Dioxin Furan Blood Lipid and Attic Dust Concentrations in Populations Living Near Four Wood Treatment Facilities in the United States

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L. Feng
C. Wu
L. Tam
A.J. Sutherland
J.J. Clark
P.E. Rosenfeld

Abstract **To evaluate historical exposure from wood treatment facilities, attic dust samples were collected from residential structures and blood samples were collected from current and past residents of four communities surrounding wood treatment facilities throughout the United States. The pattern of dioxin/furan congeners detected in both attic dust and blood samples was found to be consistent with exposure to contaminants generated during the wood treatment process. Levels in the U.S. population of 2,3,7,8-tetrachloro-p-dibenzodioxin toxic equivalents (2,3,7,8-TCDD TEQs) for all 17 carcinogenic dioxin/furan congeners as well as octa-chlorinated dibenzo-p-dioxin (OCDD) adjusted to its TEQ value and 1,2,3,4,6,7,8-hepta-chlorinated dibenzo-p-dioxin (1,2,3,4,6,7,8-HpCDD) adjusted to its TEQ value were compared to the TEQ levels in the combined data set for all four communities and in the data sets for each individual community. TEQ concentrations in these communities were found to be significantly greater than in the general U.S. population. The levels of dioxins in attic dust were compared to the U.S. Environmental Protection Agency's regional screening levels and found to far exceed the levels that are regarded as safe for the general population. These findings reveal that a very significant potential for contaminant-related health risks exists in communities surrounding wood treatment facilities.**

Introduction

Dioxins and furans were evaluated in attic dust of residential structures and in blood of residents of four communities where wood treatment facilities are located: Alexandria, Louisiana; Pineville, Louisiana; Grenada, Mississippi; and Florala, Alabama. The relationship between proximity to a wood treatment facility and levels of dioxins and furans found in dust and subjects' blood samples is of particular importance to understanding the risks of living near such industrial facilities.

The wood treatment facilities at the four locations used pentachlorophenol (PCP) and creosote as insecticides to treat wood, releasing dioxins and other hazardous substances into the surrounding communities. The Alexandria, Louisiana, facility has been in operation since 1926; the Pineville, Louisiana, facility since 1948; the Florala, Alabama, facility since the early 1900s; and the Grenada, Mississippi, facility since 1904.

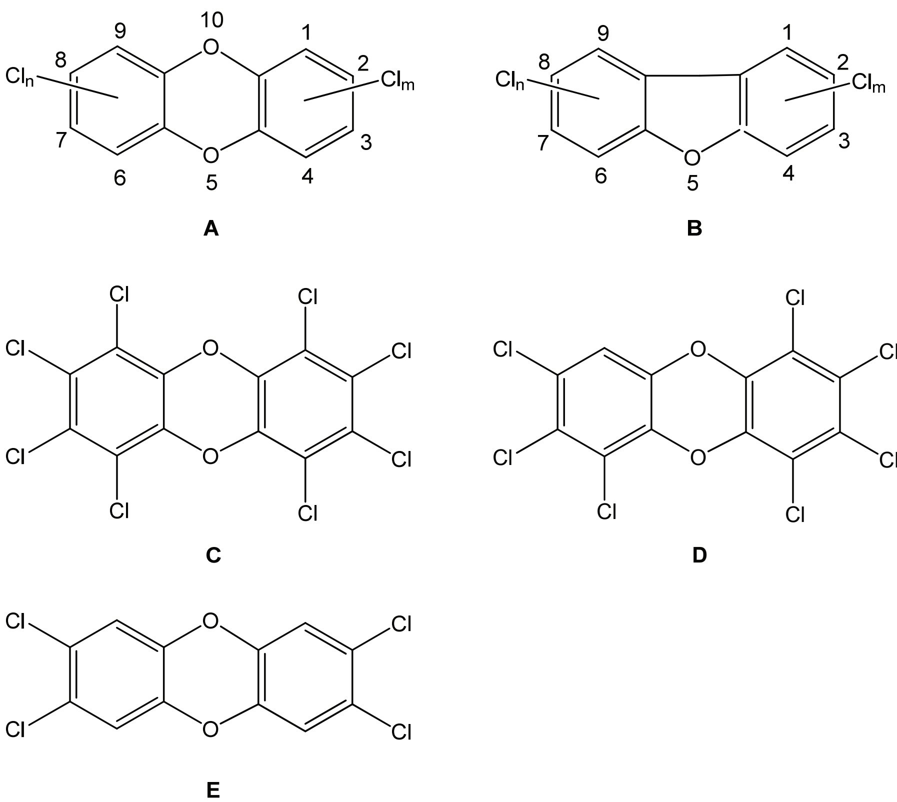
According to data from the 2000 United States Census (U.S. Census Bureau, 2002), blacks represent a higher than average proportion of each community's population—37% on average compared to 12% of the U.S. population. The proportion of whites averages 61% compared to 75% of the U.S. population. Education levels in the communities are consistently lower than average levels in the U.S.; the level of high school graduation in the four communities averages 68%, compared to 80% of the U.S. population, while college degree attainment in the four communities averages 15%, compared to 24% of the U.S. population. The median household income within the four communities averages $25,000, compared to the national median of $42,000, and the percentage of the population below the poverty line averages 26%, approximately twice the U.S. average of 12%. This background information suggests that wood treatment facilities are commonly found in areas of lower socioeconomic status, where less awareness exists of the health risks of living near an industrial facility.

Dioxins and Furans

Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), commonly referred to simply as dioxins and furans, are toxic chlorinated compounds that are usually released as mixtures into the environment. Dioxins and furans are by-products and impurities generated during human activities such as industrial, municipal, and domestic incineration/combustion and the manufacture of chlorinated phenols and other chlorinated chemicals like PCP (Agency for Toxic Substances and Disease Registry [ATS-

FIGURE **1**

Structures of Dioxins, Furans, 2,3,7,8-TCDD, OCDD, and 1,2,3,4,6,7,8-HpCDD



A. General structure of dioxins (polychlorinated dibenzo-p-dioxins), where m+n = 1 through 8. B. General structure of furans (polychlorinated dibenzofurans), where m+n = 1 through 8. C. Octa-chlorinated dibenzo-p-dioxin (OCDD). D. 1,2,3,4,6,7,8-hepta-chlorinated dibenzo-p-dioxin (1,2,3,4,6,7,8-HpCDD). E. 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD).

