

Recent Dioxin Contamination From Agent Orange in Residents of a Southern Vietnam City

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Marked elevation of dioxin associated with the herbicide Agent Orange was recently found in 19 of 20 blood samples from persons living in Bien Hoa, a large city in southern Vietnam. This city is located near an air base that was used for Agent Orange spray missions between 1962 and 1970. A spill of Agent Orange occurred at this air base more than 30 years before blood samples were collected in 1999. Samples were collected, frozen, and sent to a World Health Organization–certified dioxin laboratory for congener-specific analysis as part of a Vietnam Red Cross project. Previous analyses of more than 2200 pooled blood samples collected in the 1990s identified Bien Hoa as one of several southern Vietnam areas with persons having elevated blood dioxin levels from exposure to Agent Orange. In sharp contrast to this study, our previous research showed decreasing tissue dioxin levels over time since 1970. Only the dioxin that contaminated Agent Orange, 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), was elevated in the blood of 19 of 20 persons sampled from Bien Hoa. A comparison, pooled sample from 100 residents of Hanoi, where Agent Orange was not used, measured blood TCDD levels of 2 parts per trillion (ppt). TCDD levels of up to 271 ppt, a 135-fold increase, were found in Bien Hoa residents. TCDD contamination was also found in some nearby soil and sediment samples. Persons new to this region and children born after Agent Orange spraying ended also had elevated TCDD levels. This TCDD uptake was recent and occurred decades after spraying ended. We hypothesize that a major route of current and past exposures is from the movement of dioxin from soil into river sediment, then into fish, and from fish consumption into people. (J Occup Environ Med. 2001;43:435–443)

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Between 1962 and 1971, Agent Orange and other herbicides were sprayed for defoliation on 10% of southern Vietnam, south of the 17th parallel. Approximately 18 million gallons of Agent Orange were sprayed by fixed-wing aircraft, roughly 3 parts per trillion (ppt) of which consisted of the most toxic dioxin, 2,3,7,8-tetrachlorodibenzo-p-dioxin, also called TCDD or dioxin.^{1,2} This is the largest dioxin contamination known to date. More than 36 million persons presently live in the south of Vietnam. Previous studies have documented intake of TCDD from Agent Orange in American Vietnam War veterans and in Vietnamese.^{3–5}

Samples collected in 1970 and 1973 documented elevated levels of TCDD from Agent Orange in milk samples from southern Vietnamese women, and in fish and shrimp samples from areas in this region.^{5–7} Levels as high as 1832 ppt (measured in a nursing mother known to be a heavy fish consumer) were noted in these population-based studies but steadily declined in samples from 2000 persons collected between 1973 to 1995.⁵ Tissue samples from northern Vietnam, including Hanoi, and many locations in the south of Vietnam where no Agent Orange was sprayed or stored, had low TCDD levels, usually 2 to 3 ppt or lower.⁵ Dioxin levels in food samples collected during the 1980s from both northern and southern Vietnam were not remarkable.⁸ On the other hand, silt and sediment samples from southern riverbeds had considerably elevated levels of TCDD and other

dioxin and dibenzofuran congeners.^{9,10} The sources of these higher chlorinated dioxins, which are not contaminants of Agent Orange, are still uncertain. Their presence could be attributed to other herbicide or pesticide exposures, chlorophenol wood preservatives, or certain types of incineration.

The significance of an elevated dioxin body burden is related to the adverse health effects of dioxins. Some case reports and health studies from Vietnam suggest increases in liver cancer and congenital malformations potentially linked to Agent Orange and dioxin exposure.¹¹⁻¹⁴ In 1995, the National Institute of Environmental Health Sciences coordinated a congressionally mandated visit to Vietnam for group of dioxin scientists. It was concluded by certain members of this group, including one of the present authors (A.S.), that the evidence presented for these health effects allegedly related to dioxin or Agent Orange in Vietnam was not conclusive.

Nevertheless, with respect to dioxin health effects, in 1997 the International Agency for Research on Cancer upgraded TCDD to the status of "known human carcinogen."¹⁵ The US Public Health Service's National Toxicology Program also upgraded TCDD to "known human carcinogen status" in its 1999 Review of Carcinogens document.¹⁶ In summer 2000, after 10 years of work, the US Environmental Protection Agency released its 3000+ page "Draft Dioxin Reassessment." The EPA report concluded that TCDD (and possibly other closely related structural analogs, such as the chlorinated dibenzofurans) are carcinogenic to humans and can cause immune system alterations; reproductive, developmental, and nervous system effects; endocrine disruption; altered lipid metabolism; liver damage; and skin lesions in humans.¹⁷ Therefore, although the Vietnamese health studies are not generally accepted, other studies reviewed by various government agencies conclude that TCDD,

other dioxin congeners, and related chemicals are potent and persistent human toxicants.

