

AGENT ORANGE/DIOXIN HOT SPOTS – A LEGACY OF U.S. MILITARY BASES IN SOUTHERN VIET NAM

Overview Paper Presented by Dr. Wayne Dwernychuk at:

- **Viet Nam – United States Scientific Conference on Human Health and Environmental Effects of Agent Orange/Dioxin (Ha Noi, Viet Nam; March 2002)**
- **International Conference on the Long-Term Environmental Consequences of the Viet Nam War (Stockholm, Sweden; July 2002)**
- **International Conference on the Ecological and Health Effects of the Viet Nam War (Yale University, New Haven, Connecticut; September 2002)**
- **Rockefeller University, New York (September 2002)**
- **Agent Orange Research and Policy Briefing (Washington, DC; July 2003)**
- **Inception Workshop on the 10-80 Division/Hatfield ‘Hot Spot’ Project (Ford Foundation funding; Ha Noi, Viet Nam; November 7, 2003)**
- **University of Washington, School of Public Health and Community Medicine; Seattle Washington (April 2004)**
- **France – Viet Nam Friendship Association Conference on Agent Orange (Paris, France, March 2005; presented by a designate of Dr. Dwernychuk).**



AGENT ORANGE/DIOXIN HOT SPOTS – A LEGACY OF U.S. MILITARY BASES IN SOUTHERN VIET NAM

L. Wayne Dwernychuk^a, Hoang Dinh Cau^b, Christopher T. Hatfield^a,
Thomas G. Boivin^a, Tran Manh Hung^b, Phung Tri Dung^b, and Nguyen Dinh Thai^b

^a*Hatfield Consultants Ltd., Suite 201 – 1571 Bellevue Ave., West Vancouver, BC, V7V 1A6, Canada*

^b*10-80 Division, Ministry of Health, 35 Nguyen Huy Tuong Street, Thanh Xuan District, Ha Noi, Viet Nam*

1.0 Introduction

In 1962, the US military initiated use of herbicides in Viet Nam for general defoliation and crop destruction through a program codenamed Operation Ranch Hand (IOM, 2001). Application of herbicides was primarily through cargo aircraft (C-123s), and ground mechanisms (i.e., trucks, backpack sprayers, and riverboats); helicopters also experienced limited use in certain areas of the country. Over 72 million litres of herbicide were applied over southern Viet Nam (Westing, 1984; IOM, 1994); applications ceased in 1971. However, recent studies reviewing spray records from the war reveal that perhaps over 80 million litres of herbicide were used in Viet Nam (Stellman *et al.*, 2003).

Sixty-one percent of the herbicide used in Viet Nam was Agent Orange, a 50/50 mixture of 2,4-dichlorophenoxyacetic acid (2,4-D), and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). The 2,4,5-T fraction of the Agent Orange mixture contained the highly toxic chemical 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD). The presence of the TCDD dioxin congener in Agent Orange was initially unknown to the US military; however, this position has been challenged. Zumwalt (1990) stated that dioxin in the Agent Orange mixture was, in fact, known to the military when use of herbicides in Viet Nam was initiated in the 1960s.

Military installations throughout southern Viet Nam (e.g., Bien Hoa, Da Nang, Nha Trang, and Phu Cat) served as bulk storage and supply facilities for Agent Orange (US Army documents, 1969; Cecil, 1986). These storage sites experienced spills of herbicide. In 1970, for example, a 7,500 US gallon spill of Agent Orange occurred on the Bien Hoa base. Between January and March 1970, three other spills of lesser volume occurred at Bien Hoa (US Army documents, 1970).

As a consequence of the aerial applications and handling of Agent Orange on military installations, there exist two primary sources of major TCDD contamination in Viet Nam – from spray missions by C-123 aircraft, and contamination on former US military installations where herbicide was stored, dispensed, and spilled.

Our investigations examined the environmental consequences of aerial applications and military base scenarios of Agent Orange use from 1994-2001 in the Aluoi Valley of central Viet Nam (Hatfield Consultants and 10-80 Committee, 1998, 2000; Dwernychuk *et al.*, 2002). The valley is situated approximately 65 km west of Hue.

