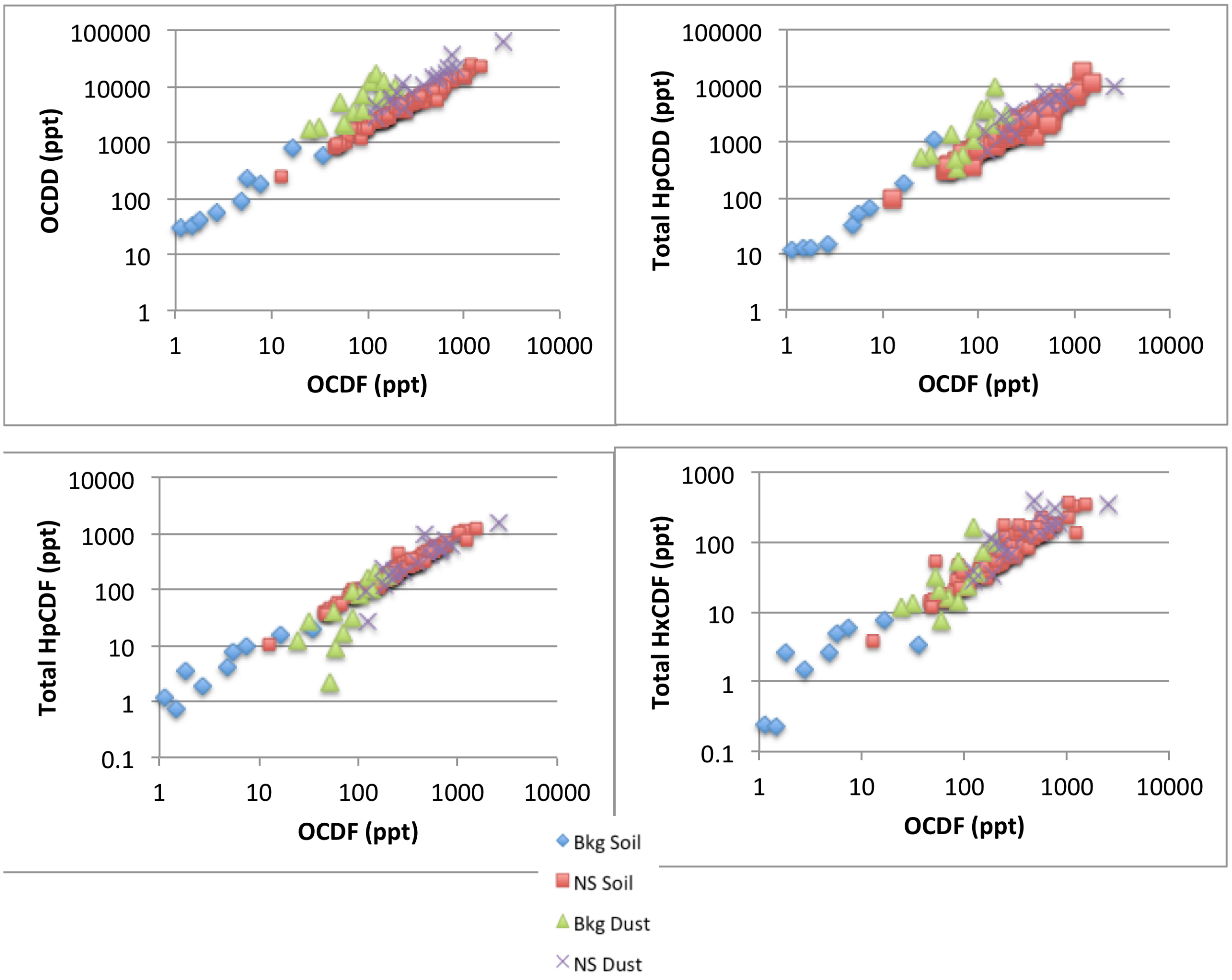


Figure 3-3 Soil and dust concentrations of selected homologues as compared to concentrations of OCDF.

3.3.5 How variable are individual background and near site samples?

While the average concentrations guide our overall understanding of the patterns, these do not accurately reflect the variability in the samples. Figures 3-4 through 3-6 illustrate profile differences in 13 background and 17 near site dust samples for detected congeners, homologue and TEQs concentrations. While individual homes are not highlighted in these figures, the overall frequency of detections and consistency in concentrations in the two groups of samples provide insights into overall differences in dust from background and near site homes.

The detected congener concentrations as shown on Figure 3-4, illustrates that many of the lower molecular weight congeners are less frequently detected, particularly in background dust samples. This highest concentrations in all samples were the HpCDD/Fs and OCDD/Fs, but typically lower in background homes. Background dust concentrations are more variable than those near the site. Because background soil concentrations are so low, the background samples likely reflect differences in patterns and concentrations that may be associated with a variety of indoor sources.

Because of differences in the TEFs, profiles of congener TCDD-TEQs (Figure 3-5) differs significantly from the congener concentrations and highlight which of these contribute most to the overall toxicity of the mixture. In all dust samples, 1,2,3,4,6,7,8-HpCDD contributed most to the overall toxicity of the mixture. Even with their elevated concentrations, OCDD/Fs and HpCDFs can have less impact on the total TEQ than trace concentrations of lower molecular weight congeners. It is not necessary to show these on a log scale, however, to better see contributions for congeners with TEQs below 5 ppt, the highest concentration shown on the graph is 30 ppt. The TCDD-TEQ for 1,2,3,4,6,7,8-HpCDD exceeded 30 ppt in three samples - 59.3 ppt for one background home and levels of 31.7 and 49.2 ppt in two of the near site homes.

The detected total homologues (Figure 3-6) also indicate some incremental increases in frequency of detection and concentration in dust from the near site homes. However, for many homologues, background concentrations in several homes are similar or in some cases higher than the near site homes indicating potential variability from sources within homes. The 2,3,7,8-congeners with four to seven chlorines represent only a fraction of the total concentration of the corresponding homologue class (Table 3-4). This results in differences in the pattern of homologues as compared with congener results.

Table 3-4 Proportion of 2,3,7,8-chlorine substituted congeners in each homologue class compared for background and near site dust samples.

Homologue Class	Median percentage of 2,3,7,8 congeners in each homologue class	
	Background	Near Site
TCDD	33%	6%
PeCDD	5%	6%
HxCDD	17%	14%
HpCDD	58%	35%
TCDF	14%	5%
PeCDF	14%	10%
HxCDF	19%	13%
HpCDF	48%	38%

Selecting specific ratios of compounds can be helpful in seeing relationships and patterns in this complex data set. Figure 3-7 illustrates the ratio of OCDD to Total HpCDD and OCDF to total HpCDF for the four homes with TCDD-TEQs > 60 ppt as compared to the ratios for the other near site homes. This suggests in home sources have different profiles that can contribute to the higher TEQs shown for outliers in this data set.

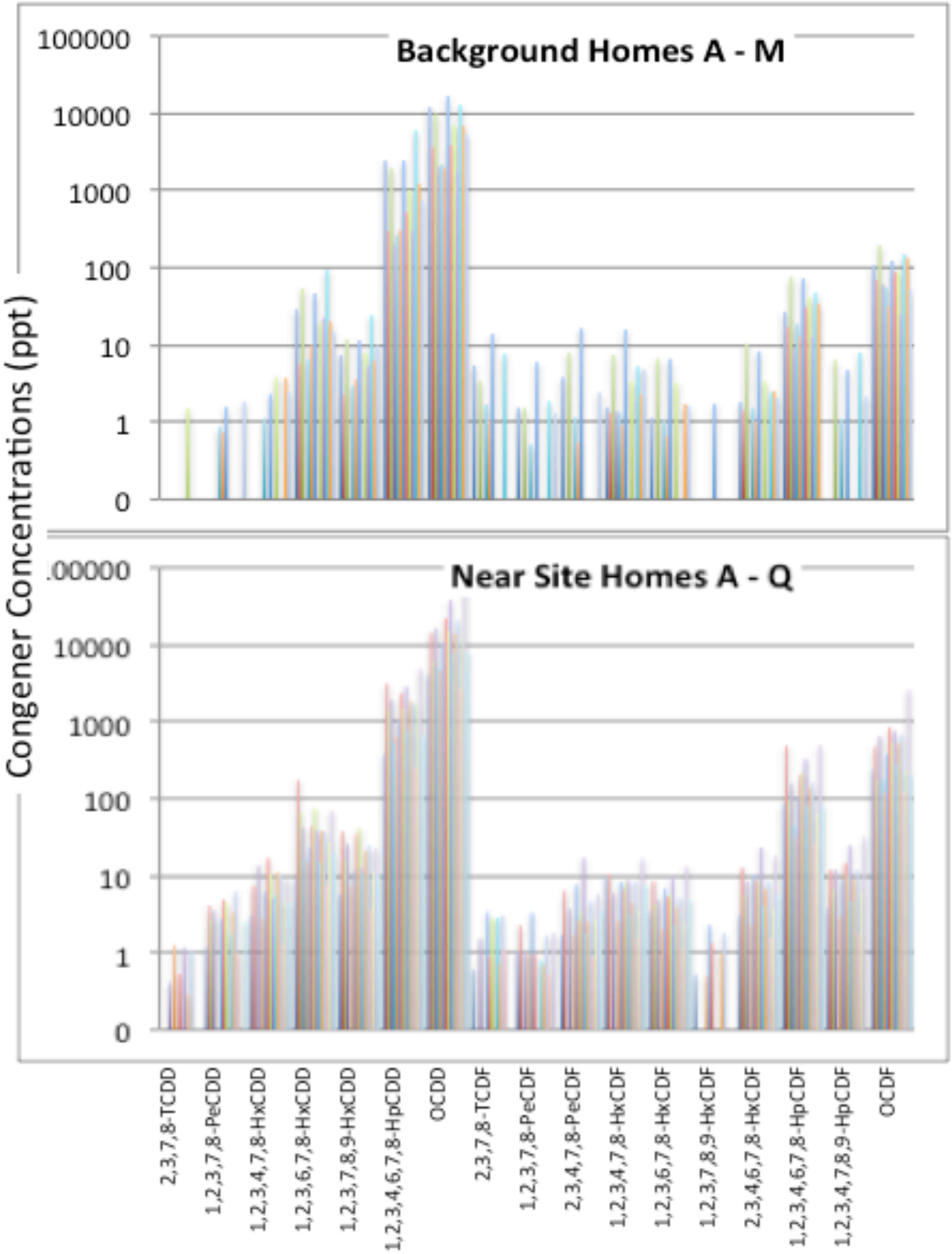


Figure 3-4 Concentrations (ppt) of detected PCDD/F congeners in background and near site dust samples.

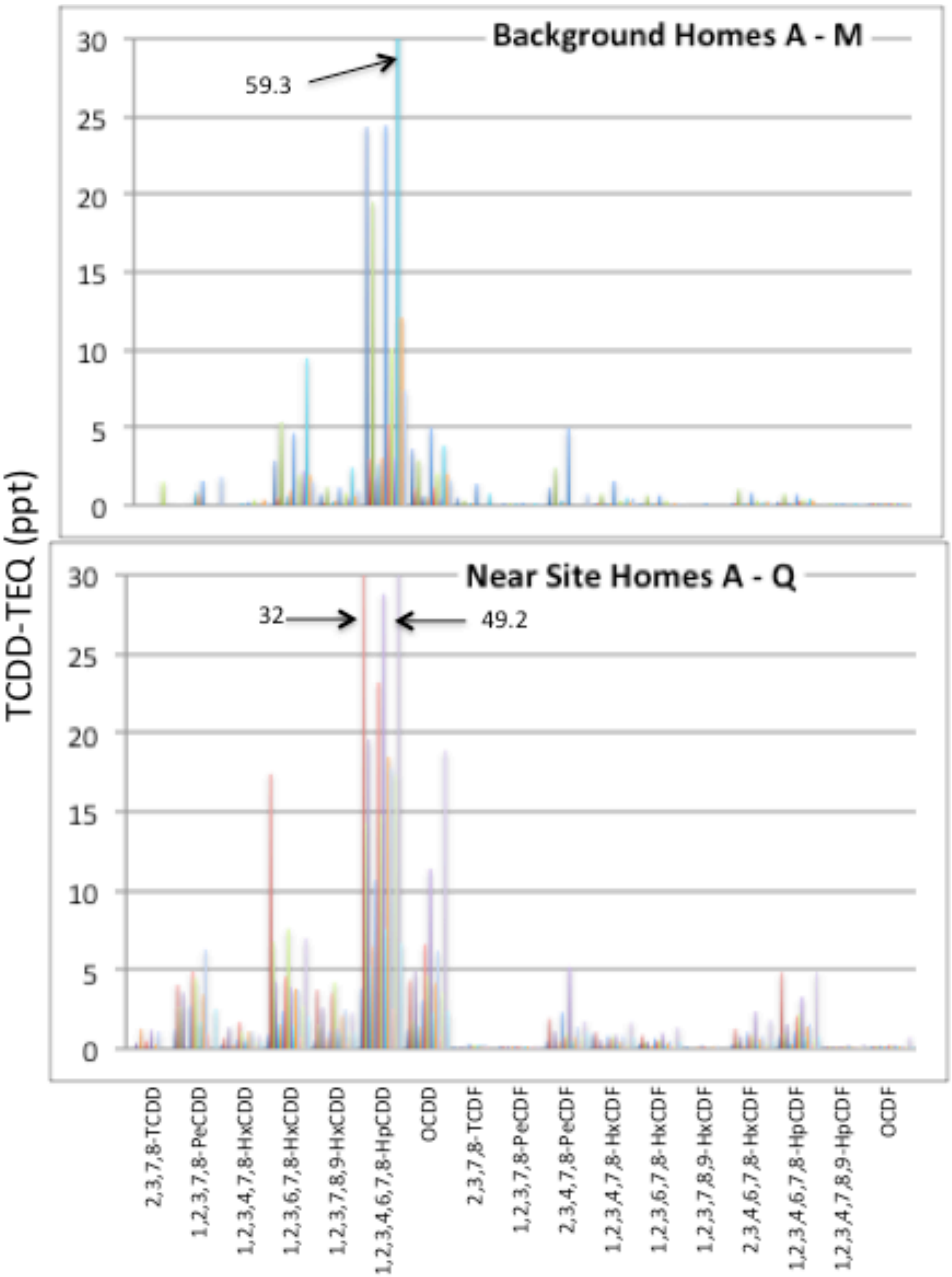


Figure 3-5 Congener TCDD-TEQ concentrations (ppt) for PCDD/Fs in background and near site dust samples.

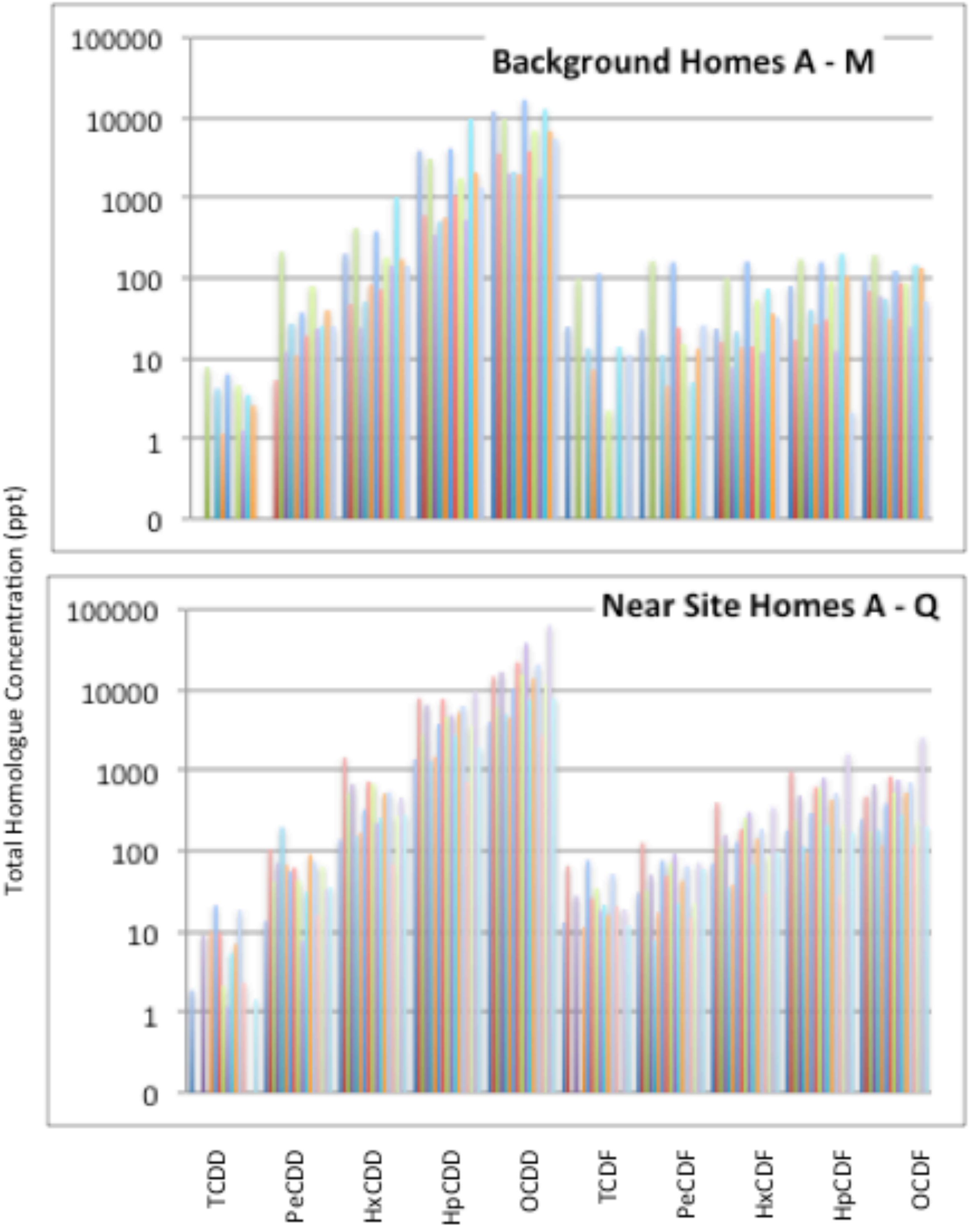


Figure 3-6 Total PCDD/F homologue concentrations in background and near site dust samples.