Bien Hoa City, with a population of 390,000, is 35 km north of Ho Chi Minh City, formerly Saigon. In 1999, under the supervision of the Vietnam Red Cross, 20 convenience blood samples were collected from residents of various ages living near Bien Hung Lake within Bien Hoa. Bien Hung Lake runs through Bien Hoa and is located in close proximity to an air base used for "Operation Ranch Hand" fixed-wing aircraft Agent Orange spray missions from

December 1966 to April 1970. This lake connects to the nearby Dong Nai River. The US Department of Defense documented at least one spill of Agent Orange that occurred before 1971, when spraying ended, from underground storage tanks at this location, with an estimated release of 5000 to 7000 gallons. Although dioxin is highly lipophilic and markedly hydrophobic, it can move through soil into lakes or rivers, where it generally attaches to organic matter in sediment.¹⁷ It then moves up the food chain from phytoplankton to zooplankton, from zoo-

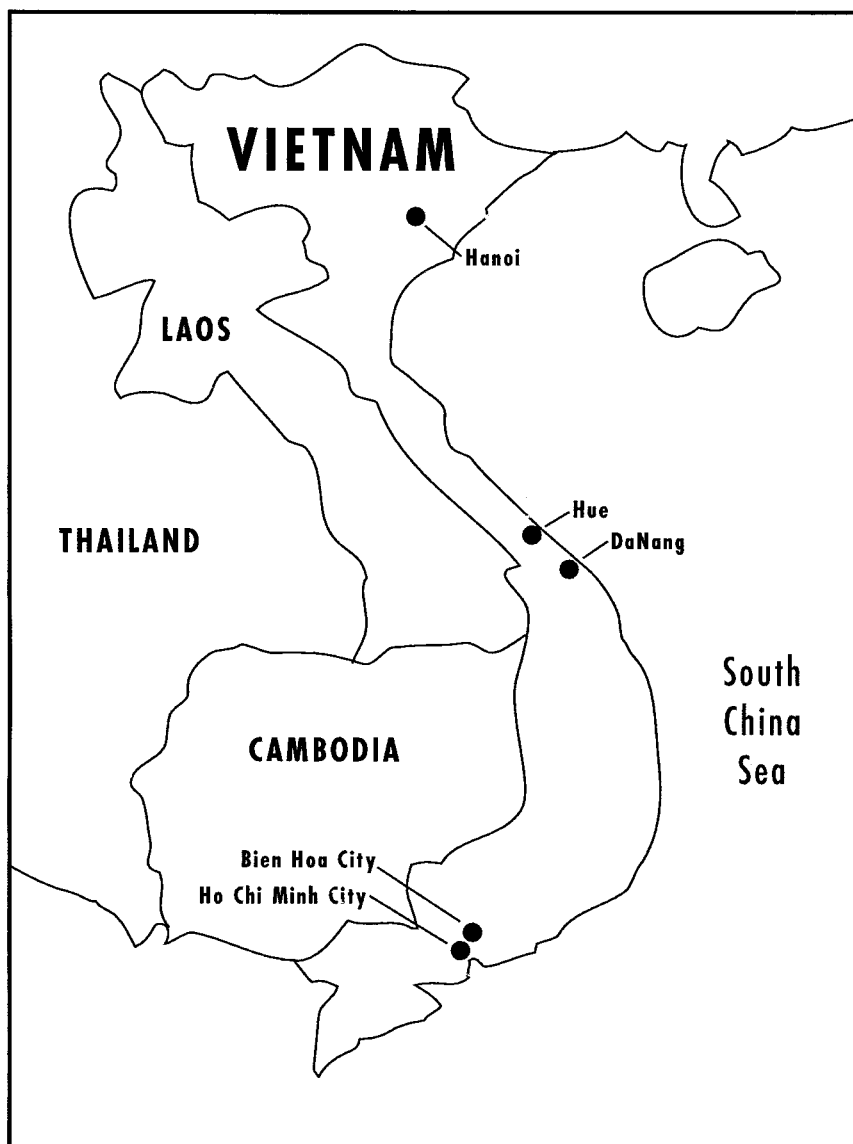


Fig. 1. Map of Vietnam.

TABLE 1

Levels of Dioxins, Dibenzofurans, and TEQs in Soil Samples Collected From Bien Hoa Air Base, a Former Agent Orange Storage Facility*

Dioxins/Furans	I-TEFs	Sample 1		Sample 2		Sample 3		Sample 4	
		Conc	TEQ	Conc	TEQ	Conc	TEQ	Conc	TEQ
2,3,7,8-T ₄ CDD	1	1,164,699	1,164,699	603,968	603,968	ND	ND	10,580	1,058
2,3,7,8-P ₅ CDD	0.5	6,920	3,460	6,953	3,477	ND	ND	ND	ND
2,3,7,8-H ₆ CDD	0.1	ND	ND	ND	ND	ND	ND	ND	ND
2,3,7,8-H ₇ CDD	0.01	163,467	1,635	28,467	285	ND	ND	439	4.4
OCDD	0.001	309,932	310	75,353	75	39.4	0.04	754	0.75
2,3,7,8-T ₄ CDF	0.1	88,524	8,852	27,863	2,786	ND	ND	ND	ND
2,3,7,8-P ₅ CDF	0.5	ND	ND	ND	ND	ND	ND	ND	ND
2,3,7,8-H ₆ CDF	0.1	ND	ND	ND	ND	ND	ND	ND	ND
2,3,7,8-H ₇ CDF	0.1	17,403	1,740	2,772	277	ND	ND	ND	ND
OCDF	0.001	40,794	41	8,217	8.2	ND	ND	ND	ND
Total PCDD		1,645,017	1,170,104	714,740	607,803	39.4	0.04	11,773	1,063
Total PCDF		146,721	10,633	38,852	3,071	ND	ND	ND	ND
Total TEQ			1,180,737		610,874		0.04		1,063

* TEQ, dioxin toxic equivalent; I-TEF, International Toxic Equivalency Factor; Conc, concentration; CDD, chlorodibenzo-p-dioxin; OCDD, octachlorodibenzodioxin; CDF, chlorodibenzofuran; OCDF, octachlorodibenzofuran; ND, not detected. Values are expressed as pg/g (ppt), related to dry matter.

plankton to fish, and then into humans. With this knowledge, a population of 20 accessible volunteers who lived near Bien Hung Lake and presumably consumed fish from the potentially contaminated lake provided blood samples under the supervision of the Vietnam Red Cross. A comparison, pooled blood sample from Hanoi, in northern Vietnam, was collected from 100 persons and analyzed so that levels could be compared between people living in the northern, unsprayed region and in

the southern exposed region of Bien Hoa. Grab, or convenience, sediment samples from a river running by the air base were collected, as were soil samples from the air base.