The Aluoi Valley was an integral portion of the Ho Chi Minh Trail. The valley had three US Special Forces bases and was extensively sprayed with Agent Orange between 1965 and 1970 (Fig. 1). Aluoi and Ta Bat bases were closed in 1965, being operational for less than one year. The A So base (formerly known as the A Shau Special Forces base), remained operational from 1963 to 1966 (Stanton, 1985). Agent Orange was used on the A So base during its operation (US Army documents, 2001).

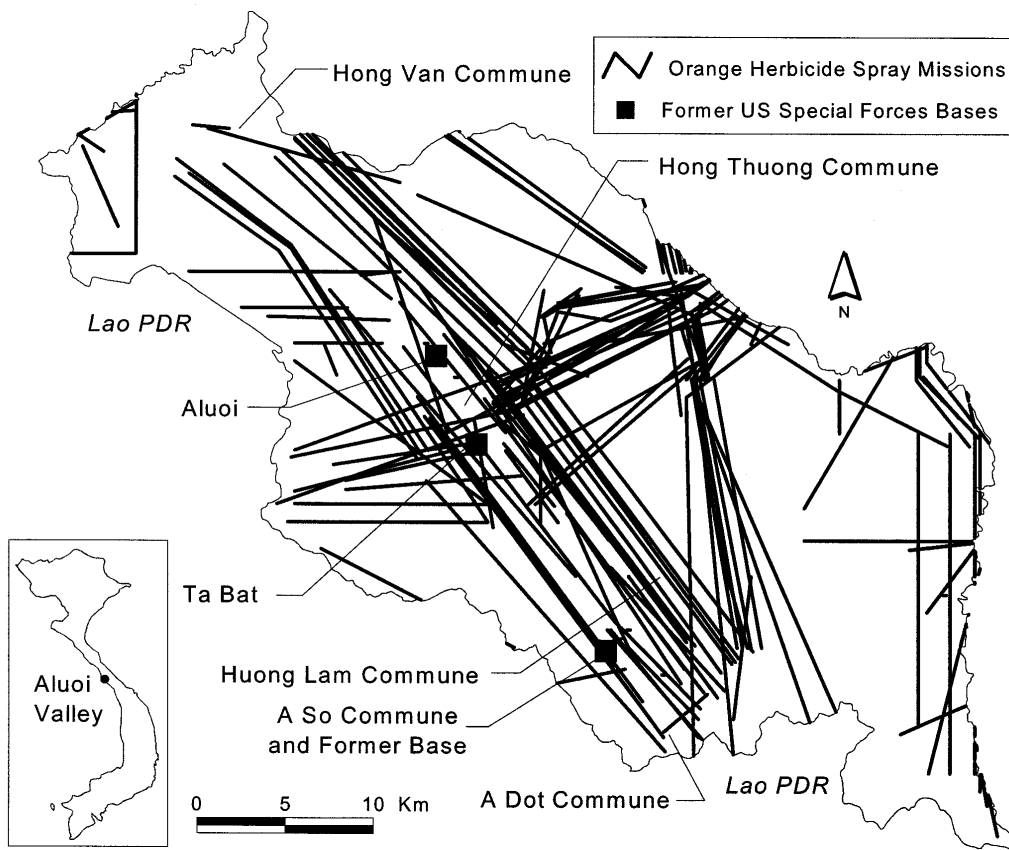


Fig. 1. Communes and Agent Orange aerial spray missions, Aluoi Valley, Viet Nam, 1965-1970 (Source: US Dept. of the Army).

The Aluoi Valley was selected to evaluate the long-term environmental consequences of Agent Orange use by providing an experimental design that would facilitate an extrapolation to other regions of southern Viet Nam, regarding where the highest levels of TCDD contamination may exist – on lands sprayed by C-123 aircraft, or on former US military installations where use/misuse of herbicides occurred.

Sites where soil dioxin levels are found to be high may be categorized as Agent Orange/dioxin ‘hot spots’. We elected to focus on an environmental component of the Aluoi Valley, soils, as a

marker medium for defining hot spots. Given that soil contamination in the valley is the precursor to present-day food chain and human contamination, it follows that dioxin levels in soil be used as the principal defining factor of a hot spot.

2.0 Methods

2.1 Soil

Soil samples were collected throughout the valley with a stainless steel core sampler. Cores were of the 0-10 cm depth fraction. At any given site, ten cores were collected, composited, and thoroughly mixed to represent a single sample for laboratory analysis.