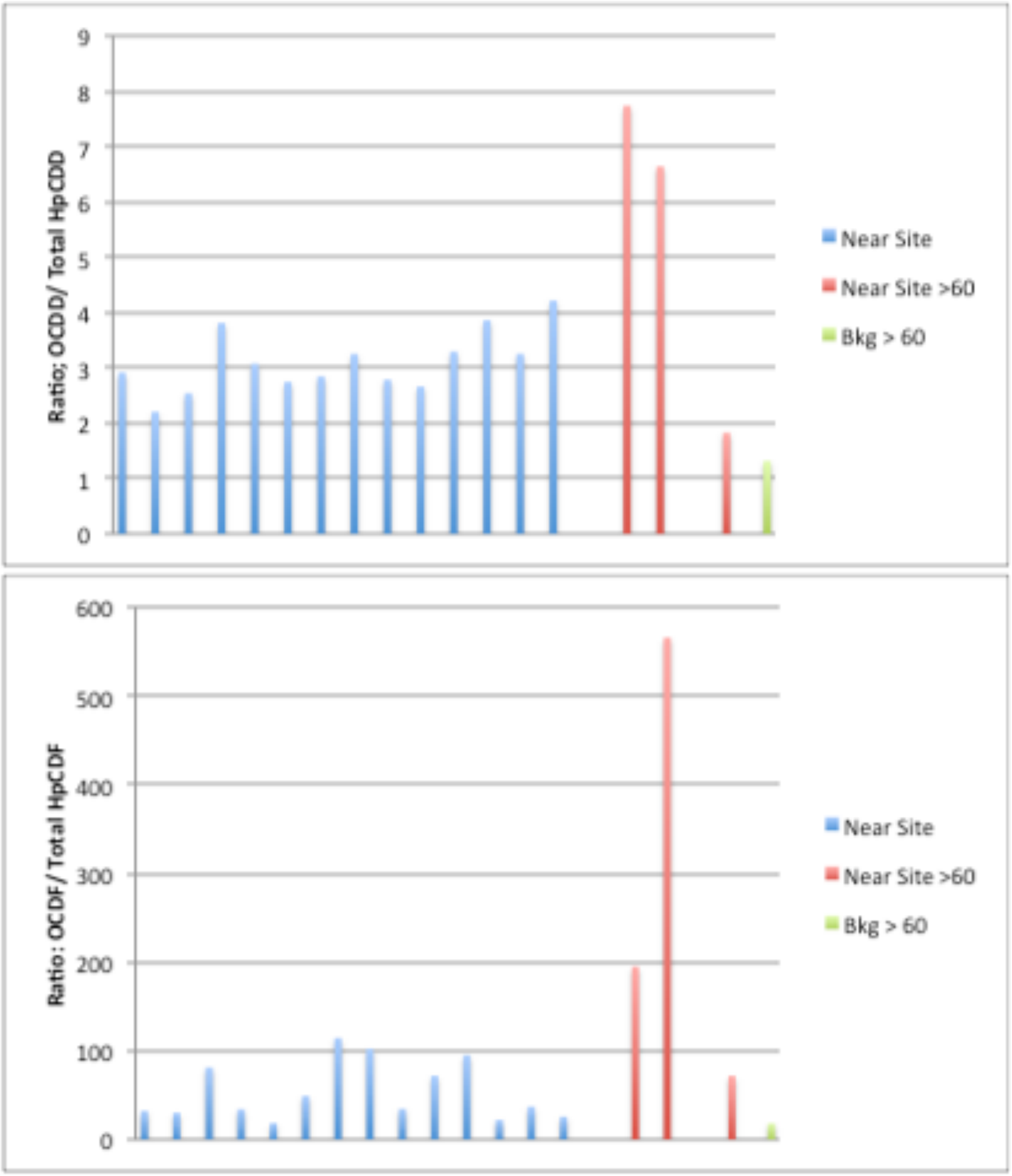


Figure 3-7 Homologue concentration ratios for dust samples with TCDD-TEQ concentrations greater than 60 ppt.

3.4 FORENSICS

While the previous sections help to understand the congener and homologue concentrations for the 30 dust samples, using forensic techniques we seek to compare the relative concentrations with patterns (or fingerprints) reported in other studies. This requires the following:

- Identifying potential “fingerprints” for comparison with our data set.
  - Dust profiles derived from published studies
  - Overview of information on wood treating and how environmental transformations may influence patterns.
  - Other potentially relevant sources
- Graphically presenting patterns, standardized consistent with commonly used forensic methods.

There are four approaches to standardizing and illustrating profiles for comparison. These are shown in Figures 3-8 to 3-11. The selection of profiles to be included in these figures are first discussed. Each standardization method is then described, and the patterns discussed.

3.4.1 Studies of Indoor Materials

While the composition of dust can vary, it is a combination of biologically derived material (fibers, pet dander, hair, food leftovers, pollen, skin flakes) as well as other indoor or outdoor particles that may enter through windows or brought in by foot traffic. In homes, cigarettes and cigarette smoke, paper products, dyes and pigments and textiles are among PCDD/F sources that have been reported.

Several studies directly characterize dust. The PCDD/F concentrations in vacuum bag samples in 40 homes from four areas of the US were evaluated by Deziel et al. (Deziel et al., 2012). Some were near potential sources (non-hazardous waste cement kilns, coal-fired power plants, sewage sludge incinerators and medical waste incinerators. The profiles presented represent the median concentration from these dust samples for the 2,3,7,8-substituted congeners. Observations made in this publication include:

- Congener profiles were similar across all homes from at all four sites and could not be distinguished from a non-specific background exposure profile.
- No relationship between home age and PCDD/F concentrations was found.
- Proximity to major roads and freight routes was associated with higher concentrations of some congeners primarily furans, recognizing the emissions from gasoline and diesel-powered vehicles are well documented.
- The median TEQ concentration was 20.3 ppt, and the interquartile range of 14.3 to 32.7 ppt (similar to the background dust in our study – median of 15.3 ppt, and the interquartile range was 6.4 to 34.6 ppt).

A study of the presence of dioxins in everyday materials including vacuum cleaner dust, room air filters, car air filters, clothes dryer lint, etc. reported 2,3,7,8-congeners and total homologue concentrations.(Berry, Luthe, & Voss, 1993) This study reported that TCDD-TEQ concentrations in plastic packaging and various paper products make a small contribution to the overall levels found in house dusts, furnace filters, car air filters, and clothes lint.

Because dust includes breakdown animal materials like food debris and animal and human hairs/dander, these are expected to contributed to the PCDD/F concentrations in the house dust. Recent measures suggest PCDD/F levels in our bodies are decreasing. Food is the major source (>90%) of human exposure to PCDD/Fs with most coming through intake of animal fats in fish, meat and dairy products. These have also been in some the foods of our pets. Dioxins can distribute preferentially to liver and fat tissues. However, they are also present in skin, oils secreted from glands and excreted in feces. One study of the intake and excretion of 20 PCDD/F and PCB congeners reported a daily intake of 84 pg TCDD-TEQ, with about 22% excreted from feces and 29% from sebum[7].(Kitamura, Nagahashi, Sunaga, Watanabe, & Nagao, 2001) They estimated each person excreted approximately one gram of sebum is each day, with a mean concentration of 24 ppt as TCDD-TEQ. [8]

Wastewater from residential areas are known to contribute PCDD/Fs to the wastewater treatment plants with the biggest source from laundering and bathing water. Studies completed in the mid-1990s (M Horstmann & McLachlan, 1994; Michael Horstmann & McLachlan, 1995) that found that detergents, bleaching agents and the washing cycle process itself were not responsible. They reported that homologue patterns measured in skin were similar to those found in textiles. However, they indicated based on the distribution in the skin layers that the transfer was from the textiles to the skin rather from the skin to the textiles.

It is possible that this issue requires further review. It is recognized that fibers from clothing are present in house dust (and textiles will accumulate dust). It is also likely dioxins secreted through our skin are transferred onto clothing. In addition, clothing may accumulate dioxins released from smoke (e.g. cigarettes, automobile emissions, wood burning), food spills, or other sources. Therefore, similarities in the profiles of these may be anticipated.

3.4.2 Overview of Sources

Many literature reviews and compilations of CDD/CDF sources have been published. An Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the United States for the Years 1987, 1995, and 2000 (EPA/600/P-03/002F, November 2006) (USEPA, 2006)is a peer reviewed report representing EPA's assessment of dioxin sources and their emissions to the environment. Over 800 references were reviewed and cited in the

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[7] Sebum is an oily or waxy material secreted by the sebaceous glands in the skin to lubricate and waterproof the skin and hair.

[8] Several references discuss increase retention of dust or contaminants in sebum, leading to increased potential for dermal absorption.

preparation of this USEPA report up to and including the year 2003, and includes consideration of comments received on the 2005 review draft. This report and updates are posted on the National Center for Environmental Assessment (NCEA) website. http://cfpub.epa.gov/ncea This source summarizes data used for profiles of various potential sources of interest including technical grade PCP, combustion sources and various potential in home sources (washing machine effluents, cigarettes).

Of the various potential industrial sources characterized by EPA, the use of PCP for wood treating is the industrial source most pertinent to this study. The PCDD/F concentrations in technical grade PCP can vary with the manufacturer and has varied over time. PCP was used at the Site from approximately 1969-1990. In 1987 regulations were imposed limiting HxCDD and 2,3,7,8-TCDD concentrations in PCP leading to overall decreases in the overall TEQ content. Technical grade PCP contains 85-90% PCP. Other chlorophenols may be present in concentrations from 2-8%. PCDD/Fs may be present at levels of about 0.1%. Additional contaminants that form during manufacture of PCP include polychlorodiphenyl ethers. The principal PCDD/Fs in technical grade PCP are those with six to eight chlorines, typically with OCDD and HpCDDs at the highest concentrations, with OCDF and HpCDF also present.

Because transformations can occur, the profile of PCDD/Fs in onsite soils may differ from their initial content in the PCP. EPA also summarized studies on the formation and degradation of PCDD/Fs highlighting that the congener profile may change over time as a result of biodegradation and/or photolysis.

- Biotransformation of chlorophenols can occur (e.g. in composting), typically dominated by the hepta- and octa-substituted CDD/CDFs.
- Under anaerobic conditions, microbial dechlorination of CDD/CDFs have been reported.
- Photolysis can play a role in the formation of CDDs from PCP, and photolysis of OCDD has been shown to result in production of lower chlorinated CDDs. The dechlorination of OCDD/OCDF favors removal of the chlorines in the 1,4,6, or 9 positions, enriching the levels of the 2,3,7,8-substituted congeners which are associated with the higher toxicity.

Regulatory actions since the 1980s have reduced the amount of dioxins released into the environment from these a number of industrial sources in the US. Currently, the uncontrolled burning of residential waste and accidental fires at landfills are thought to be among the largest sources of dioxins in the US. In general, combustion is a primary source of PCDD/Fs. This includes fuel combustion (e.g. oil, gasoline, diesel, coal and wood/forest fires). There are several smaller sources that do not significantly contribute to the total emissions on a national scale but may be present on a more local level. For example, evidence exists that fireworks can release these compounds to air and solid residues.

Other potential outdoor sources that may contribute to levels of PCDD/Fs in house dust may include exhaust from automobiles, lawnmowers, and other internal combustion engines, and smoke from grills, fireplaces and debris/trash fires. It would typically be assumed that dioxins associated with air emissions from vehicles would enter our homes with normal air exchange. However, higher levels may be present in the air in attached garages, and these may adsorb on particulates, clothing or other materials and be carried into homes.

3.4.3 Profile Evaluation Methods

Interpretation of the potential risks associated with PCDD/Fs are based the relative toxicity and abundance of the seventeen 2,3,4,8- congeners. In addition to these seventeen individual compounds, the laboratory provides results for the total homologue concentrations. While two samples may have similar TCDD-TEQ concentrations, the relative proportions of each of the congeners may vary, and these patterns may provide information on sources and how these may have changed over time (weathering).

There are many was to explore these complex data sets to better understand the underlying patterns and potentially recognize potential sources. The first step is to compare profiles of the relative concentration of either the commonly reported seventeen 2,3,7,8-substituted congeners or the 10 homologue classes. These approaches "standardize" the data profiles for samples from a variety of sources or concentrations, highlighting the relative contribution of each component. The pattern inherent in a source area with very high concentrations can then be compared with media like soils or sediments with much lower concentrations.

Four approaches for comparing profiles of individual samples have been summarized for dioxins and furans (Shields, Tondeur, Benton, & Edwards, 2006), a book chapter from "Environmental Forensics: A Contaminant Specific Guide". In this section, the average concentrations in soil or dust are compared with profiles reported for a variety of potential relevant sources.

There are several factors considered when exploring these data to clarify these patterns:

1. Environmental transformations may change ratios of congeners.
2. Multiple sources present in homes can mask the individual signatures
3. Published data from different studies for a particular source may differ.
4. Analytical data; reliability and frequency of non-detects can alter patterns

The appearance of a profile can vary significantly in the scale used to summarize the data. This includes not only the minimum and maximum, but whether a log or linear scale is used. For consistency, the profiles in this report are displayed consistent with Morrison and Murphy (2006). Multiple methods are used, each uniquely highlighting characteristics of the sources.

Before showing standardized profiles from various sources, it is useful to understand how these visually compare with the concentration graphs presented previously. When standardized, there are some changes to the appearance that may alter our impression of the importance of compounds. For example, background soils have low total concentrations. Detection of compounds with 4-6 chlorines would appear as a more significant peak, even though these would make a negligible contribution to the concentrations of these in dust samples.

3.4.4 "2,3,7,8-Sum" Standardization Method

For this commonly used approach, each reported 2,3,7,8-substituted congener is divided by the sum of the 2,3,7,8-substituted congeners reported. These are commonly shown on a log scale, with relative concentrations ranging from 0.1 to 100 percent. This is illustrated on Figure 3-8.

- Dust sample patterns are generally similar to patterns for other vacuum clean dust samples, washing machine effluent, and clothes dryer lint – as well as site soil and dioxin/furans present in PCP.
- The five congeners in dust samples that can be observed using this scale, account for approximately 99.6% of the sum of all the 17 congeners. This scale shows all congeners that contribute more than 0.1% of the total concentration.
- Wood treating sites are recognized as having predominantly the higher molecular weight dioxins, OCDD and 1,2,3,4,6,7,8-HpCDD. The higher molecular weight furans contribute about 7% to the total concentration.

For this method and scale, the low concentration congeners are masked by the relatively high concentrations of OCDD and HpCDD that are present in many samples. Presenting the relative concentrations on a truncated scale, or expanding the scale too much will show the differences in the low-percentage congeners, but the differences in the major contributing congeners become difficult to see and the low concentrations congeners can be exaggerated to an extent not justified by the analytical uncertainty.

3.4.5 "Relative Homologue" Standardization Method

Each homologue class consists of all possible orientations of the chlorines on the dioxin or furan structures. For example, there are 14 distinctly different PeCDD congeners, only one of these has chlorines in the 2,3,7,8-substituted positions (See Table 1-1). For this method, the concentration of each 2,3,7,8-substituted congener is divided by the concentration of its respective homologue class. For example, the1,2,3,7,8-PeCDD concentration is divided by the total PeCDD concentration. In this way, each class is considered separately and not dominated by concentrations of the major contributors. There is only one congener for OCDD or OCDF. For these, the OCDD concentration is divided by the sum the concentration of all the 2,3,7,8 dioxins and OCDF by the sum of all the 2,3,7,8 furans.

Profiles using this approach are shown in Figure 3-9.

- In PCP and site soil, both OCDD and OCDF represent over 80% of the sum of 2,3,7,8-dioxins and furans respectively. These proportions are lower in dust and some other sources.
- There are only two congeners for HpCDD, one of these substituted at the 2,3,7,8-positions. If present in equal amounts, as in the background dust, 1,2,3,4,6,7,8-HpCDD would be 50% of the total. However, this congener is a lower percentage in site soil and near site dust samples.

- While there are 4 HpCDF congeners, 1,2,3,4,6,7,8-HpCDF is typically at the highest concentration, frequently much greater than 25%, and as high as 60% in background dust.
- Based on the relative numbers of congeners in each class, the 2,3,7,8- proportions for congeners with 4-6 chlorines may range from ~2-10 percent if all are present at equal concentrations, so the percentages of these congeners as shown on the profile are typically lower. However, many 2,3,7,8- congeners are present at a higher proportion of the total homologue class.

3.4.6 “Relative TEQ” Standardization Method

For this method, the TEQ for each 2,3,7,8-congener is divided by the TEQ for the sample. This highlights which congeners contribute to the toxicity, and the dominance of OCDD does not mask patterns of the low concentration congeners. Dust and soil profiles are compared to other sources on Figure 3-10.

These patterns are more complex. The PCDD/Fs with 4-5 chlorines appear to contribute a significant proportion to the overall toxicity, however the variability and uncertainty in the concentrations are greater. Several sources are shown that may contribute to levels of these congeners in dust samples, that do not make a significant contribution to the TEQ of dioxins in technical grade PCP.

3.4.7 “Total Homologue” Standardization Method

For this method, each homologue class is divided by the total PCDD/Fs. These show gross differences in classes, and better represent the sum of all the congeners in the homologue classes with 4-6 chlorines. These are shown on Figure 3-11.

Although the dominant contributors in dust remain to be the higher molecular weight compounds, contributions from lower molecular weight PCDD/Fs are present (typically less than 1%). These may be associated with a range of potential other sources and/or lower relative concentrations of OCDD and total HpCDD.

3.4.8 Standardization Profile Discussion

Effort was expended reviewing literature on sources and developing standardized profiles for comparison with dust and soil samples evaluated in this report. Examples of these standard profiles are documented in this section.

The general overall profile in dust samples are similar to those reported in the literature, with the major contributors to the concentrations from the higher molecular weight congeners. Use of the average concentrations for these profiles does not appropriately reflect the significant variability found within homes. However, when standardized and placed on the scale used for comparing profiles, results follow a consistent pattern.

Profiles compiled from the literature are examples or averages that do not necessarily reflect the source variability that may be relevant for comparisons in our study. There are similarities in the congener profiles of PCP, diesel truck emissions, unleaded gasoline vehicle emissions and emissions from wood combustors. In these sources, OCDD dominates total emissions, and the relative ratio of 1,2,3,4,6,7,8-HpCDD to OCDD are also similar.