Methods

In 1999, 20 individual whole-blood samples were collected and immediately frozen from volunteer residents of Bien Hoa City, who were among the 20,000 persons living close to the potentially contaminated Bien Hung Lake. In addition,

100 whole-blood samples from the general adult population in the northern Vietnamese city of Hanoi were anonymously collected from leftover blood at a Hanoi hospital after diagnostic tests had been performed. These samples were combined and frozen for one pooled analysis. Sediment, soil, and fish were collected from the river, and additional food samples were collected from local markets, but Vietnamese authorities permitted only the blood, and later sediment and soil samples, to be

TABLE 2

Bien Hoa City, Vietnam Dioxin Sediment Data, Year 2000*

Congener	Hanoi [†]	Bien Hung Lake 1			Bien Hung Lake 2 [‡]			Dong Nai River [§]		Bien Hung Lake 3	
		A	B	C	A	B	C	A	B	1 km Downstream	1 km Upstream
2,3,7,8-TCDD	ND	10.4	14.5	1.6	177	114	98.2	0.8	1.5	1.7	1
Total PCDD	403	199	291	532	1,970	1,413	1,546	543	715	697	497
PCDD TEQ [¶]	1.4	11	15.6	3.3	185	120	103	1.6	2.5	3	2.7
Total PCDF	70	9	11	9.9	134	98.8	89.4	2	6.8	18.9	28.5
PCDF TEQ	5.1	0.5	0.77	0.6	8.2	6.05	5.2	0.1	0.4	0.9	1
Total PCDD/PCDF	473	208	302	542	2,104	1,512	1,544	544.5	721	716	526
PCDD/PCDF TEQ	6.5	11.5	16.4	3.9	193	126	108	1.7	2.9	3.9	3.7

* Values are expressed as ng/kg (ppt), related to dry matter. For definition of abbreviations, see Table 1.

[†] Hanoi sample is the northern Vietnam control sample.

[‡] Bien Hung Lake 2 sample is close to the former air base.

[§] Bien Hung Lake empties into the Dong Nai River.

^{||} Bien Hung Lake-3: downstream and upstream of pipe coming from Bien Hung Lake.

[¶] TEQs were calculated using I-TEFs.

taken out of Vietnam for dioxin analysis. The blood and sediment analyses were performed at ERGO Laboratory, a German World Health Organization–certified laboratory for human tissue and food dioxin congener-specific dioxin analysis. The soil was analyzed in Japan and Vietnam (by M.M. and V.D.T., respectively). Dioxin analyses were performed using high-resolution gas chromatography mass-spectrometry after cleanup and capillary column separation.¹⁸

Results

Figure 1, a map of Vietnam, shows the locations of Hanoi, Ho Chi Minh City, and Bien Hoa. Agent Orange spraying occurred in parts of southern Vietnam only between 1962 and

1971, with the heaviest spraying occurring between 1967 and 1969.^{1,2,19,20}

Results of dioxin analyses performed on soil samples from the air base at Bien Hoa are shown in Table 1. The TCDD level varies from not detected to over 1 million ppt for sample 1. The markedly elevated level is consistent with an Agent Orange spill at the sampling site. The over 1 million ppt figure is the highest soil-TCDD level measured in Vietnam to date. Octachlorodibenzodioxins and heptachlorodibenzodioxins were also found in relatively high concentrations in this soil sample.

Table 2 shows measured TCDD levels and dioxin and dibenzofuran total “international” dioxin toxic equivalents (I-TEQ, or TEQ) found

in air-dried riverbed sediment samples.^{21,22} As expected, TCDD levels were low in the Hanoi (northern Vietnam) sediment sample, consistent with the fact that no Agent Orange was used in northern Vietnam. Low TCDD levels also were found some distance from the air base, from Bien Hung Lake 3, and from the nearby Dong Nai River. Elevated TCDD levels were noted in the Bien Hung Lake 2 samples and, to a lesser extent, in the nearby Bien Hung Lake 1 “grab” samples, which were taken close to the air base. It can be noted that where the TCDD level was elevated, it contributed substantially to the total dioxin TEQ.