DR], 1994, 1998; Dougherty, 1978; Webster & Commoner, 2003). The use and incineration of PCP and creosote-treated wood products creates highly chlorinated dioxin and furan congeners, such as the signature congeners octa-chlorinated dibenzo-p-dioxin (OCDD) and 1,2,3,4,6,7,8-hepta-chlorinated dibenzo-p-dioxin (1,2,3,4,6,7,8-HpCDD) (ATSDR, 2001; Dahlgren, Warshaw, Horsak, Parker, & Takhar, 2003; Dahlgren et al., 2007; Harnly, Petreas, Flattery, & Goldman, 2000; Paepke, Ball, & Lis, 1992).

Dioxins and furans comprise a large class of compounds. There are 210 different dioxin and furan congeners. Seventy-five are possible dioxin congeners and 135 are possible furan congeners. The dioxin and furan congeners thought to be most toxic to humans are the seven dioxins (including OCDD and 1,2,3,4,6,7,8-HpCDD) and 10 furans with chlorines occupying at least the 2,3,7, and 8 positions (Figure 1). These 17 congeners are reported to cause cancers, and have endocrine and reproductive effects. The different PCDD/F congeners are structurally similar and have a similar mechanism of action. These chemicals are typically reported as 2,3,7,8-TCDD toxic equivalents (TEQs). (U.S. Environmental Protection Agency [U.S. EPA], 1989).

The concept of 2,3,7,8-TCDD TEQs was developed to efficiently evaluate mixtures of PCDD/Fs, and TEQs are determined by means of Toxic Equivalency Factors (TEFs) (U.S. EPA, 1987). TEFs establish the toxicity of the different congeners in relation to 2,3,7,8-Tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) for use in evaluating human health concerns. The U.S. Environmental Protection Agency (U.S. EPA) has determined that TEFs are currently the best method for evaluating complex mixtures of PCDD/Fs. The concentration of each PCDD/F is multiplied by its respective TEF to obtain a 2,3,7,8-TCDD toxic equivalents (TEQ) value (U.S. EPA, 2003). These individual TEQs are then summed to provide a total dioxin TEQ value for the mixture (Chen, Wang, Yu, Liao, & Lee, 2006).

Dioxins and Furans in Attic Dust

Attic dust sampling is a useful tool for evaluating historical exposure to airborne dust contaminants (Dahlgren et al., 2003, 2007; Hensley, Scott, Rosenfeld, & Clark, 2007). Once airborne dust infiltrates the attic, it settles and is protected from weathering, serving as a "time capsule" of contaminants associated with dust (Dahlgren et al., 2007; Hensley et al., 2007; O'Connor & Sabrsula, 2005).

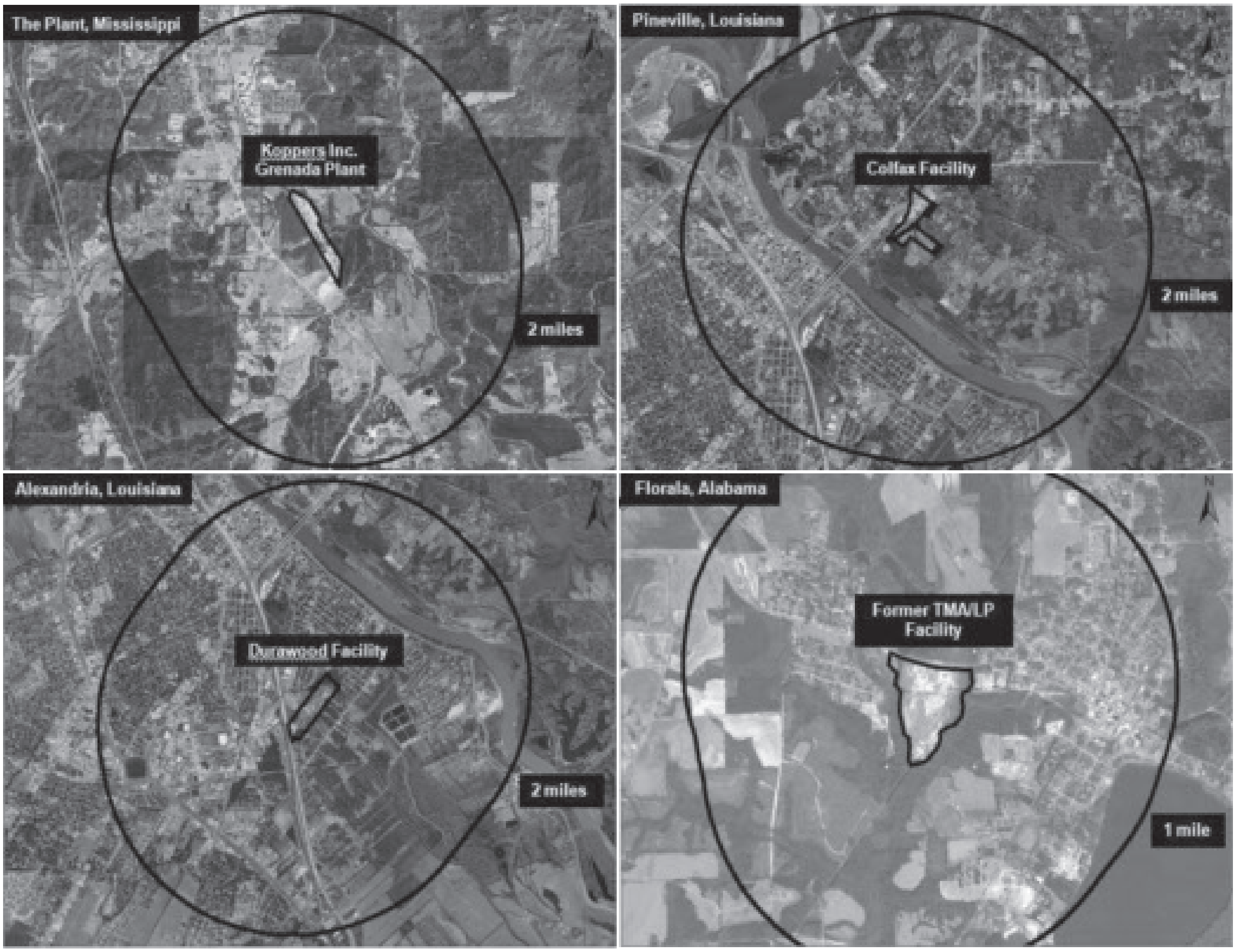
To evaluate whether exposure to contamination in the communities surrounding the four wood treatment facilities was higher than the general U.S. population, dioxins/furans in attic dust samples were compared to U.S. EPA regional screening levels (RSLs) for chemical contaminants. Representing concentrations that may warrant further investigation or site cleanup at a Superfund site, RSLs were developed to aid risk assessment and remediation at the sites. Concentrations for various chemicals in air, drinking water, and soil were derived using the latest toxicity values, default exposure assumptions, and physical and chemical properties. The RSL corresponds to a risk of one excess cancer in a population of one million.