In a study of PCDD/Fs in house dust from 40 homes, Deziel et al. (2012) reported similar congener profiles across all homes at all four areas of the U.S. sampled, and could not be distinguished from a non-specific background exposure profile. It was stated this is consistent with other studies showing that beyond the immediate vicinity of a source, the congener profile becomes less distinct. As reported by Ames et al (2012), “for a signature profile or marker to be useful in practice, the absolute impacts must be sufficiently large to be observable above the variability in the background levels.”

Other approaches (e.g. principle component analysis) were also applied, but the complexity of the patterns were not as direct and transparent as the differences presented in Section 3.3 of this report.

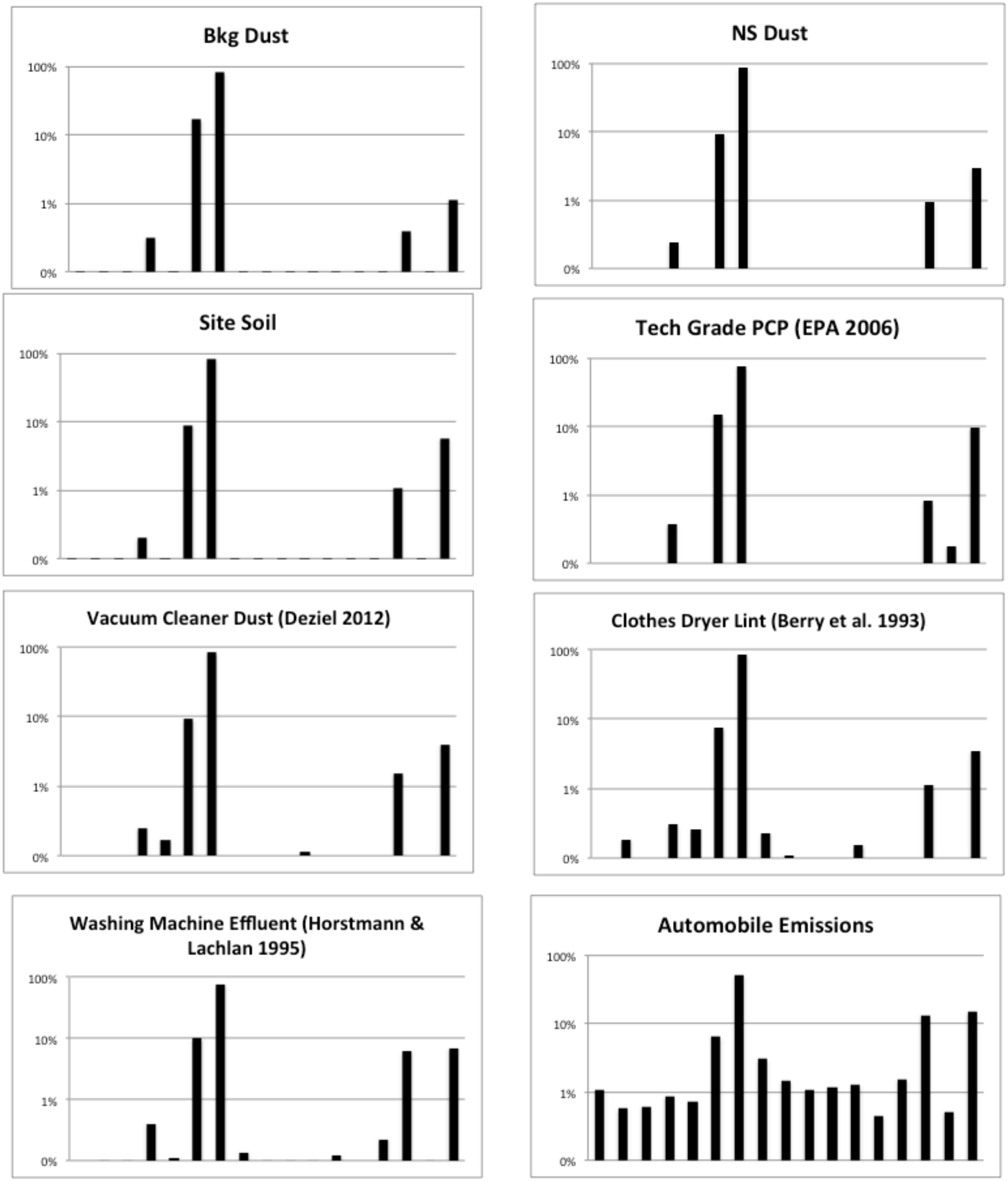
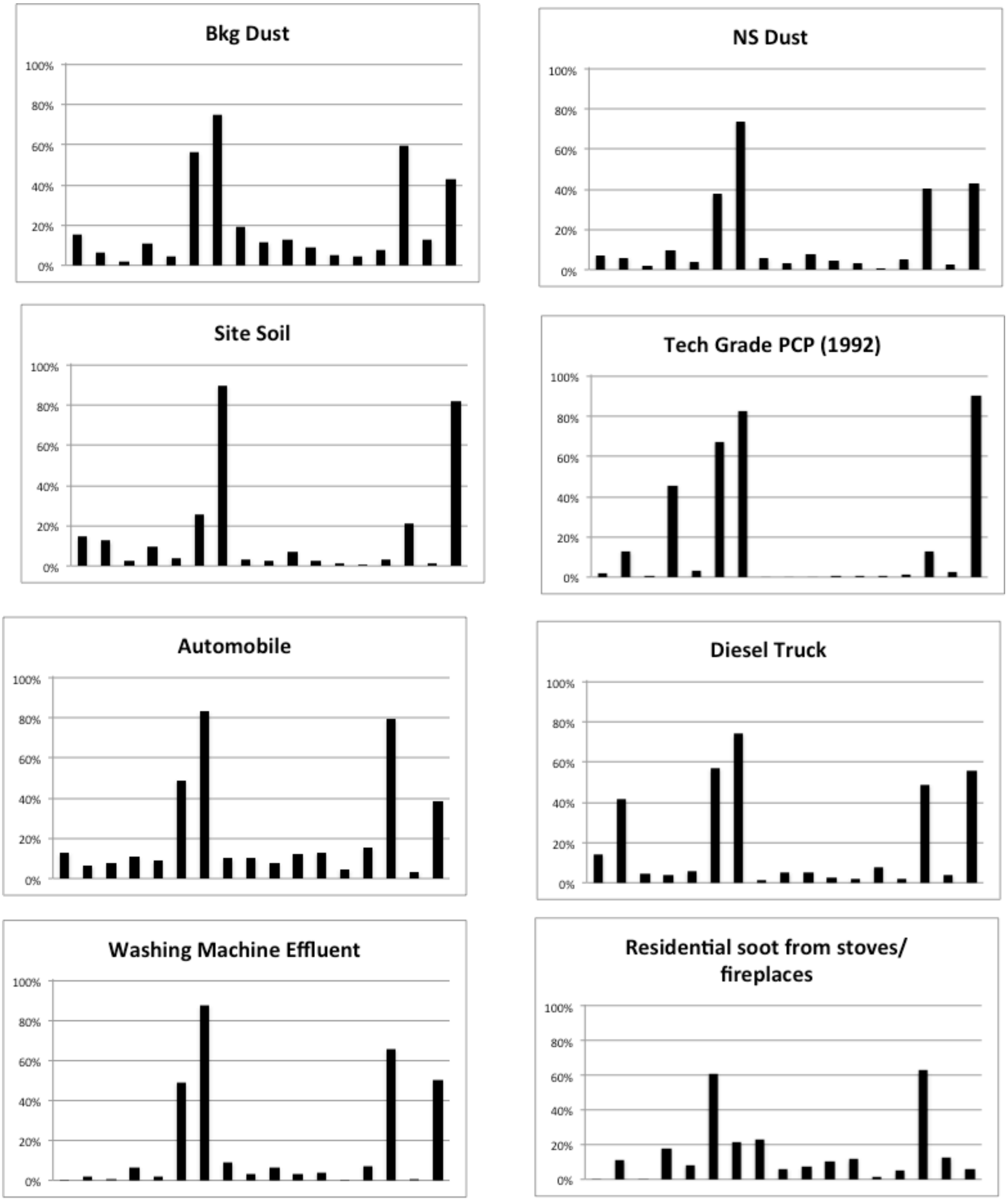


Figure 3-8 Congener profiles for project samples and example sources standardized by the “2,3,7,8-sum” method.



Bkg Dust

NS Dust

Site Soil

Tech Grade PCP (1992)

Automobile

Diesel Truck

Washing Machine Effluent

Residential soot from stoves/ fireplaces

Figure 3-9 Profiles for site samples and sources by the "relative homologue" standardization method.

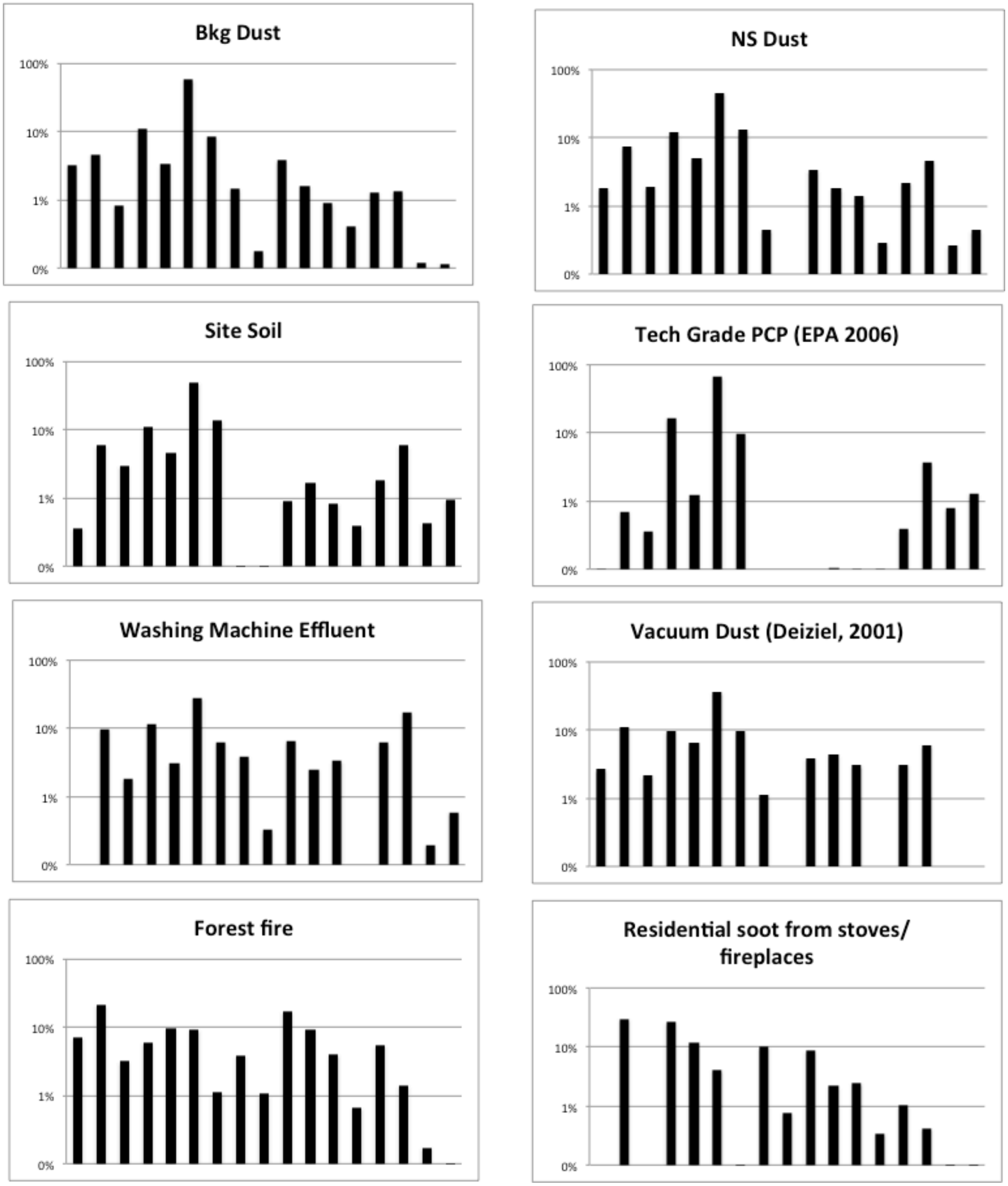


Figure 3-10 Profiles by the "Relative TEQ" standardization method.

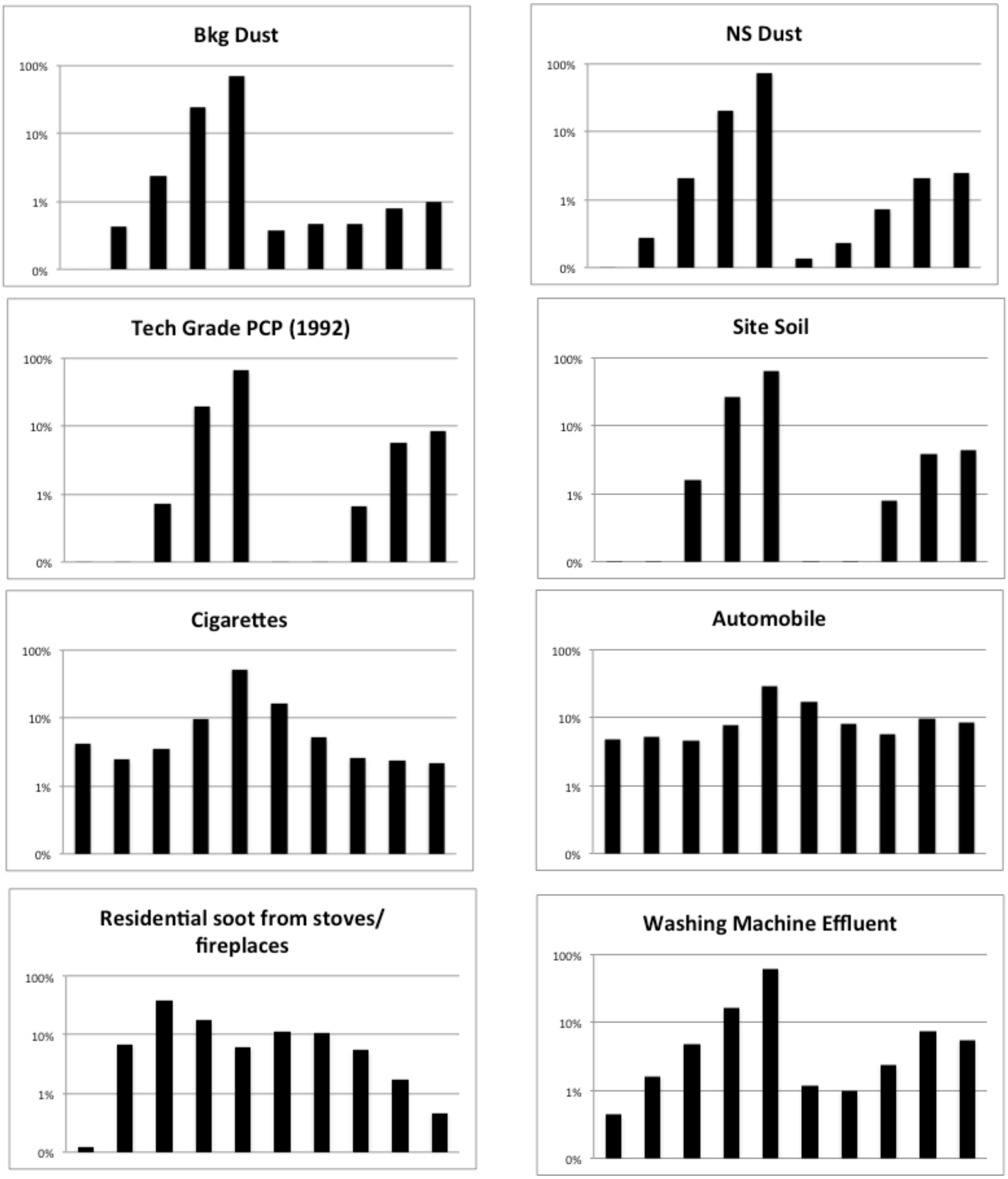


Figure 3-11 Profile comparisons by the "total homologue" standardization method.

4 BROMINATED DIOXINS/FURANS IN HOUSE DUST

Several studies in recent years have indicated that polybrominated dioxins and furans (PBDD/Fs) may be present in our homes associated with the use of polybrominated diphenyl ethers (PBDEs) used as flame retardants in plastics, textiles and paints.

4.1 SOURCES

To place the presence of PBDD/Fs in house dust samples in context, basic information on the sources of these are highlighted in this section.

4.1.1 What are PBDEs and how do they relate to the PBDD/Fs?

The terminology for understanding PBDEs is similar to dioxins. These are mixtures of chemicals with varying numbers and arrangement of bromines on the ring structure. (See Figure 4-1). There are a total of 209 different possible PBDE congeners, however, there appear to be many fewer actual congeners in commercial mixtures largely because many of them lack stability and tend to debrominate. (Birnbaum and Staskal 2003). The major commercial PBDEs historically used as flame retardants are:

- PentaBDE – Predominantly congeners with 5 bromines, but typically a mixture for triBDE to hexaBDE congeners (congeners containing 3-6 bromines). The major congeners are number 47 (TBDE) and 99 (pentaBDE)[9]
- DecaBDE –approximately 97% of the commercial products are the fully brominated BDE congener with 10 bromines (number 209), but may include other congeners, particularly those with 9 bromines (nonaBDE)

These flame retardants can have traces of PBDD/Fs, and (Ren et al 2011, Brown et al 2001). In addition, furans can form from PBDD/Fs through intra-molecular elimination of Br2 or HBr. For example, the elimination of Br2 from decaBDE (10 bromines) would form OCDF (8 bromines).

Among the twelve 2,3,7,8-substituted tetra- to octaBDD/Fs, the lower brominated congeners were generally more toxic and more stable than the higher brominated congeners. (Ren et al 2011).