Table 3 shows complete congener-specific sediment data. Only TCDD is a characteristic contaminant of

TABLE 3

Measured Dioxin and Dibenzofuran Levels and Total TEQs in Sediment Samples From Lake Bien Hung, Bien Hoa City, Vietnam*

Congener	I-TEF	Hanoi [†]	Bien Hung Lake 1			Bien Hung Lake 2 [‡]			Dong Nai River [§]		Bien Hung Lake 3	
			A	B	C	A	B	C	A	B	1 km Downstream	1 km Upstream
2,3,7,8-TCDD	1	ND	10.4	14.5	1.6	177	114	98.2	0.8	1.5	1.7	1.1
1,2,3,7,8-PCDD	0.5	0.9	0.3	0.4	0.2	4.2	3.7	1.9	0	NA	NA	NA
1,2,3,4,7,8-HxCDD	0.1	0.6	0.2	ND	ND	4	1.9	2	ND	ND	0.6	1.2
1,2,3,6,7,8-HxCDD	0.1	1.7	0.7	1.6	2.3	7.5	6	5.4	0.2	0.5	1.3	3
1,2,3,7,8,9-HxCDD	0.1	1	0.8	3.6	3.8	7.1	5.5	5.3	0.6	0.9	1.5	3
1,2,3,4,6,7,8-HpCDD	0.01	25.7	13.9	22.2	48.1	160	119	113	11.6	16.5	32	42.9
OCDD	0.001	373	173	249	476	1,610	1,163	1,228	529	695	660	446
2,3,7,8-TCDF	0.1	9.8	2.4	3	1.4	62.3	43.2	37.3	0.4	1.3	2.7	3.6
1,2,3,7,8-PeCDF	0.05	5.7	0.3	0.7	1.1	3	1.8	3	0.1	0.4	1	1.1
2,3,4,7,8-PeCDF	0.5	4.3	0.1	0.3	0.1	1.3	1.1	0.8	0.1	0.3	0.5	0.6
1,2,3,4,7,8-HxCDF	0.1	9.7	0.4	0.3	0.2	2	2.7	1.7	0.1	0.3	0.7	1.1
1,2,3,6,7,8-HxCDF	0.1	3.4	0.3	0.4	0.2	4.4	3.3	2.7	0.1	0.2	0.5	0.7
1,2,3,7,8,9-HxCDF	0.1	1.2	0.3	1.9	2.9	1	1.5	0.7	0.1	0.2	0.4	0.4
2,3,4,6,7,8-HxCDF	0.1	1.8	0.2	0.3	0.4	2.3	2.2	1.9	0.2	0.3	0.8	0.8
1,2,3,4,6,7,8-HpCDF	0.01	8.2	1.1	1.3	0.7	13.2	9.9	10.6	0.2	0.9	2.9	4
1,2,3,4,7,8,9-HpCDF	0.01	2.7	0.2	ND	ND	2	1.7	1.5	ND	0.1	0.4	0.4
OCDF	0.001	23.5	3.9	2.9	2.8	42.3	31.5	29.1	0.8	2.9	8.9	15.7
Total PCDD		403	199	291	532	1,970	1,413	1,455	543	715	697	497
PCDD TEQ		1.4	11	15.7	3.3	185	120	103	1.6	2.5	3	2.7
Total PCDF		70.3	9.2	11	9.9	134	98.8	89.4	2.1	6.8	18.9	28.5
PCDF TEQ		5.1	0.5	0.77	0.6	8.2	6.05	5.2	0.2	0.4	0.9	1
Total PCDD/PCDF		473	208	302	542	2,104	1,512	1,544	545	721	716	526
Total TEQ		6.5	11.5	16.5	3.9	193	126	108	1.8	2.9	3.9	3.7

NA, not analyzed; Hx, hexa; Hp, hepta; Pe, penta.

* Values are expressed as pg/kg (ppt), related to dry matter. For definition of other abbreviations, see Table 1.

[†] Hanoi sample is the northern Vietnam control sample.

[‡] Lake Bien Hung 2 sample is close to the former air base.

[§] Bien Hung Lake empties into the Dong Nai River.

^{||} Bien Hung Lake 3 is downstream and upstream of a pipe coming from Bien Hung Lake.