Dioxins and Furans in Human Blood

Blood analysis is a useful tool for evaluating historical exposure to airborne contaminants. Dioxins and furans have relatively long half-lives in human blood; therefore, sampling human blood can be used to assess historical exposure. Pirkle and co-authors (1989) estimated the serum half-life of 2,3,7,8-TCDD in humans to be 7.1 years (range of 2.9–26.9 years) in a group of 36 Vietnam veterans. In a subsequent study, Michalek (1996) estimated the serum half-life of 2,3,7,8-TCDD in humans to be 8.7 years (95% confidence interval [CI]

FIGURE **2**

Proximity of Sampling Locations to Facilities



of 8.0–9.5 years) in a group of 343 Vietnam veterans. A half-life range from 3.5 to 15.7 years was estimated for dioxin congeners other than 2,3,7,8-TCDD in a study performed by Flesch-Janys and co-authors (1996).

To evaluate whether exposure to contamination in the communities surrounding the four wood treatment facilities was higher than the general U.S. population, blood samples were compared to the Centers for Disease Control and Prevention (CDC) National Health and Nutrition Examination and Survey (NHANES) data set for 2003 to 2004. CDC conducts a survey, the National Health and Nutrition Examination Survey (NHANES), every two years through the National Center for Health Statistics (NCHS). The NHANES data set contains health and nutritional information on the U.S. population. The 1999–2000 survey collected data on 116 chemicals and was the first to include PCDD/F serum analyses. The 2001–2002 NHANES survey collected data on 135 chemicals. The data were updated in 2003–2004. The 2003–2004 NHANES data set was used as descriptive reference statistics for 2,3,7,8-TCDD TEQ in blood-lipid in the U.S. population.

Materials and Methods

Attic Dust Sampling

Attic dust sampling was conducted by 3TM International, Inc., and Soil Water Air Protection Enterprise (SWAPE), environmental consulting firms located in Houston, Texas, and Santa Monica, California, respectively. Attic dust was collected from buildings surrounding the four wood treatment facilities, with building selection based on building access and the presence of a gable vent allowing air flow into the attic. Sampling was performed in the following places: 1) 21 buildings surrounding the Alexandria wood treatment facility, 2) 14 buildings surrounding the Grenada wood treatment facility, 3) 14 buildings surrounding the Pineville wood treatment facility, and 4) 11 buildings surrounding the Florala wood treatment facility. Maps showing the general proximity of the sampling around each facility are given in Figure 2.

Attic dust samples were collected using a High Volume Simplified Small Surface Sampler (HVS4) in general accordance with American Society for Testing and Materials (ASTM) method D5438, "Standard Practice for Collection of Floor Dust for Chemical Analysis (ASTM, 2005)." Dust was collected near hard surfaces near the gable vent where undisturbed dust accumulated over time.

Dioxins/furans were analyzed in general accordance with U.S. EPA Method 8290 using HRGC/HRMS. Internal standards were added to all samples and each sample batch included a method blank, a laboratory control sample, and the unknown attic dust sample. The analytical data were reviewed using comprehensive multitiered quality assurance and quality control procedures.

Nondetect results were assigned values equal to the detection limit divided by two, as is historically done in the evaluation of nondetects in environmental samples. Detection limits differed by sample and congener, but represented a minor contribution to total dioxin concentration. Concentrations of OCDD (adjusted to TEQs), 1,2,3,4,6,7,8-HpCDD (adjusted to TEQs), and total dioxins/furans (adjusted to TEQs), were calculated for each location sampled using World Health Organization (WHO) 2005 TEF values. Mean, median, and upper confidence limit (UCL) concentrations were then calculated for the entire site. The U.S. EPA ProUCL 4.0 (U.S. EPA, 2007) software was used to calculate the UCL, a value approximately providing the 95% coverage for the unknown population arithmetic mean. All UCL computation methods are available in the ProUCL user guide (U.S. EPA, 2007).

Blood Sampling

Blood samples were collected from 65 current and past residents of the four communities: 1) 22 from Grenada, Mississippi; 2) 11 from Pineville, Louisiana; 3) 11 from Alexandria, Louisiana; and 4) 21 from Florala, Alabama. The participants were identified using previously conducted health survey information indicating they had health conditions that could potentially be linked to persistent exposure to dioxin and furan congeners, byproducts of the wood treatment facilities. Subjects residing in close proximity to the wood treatment facilities for years or decades provided the most suitable candidates, and thus duration of exposure played a role in determining sample selection. Each resident had lived in close proximity (within two miles) of the local facility during its operation for multiple years, up to several decades. Submission of blood samples was voluntary from individuals within these health parameters, and no sociodemographic profiling was performed.

In accordance with U.S. EPA Method 8290, high resolution gas chromatography (HRGC)/mass spectrometry (HRMS) was used to analyze the blood samples for dioxins and furans in blood lipid. Each serum sample was spiked with $^{13}C_{12}$-labeled internal standards prior to extraction. A DB-5 capillary column was used to separate the target analytes. Each sample batch included a method blank (MB), a laboratory control sample (LCS), and the unknown serum samples. Blood lipid content was determined gravimetrically. Data were reviewed using comprehensive multitiered quality assurance and quality control procedures. Nondetect results were evaluated as the detection limit divided by the square-root of two, as is common for biological samples. Detection limits varied by congener and sample but represented a minor contribution to total dioxin concentration.

Concentrations of OCDD (adjusted to 2,3,7,8-TCDD TEQs), 1,2,3,4,6,7,8-HpCDD (adjusted to TEQs), and total dioxins/furans (adjusted to TEQs), were calculated for each blood sample using WHO 2005 TEF values. Mean, maximum, 50th, 75th, 90th, and 95th percentile concentrations of were then calculated for each site.

NHANES Data Set Analysis

The 2003 to 2004 NHANES data for dioxins and furans were downloaded from the CDC Web site (National Center for Health Statistics, 2003). The data was downloaded in SAS format, but converted to Microsoft Excel format using SYSTAT 11.0 statistical software package. In order to facilitate the comparison, the NHANES data was narrowed down to individuals 25 to 88 years of age to correspond with the age range of test subjects from all four communities. For individual site comparisons, the NHANES data was narrowed down to correspond to the age range of the site's test subjects: 44 to 88 years of age for Grenada, 34 to 80 years of age for Pineville, 37 to 79 years of age for Alexandria, and 25 to 76 years of age for Florala. Concentrations of total 2,3,7,8-TCDD TEQs, OCDD (adjusted to TEQs), and 1,2,3,4,6,7,8-HpCDD (adjusted to TEQs) were calculated for the NHANES data set corresponding to each site, using the WHO 2005 TEF values. (For concentrations below the detection limit in the NHANES data set, CDC assigned a value of the detection limit divided by the square root of two [CDC, 2005].) The mean, maximum, 50th percentile, 75th percentile, 90th percentile, 95th percentile, and standard deviation for total 2,3,7,8-TCDD TEQs, OCDD, and 1,2,3,4,6,7,8-HpCDD concentrations were calculated.