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[9] Each congener is assigned a number from 1-209. The congener numbers and the location/number of the bromines are included in the toxicological profile. http://www.atsdr.cdc.gov/toxprofiles/tp68-c6.pdf

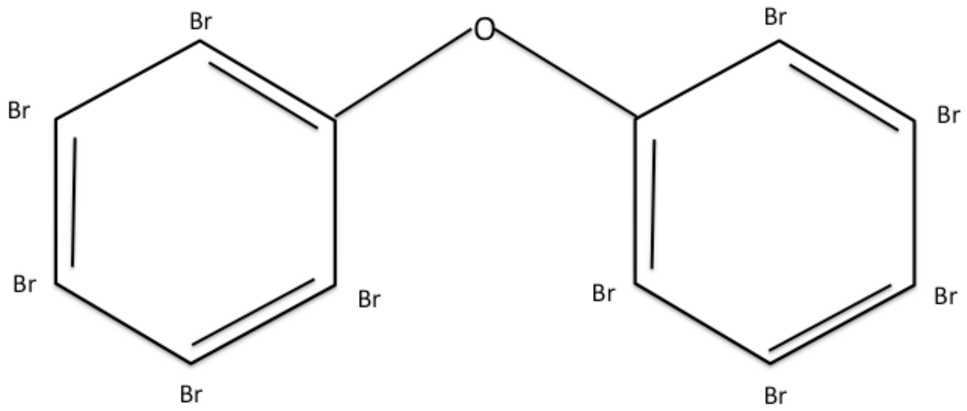

Figure 4-1 Polybrominated diphenyl ethers have 209 potential congeners with number of bromines ranging from 1 to 10. Shown is the fully brominated decaBDE.

4.1.2 How have PBDEs been used?

PentaBDE – is a viscous liquid used primarily in textiles and as an additive in polyurethane foams, where up to 30% of the weight of the foam can be accounted for by this flame retardant. Birnbaum and Staskal 2003) This is found in materials including foam furniture, mattresses, automobile seats.

DecaBDE – are plastics in found in electronics, wire/cable insulation, textiles

These are physically, rather than chemically, combined with polymers so some my diffuse out of the treated materials to some extent.

4.1.3 Why are/were chemical flame retardants used?

Flame retardants are used to prevent ignition by increasing the threshold required to start a fire and reduce the spread of fire. According to the NFPA statistics, upholstered furniture, as either the first item ignited or the principal item contributing to fire spread, played a part in nearly a quarter of all deaths in home structure fires in recent years. The number of fires has decrease significantly since 1980 with decreases in smoking, use of smoke alarms, etc.

A California furniture flammability standard called Technical Bulletin 117 (TB 117) was passed in 1975, and the standard was met by addition of flame retardant chemicals. This became, in effect, an approach that was used nationally. PBDEs were used most often to meet the standard. The majority of the world's use of pentaBDE was in the US resulting in the US body burdens of PBDEs to be 10 times higher than those of Europeans.

The effectiveness and need for the use of chemical flame retardants has been challenged, suggesting they do not prevent ignition, reduce fire severity, or provide increased escape time. A new law (TB 117-2013) took effect in January 2014 that changed the flammability test, allowing furniture makers to meet this standard without necessarily using flame-retardant chemicals.

4.1.4 How are they regulated?

In the United States, only chemicals in foods, drugs, and pesticides are regulated prior to reaching the marketplace. There is no requirement for health data nor sufficient authority to regulate other chemicals. The Toxic Substances Control Act (TSCA) must identify and establish a chemical poses an unreasonable risk before regulating a chemical. When some of the halogenated flame retardants, including PBDEs) were studied, they were found to be persistent and have health consequences.

The EPA Office of Pollution Prevention and Toxics (OPPT) manages programs under TSCA. Under these laws, EPA is to evaluate new and existing chemicals and their risks, and find ways to prevent or reduce pollution. They also manage environmental stewardship programs that encourage companies to reduce and prevent pollution.

Under this program there was a voluntary phase out on the manufacture and import of penta- and octaBDE in 2004. EPA is supporting and encouraging the voluntary phase-out of manufacture and import of decaBDE, with all sales to cease by December 2013. The European Union passed a ban on PBDEs in 2002.

While we focus on PBDEs in our report, it is important to recognize that other chemicals may be used as flame retardants, and manufacturers are not required to report what is used in consumer products. EPA began an evaluation of possible chemical alternatives to the use of decaBDE.

4.2 WHAT HAS BEEN LEARNED ABOUT THEIR PRESENCE IN HOUSE DUST?

Studies indicate that concentrations of PBDEs in house dust can be highly variable. EPA reviewed these studies as part of their exposure assessment (USEPA, 2010a)and determined the data were insufficient to derive concentrations that could be considered statistically representative. However the average or geometric mean of the concentrations were used for the assessment. This included the following concentrations for the dominant congeners:

Congener	Indoor dust concentration (ppb)[10]
BDE47 (tetraBDE)	1857
BDE99 (pentaBDE)	2352
BDE209 (decaBDE)	2394
Total BDE	8154

Allen et al. 2008 reported concentrations in vacuum bags from 20 homes. The decaBDE congener concentrations ranged from 235-268,000 ppb, the pentaBDEs ranged from 201-18,130 ppb. (Allen et al., 2008)

The dominant PBDE congeners tend to be associated with decaBDE (predominantly BDE209) or pentaBDE, where the primary congeners are tetraBDE (BDE47) and pentaBDE (BDE99).

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[10] Concentrations of PBDEs are generally reported in ng/g, which is equivalent to parts per billion (ppb), as opposed to ppt concentrations reported for dioxin/furans.

PBDD/Fs that may be associated with the PBDEs are found at concentrations four to five orders of magnitude lower.

4.3 HOW DOES THE TOXICITY OF BROMINATED DIOXINS/FURANS COMPARE WITH CHLORINATED ANALOGS?

Point 1. There are uncertainties in estimating toxicity/risks. The response in the CALUX Assay is only one potential measure.

For our study, we are focused on the response of brominated dioxins/furans in the CALUX assay as an indication of potential toxicity of dust samples. The CALUX assay is one protocol that measures the relative potency (REP) of a dioxin-like compound compared to TCDD. There is a difference between REP and the TEFs that are used to estimate risk for chlorinated dioxin/furans.

- Relative potency value or REP. Numerous toxicity studies have been completed for TCDD, the index chemical for defining toxicity of dioxin-like compounds. A database was established by WHO of all identified studies completed by a single laboratory and single endpoint that provides a numerical value for a dioxin-like compound (DLC) that can be compared to TCDD. This is defined as "relative potency" or REP. These may include in vivo, in vitro, chronic, acute, etc. studies. CALUX is one assay that can measure the response of PBDD/Fs relative to TCDD.
- TEF. The term TEF describes an order-of-magnitude consensus estimate of the toxicity of a compound relative to the toxicity of TCDD that is derived using scientific judgment of all available REP data. The uncertainty is considered to be an order-of-magnitude

Screening assays like CALUX may be used for analyzing soil, sediment, food etc. but results are considered qualitative, requiring confirmatory analysis by definitive methods. Ultimately, it must be established that the compounds not only activate the AhR pathway, but show dioxin-like adverse effects and persist in biological systems.

Point 2. Different in vitro assays generate different REPs for PBDD/Fs and other toxicity tests on these compounds are limited. On an interim basis, use of the TEFs for the chlorinated analogs has been recommended.

A joint WHO and United Nations Environment Programme (UNEP) expert consultation took place in 2011 to consider the possible use of TEFs for brominated analogues of the dioxin-like compounds. The panel concluded that PBDD/Fs may contribute to daily human background exposure to TCDD-TEQs. As summarized by Vandenberg et al (2013) "If the assumed uncertainty of one order of magnitude in WHO TEFs is taken into account, it can be concluded that the relative potencies of 2,3,7,8- substituted PBDD/Fs are comparable to their corresponding chlorinated congeners in mammalian systems." It was recommended that these be included in the TEF approach for evaluating potency of dioxin-like compounds.

As part of this evaluation, the panel summarized ranges of combined in vivo and in vitro relative potencies compared to the WHO 2005 TEFs. Table 4-1 compares these ranges with the WHO 2005 TEFs, and REPs measured in the DR-CALUX (D'Silva et al. 2004) and XDS-CALUX (Samara et al. 2009) assays. The DR-CALUX REPs were used in 2012 to estimate a CALUX-TEQ (FDOH 2012). The samples from this study were analyzed by XDS laboratory. Therefore the XDS-CALUX REP would be expected to reflect the response to chlorinated and brominated dioxin/furans in the dust samples analyzed.

Table 4-1 Chlorinated and brominated dioxin/furan TEFs and range of relative potencies (REPs)

Congener	WHO 2005 TEF	Range of REPs (van den BERG et al. 2013)		DR-CALUX REP	XDS-CALUX REP	
		Chlorinated Congeners	Brominated Congeners		Chlorinated Congeners	Brominated Congeners
PXDD						
2,3,7	n.d.	0.0008 - 0.015	<0.0001 – 0.85		0.0025	0.0017
2,3,7,8	1	1	0.02 – 8.45[c]	0.54	1	0.99
1,2,3,7,8	1	0.54 - 0.73	0.02 – 1.4	0.49	0.69	0.05
1,2,3,4,7,8	0.1	0.075 - 0.3	0.01 – 0.12	0.001	0.3	0.03
1,2,3,6,7,8	0.1	0.098 - 0.14	0.015 – 0.30			
1,2,3,7,8,9	0.1	0.061 - 0.066	0.017 – 0.15			
1,2,3,4,6,7,8	0.01	0.031 - 0.046	n.r.[e]			
1,2,3,4,6,7,8,9	0.0003	0.0034 - 0.00047	≤ 0.00009 – 0.00035			
PXDF						
2,3,7	n.d	n.d.	0.0008 – 0.0015			
2,3,8	n.d.	n.d.	0.00003 – 0.0013			
2,3,7,8	0.1	0.067 - 0.32	0.10 – 0.97	0.49	0.07	0.41
1,2,3,7,8	0.03	0.14 - 0.21	0.004 – 0.69	0.41	0.24	0.11
2,3,4,7,8	0.3	0.5 - 0.58	0.08 – 0.4	0.001	0.46	0.4
1,2,3,4,7,8	0.1	0.013 - 0.13	0.008 – 0.09		0.3	0.03
1,2,3,6,7,8	0.1	0.039 - 0.14	n.r.			
1,2,3,7,8,9	0.1	0.18 - 0.31	n.r.			
2,3,4,6,7,8	0.1	0.11	n.r.			
1,2,3,4,6,7,8	0.01	0.024 - 0.029	0.0014 – 0.004	0.002		
1,2,3,4,7,8,9	0.01	0.04	n.r.			
1,2,3,4,6,7,8,9	0.0003	0.0065	n.r.			

n.d. not determined. n.r. not reported

DR-CALUX REPS from D'Silva et al. 2004; XDS-CALUX REPS from Samara et al. 2009.

"X" - halogen; either bromine or chlorine.

4.4 CONGENER/HOMOLOGUE CONCENTRATIONS

The frequency of detection of the PBDD/F congeners and total homologues reported by the laboratory for the 30 home dust samples collected by EPA standard protocol are shown on Table 4-2. For the PBDD/Fs, there is no distinction between background and near site samples for these compounds.

Table 4-2 Summary of PBDD/F detected concentrations (ppt) for dust samples from 30 homes.

Analyte	Count	Min	Max	Average	Median
Dioxin Congeners					
2,3,7,8-TBDD	0				
1,2,3,7,8-PeBDD	0				
1,2,3,4,7,8/1,2,3,6,7,8-HxBDD	0				
1,2,3,7,8,9-HxBDD	0				
1,2,3,4,6,7,8-HpBDD	10	19.1	104	64	
OBDD	8	52.3	632	234	
Furan Congeners					
2,3,7,8-TBDF	0				
1,2,3,7,8-PeBDF	6	72.8	2810	1124	
2,3,4,7,8-PeBDF	0				
1,2,3,4,7,8-HxBDF	8	14	608	226	
1,2,3,4,6,7,8-HpBDF	28	132	52300	6988	3285
OBDF	29	403	570000	88569	46200
Total Homologues					
Total TBDD	2	3.25	85	44	
Total PeBDD	0				
Total HxBDD	0				
Total HpBDD	11	19.1	104	67	67
OBDD	8	52.3	632	234	247
Total TBDF	30	267	379000	53917	11200
Total PeBDF	22	329	30200	7103	5485
Total HxBDF	17	76.8	13550	1508	502
Total HpBDF	30	132	52300	6740	3285
OBDF	29	403	570000	88569	46200

4.4.1 Which congeners and homologues are present? What is the reason?

Congeners. OBDF is the congener with the highest concentration, with 1,2,3,4,6,7,8-HpBDF the other frequently detected congener with elevated concentrations. The concentration of HpBDF was on average, 9% of the concentration of OBDF for the 30 dust samples.

OBDF and HpBDF are present in commercial mixtures of decaBDE (Ren et al., 2011). Comparing mean PBDD/F dust concentrations from an e-waste recycling facility,

> OBDF was present at 0.3% of the concentration of BDE-209, and 1,2,3,4,6,7,8-HpBDF was present at 12% of the concentration of OBDF. These two congeners comprise over 98% of the total PBDD/Fs (Ma et al., 2009).

Over 99% of the congeners/homologues were furans.

> Furans form PBDEs by an intramolecular elimination of Br_2/HBr. (Ren et al., 2011) Dioxins can form in low amounts and require insertion of oxygen, a less favorable reaction at normal temperatures.

Total TBDF was present in all samples and frequently at high concentrations. However, 2,3,7,8-TBDF was not present above the detection limit in any of the samples.

> PBDFs form from the elimination of 2 bromines, or a bromine and hydrogen from the molecule. Elimination of HBr is favored for the lower molecular weight PBDEs. Therefore, BDE-44 which is present in commercial pentaBDE would likely form TrBDF (3 bromines) which are not reported in this analysis.
>
> BDE-99, ~45-50% of commercial pentaBDE mixtures, form TBDF from the elimination of HBr. The options for the bromine to be eliminated, and the orientation of the remaining bromines on the furan ring are limited, and could not result in formation of 2,3,7,8-TBDF.

Highest frequencies of detection and concentration of the total homologues are for the furans, with OBDF and total TBDF typically accounting for 90% or more of the sum of the total furan homologues. However, relative percentages of these homologues differ among dust samples from the 30 homes. This is illustrated on Figure 4-2. Samples range from nearly 100% total TBDF to nearly 100% OBDF. This is not a function of the total concentration. Figure 4.3 highlights that the proportion of TBDF and OBDF are not correlated with the total concentration, and that the remaining homologue concentrations are typically less than 10% of the total PBDF concentration.

> OBDF is indicative of a source of decaBDE treated materials in the home, while TBDF would be indicative of pentaBDE treated materials. The distinctive differences among homes appear to be related to the presence of specific electronics and/or foam furniture. Photolysis of decaBDE in textiles exposed to natural sunlight have been shown to increase the concentrations of furans.(Kajiwara, Desborough, Harrad, & Takigami, 2013)

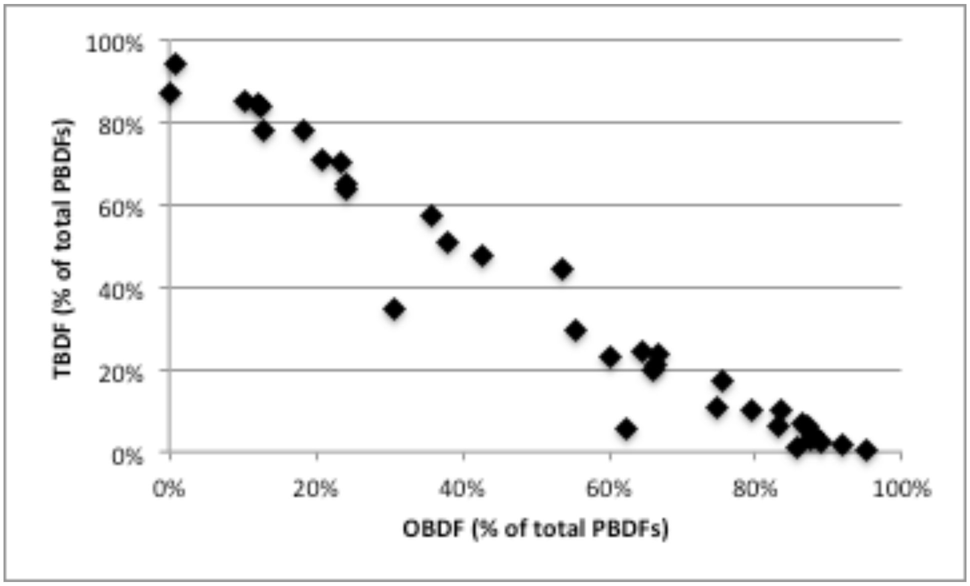

Figure 4-2 Percentages of the total PBDF homologues represented by OBDF and total TBDF. These comprise over 80% of the total PBDFs in all but one dust sample.

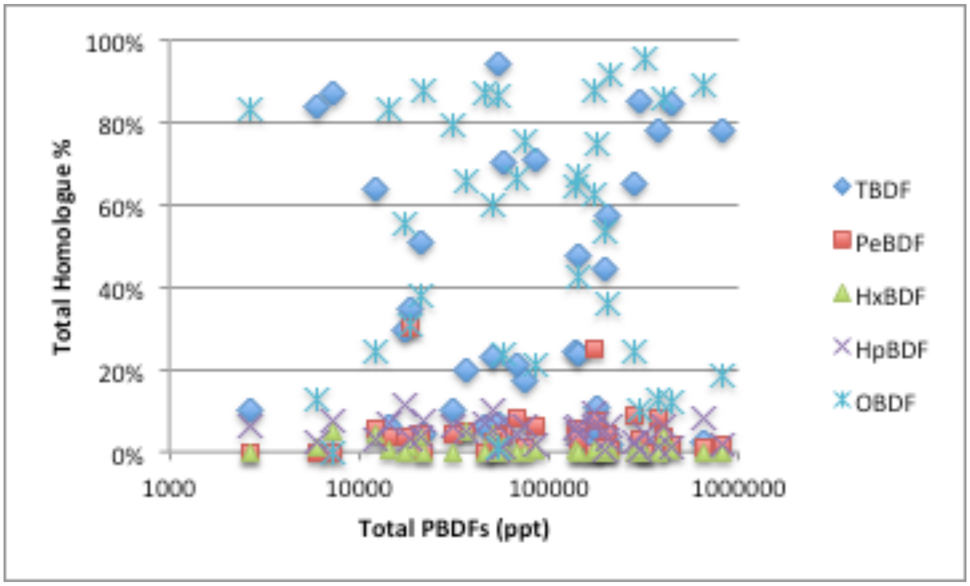

Figure 4-3 Total homologue percentage for each of the furans as compared to the sum of all PBDF homologues.