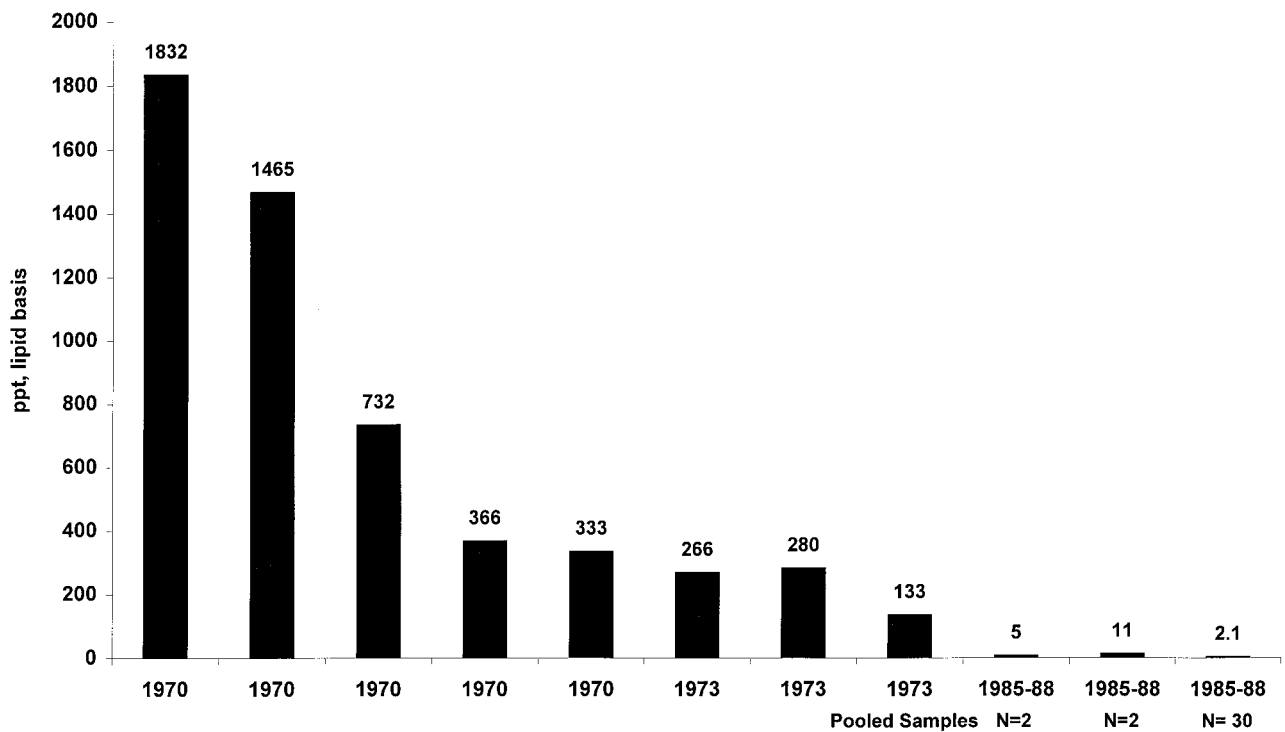


Fig. 2. 2,3,7,8-TCDD in human milk from the south of Vietnam, 1970 to 1990 (ppt, lipid basis). The 1970 and 1973 analyses were from individual samples and were calculated assuming 3% milk lipid. Collection sites (1970 and 1973): the villages of Tan Uyen, Can Gio, Quang Xuen, Dau Tieng, and Phu Cuong.

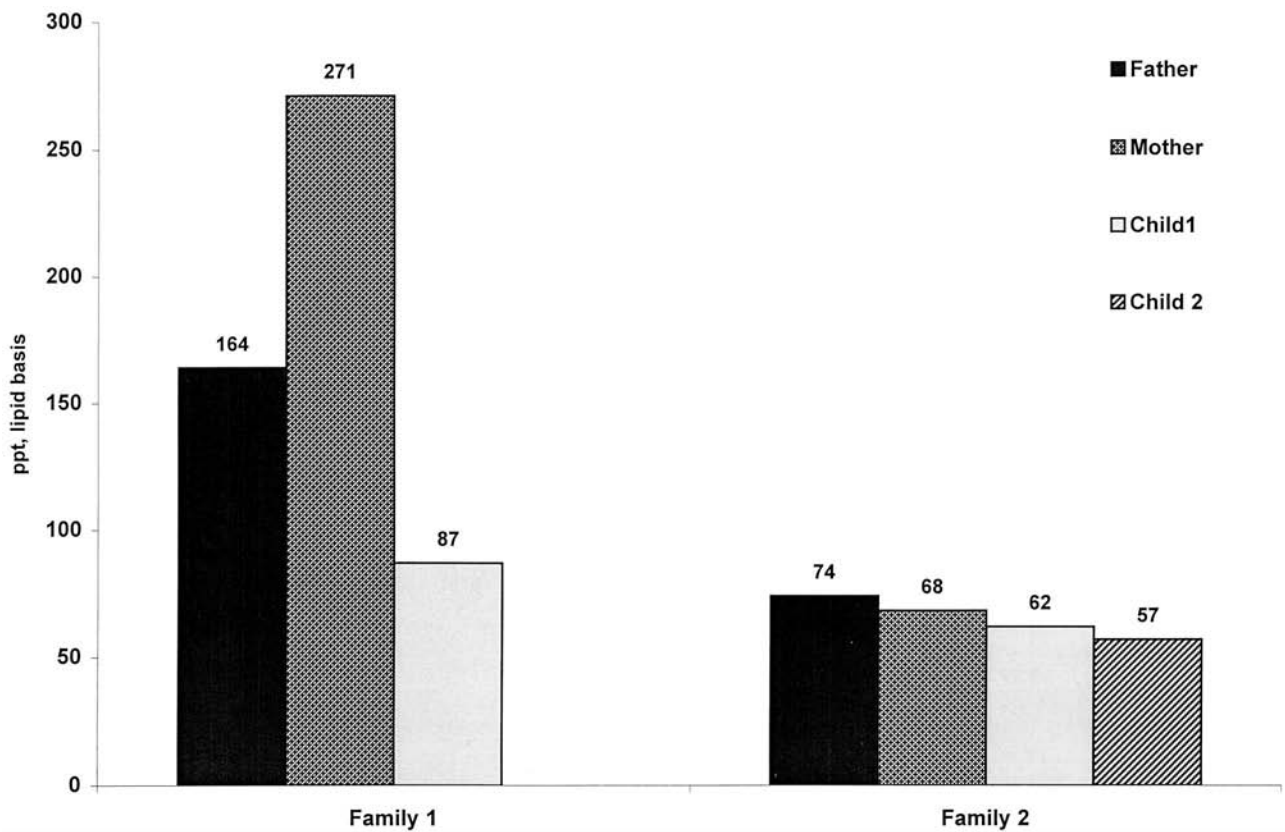


Fig. 3. TCDD blood levels in Vietnam, 1999. Family 1 had a high level of fish consumption. Family 2 moved from North Vietnam after the spraying in southern Vietnam ended.