Statistical Analysis

Statistical analysis of the data sets was used to determine if the cohorts' total 2,3,7,8-TCDD-TEQ, OCDD (adjusted to TEQs) and 1,2,3,4,6,7,8-HpCDD (adjusted to TEQs) blood lipid concentrations are statistically different and greater than in the general U.S. population of the same age range. The Statistics Online Computational Resource (SOCR) software developed by the University of California Los Angeles (UCLA) was used for the analysis of the data (UCLA, 2007). The combined four communities, individual community, and NHANES data sets are not normally distributed. Therefore, the Wilcoxon rank-sum test, a nonparametric test for assessing whether two samples of observations come from the same distribution, was used to evaluate the data sets.

The Wilcoxon rank-sum tests the null hypothesis that the two sample sets are drawn from a single population, and therefore their probability distributions are equal. The samples must be independent, and the observations must be continuous measurements. The Wilcoxon rank-sum test generates a *z*-score and *p*-value for the data sets. A positive *z*-score indicates that group A (NHANES) values exceed group B (individual site) values, and a negative *z*-score indicates that group B values exceed group A values. The further the *z*-score is from zero, the greater the disparity between group A and B. The *p*-value is the probability that two groups of data sets come from the same population.

Statistical analysis was performed for total 2,3,7,8-TCDD TEQ (all 17 carcinogenic

TABLE **1**

Attic Dust Sampling TEQ Concentrations

Site	Sample Number	OCDD Concentration Adjusted to 2,3,7,8-TCDD TEQ (ng/kg)	1,2,3,4,6,7,8-HpCDD Concentration Adjusted to 2,3,7,8-TCDD TEQ (ng/kg)	Total 2,3,7,8-TCDD TEQ Concentration (ng/kg)
Grenada, MS	1	16.80	91.60	292.14
	2	4.80	20.70	66.87
	3	20.43	109.00	309.33
	4	5.22	30.60	109.99
	5	18.15	39.60	112.92
	6	7.80	39.40	121.67
	7	1.40	4.79	16.70
	8	6.18	31.50	111.70
	9	1.91	7.41	59.20
	10	28.92	58.30	148.41
	11	0.80	2.78	13.30
	12	3.48	9.08	40.44
	13	5.25	29.70	382.84
	14	15.36	28.00	116.22
Site UCL		15.98	58.34	214.00
Site mean		9.75	35.89	135.80
Site median		5.72	30.15	112.30
Pineville, LA	15	5.73	24.40	447.06
	16	22.56	101.00	294.80
	17	21.63	106.00	301.99
	18	64.50	355.00	940.90
	19	1.27	6.84	28.29
	20	4.05	28.20	215.39
	21	27.12	112.00	301.63
	22	495.00	1690.00	3436.56
	23	36.60	232.00	783.40
	24	6.18	26.40	118.76
	25	3.57	15.50	59.72
	26	27.42	85.80	313.25
	27	0.76	2.32	11.36
	28	15.99	56.30	164.68
Site UCL		258.20	516.50	1045.00
Site mean		52.31	203.00	529.80
Site median		18.81	71.05	298.20

continued on page 39

dioxin/furan congeners), OCDD (adjusted to its TEQ value), and 1,2,3,4,6,7,8-HpCDD (adjusted to its TEQ value) blood lipid concentrations for the combined four communities and the individual communities against the NHANES data set. The age-range of the NHANES data set was adjusted to match each comparison group.

Results

Attic Dust Samples

Table 1 displays the total 2,3,7,8-TCDD toxic equivalencies (TEQs), OCDD concentrations adjusted to 2,3,7,8-TCDD TEQs, and 1,2,3,4,6,7,8-HpCDD concentrations adjusted to 2,3,7,8-TCDD TEQs, for the attic dust samples collected at each site. The table presents the upper confidence limit (UCL), mean, and median concentrations for each site. Additionally, the table presents the summary statistics of the pooled samples from all four locations. The mean total 2,3,7,8-TCDD TEQs, OCDD (TEQs), and 1,2,3,4,6,7,8-HpCDD (TEQs) for the four sites combined as one data set were

TABLE **1** *continued from page 38*

Attic Dust Sampling TEQ Concentrations

Site	Sample Number	OCDD Concentration Adjusted to 2,3,7,8-TCDD TEQ (ng/kg)	1,2,3,4,6,7,8-HpCDD Concentration Adjusted to 2,3,7,8-TCDD TEQ (ng/kg)	Total 2,3,7,8-TCDD TEQ Concentration (ng/kg)
Alexandria, LA	29	90.00	273.00	540.97
	30	6.51	44.70	208.51
	31	15.27	74.60	220.35
	32	2.50	8.26	31.83
	33	26.61	99.30	351.73
	34	8.43	44.80	143.89
	35	1.83	6.46	225.63
	36	0.73	2.63	31.73
	37	5.46	26.50	75.41
	38	9.00	89.40	331.16
	39	34.20	199.00	418.09
	40	11.22	36.10	81.96
	41	2.17	10.20	38.89
	42	1.84	7.31	46.76
	43	51.30	199.00	756.82
	44	7.50	40.00	119.60
	45	15.00	35.00	133.89
	46	135.00	720.00	1151.28
	47	11.40	56.00	164.49
	48	14.40	53.00	153.33
	49	330.00	2700.00	3936.13
Site UCL		91.78	509.50	880.00
Site mean		37.16	225.00	436.30
Site median		11.22	44.80	164.50
Florala, AL	50	3.60	19.00	80.86
	51	3.90	20.00	78.21
	52	9.00	77.00	283.33
	53	1.02	5.80	77.99
	54	0.78	4.70	55.97
	55	1.59	7.90	43.88
	56	0.69	2.70	8.16
	57	2.31	6.60	23.98
	58	11.70	71.00	359.85
	59	0.72	5.90	30.40
	60	17.10	59.00	640.79
Site UCL		9.42	50.93	318.40
Site mean		4.77	25.42	153.00
Site median		2.31	7.90	77.99
Combined sample	Total of 60 samples			
Maximum		495.00	2700.00	3936.13
UCL		39.26	186.70	445.60
Mean		28.36	139.20	336.10
Median		7.65	35.55	138.90
U.S. EPA RSL		**4.5**	**4.5**	**4.5**