4.5 TOXICITY EQUIVALENTS, RELATIVE POTENCY AND BIOLOGICAL EQUIVALENTS

TEQ estimates will vary when using the 2005 WHO TEFs as compared to the REPs derived from the CALUX assays. The biological equivalent (BEQ) of the mixture of dioxin/furans as measure by XDS was expected to reflect the REPs reported in the literature for this laboratory. These calculated and measured values are shown on Table 4-3.

Table 4-3 Theoretical TEQ concentrations (ppt) for the chlorinated and brominated dioxin/furans in dust samples and the reported CALUX-BEQ.

House ID	PCDD/F WHO-TEQ	Brominated Dioxin & Furan-TEQ			CALUX-BEQ
		WHO-TEQ	DR-CALUX	XDS-CALUX	
Background Area					
A	34	41	5.7	<0.1	11.5
B	5.37	140	1160	393.4	47.5
C	35.1	694	105	0.1	52.0
D	2.66	227	33.8	282.1	27.9
E	6.34	126	19.9	163.5	30.5
F	6.45	23	3.4	0.0	12.0
G	47.6	416	62.4	407.4	84.5
H	6.69	79	12.2		24.2
I	18.3	7			
J	6.52	125	635	212.8	8.3
K	77.3	17			
L	18.2	27	206	70.0	200.7
M	15.3	123	18.9		
Near Site Area					
A	11.4	3	0.5	9.4	15
B	72.3	6	1.1	0.0	22
C	29.2	46	6.2	<0.1	33
D	38.1	39	161.8	109.0	74
E	8.92	231	27.8	<0.1	42
F	13.4	226	36	0.0	43
G	27.6	17	32.1	37.9	7
H	50.6	87	605	279.4	39
I	42.9	2	0.4	<0.1	54
J	60.3	60	10.2	0.0	54
K	17.5	184	28.6	188.9	55
L	37.6	2	0.3	0.0	25
M	44.9	8	1.2	0.0	29
N	6.78	53	7.7	0.0	8
O	27.7	45	2.8	0.0	16
P	90.9	23	3.9	0.0	150
Q	19	43	5.7	<0.1	34

4.5.1 How do the estimated TEQs for the brominated dioxins/furans compare with levels calculated for the chlorinated congeners?

The TCDD-TEQs calculated for the chlorinated dioxins/furans were all below 100 ppt. For the brominated congeners, the theoretical TEQs differ based on the TEFs or REPs used for the estimate. For the 2,3,7,8- brominate substituted congeners, theoretical TEQs above 100 ppt were calculated by each approach for several of the 30 homes.

- WHO TEQs: 10 homes had a TEQ above 100 ppt.
- DR-CALUX REPs: Six homes had concentrations above 100 ppt, but for five of these, the concentrations were much higher than calculated by other methods.
- XDS-CALUX REPs: Eight homes had estimated TEQs above 100 ppt (five in the background neighborhood, and three in the near site neighborhood).

4.5.2 Why are the calculated TEQs so different?

There is no standard protocol to estimate the toxicity of brominated dioxin/furans as compared to the extensive studies conducted on the chlorinated compounds. Individual tests – for example different bioassays – can vary significantly in their responses to different compounds in the mixtures.

The TEFs developed for the chlorinated compounds incorporate results from a number of tests, and may not relate directly to any single in vitro test. There is a WHO TEF for each of the congeners, including the higher molecular weight furans which showed little or no response in the bioassay. Conversely, the TEQs for the CALUX assays tend to be higher for those six samples with detectable 1,2,3,7,8-PeBDF, since the REPs are higher than the WHO TEF.

Because of the different TEFs used in the calculations, both the magnitude of the estimated TEQ, and the compounds that contribute to the toxicity, are dissimilar (Figure 4-4). This illustration emphasizes the uncertainties currently associated with interpreting the toxicity of these compounds.

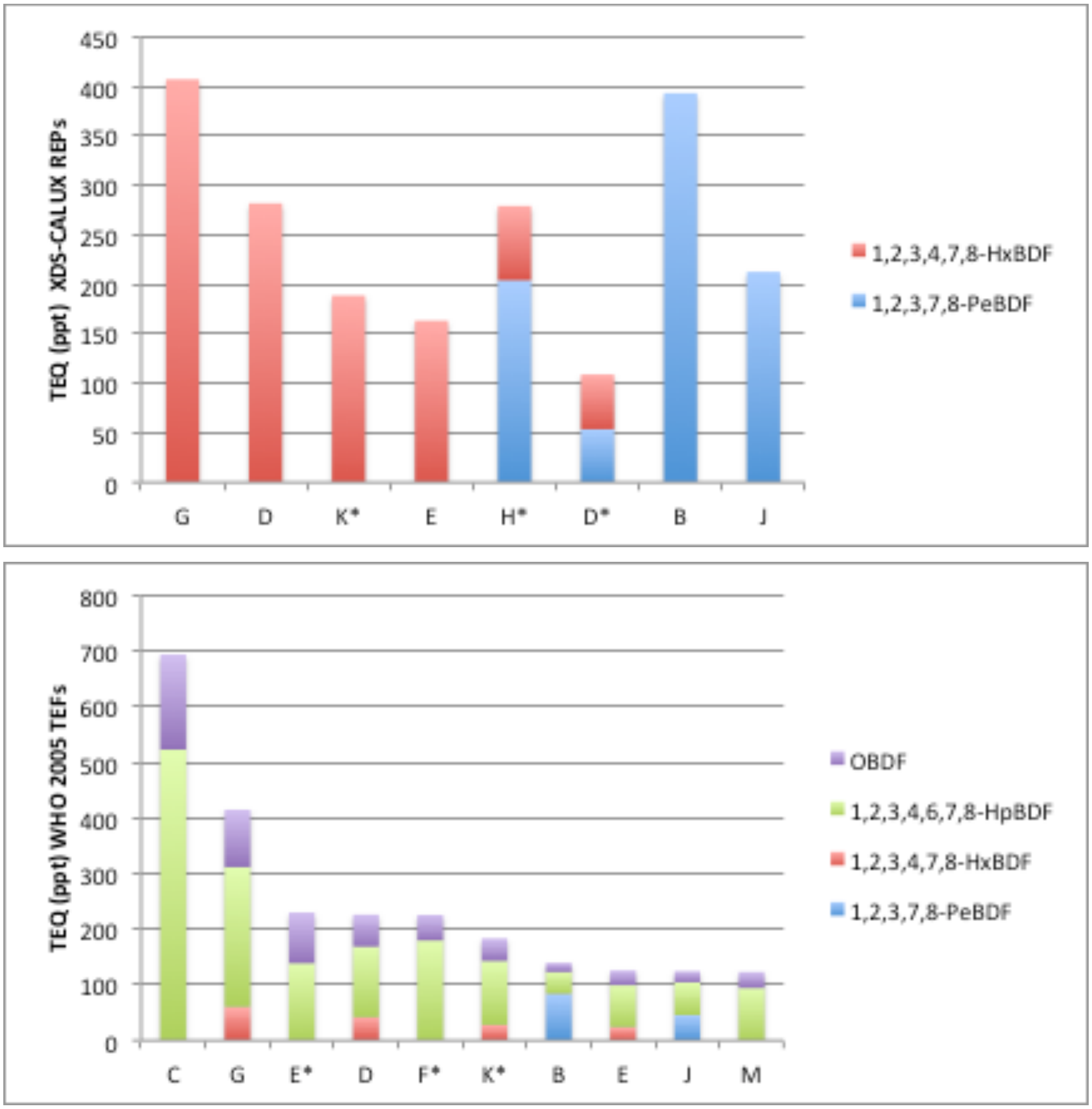

Figure 4-4 TEQs estimated with WHO TEFs and XDS-CALUX REPs (Samara et al. 2009) **where total TEQ exceeds 100 ppt. TEQs calculated by these two methods differ in the total sample TEQ and congeners that contribute to these totals.** (*near site homes, other from background areas)

4.5.3 How do the estimated TEQs for the brominated compounds compare with the CALUX- BEQ results for the dust samples from the homes analyzed by XDS Laboratory?

The REPS for brominated congeners published by Samara et al. in 2009 were done in the XDS laboratory. Therefore, the TEQs calculated for the brominated dioxin/furans were expected to be reflected in the XDS-CALUX bioassay results for dust from the 30 homes.

Of the eight samples with a calculated TEQ above 100 ppt using the XDS-CALUX REPs, none of the bioassay BEQ results were above 100 ppt. In addition, because the CALUX-BEQ also includes the response from the chlorinated congeners, it is clear that the laboratory results reported in our study did not measure a total response consistent with their published findings.

In February 2011, representatives of the neighborhood residents provided CALUX-BEQs results for dust samples collected in 2010 from 105 homes within a two mile radius of the Site (Calwell 2011). These samples were analyzed by XDS laboratory. Approximately two/thirds of these samples had a CALUX-BEQ greater than 100 ppt, much different pattern from the 2012 results from our 17 samples near the site.

The CALUX-BEQ from two homes analyzed in 2010 were also among the 30 homes sampled and analyzed in 2012. The 2010 and 2014 CALUX-BEQ results are compared on Figure 4-5. Also shown is the calculated TEQ based on the 2012 HRGC/HRMS results estimated using the XDS-CALUX REPs. Typically, it is expected that the measured response in the bioassay would be higher than the TEQ estimated based on the GC/MS concentrations because frequently other compounds are present that may also contribute to the response. For example, Samara (2009) reports that triBDD has a relative potency in this assay higher than the WHO TEFs for OCDD and OCDF.

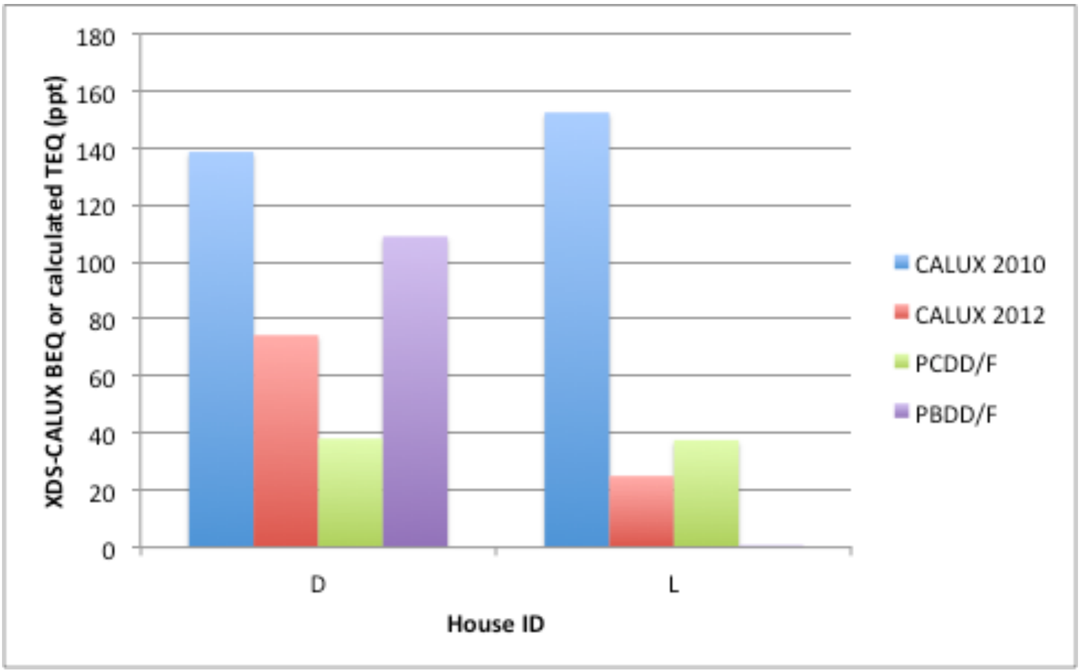

Figure 4-5 The 2012 CALUX-BEQ was below the calculated TEQs and the reported 2010 BEQ results for these two locations.

4.6 DISCUSSION

The concentrations and patterns are consistent with results shown in other studies. Over 99% of the total homologue concentrations are furans. Only six 2,3,7,8-bromine substituted congeners were reported. When detected, the "TEQ" for the two dioxins (OBDD and HpBDD) was one or less. Therefore, the four furans are the primary contributors to of the TEQ/BEQ.

Furans are formed with the removal of two bromines, or a hydrogen and bromine from the PBDE. The relative concentrations of TBDFs and OBDFs may indicate potential sources of these compounds.

- OBDF, with 8 substituted bromines, can only be formed from commercial decaBDE which has been used in televisions, printers, and other electrical equipment, plastic coatings around wires, and textile coatings. It was phased out at the end of 2013.
- TBDF was likely formed from pentaBDE, which was phased out in 2004 and was commonly used in polyurethane foam for furniture and upholstery.
- Debromination of decaBDE and/or the furans can increase the proportion of congeners with fewer bromines.

PBDD/F impurities in some commercial decaBDE mixtures were tested by Ren et al. 2011. OBDF was the prevailing congener, followed by 1,2,3,4,6,7,8-HpBDF. OBDD and 1,2,3,4,7,8 HxBDF were also detectable. The total concentrations varied between manufacturers and between the lots.

Several studies show high BEQs using CALUX assays, with PCDD/Fs not the primary contributor to the dioxin-like response. For example, dust samples obtained from vacuum cleaner bags in 21 homes in New York State measured dioxin-like activity using the DR-CALUX assay (Tue et al., 2013). The sample extracts were fractionated, separating PCBs, PCDD/Fs, and PBDD/Fs before measuring in the bioassay. The sixteen samples with at least a response of 100 ppt TEQ in the bioassay were analyzed by GC/MS.

- In the bioassay, the DL activities ranged from 30-8000, median of 210, pg DR-CALUX-BEQ/g.
- Concentrations of chlorinated and brominated dioxins/furans and dioxin like PCBs measured by GC/MS were detected in wide variation, and a substantial portion of the CALUX-BEQ was attributed to unknown dust contaminants.

The phase out of PBDEs was based on the potential toxicity and persistence of these flame retardants, not the presence the trace concentrations of the brominated furans. The overall exposures and relative risks associated with chemicals in homes may consider overall exposure to multiple chemicals.

5 POST SOIL-REMEDIATION DUST INVESTIGATION

Protect Gainesville's Citizens (PGC) collected indoor dust samples from five residential homes in the Near Site neighborhood in July 2014, after completion of the soil replacement. Post soil-remediation data will provide information on PCDD/F trends after soil replacement was complete, and qualitative review of changes in PBDD/F concentrations.

5.1 SAMPLE COLLECTION AND ANALYSIS

5.1.1 Selection of Homes

Dust from 30 homes were sampled in 2012. Seventeen of these were from homes in the Stephen Foster Neighborhood, as discussed in Sections 3 and 4. Of the 17 homes in the soil remediation area, soils were replaced in twelve of these. Of these, the five selected homes meet the following additional criteria:

- Owner has agreed to the resampling of dust in their home.
- PCDD/Fs concentrations were above the median and average of the background homes, and are five of the seven highest levels measured.
- Two of these had higher brominated dioxin levels, which will be reanalyzed at these locations.

The same house IDs were used for each of the homes sampled. These are shown in table 5-1. As discussed in Section 4, there is significant uncertainty in the estimation of a TEQ for the brominated congeners. These were the estimates as included in the Health Consultation (FDOH 2012) used as the basis for selecting two homes for re-testing.

Table 5-1 Five near site homes within the soil remediation area selected for resampling of dust in 2014. Analyses considered 2012 results.

Location ID	May 2012 Dust Results			Analyses for 2014 Dust Samples
	Dioxins TEQ (ppt)		Dust Loading mg/m2	
	PCDD/Fs	PBDD/Fs[a]		
D	42.1	160.2	741	b
H	50.6	603.1	1108	b
I	42.9	0.4	182	c
J	62.9	10.2	110	c
L	37.6	0.3	901	c

[a] *TEQ as estimated in 2012, D'Silva et al. 2004.*

[b] *Dust analyzed for both PBDD/Fs and PCDD/Fs*

[c] *Dust analyzed for PCDD/Fs only.*

5.1.2 Sample Collection

Dust samples were collected between July 24 and July 27, 2014. These were collected using a Miele Hepa Filter vacuum. One composite sample was collected by vacuuming easily accessible areas. These surfaces include carpets, rugs, tile and wood floors. One objective was to follow the protocol used in the 2012 sampling by EPA in which a poly liner was placed within the vacuum surrounding the Hepa bag. When implementing this protocol with the Miele, the air flow vents were blocked resulting in overheating. The interior of the vacuums were cleaned after each sampling, however, the Hepa bag retained the sample dust and little or no dust was found within the vacuum compartment. Care was taken to place allow dust to settle, and the bag placed within the Ziploc bag to avoid any loss of the sample through the valve.

One objective was to maximize time between completion of the soil replacement and collection of dust, yet meet the project schedule. Table 5-2 summarizes the interval, area sampled, and the estimated weight of the total dust collected. Details of the specific dates are retained in the confidential files.

Table 5-2 2014 Dust sample collection summary

Location	Interval (Days)[a]	Area (sq. ft.)	~net weight (gms) [b]
D	48	780	49
H	42	924	80
I	44	890	41
J	85	670	20
L	47	1100	190

[a] *Interval - Number of days between completion of soil replacement and dust sample collection at each location.*

[b] *Estimated total weight of dust collected, to be sieved at the laboratory.*

5.1.3 Analytical Methods

Consistent with the 2012 investigation, all five dust samples collected were analyzed using the definitive HRGC/HRMS by Vista Analytical Laboratory, El Dorado Hills, California (CA). Vista is NELAP certified for analysis of CDD/Fs in solid matrices using EPA Method 1613B. This was the priority method of analysis for all dust samples, reporting results for all seventeen 2,3,7,8- substituted CDD/Fs, eight total homologue concentrations, and the minimum sample TEQ (TEQ min) based on the detected congeners.

There is no standard method for analysis of brominated dioxins and furans (PBDD/Fs), but these can be detected by a modification of EPA method 1613B as developed by Vista. Analytical standards are not available for all of the brominated congeners, so all seventeen possible 2,3,7,8-substituted congeners were not quantified. PBDD/Fs were analyzed in two of the five homes where previous dust results were above the estimated TEQ of 100 ppt (using the DR-CALUX REPs)

5.1.4 Data Evaluation and Review

The laboratory provided results as requested for the five dust samples. Samples were extracted and analyzed within the method holding times. The initial and continuing calibration verifications met the method acceptance criteria. No analytes were detected in the method blank.