TABLE 4

Measured Blood Dioxin, Dibenzofuran, and Coplanar PCB Levels and TEQs from Bien Hoa Village, Dong Nai Province, Vietnam, 1999 (Hanoi, VN1 to 7, and VN 6/99-1 to 3)*

Congeners	I-TEF	Hanoi 1999	VN1	VN2	VN3	VN4	VN5	VN6	VN7	VN 6/99-1	VN 6/99-2	VN 6/99-3
PCDDs												
2,3,7,8-TCDD	1	2.2	21.0	5.6	68.3	7.8	7.1	163.8	101.2	271.1	87.4	38.2
1,2,3,7,8-PeCDD	0.5	3.5	2.7	3.4	7.1	4.3	6.2	6.1	6.4	12.6	6.2	6.7
1,2,3,4,7,8-HxCDD	0.1	3.5	4.2	5.1	5.9	4.1	7.6	6.4	5.4	9	4	4.1
1,2,3,6,7,8-HxCDD	0.1	7.7	12.6	12.4	21.3	15.2	33.2	26.0	16.5	30.7	19.8	14.2
1,2,3,7,8,9-HxCDD	0.1	2.4	3.3	4.0	5.3	2.8	9.0	7.4	5.4	6.4	4.2	2.9
1,2,3,4,6,7,8-HpCDD	0.01	15.4	26.7	38.4	44.5	14.4	71.4	65.0	36.6	89.9	51.5	24.1
OCDD	0.001	114	290	279	476	297	1,273	597	212.0	690	386	217
PCDFs												
2,3,7,8-TCDF	0.1	1.0	1.0	0.8	0.8	0.8	0.8	1.0	0.9	1.5	1.5	1.6
1,2,3,7,8-PeCDF	0.05	0.5	0.8	0.5	0.5	0.5	0.5	0.6	0.5	1.2	1.2	ND
2,3,4,7,8-PeCDF	0.5	6.8	3.3	3.5	4.0	3.7	6.1	5.1	3.1	9.2	5.1	5.3
1,2,3,4,7,8-HxCDF	0.1	10.1	7.7	14.0	19.0	12.3	34.3	22.0	7.8	29.5	13	11.6
1,2,3,6,7,8-HxCDF	0.1	7.8	4.9	8.1	10.2	6.8	19.0	10.7	4.0	19	6.7	5.7
1,2,3,7,8,9-HxCDF	0.1	0.5	0.5	0.5	1.1	0.5	1.0	2.3	0.5	ND	ND	ND
2,3,4,6,7,8-HxCDF	0.1	2.1	1.0	1.8	1.3	1.0	2.4	2.6	1.5	3.1	1.5	1.2
1,2,3,4,6,7,8-HpCDF	0.01	8.6	6.8	26.8	27.3	11.4	41.7	26.1	10.4	48.4	18.5	15
1,2,3,4,7,8,9-HpCDF	0.01	0.8	0.9	4.0	5.4	0.9	8.2	4.5	0.9	2.5	2.5	2.3
OCDF	0.001	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	5	5	5
Coplanar PCBs												
3,3',4,4'-Tetra-CB	0.0005	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3,3',4,4',5-Penta-CB	0.1	NA	NA	37.0	NA	52.0	NA	NA	NA	58	50	34
3,3',4,4',5,5'-Hexa-CB	0.01	29.0	24.0	15.0	20.0	51.0	52.0	74.0	22.0	35	35	20
Total PCDD		149	360	348	629	346	1,407	871	384	1,110	559	308
PCDD TEQ		5.57	24.9	10.2	76	12.6	17.2	172	108	284	94.2	44.3
Total PCDF		39.6	28	61.5	71.6	39.3	116	76.9	31.2	114	49.9	43.3
PCDF TEQ		5.58	3.16	4.53	5.58	4.06	9.31	6.73	3.11	10.3	4.98	4.76
Total PCDD/PCDF		189	388	410	701	385	1,523	948	415	1,224	609	351
PCDD/PCDF TEQ		11.1	28.1	14.7	81.58	16.7	26.5	179	111	294	99.2	49
Total PCB		29	24	51	20	103	52	74	22	94	84	54
PCB TEQ		0.288	0.239	3.83	0.196	5.7	0.521	0.741	0.22	6.2	5.32	3.55
Total TEQ		11.4	28.3	18.5	82	22.4	27	180	111	301	105	52.5

* Values are expressed as pg/g (ppt), lipid basis. PCB, polychlorinated biphenyl; VN, Vietnam; NA, not analyzed. For definition of other abbreviations, see Table 1.

Agent Orange; the other dioxin congeners originate from different sources. Although other dioxin congeners are present in the sediment, the elevated total TEQ usually reflects elevated TCDD levels.

Figure 2 illustrates declining levels of TCDD in Vietnamese since Agent Orange spraying ended by presenting previously measured TCDD levels found in milk samples collected from 1970 through 1988. TCDD levels from southern Vietnamese mothers who were nursing at the time of sample collection decreased from a high of 1832 ppt in 1970 to between 2 and 11 ppt in 1985 to 1988.⁵

The Bien Hoa and Hanoi blood dioxin, dibenzofuran, and dioxin-like polychlorinated biphenyl congener analyses are presented in Tables 4 and 5. The International Toxic Equivalency Factors are also included in these tables.^{21,22} Except for TCDD, the dioxin responsible for contaminating Agent Orange, the other dioxin congeners from Bien Hoa blood samples were not found to be elevated. TCDD congeners are presented on a lipid-normalized basis from whole-blood samples. A TCDD level of 2 ppt was found for the pooled blood analysis from the Hanoi control subjects ($n = 100$). The lowest level of TCDD measured

in the southern samples was also 2 ppt for sample VN 6/99-5. All 19 other TCDD levels were elevated (at or above 6 ppt), with levels up to 271 ppt, 135-fold higher than that found in the general population not exposed to Agent Orange. This compares with previous data showing 2 to 4 ppt in the general US population.²³ The lowest total dioxin toxic equivalency of 8.59 ppt TEQ in blood was found in a southern Vietnamese resident (VN 6/99-5), although the northern Vietnamese pooled sample was the next lowest, measuring 11.4 ppt, with other southern Vietnamese blood TEQs ranging from 14.4 to 301 ppt. We