TABLE 2

Data Statistical Summary for TEQ Blood Lipid Concentrations

Contaminant	Location	Grenada, MS	NHANES Control Group (44-88)*	Pineville, LA	NHANES Control Group (34-80)*	Alexandria, LA	NHANES Control Group (37-73)*	Florala, AL	NHANES Control Group (25-76)*	All Four Communi-ties	NHANES Control Group (25-88)*
Total 2,3,7,8-TCDD TEQs (ng/kg)	Mean	53.41	20.75	129.29	16.67	61.23	17.21	162.04	14.32	102.67	16.45
	Max	332.51	103.70	381.95	103.70	127.80	103.70	267.23	76.54	381.95	103.70
	95th percentile	123.86	44.62	303.00	34.76	105.08	34.92	238.15	30.75	237.39	38.26
	90th percentile	84.99	34.70	224.05	28.40	82.37	29.16	234.35	25.43	214.14	30.47
	75th percentile	50.88	25.44	155.30	21.69	70.87	22.07	202.59	18.62	131.96	21.48
	Median (50th %)	31.42	17.92	105.49	14.57	58.35	15.31	159.69	12.23	80.66	13.38
	Standard deviation	67.66	12.69	102.03	10.51	27.52	10.59	52.95	9.23	80.82	11.89
	Sample size	22	737	11	859	11	773	21	1003	65	1159
OCDD (2,3,7,8-TCDD TEQs, ng/kg)	Mean	0.39	0.13	0.62	0.11	0.26	0.11	0.42	0.09	0.42	0.11
	Max	1.69	0.98	3.68	0.98	0.59	0.98	1.72	0.98	3.68	0.98
	95th percentile	0.88	0.32	2.32	0.28	0.53	0.28	0.91	0.24	0.95	0.29
	90th percentile	0.69	0.26	0.96	0.22	0.47	0.22	0.83	0.19	0.80	0.22
	75th percentile	0.39	0.17	0.35	0.14	0.29	0.14	0.54	0.11	0.46	0.13
	Median (50th %)	0.28	0.10	0.26	0.08	0.21	0.08	0.37	0.07	0.27	0.08
	Standard deviation	0.35	0.11	1.04	0.09	0.15	0.09	0.41	0.08	0.53	0.09
	Sample size	22	724	11	847	11	761	21	987	65	1140
1,2,3,4,5,6,7,8,-HpCDD (2,3,7,8-TCDD TEQs, ng/kg)	Mean	1.26	0.51	1.69	0.44	1.05	0.45	2.37	0.39	1.66	0.42
	Max	4.67	4.56	9.09	4.56	3.54	4.56	7.60	4.56	9.09	4.56
	95th percentile	3.75	1.27	6.02	1.09	2.97	1.11	6.62	0.96	4.50	1.06
	90th percentile	2.19	0.95	2.94	0.88	2.40	0.89	3.50	0.76	3.42	0.83
	75th percentile	1.19	0.66	1.30	0.58	0.95	0.60	2.70	0.50	2.20	0.55
	Median (50th %)	0.85	0.41	0.82	0.35	0.70	0.36	1.87	0.30	0.97	0.32
	Standard deviation	1.07	0.43	2.57	0.38	1.01	0.38	1.77	0.35	1.68	0.42
	Sample size	22	734	11	856	11	770	21	1000	65	1155

* The NHANES control groups were designated by narrowing the NHANES data set to subjects whose ages fell within the age range of each community. Only subjects within the age range of a given community were included in the stastistical comparison.

TABLE 3

Wilcoxon Rank-Sum Test for Two Samples Assuming Unequal Variances

Contaminant	Location	Grenada, MS	NHANES Control Group (44-88)*	Pineville, LA	NHANES Control Group (34-80)*	Alexandria, LA	NHANES Control Group (37-73)*	Florala, AL	NHANES Control Group (25-76)*	All Four Communities	NHANES Control Group (25-88)*
Total 2,3,7,8-TCDD TEQs (ng/kg)	Mean (ng/kg)	53.41	20.75	129.29	16.67	61.23	17.21	162.04	14.32	102.67	16.45
	Rank sum	13260	275161	9423	369462	8380	299340	21294	503506	73614	676087
	Test statistics	3208	13007	92	9357	189	8314	0	21063	3867	71469
	Z-score	-4.84		-5.59		-5.45		-7.85		-12.19	
	P (T ≤ t) 1-tail	0.000		0.000		0.000		0.000		0.000	
	P (T ≤ t) 2-tail	0.000		0.000		0.000		0.000		0.000	
	Sample size	22	737	11	859	11	773	21	1003	65	1159
OCDD (2,3,7,8-TCDD TEQs, ng/kg)	Mean (ng/kg)	0.39	0.13	0.62	0.11	0.26	0.11	0.42	0.09	0.42	0.11
	Rank sum	14248	264384	8589	359921	7386	290993	16731	491805	66350	660266
	Test statistics	1934	13995	793	8523	1052	7320	4227	16500	9896	64205
	Z-score	-6.06		-4.73		-4.27		-4.65		-9.95	
	P (T ≤ t) 1-tail	0.000		0.000		0.000		0.000		0.000	
	P (T ≤ t) 2-tail	0.000		0.000		0.000		0.000		0.000	
	Sample size	22	724	11	847	11	761	21	987	65	1140
1,2,3,4,6,7,8-HpCDD (2,3,7,8-TCDD TEQs, ng/kg)	Mean (ng/kg)	1.26	0.51	1.69	0.44	1.05	0.45	2.38	0.39	1.66	0.42
	Rank sum	13807	272340	7523	368754	6540	298832	20794	500937	68345	676465
	Test statistics	2595	13554	1958	7457	1997	6474	437	20563	8875	66200
	Z-score	-5.43		-3.33		-3.01		-7.53		-10.37	
	P (T ≤ t) 1-tail	0.000		0.000		0.001		0.000		0.000	
	P (T ≤ t) 2-tail	0.000		0.001		0.003		0.000		0.000	
	Sample size	22	734	11	856	11	770	21	1000	65	1155

* The NHANES control groups were designated by narrowing the NHANES data set to subjects whose ages fell within the age range of each community. Only subjects within the age range of a given community were included in the stastistical comparison.