Labeled standard recoveries were within method acceptance criteria for the PCDD/Fs.

Due to matrix effects, recoveries of internal standards of ^{13}C-OBDD and ^{13}C-OBDF were below 25% in the both samples analyzed for PBDD/Fs, and ^{13}C-TBDD was below 25% in sample D. The interferences with the TBDD and OBDD are not likely to impact the interpretation, since these concentrations have not been significant in previous results, or findings in the literature. This does contribute to uncertainty particularly for the brominated furans.

The sample sizes of 1-3 grams, were lower than the mass previously used for analysis of dust samples from these homes. This potentially impacts detection limit, and are considered in the uncertainty discussion when comparing the results from these five homes with concentrations reported in 2012.

5.2 CHLORINATED DIOXIN/FURAN RESULTS

This section summarizes observations on the changes in concentrations of PCDD/Fs between 2012, and the samples collected in 2014 following soil replacement. It was anticipated that after impacted soils were no longer being tracked into the homes, dioxin concentrations would decrease over time.

5.2.1 TCDD-TEQ

Of the five homes resampled, four had a lower TCDD-TEQ (Table 5-3) for the dust sample collected in 2014. These four locations were in an area with higher average soil concentrations, and an interval between soil replacement and dust sample collection fewer than 50 days. For these homes, impacted surface soils contributed to the levels of PCDD/Fs in the house dust. The decrease in the average concentrations is 16 ppt, similar to the level estimated for overall contribution of soil to indoor dust concentrations.

One home showed an increase in the TEQ, from 60 to 75 ppt. The mass of sample for the analysis was low, and this change may reflect simple variability/ uncertainty in the sampling and analytical protocols. This was not in an area with significantly elevated soil concentrations, and the interval between completion of the soil replacement and collection of the dust sample (85 days) was greater than for other homes sampled in 2014. This concentration was lower than the maximum level reported in background dust (77.3 ppt), and another near site home with soil concentrations well below 7 ppt and a dust concentration of 90.9 ppt. This suggests that some indoor source contributes to these concentrations.

Table 5-3 Chlorinated dioxin/furan dust concentrations as TCDD-TEFs (ppt) for samples collected in 2012 and 2014

House ID	2012 Dust TEQ	2014 Dust TEQ
D	38	19
H	51	43
I	43	10
J	60	75
L	38	5
Average	46	30

Focusing on only these four homes, the average, geometric mean and median concentrations are compared to those for results for dust samples collected from the background neighborhoods in 2012. These homes were selected in part because concentrations in 2012 were above background levels. As illustrated in Figure 5-1, concentrations decreased to background levels for these four homes.

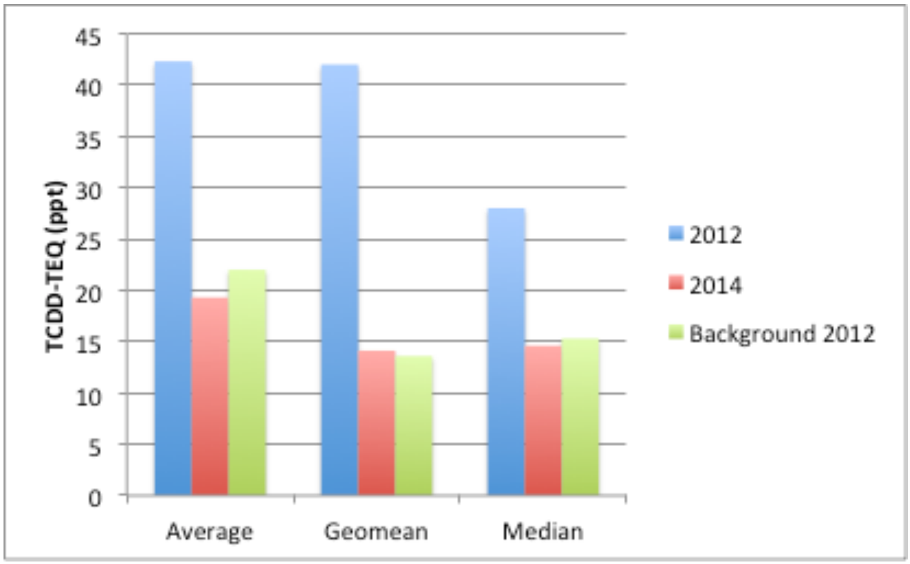

Figure 5-1 The 2012 average, geometric mean and median dust concentions from four homes (D, H, I, and L) decreased to background levels for these locations in 2014 dust samples.

5.2.2 Congeners/Homologues

The decreases in concentrations at four of the five properties are best illustrated by the homologue concentrations as shown in Figure 5-2. Significant decreases in the concentrations of OCDD and total HpCDD are apparent. Concentrations of these homologues remain higher at location H than the other three locations. Several factors may contribute to this: initial concentrations at location H were higher, lower elapsed time between the soil replacement and dust sampling, and the closer proximity of this property to the Site.

The homologue concentrations at location J were higher than the other locations in 2012, and these showed some increases in 2014. Differences in the relative proportions of the higher molecular weight dioxin homologues are also present as shown on Figure 5-3. There are significant similarities in the percentages at locations D, H, I and L both in the 2012 and 2014 dust samples. OCDD at location J was above 80% of the total homologue concentrations, while this percentage was below 70 at the other locations. The percentages of HpCDD and HxCDD were lower, again in a consistent pattern. As indicated previously, location J was farther from the site in an area with lower dioxin concentrations in soil, suggesting contributions from another source within the home.

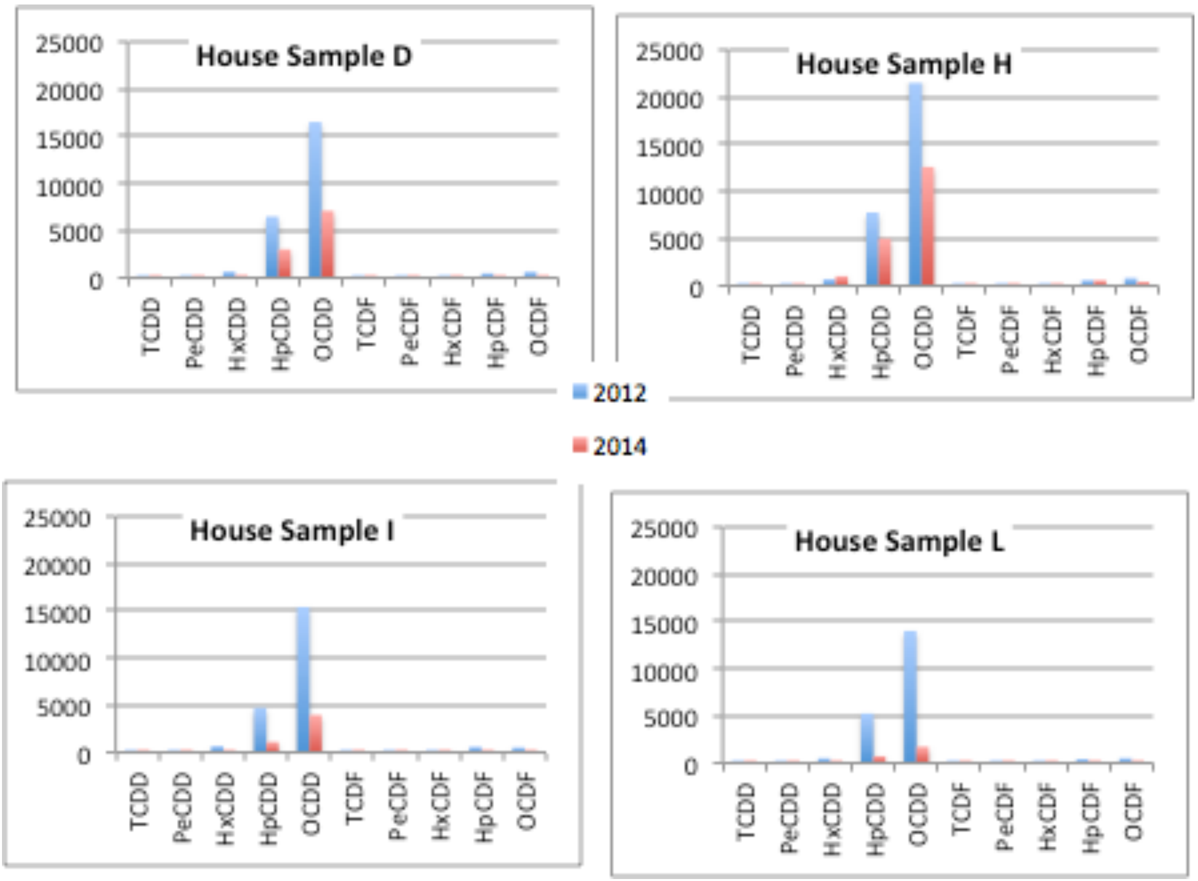

Figure 5-2 Total homologue concentrations in four homes decreased by 12,000 to over 18,000 ppt for dust samples collected after soil replacement compared to results from 2012 dust samples.

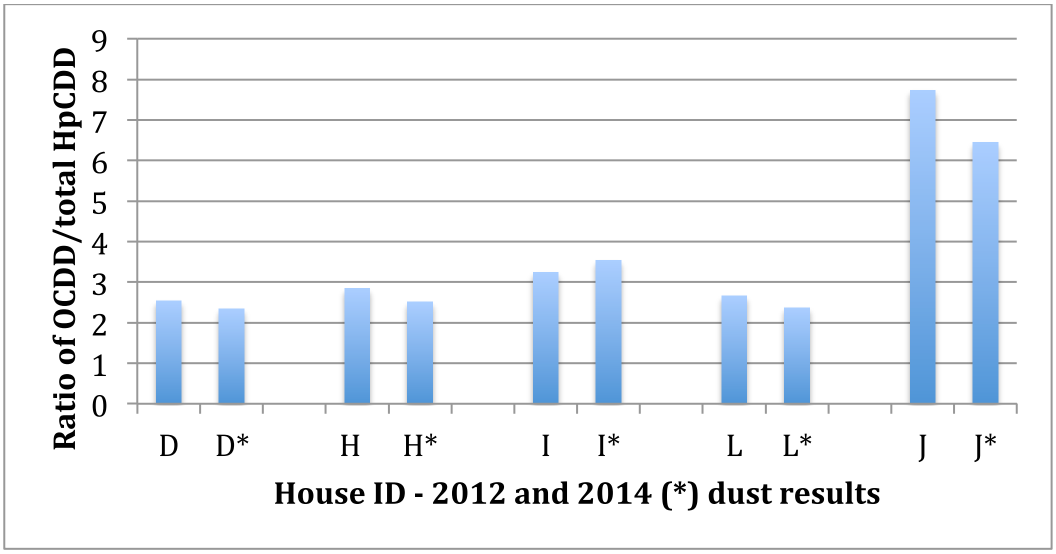

Figure 5-3 Homologue ratios differ for 2012 and 2014 dust samples collected from house J compared to other near site homes, suggesting a source from within the home.

5.3 BROMINATED DIOXINS/FURANS

Brominated dioxins/furans were analyzed in only two homes. Results are shown in Table 5- 4. As with the previous results (and consistent with patterns reported in the literature) these are predominantly the brominated furans. No 2,3,7,8-bromine substituted congeners were detected in location H in the dust sample collected in 2014, and only 1,2,3,4,6,7,8-HpBDF was above detection limits in sample D. However, the sample volume was lower and in some cases the detection limits higher than the 2012 samples increasing the uncertainty.

Previously, the brominated furans were dominated by TBDF and OBDF. For the samples collected in 2012, these represent over 90% of the brominated furan homologue concentrations. However, this decreased to less than 70% in the samples analyzed in 2014. As indicated in the data review, the recovery of OBDF was low, so its concentration is likely underestimated.

The change in the PBDF homologue concentrations for these two locations are illustrated on Figure 5-4. At both locations, TBDF was the dominant homologue in 2012. This is likely indicative of pentaBDE, possibly foam in furniture. The concentrations of TBDF decreased at both locations, at one location (D) the previous owner moved out and the property is currently occupied by renters.

There were also significantly increased concentrations of total HxBDF at both locations.

Table 5-4 Dust concentrations (ppt) of PBDD/F congeners and homologues for dust from two homes tested in 2012 and 2014.

Congener	H				D			
	2012		2014		2012		2014	
2,3,7,8-TBDD	31.5	U	50.6	U	1540	U	60.3	U
1,2,3,7,8-PeBDD	9.02	U	141	U	17.2	U	20.7	U
1,2,3,4,7,8/1,2,3,6,7,8-HxBDD	11.2	U	90.2	U	11.6	U	30.8	U
1,2,3,7,8,9-HxBDD	13.4	U	129	U	10.1	U	41.2	U
1,2,3,4,6,7,8-HpBDD	32.4	J	162	U	31	J	49.3	U
OBDD	65.2	J	7050	U	17	UJ	512	U
2,3,7,8-TBDF	15.9	U	49.8	U	129	U	396	U
1,2,3,7,8-PeBDF	1460		178	U	384		331	U
2,3,4,7,8-PeBDF	22.7	U	57.1	U	517	U	17.7	U
1,2,3,4,7,8-HxBDF	112	J	137	U	82.5	J	72.4	U
1,2,3,4,6,7,8-HpBDF	2190		295	U	1330	J	796	
OBDF	31500		4120	UJ	17900		1830	UJ
Homologue								
Total TBDD	210	U	50.6	U	3.25		36.7	
Total PeBDD	9.02	U	141		17.2	U	20.7	U
Total HxBDD	5.31	U	64.4	U	206	U	157	U
Total HpBDD	32.4		162	U	31		31.3	U
OBDD	65.2	J	7050	U	17	UJ	512	U
Total TBDF	260000		22300		60700		36600	
Total PeBDF	10100		371		5500		745	
Total HxBDF	1160		10200		570		18800	
Total HpBDF	2190		1110		1330		2920	
OBDF	31500		4120	U	17900		1830	U

U - Below detection limit; J - estimated concentration

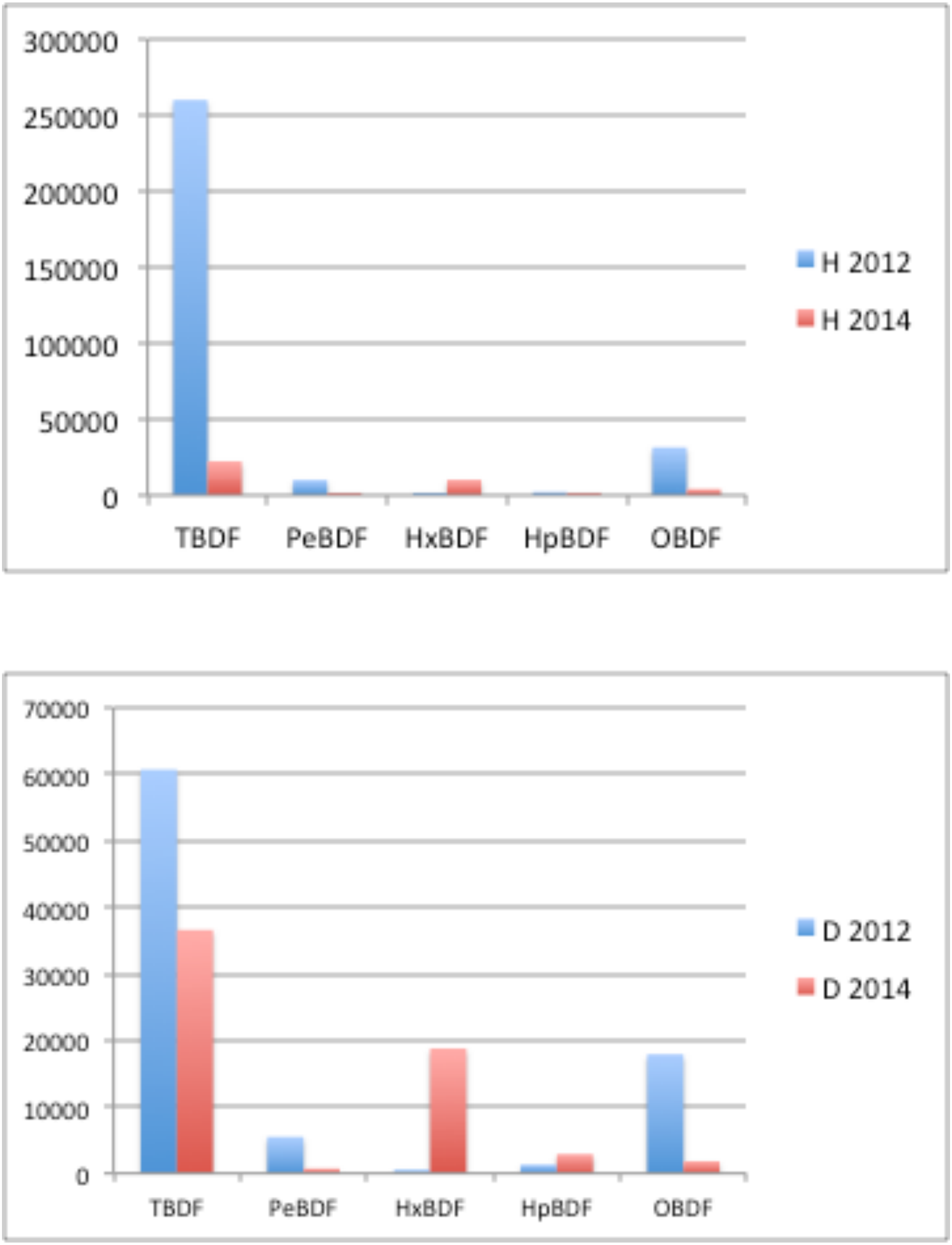

Figure 5-4 Homologue concentrations (ppt) of TBDF and OBDF decreased in dust samples from homes H and D between 2012 and 2014.

5.4 DISCUSSION OF MITIGATION AND TEMPORAL PATTERNS

Concerns had been raised by residents that soil replacement would not result in a significant decrease in the levels of dioxins/furans within homes. Based on review of the literature, soil contaminants typically account for only some of the variability in dust concentrations for many contaminants including dioxins. If a home was thoroughly cleaned without first remediating the soil, house dust concentrations would increase again over time from tracking in of contaminated soil (Von Lindern, Spalinger, Bero, Petrosyan, & Von Braun, 2003).