TABLE 5

Measured Blood Dioxin, Dibenzofuran, and Coplanar PCB Levels and TEQs from Bien Hoa Village, Dong Nai Province, Vietnam, 1999 (VN 6/99-4 to 13)*

Congeners	I-TEF	VN 6/99-4	VN 6/99-5	VN 6/99-6	VN 6/99-7	VN 6/99-8	VN 6/99-9	VN 6/99-10	VN 6/99-11	VN 6/99-12	VN 6/99-13
PCDDs											
2,3,7,8-TCDD	1	103	2.4	70.2	66.9	162	5.1	73.9	62.2	57.3	19.8
1,2,3,7,8-PeCDD	0.5	8.3	23.1	9	10.8	13.8	3.9	6.4	6.9	3.7	14.4
1,2,3,4,7,8-HxCDD	0.1	5	2.4	11.1	8.5	8.5	3.1	3	3.3	2.7	9.9
1,2,3,6,7,8-HxCDD	0.1	17.9	6.7	34.5	33.4	39.3	9.3	14.5	16.2	9.8	41.1
1,2,3,7,8,9-HxCDD	0.1	3.4	1	5.5	10.3	8.6	4.3	3.5	4	2.2	9.3
1,2,3,4,6,7,8-HpCDD	0.01	50.5	22.9	99.7	74	41.6	62.8	28.9	33.9	20.3	73.3
OCDD	0.001	757	104	903	548	322	403	256	341	206	378
PCDFs											
2,3,7,8-TCDF	0.1	1.8	1.5	2	2	2	2	1.5	1.4	1.4	3
1,2,3,7,8-PeCDF	0.05	ND	1.4	1.8	1	1.1	2	ND	ND	ND	1.9
2,3,4,7,8-PeCDF	0.5	4	2.5	8.4	6.6	7.4	2.9	4	4.6	3.3	15.5
1,2,3,4,7,8-HxCDF	0.1	10.9	8.8	39.6	14	13.7	12.7	18	20.6	14.9	11.6
1,2,3,6,7,8-HxCDF	0.1	11.6	7.6	40	14.9	12.5	11.9	8.1	11	8.1	7.9
1,2,3,7,8,9-HxCDF	0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,3,4,6,7,8-HxCDF	0.1	1.3	1	4.3	2.2	1.2	1.2	1	1	1	1.5
1,2,3,4,6,7,8-HpCDF	0.01	20	16.3	75.2	23.9	18.2	29.9	19.8	28.7	20.5	5.9
1,2,3,4,7,8,9-HpCDF	0.01	ND	5.3	10.7	2.9	1.8	5.4	2.2	2.5	2.5	1.5
OCDF	0.001	6	5	5	4	4	5	5	5	5	5
Coplanar PCBs											
3,3',4,4'-Tetra-CB	0.0005	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3,3',4,4',5-Penta-CB	0.1	41	24	52	20	47	19	16	26	18	89
3,3',4,4',5,5'-Hexa-CB	0.01	20	14	38	16	45	12	15	19	17	67
Total PCDD		945	143	1,133	752	596	192	386	469	302	546
PCDD TEQ		107	5.26	81.7	78.6	175	9.77	79.8	68.7	61	34.1
Total PCDF		51.2	46.1	184	68.4	58.9	69.6	55.2	70.4	52	49.1
PCDF TEQ		4.69	3.33	13.7	6.83	6.8	4.59	4.98	5.92	4.35	10.2
Total PCDD/PCDF		996	189	1,317	820	656	561	441	539	354	595
PCDD/PCDF TEQ		112	8.58	95.4	85.4	182	14.4	84.7	74.6	65.4	44.3
Total PCB		61	38	90	36	92	31	31	45	35	156
PCB TEQ								1.7	2.79	1.98	9.52
Total TEQ		115	8.59	95.4	85.6	183	14.4	86.4	77.4	67.4	53.8

* Values are expressed as pg/g (ppt), lipid basis. PCB, polychlorinated biphenyl; VN, Vietnam; NA, not analyzed. For definition of other abbreviations, see Table 1.

have no explanation for the very low value of 8.59 ppt in the southern Vietnamese individual samples, VN 6/99-5.

The TCDD blood levels from Bien Hoa and Hanoi residents presented in Table 6 show that some persons had markedly higher TCDD levels than those measured during the 1970-to-1973 samples, collected during wartime spraying and immediately after the spraying ended early in 1971. Numbers 3, 4, 7, and 17 were taken from persons born after Agent Orange spraying had ended.

Figure 3 presents blood TCDD data from two Bien Hoa families.

The first family (samples 5 to 7 in Table 6) were heavy consumers of fish from Bien Hung Lake, which runs adjacent to their home. All members of this family had elevated TCDD levels: 271 in the mother, 164 in the father, and 87 ppt in the child born in 1980, almost a decade after Agent Orange spraying ended. These findings suggest that this substantial contamination is probably from dietary intake of TCDD from contaminated fish consumed long after Agent Orange spraying ended early in 1971. The second family (samples 1 to 4 in Table 6) moved from northern Vietnam to southern Viet-

nam after Agent Orange spraying ended in 1971. Each individual in this family exhibited elevated TCDD levels, from 57 to 74 ppt. TCDD measurements from the two twin boys (samples 3 and 4 in Table 6), born in 1981, measured 57 ppt and 62 ppt, respectively. These levels are almost the same as those found in their parents, 68 and 74 ppt, respectively.