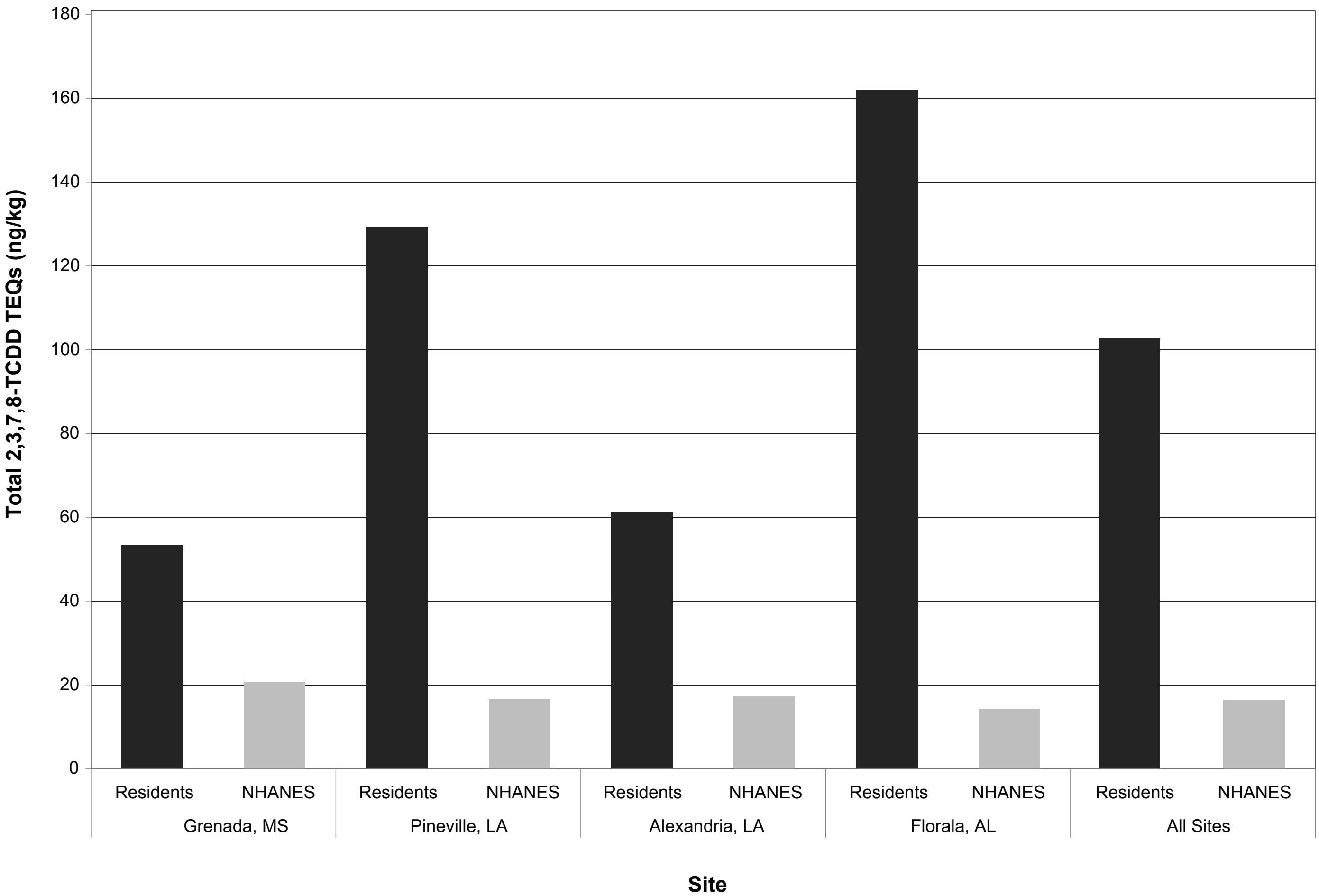
336.10 ng/kg, 28.36 ng/kg, and 139.20 ng/kg, respectively. Each of these values exceeds the U.S. EPA RSL for dioxins in residential soil, which is 4.5 ng/kg of 2,3,7,8-TCDD.

Blood Samples

Table 2 presents a summary of the distribution of concentrations of total 2,3,7,8-TCDD TEQs, OCDD (adjusted to TEQs), and 1,2,3,4,6,7,8-HpCDD (adjusted to TEQs) for the blood lipid samples from each site and from the NHANES data set. The NHANES data set was considered a national control group reflecting the distribution of blood lipid TEQ concentrations in a normal population. For comparative purposes, only the subjects in the NHANES data set falling within the age range of each respective community's participants were included in the samples. The age ranges of the communities were 44–88 for Grenada, 34–80 for Pineville, 37–73 for Alexandria, and 25–76 for Florala. The Grenada data set had on average twice the total 2,3,7,8-TCDD TEQs as the corresponding control group, with a mean concentration 53.41 ng/kg compared to 20.75 ng/kg from the

FIGURE **3**

Total 2,3,7,8-TCDD TEQ Concentrations in Blood Lipid



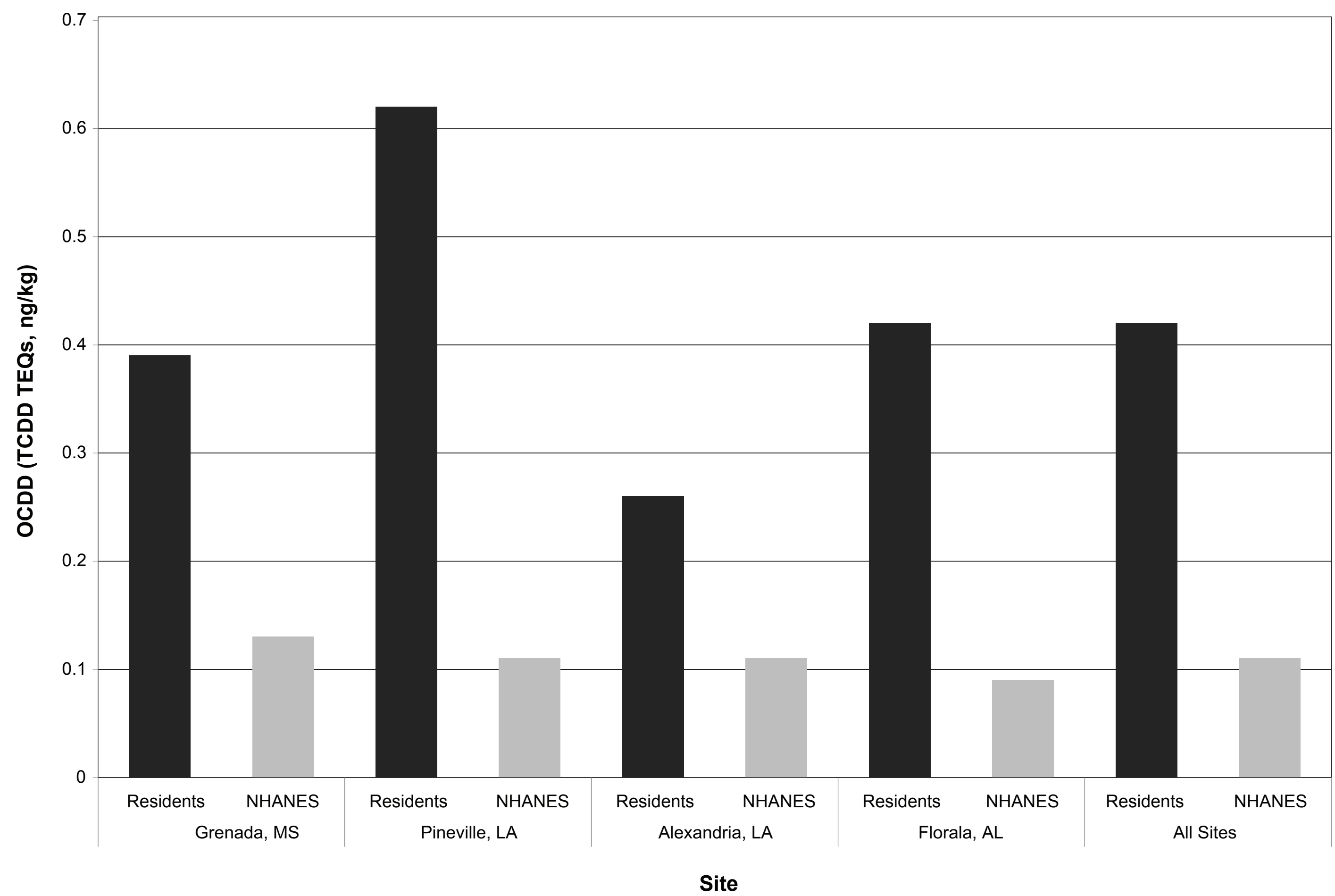
NHANES data set. Pineville, Alexandria, and Florala had eight, four, and 10 times the total 2,3,7,8-TCDD TEQs, respectively, as the NHANES data sets of equivalent age ranges. The concentrations of 2,3,7,8-TCDD TEQs, OCDD (adjusted to TEQs), and 1,2,3,4,6,7,8-HpCDD (adjusted to TEQs) for the pooled samples from all four sites were 102.67 ng/kg, .42 ng/kg, and 1.66 ng/kg. These values are approximately six, four, and four times the concentrations found in the NHANES data set for the equivalent 25–88 age range.