USEPA (2003) reviewed assumptions for dissipation of contaminants in house dust when setting health-based benchmarks related to cleanup of indoor environments after the collapse of the World Trade Center. Assuming cleaning on a periodic basis, newly tracked in dust would continually be mixed with and removed by cleaning, eventually replacing dusts from past tracking events. (USEPA, 2003) The following highlight EPA's review of this issue:

> Dust on floors is much more easily removed from hard surfaces than carpets or rugs. EPA concluded that if a carpet is initially loaded with contaminated dust, a half-life for its removal can be calculated assuming 90% removal in 6 months. This results in a 2-month half-life for dust removal from carpets assuming vigorous cleaning by vacuuming, taking about 12 months to reduce the initial contaminant load by 99.9%. This was based on a study by Roberts et al.(1999) that determined that residual lead loading in carpets would be reduced by 90-99% in 6 months by removing shoes on entering, use of a doormat and use of an efficient vacuum twice a week (this is without making change in the soil concentrations). Vigorous vacuuming was efficient in removing lead contaminated dust from carpets. If there were no new inputs, he showed that dust on the surface of 11 carpets were reduced by 90% in one week with the use of a "Hoover Self-Propelled Vacuum with Embedded Dirt Finder (HSPF). This suggests that after soil replacement, it is possible to significant reduce the concentration of contaminants more rapidly than the 2 month half-life.
>
> Elevated non-porous surfaces like walls, table tops, counters, etc. receive much of their dust loads from deposition of suspended dust. The amount of dust on these surfaces is much smaller than track-in for carpets near entry ways. In general, the same principal applies in that concentrations would decrease with cleaning. Some dusts may be present in areas that are infrequently cleaned – like tops of light fixtures, etc. A PCDD/F half-life of 22 months was estimated for dust on light fixtures based on dust wipe sampling on surfaces that were inaccessible to regular cleaning and only cleaned twice in five years. The reduction in concentration over time was thought to be a combination of cleaning, resuspension and dilution with uncontaminated dust, and possibly some volatilization. To be conservative, EPA used this 22 month half-life in estimating their PCDD/F benchmark concentration of 2 ng/m^2 for buildings/ residences near the World Trade Center.

The five homes included in our study primarily had hard surface floors (wood, tile). Smaller areas of carpet and/or rugs were present. Residual dust from the hard surfaces is much more easily removed than from carpets. Because of the short time interval between completion of soil replacement and resampling of dust, residents were encouraged to consider a rigorous cleaning including HEPA vacuuming, followed by washing of walls and surfaces, and addressing areas that are less accessible (closets, under beds/furniture, behind refrigerators, etc.). However, based on follow up discussions during sampling, normal routine cleaning procedures were used.

The conclusion regarding the concentration of PCDD/Fs attributed to tracking in of soil are based on the four homes in the area of higher soil impacts and no indication of an alternate significant contribution from within the home. For these homes, PCDD/F dust concentrations were reduced an average of 57% (ranged from 15% to 87%) in an average of 45 days. Essentially, the concentrations of PCDD/Fs in dust collected from the accessible floor areas were reduced to background levels. That is, the average, median and geometric mean of these four samples are the same as those measured in the dust from background homes in 2012. This suggests a reduction of 90-99% of the PCDD/Fs attributed to tracking in of soil.

There are likely some other residuals present that will gradually be dissipated over time as other less accessible areas are cleaned, walls washed, etc. However, the amount of dust and exposure to these dusts are low. The data also suggests that if some of this dust re-enters the homes from vents or attics, these would readily be removed from accessible areas by routine cleaning.

The observed reduction in concentrations of dioxin/furans attributed to a specific source that has been removed, suggests that these types of compounds can be removed during cleaning. Therefore, if a different source within a home is identified and removed or controlled, exposures to these compounds would be reduced.

The brominated furans are attributed to flame retardants present in materials within the home. The results from the two homes that were resampled showed decreases in the total furan homologues. There were also changes in the relative contributions, particularly of Total HxBDF. The following compare changes in concentrations observed for PBDFs and PCDD/Fs at these two homes between samples collected in May 2012 and July 2014.

In home H,

- Total PBDF concentration decreased by 88% from the concentrations in 2012, and total TBDF homologues decreased by 91%.
- The PCDD/F TCDD-TEQ decreased by 15% and total PCDD/F homologue concentration decreased by 38%.

In home D,

- Total PBDF concentration decreased by 29% from the concentrations in 2012, and total TBDF decreased by 40%.
- The PCDD/F TCDD-TEQ decreased by 50% (to a concentration below the average background) and total PCDD/F homologue concentration decreased by 56%.

The dioxin/furan sources within homes can vary. Because routine cleaning appears to significantly remove contributions from a specific know source – like tracking in of contaminated soil – other changes in concentrations of these compounds in house dust appear related to more short term changes that occur for sources within the homes. That is, concentrations of PBDFs could increase or decrease as furniture, electronics, etc. within the home are changed.

The greatest decrease was shown for the total TBDF homologue. This is associated with the use of pentaBDE, which was phased out in 2005. A study by Dodson et al. (2012) looked at flame retardants in 16 homes in California sampled in 2006, and resampled in 2011. Substantial decreases in pentaBDE (up to 20-fold) were observed in three homes where participants reported remodeling or acquiring new furniture and/or rugs/carpet between 2006 and 2011. This suggested that new furniture electronics and flooring is no longer present in new household items, and reductions were attributed to the phase outs in 2005. Concentrations of other flame retardants were higher in 2011 than 2006 consistent with their use as a pentaBDE replacement.(Dodson et al., 2012)

6 RESEARCH SUMMARY

Residents near Superfund sites have concerns about increased involuntary exposures to site contaminants. This research project examines a range of potential exposures to dioxins and dioxin-like compounds, placing multiple sources and cumulative exposures in context. These data answer questions and address issues that could not be derived simply from a review of the literature, and contribute to research on these compounds and implications for regulatory decision making. This section highlights some of the findings/ conclusions from this study.

Background Concentrations. Many studies reviewed for this project gather samples over wide areas. In some cases, authors eliminate outliers as not representative of background, or assign a potential external environmental contribution for these outliers. The background locations in our study are clustered, with no nearby external sources that would explain the variability in the results. The lowest and highest dioxin TEQs were in homes that were nearly adjacent. Until we better understand in-home sources, these higher levels represent concentrations that may not be common, but are not atypical of what may be found in homes that are not impacted by a specific external source.

Sample Collection. To be cautious, standard protocols are used for decision-making for consistency and confidence in the results. However, it was unclear from the literature how much deviation from these protocols would impact the results. It was necessary to document the extent to which a change in equipment or approach would impact the results for PGC samples collected in 2014, but also to interpret the entire data set in the context of published results.

Use of home vacuum samples remains controversial in the literature. Documenting that chlorinated dioxins in samples from home vacuums can replicate samples collected by EPA SOP 2040 was important. The use of a new vacuum bag to be used only for floors within the home would be recommended, but some flexibility in the equipment used for the sampling has been demonstrated.

However, brominated dioxin/furans are not as well correlated for samples collected by these two methods. These flame retardant materials are more localized and have different physical-chemical properties. Therefore, there is no simple single answer for protocols to characterize exposures to different chemicals.

PCDD/F Congener and Homologue Profiles. When developing this study, several stakeholders stated it is not possible to “fingerprint” or see patterns associated with impacts from specific sources. It is true that no clear patterns led to identifying contributions from in-home and background sources. However, contributions of contaminants associated with the former wood treating sites are observed. Many studies do not provide complete data sets, only statistical summaries, therefore, it is not clear whether similar patterns could be identified at other locations.

Bioassays and Toxicity. Bioassays can be helpful. These can lead to expanding research on exposures to compounds that are not typically analyzed or regulated. The CALUX assay was run by XDS, the only US commercial laboratory using this method. It has been approved by EPA for screening soil and sediment samples for dioxins, but requires confirmatory sampling. This has been successful at many sites, since soil/sediment investigated are predominantly contaminated with only the chlorinated dioxins. In other matrices like house dust or food, other dioxin-like compounds are frequently present.

The high responses in many dust samples should not be attributed to contamination from a Superfund site without sufficient confirmatory analyses. Data suggest most of the high levels are from in-home sources. In addition, reporting results as TCDD-TEQs, and inferring the level of confidence in the assay is equivalent to results using the definitive method, is misleading to the community. Finally, if these are to be used, the complete sample preparation protocols should be provided.

Brominated Flame Retardants. Many research studies have been focused on materials used in materials like foam furniture or electronics. PBDEs have been phased out based on concerns over exposure to these compounds. The PBDEs are present at much higher concentrations than the brominated dioxins. However, new chemicals used as flame retardants may also consider exposures to these potentially toxic contaminants

Temporal Patterns/ Mitigation. Dust samples were collected from 5 homes, relatively soon after soil replacement was completed. Only normal cleaning procedures were used by residents. Based on 2014 results, normal cleaning (dusting and vacuuming) addressed contributions from tracking in of contaminated soils. Some in-home sources may be present in matrices like oils or soot that are not easily cleaned by vacuuming and dusting and my require more rigorous cleaning with wet wiping of surface. The use of PBDEs have been phased out. Brominated dioxins/furans concentrations decreased over the past two years in the dust samples collected from two homes suggesting they are not persistent in dust. Removing sources will result in reduced exposures.

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Appendix A Dust Sample Results - 2012

Table A-1. Background Area Homes: Dioxin Concentrations in Indoor Dust (pg/g)

Analyte	A	B	C	D	E	F	G
2,3,7,8-TCDD	1.4 U	1.12 U	0.921 U	1.17 U	0.135 U	0.455 U	0.475
1,2,3,7,8-PeCDD	1.21 U	1.37 U	1.41 U	1.45 U	0.876 J	0.743 J	1.58
1,2,3,4,7,8-HxCDD	2.71 U	1.53 U	1.75 U	2.58 U	1.12 J	573 U	2.3
1,2,3,6,7,8-HxCDD	28.9 J	5.77 J	53.6	2.54 U	6.53	9.93 J	46.6
1,2,3,7,8,9-HxCDD	7.33 J	2.26 J	11.8 J	3.07 U	2.93	3.58 J	11.5
1,2,3,4,6,7,8-HpCDD	2430	302	1950	193	262	309	2440
OCDD	12000	3590	9680	2020	2150	1980	16600
2,3,7,8-TCDF	5.45 J	1.68 U	3.46 J	2.15 U	1.7	1.06 J	13.9
1,2,3,7,8-PeCDF	1.54 J	0.856 U	1.54 J	0.913 U	0.519 J	0.363 U	5.99
2,3,4,7,8-PeCDF	3.83 J	0.826 U	8.02 J	0.95 U	1.15 J	0.553 J	16.5
1,2,3,4,7,8-HxCDF	1.56 J	1.32 J	7.42 J	1.39 J	1.35 J	0.917 J	15.8
1,2,3,6,7,8-HxCDF	1.14 J	0.934 U	6.7 J	0.726 U	1.06 J	0.675 J	6.62
1,2,3,7,8,9-HxCDF	1.77 U	1.57 U	1.45 U	1.31 U	0.353 U	0.407 U	1.73
2,3,4,6,7,8-HxCDF	1.82 J	1.39 J	10.4 J	1.23 U	1.54 J	1.03 J	8.25
1,2,3,4,6,7,8-HpCDF	26.9 J	17.2 J	75.6	8.95 J	18.7	12.7 J	72.6
1,2,3,4,7,8,9-HpCDF	2.7 U	3.42 U	6.41 J	2.05 U	1.11 J	0.602 U	4.73
OCDF	106 J	69.4 J	194	59.8 J	56.1	31.3 J	123
Total TCDD	1.4 U	1.12 U	7.7	1.17 U	4.23	1.18	6.42
Total PeCDD	7.7 U	5.4	214	12.3	27.3	11.1	37
Total HxCDD	201	48	424	24.2	51.7	84.6	383
Total HpCDD	3890	604	3050	344	509	569	4140
Total TCDF	24.8	1.68 U	98.8	2.15 U	13.3	7.25	113
Total PeCDF	22.5	2.14 U	165	0.609 U	11.3	4.55	160
Total HxCDF	23.2	16.1	101	7.69	21.4	13.7	163
Total HpCDF	79.9	17.2	173	8.95	40.2	26.7	160
TEQ (min)	34	5.37	35.1	2.66	6.34	6.45	47.6
2,3,7,8-TBrDD	32.1 U	87 U	642 U	14.7 U	4.77 U	19.3 U	38.2
1,2,3,7,8-PeBrDD	83 UJ	176 UJ	158 U	110 UJ	60.9 U	167 U	100
1,2,3,4,7,8/1,2,3,6,7,8-HxBrDD	113 UJ	202 UJ	204 UJ	48.8 UJ	12.5 U	102 U	89.3
1,2,3,7,8,9-HxBrDD	131 UJ	307 UJ	199 UJ	59.1 UJ	9.21 U	109 U	112
1,2,3,4,6,7,8-HpBrDD	33.6 U	127 U	110 UJ	59.4 J	34.1 U	59.7 U	64.7
OBrDD	79.7 J	567 UJ	632 J	205 J	160 UJ	471 UJ	313
2,3,7,8-TBrDF	46 U	233 U	50.1 U	29.9 U	64 U	352 U	9.74
1,2,3,7,8-PeBrDF	733 U	2810 J	315 U	270 U	213 U	674 U	627
2,3,4,7,8-PeBrDF	220 UJ	1820 UJ	327 U	117 U	37.4 U	309 U	158
1,2,3,4,7,8-HxBrDF	125 UJ	561 UJ	1260 UJ	421 J	244	215 U	608
1,2,3,4,6,7,8-HpBrDF	2870	3900	52300	12700	7500	1680	25100
OBrDF	40200	54900 J	570000 J	191000	89300	19000 J	344000
Total TBrDD	864 U	345 U	642 U	6100 U	143 U	495 U	25100
Total PeBrDD	100 U	176 U	158 U	274 U	60.9 U	167 U	100
Total HxBrDD	258 U	239 U	201 U	53 U	44.9 U	104 U	99.1
Total HpBrDD	51.7 U	127 U	110 U	59.4	34.1 U	1520 U	64.7
Total TBrDF	2800	379000	14200	3530	33400	952	3730
Total PeBrDF	374 U	7700	5620	329	7750	1230 U	15800
Total HxBrDF	183 U	2180	1260 U	421	341	215 U	13550
Total HpBrDF	3140	3900	52300	12700	7830	1680	25100

Table A-1. Background Area Hc

Analyte		H		I		J		K		L		M	
2,3,7,8-TCDD	U	6.59	U	1.52	J	1.19	U	1.39	U	1.35	U	0.651	U
1,2,3,7,8-PeCDD	J	6.78	U	1.62	U	1.25	U	1.45	U	1.65	U	1.85	J
1,2,3,4,7,8-HxCDD	J	8.84	U	3.8	J	2.04	U	3.2	U	3.75	J	2.46	J
1,2,3,6,7,8-HxCDD		9.27	U	20	J	22.4	J	94.9		20	J	15	J
1,2,3,7,8,9-HxCDD	J	10.8	U	7.92	J	5.44	J	24.3	J	6.25	J	9.94	J
1,2,3,4,6,7,8-HpCDD		521		1010		308		5930		1210		740	
OCDD		3850		7010		1740		12800		6900		5380	
2,3,7,8-TCDF		9.12	U	2.08	U	1.83	U	7.69	J	2.27	U	2.9	U
1,2,3,7,8-PeCDF	J	4.46	U	1.23	U	0.858	U	1.88	J	1.27	U	1.3	J
2,3,4,7,8-PeCDF		4.38	U	1.48	U	0.888	U	1.62	U	1.94	U	2.43	J
1,2,3,4,7,8-HxCDF		4.8	U	3.4	J	1.01	U	5.32	J	2.24	J	4.81	J
1,2,3,6,7,8-HxCDF	J	4.77	U	3.28	J	0.981	U	1.06	U	1.72	J	1.62	J
1,2,3,7,8,9-HxCDF	J	7.53	U	1.39	U	1.48	U	1.77	U	1.74	U	0.951	U
2,3,4,6,7,8-HxCDF	J	5.28	U	3.41	J	1.19	U	2.43	J	2.55	J	2.07	J
1,2,3,4,6,7,8-HpCDF		30.4	J	41.1	J	12.4	J	47.8	J	33.9	J	19.7	U
1,2,3,4,7,8,9-HpCDF	J	11.5	U	2.13	U	2.12	U	7.96	J	2.49	U	2.14	J
OCDF		88	J	87.9	J	24.5	J	148		135		52.1	
Total TCDD		6.59	U	4.62		1.28		3.58		2.57		0.651	U
Total PeCDD		19.4		80		23.4		25.6		39.7		25.2	
Total HxCDD		72.9		182		142		1020		173		143	
Total HpCDD		1070		1750		530		9730		2070		1350	
Total TCDF		9.12	U	2.25		1.83	U	13.9		1.27	U	11.2	
Total PeCDF		24.1		15.3		5.21	U	5.07		13.2		25.9	
Total HxCDF		14.1		54.4		11.9		73.9		35.8		32.5	
Total HpCDF		30.4		92.3		12.4		200		105		2.14	
TEQ (min)		6.69		18.3		6.52		77.3		18.2		15.3	
2,3,7,8-TBrDD	U	471	U	60.8	U	29.3	U	232	U	26.6	U	185	U
1,2,3,7,8-PeBrDD	UJ	445	U	317	UJ	116	UJ	257	UJ	94.2	UJ	140	UJ
1,2,3,4,7,8/1,2,3,6,7,8-HxBrDD	UJ	516	U	206	UJ	194	UJ	256	UJ	122	UJ	276	UJ
1,2,3,7,8,9-HxBrDD	UJ	490	U	266	U	228	UJ	303	UJ	152	UJ	308	U
1,2,3,4,6,7,8-HpBrDD	J	923	U	111	U	106	U	124	U	99		43.6	U
OBrDD	UJ	3580	UJ	708	UJ	478	UJ	477	UJ	368	UJ	367	UJ
2,3,7,8-TBrDF	UJ	502	U	47	U	146	U	134	U	53.7	U	111	U
1,2,3,7,8-PeBrDF	UJ	871	U	346	UJ	1520	J	735	U	500	J	386	UJ
2,3,4,7,8-PeBrDF	UJ	810	U	130	UJ	176	UJ	321	UJ	42.4	UJ	309	UJ
1,2,3,4,7,8-HxBrDF	J	1230	U	149	U	459	UJ	476	UJ	226	UJ	656	UJ
1,2,3,4,6,7,8-HpBrDF		6090	J	1810	U	5920		4950	U	674		9440	
OBrDF	J	59900	J	24200	J	66900	J	57200	J	13400	J	96500	J
Total TBrDD	U	471	U	1620	U	194	U	59	U	585	U	185	U
Total PeBrDD	U	445	U	317	U	116	U	257	U	94.2	U	140	U
Total HxBrDD	U	510	U	230	U	207	U	273	U	135	U	294	U
Total HpBrDD		422	U	111	U	106	U	124	U	99		43.6	U
Total TBrDF		66900		7180		181000		12900		39800		34400	
Total PeBrDF		7870		1760		24200		777		2350		4260	
Total HxBrDF		1230	U	1750		640	U	476	U	625		655	U
Total HpBrDF		6090		1810		5920		4950		674		9440	