Comments

The strikingly elevated TCDD blood values in those who primarily consume fish for sustenance, in recent residents to this area, and in children born after Agent Orange

TABLE 6
Vietnamese Blood Dioxin Levels, 1999

Sample	Year of Birth	TCDD* Level (ppt Lipid Basis)
North Vietnam (pooled control, <i>n</i> = 100)		
Hanoi	1959–1979	2.0
South Vietnam (individual samples)		
1	1942	68
2	1935	74
3†	1981	62
4†	1981	57
5	1945	164
6	1954	271
7†	1980	87
8	1962	101
9	1947	21
10	1962	6.0
11	1950	8.0
12	1942	7.0
13	1955	38
14	1963	103
15	1962	2.0
16	1962	70
17†	1988	67
18	1954	162
19	1952	5.0
20	1930	20

* TCDD, 2,3,7,8-tetrachlorodibenzo-p-dioxin.

† Individuals born after Agent Orange spraying ended.

spraying ended almost 30 years before the 1999 blood collection is surprising and a cause for concern. Food sources of dioxin exposure include fish, meat, and dairy products, which account for the immediate source of almost all dioxins in humans.¹⁷ The major contribution of TCDD is suspected to be from contaminated fish, because this is the most typical “animal” foodstuff in the Vietnamese diet and it is known to accumulate dioxins. The unexpected finding of soil, sediment, and human contamination with TCDD that was last applied 30 years ago suggests the existence of other dioxin-contaminated sites in Vietnam and elsewhere that may result in substantial environmental contamination and human exposure decades later.

We believe our conclusion regarding the source and route of contamination is probable, but it cannot be regarded as conclusive without more environmental data, including sam-

ples from soil, riverbeds, and local fish and food. Health implications from this spill are of concern because TCDD and other dioxins have been causally linked to cancer and cancer mortality at relatively high levels in chemical workers and in toxicology studies,^{2,16,17,24–29} and to reproductive and developmental effects at general-population levels and higher. A review of Vietnamese developmental studies concluded that Vietnamese-designed studies were not conclusive, in contrast to the reports of other studies.^{17,30–33} Nervous system, immune system, and endocrine system perturbations are also believed to be linked to dioxin exposures in humans.^{17,34–36}

In this study, blood samples and analyses were limited to 21 for several reasons, including restriction of the number of samples permitted to be removed from Vietnam by government authorities, a paucity of World Health Organization certified laboratories for blood dioxin analysis, and monetary constraints for the costly dioxin analyses (which usually average approximately \$1000 per blood analysis). Nevertheless, elevated TCDD levels in 19 of 20 persons living near the location of a dioxin spill occurred decades previously is striking.

From a public health perspective, appropriate research on the existence and extent of dioxin “hot spots” in Bien Hoa and elsewhere in Vietnam, and remediation measures, seem evident, yet follow-up will be challenging because of cultural and political obstacles. Further sampling of people and the environment in a representative fashion is clearly indicated for Bien Hoa in particular because of its relatively large population and geographic location near Ho Chi Minh City, the most populated city in Vietnam. It is not clear from current data how many hot spots exist in Vietnam, nor how many Vietnamese have been or are being contaminated with dioxin from Agent Orange. This study documents one geographic area where dioxin from Agent Orange contaminated and continues to

contaminate people living in Vietnam. It is possible that American Vietnam War veterans who served in this area may also have been contaminated with dioxin.

If soil, sediment, and the food chain are contaminated with TCDD, as seems to be the case in this region, then food without elevated dioxin content should be substituted for contaminated food as a public health measure. Appropriate cleanup of the Agent Orange spill affecting the area near the air base may be indicated as a long-term project if substantial contamination is found. However, remediation of contaminated silt or sediment is a difficult and expensive process, which might lead to further mobilization of dioxin elsewhere downstream.

Further research on the fate and transport of dioxin in this area of Vietnam should prove useful in better characterizing the movement of dioxins through the environment and into the food chain. It should also provide information concerning the bioavailability of TCDD, which can vary depending on the matrix within which it is carried.³⁷ The effects of dioxins on human health can be studied in Vietnam because of the unique situation where both current and older dioxin contamination exists for a potentially large population of exposed men, women, and children over several generations.

Acknowledgments

We wish to acknowledge and thank the people of Vietnam who have been exposed with dioxin from Agent Orange, especially those who contributed their blood or other tissues and those who helped to collect the samples. We also thank the government of Vietnam, including the Committee 33 and the former 10–80 Committee, for assistance with the work. The cooperation of the Vietnam Red Cross is especially acknowledged, including Professor Nguyen Trong Nham, Director, and Ms. Mac Thi Hoa. Funding was received from the CS Fund, The Samuel Rubin Foundation, The Albert Kunstadter Family Foundation, the Christopher Reynolds Foundation, The Zumwalt Institute for Public Health and Environmental Medicine, the Vietnam Veterans of America Foundation, and the American Friends Service Commit-

tee. We also thank our colleagues and associates, especially Hatfield Consulting associates for sharing copies of US Department of Defense documents concerning an Agent Orange leak or "spill" at the Bien Hoa Air Base during the Vietnam War.

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