Table 3 presents the results of a two-sample Wilcoxon rank sum test assuming unequal variances, which attempted to describe the likelihood of the blood samples collected coming from the same population as the NHANES data set. The statistical analysis is presented in the form of probabilities describing the chance of the site data set and NHANES data set being representative of the same population based on their respective means and distributions. A statistical analysis of the pooled data is given as well. Any probability below .05 is typically considered significant in statistical analysis between two samples. The *p*-value determined in each analysis was .000, with the exception of 1,2,3,4,6,7,8-HpCDD for Alexandria.

Figure 3, Figure 4, and Figure 5 present the TEQ concentrations found in the blood samples from the four locations and the NHANES control group. Figure 3 uses the mean total 2,3,7,8-TCDD TEQ concentrations from each community for visual comparison to the mean 2,3,7,8-TCDD TEQs reported in the NHANES data set. The figure illustrates that the means from the communities are at least twice as high as the corresponding control group, and the mean for the combined data set is over five times the NHANES average. Figure 4 presents the mean OCDD concentration for each site, along with the corresponding NHANES data set. Again, each individual site's mean is at least twice that of the corresponding NHANES data set. Figure 5 presents the mean 1,2,3,4,6,7,8-HpCDD concentration for each site, along with the corresponding NHANES data set. The graph illustrates that levels of 1,2,3,4,6,7,8-HpCDD concentrations are consistently higher in the samples collected than in the national control group, with the mean of all four sites being nearly four times that of the corresponding NHANES data set.

FIGURE 4

OCDD Concentrations in Blood Lipid



Discussion

Attic Dust Samples

The levels of dioxins and furans (total TEQ concentrations) in attic dust were compared to U.S. EPA's RSLs and found to exceed the levels that are regarded as safe for the general population (U.S. EPA, 2008).

The attic dust samples have significantly elevated OCDD and 1,2,3,4,6,7,8-HpCDD levels. The elevated OCDD and 1,2,3,4,6,7,8-HpCDD levels are consistent throughout the sampled homes. A similar pattern was also observed in Dahlgren and co-authors (2003, 2007), and Hensley and co-authors (2007) studies, which evaluated the impact of wood treatment facilities on local communities using attic dust as a parameter of evidence for historic exposure to airborne pollutants. This pattern indicates that hazardous material originating from the wood treatment facilities traveled off site, impacting the surrounding residential areas. The elevated levels of dioxins and furans in attic dust show that the residential areas surrounding the Pineville, Alexandria, Grenada, and Florala facilities have been exposed to dust that potentially contained unsafe levels of these contaminants.