Table A-2. Near Site Homes: Dioxin Concentrations in Indoor Dust (ppt)

Analyte	A	B	C	D	E	F	G
2,3,7,8-TCDD	0.16 U	1.43 U	2.62 U	0.419 J	2.67 U	1.26 J	0.49 U
1,2,3,7,8-PeCDD	1.22 J	4.08 J	2.67 J	3.56 J	3.69 U	1.41 U	2.77 J
1,2,3,4,7,8-HxCDD	3.06 J	7.45 J	4.41 U	13.6	5.14 U	2.82 J	6.36 J
1,2,3,6,7,8-HxCDD	9.32	174	67.5 J	43	16.6 J	15.6	24
1,2,3,7,8,9-HxCDD	5.76	37.5 J	15.5 J	26.2	6.3 U	7.45 J	11.6 J
1,2,3,4,6,7,8-HpCDD	384	3170	1430	1960	527	651	1070
OCDD	4020	14500	6060	16500 J	4990	4610	10400
2,3,7,8-TCDF	0.62 J	2.98 U	4.51 U	1.54	3.7 U	1.3 U	3.41
1,2,3,7,8-PeCDF	1.07 J	2.27 J	2.12 U	1.05 J	2.16 U	0.985 J	3.35 J
2,3,4,7,8-PeCDF	1.73 J	6.45 J	2.15 U	3.72 J	2.18 U	1.77 J	7.66 J
1,2,3,4,7,8-HxCDF	9.96	10.5 J	3.58 U	6.05	1.71 U	2.6 J	8.35 J
1,2,3,6,7,8-HxCDF	3.46 J	8.61 J	4.29 J	4.96 J	1.71 U	2.06 J	6.85 J
1,2,3,7,8,9-HxCDF	0.517 J	2.08 U	2.54 U	1.36 U	2.85 U	0.505 J	2.29 J
2,3,4,6,7,8-HxCDF	3.11 J	12.6 J	5.79 J	8.4	2.05 U	2.36 J	10.5 J
1,2,3,4,6,7,8-HpCDF	87.7	484	96.5	158	43.1 J	32.3	108
1,2,3,4,7,8,9-HpCDF	3.81 J	12 J	6.57 J	11.9	4.64 U	3.02 J	8.99 J
OCDF	246	474	178	658	184 J	120	385
Total TCDD	1.88	3.58 U	2.62 U	9.09	2.67 U	10.2	21.3
Total PeCDD	13.7	106	42.1	71.3	200	68.5	55.1
Total HxCDD	139	1450	519	672	152	170	330
Total HpCDD	1380	7940	2750	6500	1310	1500	3790
Total TCDF	13.1	66	4.51 U	27.7	3.7 U	11.4	76.8
Total PeCDF	30.2	128	32.6	50.3	7.86	17.3	76.2
Total HxCDF	71	395	117	158	35.5	38.6	131
Total HpCDF	182	981	243	488	115	96	299
TEQ (min)	11.4	72.3	29.2	38.1	8.92	13.4	27.6
2,3,7,8-TBrDD	85.6 U	56.8 U	13.4 U	1540 U	48 U	659 U	14.1 U
1,2,3,7,8-PeBrDD	5.89 U	111 UJ	217 U	17.2 U	372 U	225 U	36.8 U
1,2,3,4,7,8/1,2,3,6,7,8-HxBrDD	3.72 U	129 UJ	204 UJ	11.6 U	126 UJ	267 R	11.3 U
1,2,3,7,8,9-HxBrDD	4.35 U	166 UJ	215 UJ	10.1 U	135 UJ	312 R	12.3 U
1,2,3,4,6,7,8-HpBrDD	19.1 J	139 U	76.4 J	31 J	104 J	122 U	68.6 J
OBrDD	13.1 UJ	226 UJ	251 J	17 UJ	338 J	480 UJ	57.2 UJ
2,3,7,8-TBrDF	8.46 U	19.3 U	74.9 U	129 U	29.4 U	54.7 U	50.7 U
1,2,3,7,8-PeBrDF	128 U	193 UJ	570 U	384	425 U	575 U	72.8 J
2,3,4,7,8-PeBrDF	43.4 U	135 UJ	230 U	517 U	290 U	448 UJ	21.8 U
1,2,3,4,7,8-HxBrDF	14 J	77.7 U	199 UJ	82.5 J	399 UJ	1110 UJ	41.3 J
1,2,3,4,6,7,8-HpBrDF	134 J	555 J	3090	1330 J	13900	18000	716 J
OBrDF	403 J	5990 UJ	46200	17900	304000	153000 J	8120 J
Total TBrDD	85	8720 U	1200 U	3.25	692 U	659 U	877 U
Total PeBrDD	1.73 U		540 U	17.2 U	372 U	225 U	5.67 U
Total HxBrDD	1.99 U	143 U	204 U	206 U	140 U	286 U	6.63 U
Total HpBrDD	19.1	138 U	76.4	31	104	122 U	68.6
Total TBrDF	50400	6280	3770	60700	1530	5630	10900
Total PeBrDF	1890	704 U	729 U	5500	1170 U	577 U	886
Total HxBrDF	648	370	403 U	570	399 U	1110 U	744
Total HpBrDF	134	555	3430	1330	13900	18000	716

Table A-2. Near Site Homes: Di

Analyte	H	I	J	K	L	M	N
2,3,7,8-TCDD	0.531 J	1.01 U	1.19 J	0.241 U	0.289 J	1.1 J	0.252 U
1,2,3,7,8-PeCDD	4.91	4.49 J	2.44 U	1.75 J	3.45	6.31 J	0.988 J
1,2,3,4,7,8-HxCDD	17.1	10.6 J	5.04 J	5.72 J	11	10.6	1.31 J
1,2,3,6,7,8-HxCDD	45.5	76.1	39.1 J	15.1	38.3	37.6	7.58
1,2,3,7,8,9-HxCDD	35.2	42.4	12.7 J	10.3	21	24.9	3.72 J
1,2,3,4,6,7,8-HpCDD	2320	1480	2880	760	1850	1780	256
OCDD	22100 J	15400	37900	7630	14000 J	20800 J	2740
2,3,7,8-TCDF	0.9 J	2.8 J	1.35 U	2.87	0.725	3.07	1.13 J
1,2,3,7,8-PeCDF	0.972 J	0.858 U	0.78 U	0.793 J	0.696 J	1.66 J	0.537 J
2,3,4,7,8-PeCDF	2.6 J	3.38 J	17.4 J	1.82 J	2.55 J	4.6 J	0.898 J
1,2,3,4,7,8-HxCDF	6.63	8.51 J	8.95 J	3.13 J	4.58	8.56 J	1.56 J
1,2,3,6,7,8-HxCDF	5.32	5.78 J	9.86 J	2.26 J	3.83	5.23 J	1.17 J
1,2,3,7,8,9-HxCDF	1.33 J	1.24 U	3.63 U	0.651 U	1 J	1.82 J	0.285 U
2,3,4,6,7,8-HxCDF	8.88	8.76 J	23.5 J	3.96 J	6.63	8.55 J	1.59 J
1,2,3,4,6,7,8-HpCDF	208	220	330	79.9	140	162	26.2
1,2,3,4,7,8,9-HpCDF	14.7	10.3 J	25.3 J	4.7 J	9.08	12.1	1.78 J
OCDF	843	538	760	284	533	703	122
Total TCDD	9.85	2.1	1.19	5.53	7.07	18.4	2.31
Total PeCDD	62.4	43.5	7.69	30.9	90	73.3	16
Total HxCDD	722	681	222	257	523	542	69.9
Total HpCDD	7770	4740	4900	2740	5260	6320	710
Total TCDF	26.2	34.7	18	21.7	16.1	51.5	20.7
Total PeCDF	48.8	71.5	92	22.6	43.2	65.7	15.1
Total HxCDF	188	256	307	68.7	142	190	29.5
Total HpCDF	623	612	810	213	430	527	28
TEQ (min)	50.6	42.9	60.3	17.5	37.6	44.9	6.78
2,3,7,8-TBrDD	31.5 U	29.6 U	13.7 U	8.29 U	4.93 U	66.9 R	20.2 U
1,2,3,7,8-PeBrDD	9.02 U	38.2 U	128 UJ	94.2 U	19.7 U	241 U	242 U
1,2,3,4,7,8/1,2,3,6,7,8-HxBrDD	11.2 U	32.6 UJ	165 UJ	7.98 U	5.72 U	31.5 U	54.1 U
1,2,3,7,8,9-HxBrDD	13.4 U	43.9 UJ	290 UJ	5.78 U	6.59 U	42.5 U	40 U
1,2,3,4,6,7,8-HpBrDD	32.4 J	19.2 U	80 U	79 U	18.2 U	93.7 U	55.2 U
OBrDD	65.2 J	52.3 J	360 UJ	245 UJ	36.2 UJ	278 UJ	310 UJ
2,3,7,8-TBrDF	15.9 U	4.53 U	99.4 U	85.3 U	32.5 U	63.9 U	298 U
1,2,3,7,8-PeBrDF	1460	126 U	185 UJ	503 U	63.8 U	65.8 U	2120 U
2,3,4,7,8-PeBrDF	22.7 U	56.5 U	106 UJ	384 U	12.2 U	53.1 U	158 U
1,2,3,4,7,8-HxBrDF	112 J	28.5 UJ	391 UJ	282	3.86 U	28.6 U	108 U
1,2,3,4,6,7,8-HpBrDF	2190	176 J	5080	11500	132 J	607 J	3870
OBrDF	31500	2240 J	30300 J	135000	766 J	5730 J	47700
Total TBrDD	210 U	11400 U	1340 U	204 U	447 U	9210 U	145 U
Total PeBrDD	9.02 U	38.2 U	128 U	94.2 U	2.18 U	125 U	242 U
Total HxBrDD	5.31 U	43.9 U	213 U	3860 U	3.42 U	16.5 U	47.7 U
Total HpBrDD	32.4	19.2 U	80 U	79 U	18.2 U	93.7	55.2 U
Total TBrDF	260000	267	11500	19500	5110	6520	289000
Total PeBrDF	10100	218 U	1290	14100	594 U	5700	30200
Total HxBrDF	1160	28.5 U	2320	282	76.8	216	109
Total HpBrDF	2190	176	5080	12000	132	607	4210

Table A-2. Near Site Homes: Dic

Analyte	O		P		Q	
2,3,7,8-TCDD	1.75	U	0.741	U	1.32	U
1,2,3,7,8-PeCDD	2.43	U	2.72	U	2.54	J
1,2,3,4,7,8-HxCDD	4.59	J	8.92	J	4.53	J
1,2,3,6,7,8-HxCDD	27.4	J	69.9		20.4	J
1,2,3,7,8,9-HxCDD	10.8	J	22.8		10.3	J
1,2,3,4,6,7,8-HpCDD	1730		4920		670	
OCDD	11900		63000	J	8050	
2,3,7,8-TCDF	2.76	U	1.4	U	2.44	U
1,2,3,7,8-PeCDF	1.83	U	1.84	J	0.819	U
2,3,4,7,8-PeCDF	2.72	J	5.83	J	3.58	J
1,2,3,4,7,8-HxCDF	3.54	J	16.8	J	7.68	J
1,2,3,6,7,8-HxCDF	2.34	J	13.4	J	5.11	J
1,2,3,7,8,9-HxCDF	2.3	U	2.7	U	1.19	U
2,3,4,6,7,8-HxCDF	3.68	J	18.4	J	5.67	J
1,2,3,4,6,7,8-HpCDF	65.9	J	487		84.8	
1,2,3,4,7,8,9-HpCDF	6.18	J	31.8		3.48	U
OCDF	235		2560		206	
Total TCDD	1.75	U	0.741	U	1.45	
Total PeCDD	65.3		33.2		35.8	
Total HxCDD	273		460		285	
Total HpCDD	3660		9490		1910	
Total TCDF	2.84	U	18.7		12	
Total PeCDF	22.9		71.2		60.2	
Total HxCDF	86.7		351		98	
Total HpCDF	215		1600		172	
TEQ (min)	27.7		90.9		19	
2,3,7,8-TBrDD	16	U	1420	U	30.3	U
1,2,3,7,8-PeBrDD	259	UJ	280	UJ	784	U
1,2,3,4,7,8/1,2,3,6,7,8-HxBrDD	309	UJ	277	U	140	UJ
1,2,3,7,8,9-HxBrDD	174	U	285	U	149	UJ
1,2,3,4,6,7,8-HpBrDD	98.4	U	130	U	86.2	J
OBrDD	1170	UJ	322	UJ	247	J
2,3,7,8-TBrDF	120	U	25.5	U	70.4	U
1,2,3,7,8-PeBrDF	1800	UJ	208	UJ	365	U
2,3,4,7,8-PeBrDF	463	UJ	173	UJ	611	U
1,2,3,4,7,8-HxBrDF	210	UJ	436	U	205	U
1,2,3,4,6,7,8-HpBrDF	1390		1970		2840	J
OBrDF	105000	J	9640	J	44500	
Total TBrDD	1520	U	1420	U	744	U
Total PeBrDD	259	U	280	U	784	U
Total HxBrDD	241	U	281	U	142	U
Total HpBrDD	98.4	U	83.7	U	86.2	
Total TBrDF	87200		5120		14300	
Total PeBrDF	2030		688		5470	
Total HxBrDF	277		436	U	780	U
Total HpBrDF	1390		1970		2840	

Appendix B Dust Sample Results - 2014

Table B-1. Chlorinated Dioxin/Furan Dust Results - 2014

	House ID - Near Site Homes									
Analyte	I		H		J		D		L	
2,3,7,8-TCDD	0.864	U	0.65	U	1.62	U	1.2	U	0.273	U
1,2,3,7,8-PeCDD	1.74	U	1.75	J	1.68	U	2.66	J	0.671	J
1,2,3,4,7,8-HxCDD	3.09	J	8.27	J	6.24	U	7.35	J	1.6	J
1,2,3,6,7,8-HxCDD	26.1		105		44.5		22.4	J	5.64	J
1,2,3,7,8,9-HxCDD	12.3	U	37.2		14.8	J	9.88	J	0.024	U
1,2,3,4,6,7,8-HpCDD	331		1690		4480		829		236	
OCDD	3970		12600		52200	E	7100		1740	
2,3,7,8-TCDF	0.743	U	1.5	J	1.78	U	1.47	U	0.409	U
1,2,3,7,8-PeCDF	1.13	U	1.5	J	1.17	U	1.17	U	0.174	U
2,3,4,7,8-PeCDF	0.759	U	1.61	J	1.75	J	0.699	U	0.224	U
1,2,3,4,7,8-HxCDF	2.6	J	7.23	J	7.79	J	3.25	J	1.04	J
1,2,3,6,7,8-HxCDF	1.59	U	4.64	J	8.18	J	3.58	J	0.713	J
1,2,3,7,8,9-HxCDF	0.849	U	1.74	J	3.42	U	1.29	U	0.456	
2,3,4,6,7,8-HxCDF	3.34	J	7.19	J	12.9	J	4.63	J	0.974	J
1,2,3,4,6,7,8-HpCDF	68.5		271		435		86.8		20.9	
1,2,3,4,7,8,9-HpCDF	3.64	J	8.43	J	30.7		5.41	J	1.47	J
OCDF	125		412		1210		264		69.4	
Total TCDD	2.29		19.9		2.01	U	1.2	U	0.494	
Total PeCDD	6.37		63.2		1.96		15.8		10.1	
Total HxCDD	215		1030		271		300		72.1	
Total HpCDD	1120		43.2		8100		3030		734	
Total TCDF	6.97		75.9		6.28		6.39		0.96	
Total PeCDF	18.8		261		41.2		17.8		5.78	
Total HxCDF	87.3		608		204		81.7		20.4	
Total HpCDF	200				1140		246		61.1	
TEQmin	10		43.2		74.8		19.2		4.79	

U - Below detection limit; J - estimated concentration; E-Estimated

Table B-2. Brominated Dioxin Furan Results - 2014

	House ID - Near Site			
	H		D	
2,3,7,8-TBDD	50.6	U	60.3	U
1,2,3,7,8-PeBDD	141	U	20.7	U
1,2,3,4,7,8/1,2,3,6,7,8-HxBDD	90.2	U	30.8	U
1,2,3,7,8,9-HxBDD	129	U	41.2	U
1,2,3,4,6,7,8-HpBDD	162	U	49.3	U
OBDD	7050	U	512	U
2,3,7,8-TBDF	49.8	U	396	U
1,2,3,7,8-PeBDF	178	U	331	U
2,3,4,7,8-PeBDF	57.1	U	17.7	U
1,2,3,4,7,8-HxBDF	137	U	72.4	U
1,2,3,4,6,7,8-HpBDF	295	U	796	
OBDF	4120	UJ	1830	UJ
Total TBDD	50.6	U	36.7	
Total PeBDD	141		20.7	U
Total HxBDD	64.4	U	157	U
Total HpBDD	162	U	31.3	U
OBDD	7050	U	512	U
Total TBDF	22300		36600	
Total PeBDF	371		745	
Total HxBDF	10200		18800	
Total HpBDF	1110		2920	
OBDF	4120	U	1830	U

U - Below detection limit; J - estimated concentration