Blood Samples

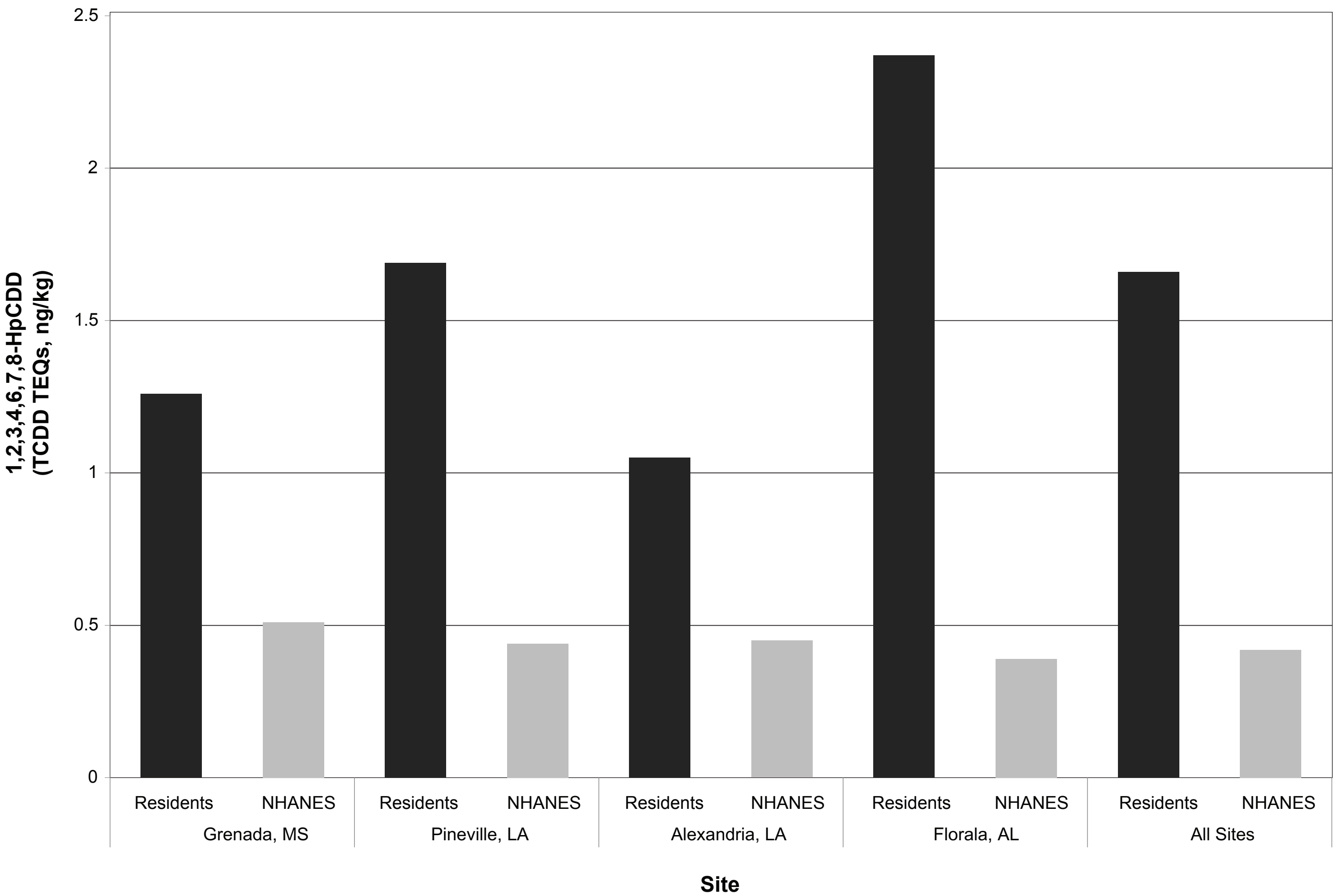
The results of the statistical analyses of the concentrations of total 2,3,7,8-TCDD TEQ (all 17 carcinogenic dioxin/furan congeners), OCDD (adjusted to its TEQ value), and 1,2,3,4,6,7,8-HpCDD (adjusted to its TEQ value) blood lipid concentrations demonstrate that the populations surrounding the wood treatment facilities combined and individually have statistically higher TEQs in blood lipid than the general population of the U.S. of the same age range ($p < .05$).

Table 2 and Figures 3–5 present the data and its statistical summary for the communities and NHANES TEQ blood lipid data. The mean TEQs for all congeners at each of the sites and the combined data set are consistently higher than the corresponding NHANES data set that was used for comparison, with each value being at least twice that of NHANES.

Table 3 presents the Wilcoxon rank-sum test data outputs comparing the NHANES data set to the combined four communities and the four individual communities' TEQ blood lipid data sets. The Wilcoxon rank sum test was used to determine the probability of the blood sample communities and the NHANES data subjects being drawn

FIGURE **5**

1,2,3,4,6,7,8-HpCDD Concentrations in Blood Lipid



from congruent populations with the same true mean and distribution. If the probability that the two samples were drawn from congruent populations is less than .05, then there is significant evidence supporting the claim that there is an inherent difference in the populations from which they were drawn. Only two of the *p*-values presented in Table 3 were above .000, and these values were nearly zero (.001 and .003). The results of the Wilcoxon rank sum test demonstrated that there is significant reason to believe that the samples do not come from populations described by equal parameters, such as mean and distribution. The levels of total TCDD TEQs, OCDD, and 1,2,3,4,6,7,8-HpCDD were consistently significantly higher than the national control groups described by the NHANES data set.

Conclusion

A study in Germany determined that ambient air and soil deposition concentrations of PCDDs and PCDFs near a large point source performing industrial thermal processes were significantly higher than in general urban or rural areas (Fiedler, 1996). Exposure to chemicals such as dioxins, furans, and PAHs has been correlated with increased risk of developing a variety of diseases. Exposure to dioxins and furans can lead to endocrine disruption, reproductive & developmental defects, immunotoxicity, hepatotoxicity, neurotoxicity, and a variety of cancers (ATSDR, 1994, 1998; Mandal, 2005; Schecter & Gasiewicz, 2003). Additionally, exposure to PCDDs and PCDFs has been linked to myeloid leukemia, chloracne, hemorrhaging, and carcinogenic effects, as well as promoting increased risk of cardiovascular and respiratory diseases (Bertazzi et al., 2001; Geyer et al., 2002; Pesatori et al., 1998). Exposure to PAHs can increase the risk of developing breast, lung, and skin cancer, leukemia, respiratory toxicity, and reproductive toxicity (ATSDR, 1995; Bostrom et al., 2002). Exposure to a mixture of dioxins, furans, and PAHs may significantly increase the risk of developing adverse health effects since these chemicals may have additive and synergistic properties (Carpenter, Arcaro, & Spink, 2002).

Similar to other studies that have investigated exposure from residing near wood treatment facilities (Dahlgren et al., 2003, 2007; Hensley et al., 2007), the levels of dioxins and furans found in human blood in this study further demonstrate that the residential areas have been and are being exposed to potentially unsafe levels of these contaminants due to past management practices of these wood treatment facilities. The pattern of dioxins and furans found in the blood samples is consistent with dust generated during the incineration of PCP and creosote-treated wood. The residents near the wood treatment facilities also have statistically higher concentrations of total 2,3,7,8-TCDD TEQs and the specific congeners associated with PCP in blood than the general population of the U.S. of the same age range. Furthermore, considering dioxin's long half-life in blood, these concentrations are even more significant. Comparing the exposure of residents around these similar sites gives insight into the pattern of exposure that communities adjacent to other wood treatment facilities might experience.

Our study was limited, for it focused on only two select congeners out of the 75 dioxin and 135 furans that exist, and only looked at the sum of 17 dioxin/furan congeners to evaluate total TEQs. Analysis of other congeners could prove to be equally if not more significant, considering certain other congeners have higher toxicity values than the congeners selected for study here. Larger sample sizes for both attic and dust sampling would improve the statistical analysis as well. Also, while all persons used for blood sampling lived near the identified wood treatment facilities for at least several years, the relative contribution of chemicals in blood derived from the wood treatment facilities versus other sources and other locations is unknown. A further uncertainty of the study involves being unable to determine whether the elevated dioxin/furan levels in blood lipid resulted from current or historic exposure to contaminants released from the wood treatment facilities. The presence of dioxins and furans in attic dust demonstrates that historic exposure was certainly a valid exposure pathway.

Corresponding Author: Lydia Feng, Consultant, Soil Water Air Protection Enterprise (SWAPE), 3110 Main St. Suite 205, Santa Monica, CA 90405. E-mail: lydia@swape.com.

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continued on page 46

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