Regions of the valley aerially sprayed by C-123 aircraft were sampled along the main access road extending from the A Dot commune in the south, through Hong Van commune in the north (Fig. 1). This road was one of the most heavily sprayed sectors of the valley. Hong Van received the least amount of aerial applications of Agent Orange, and served as an “in-valley” reference site for our studies. A total of 9 analytical soil samples were prepared from each of the three former Special Forces bases (Fig. 1).

In 1996 and 1997, sediments were also collected from fish ponds excavated in the soils of the former A So base.

2.2 Plant and Animal Tissues

Rice, manioc and vegetable oil samples were collected from residents inhabiting the four study communes in the valley. Ducks, chickens, cultured fish, wild fish, pork and beef were purchased from commune residents.

2.3 Human Blood and Breast Milk

In 1997, whole blood was collected from A So residents (maximum of 3.5 mL per person). In 1999, blood was collected from residents of A So, Houg Lam, Hong Thuong and Hong Van (Fig. 1). People were grouped according to sex and age (i.e., ≥ 25 years of age [born before or during the war] and < 25 years of age [born after the war]).

In 2001, 636 whole blood samples were collected from residents of four communes in the Aluoi Valley employing the age/sex categories of earlier programs.

Four lactating primiparous females from each of the four communes listed above donated breast milk (15-50 mL) in 1999. Additional milk sampling was undertaken in 2001; sixteen lactating primiparous females from the four communes of interest provided samples (four per commune).

All samples were frozen within one hour of sampling.

2.4 Laboratory Analysis

Soil, food, blood and milk samples were processed in Canada at AXYS Analytical Services, Sidney, British Columbia, a World Health Organization certified laboratory (WHO/EURO, 2001). Analysis occurred using high resolution gas chromatography with high resolution mass spectrometric detection (HRGC/HRMS). Total toxic equivalents for analyzed samples were calculated employing the “international” dioxin TEQ (I-TEQ; NATO, 1988).

3.0 Results

3.1 Soil

TCDD levels in the soils of the three former Special Forces bases were elevated when compared to soils from areas of the Aluoi Valley that received aerial applications of Agent Orange.

The highest TCDD levels were recorded at A So, 897.85 pg/g (Total I-TEQ, 901.22 pg/g; Fig. 2). The grid sampling pattern employed on the bases in 1999 yielded TCDD concentrations at A So which indicated the highest levels of contamination were located along the northern sector of the former base (i.e., 220 pg/g, 360 pg/g, and 260 pg/g; Fig. 2). Purchased CORONA satellite imagery and declassified documents from the US military revealed the base layout, with evidence of those areas probably being used for storage and/or handling of Agent Orange; these were situated in the northern sector of the base (US Army documents, 2001). Areas near the base that probably received ground applications of herbicide were visible in satellite images.

Aluoi and Ta Bat Special Forces bases were operational for less than one year, while A So was operational for approximately three years. Even though the two short-lived bases did not experience on-site military activity for a duration comparable to A So, TCDD contamination was generally higher than that measured in soils along the valley bottom where aerial applications of Agent Orange had occurred (Fig. 2). Soil TCDD levels on the Aluoi base ranged from 5.0 pg/g to 19 pg/g; on the Ta Bat base, 4.3 pg/g to 35 pg/g.

The Total I-TEQs of soils, particularly those from the former bases, reflected the high contribution of TCDD to the Total I-TEQ calculation (approximately 83% to >99% TCDD contribution to Total I-TEQs). These high percentages strongly indicate that Agent Orange was the origin of TCDD contamination in the region.

The highest TCDD levels along the valley bottom, sprayed by C-123 aircraft, was 15 pg/g (Total I-TEQ, 17 pg/g). Other values along the valley bottom ranged from non-detect (ND) to 7.9 pg/g (Fig. 2).

TCDD at levels of 1.8 pg/g, 5.2 pg/g, 5.4 pg/g, 8.5 pg/g and 6.9 pg/g were detected in bottom sediments of fish ponds excavated on the former A So base. The percent TCDD contribution to Total I-TEQs of these sediment samples ranged from 88% to 92.4%, indicating that Agent Orange was the source of contamination.

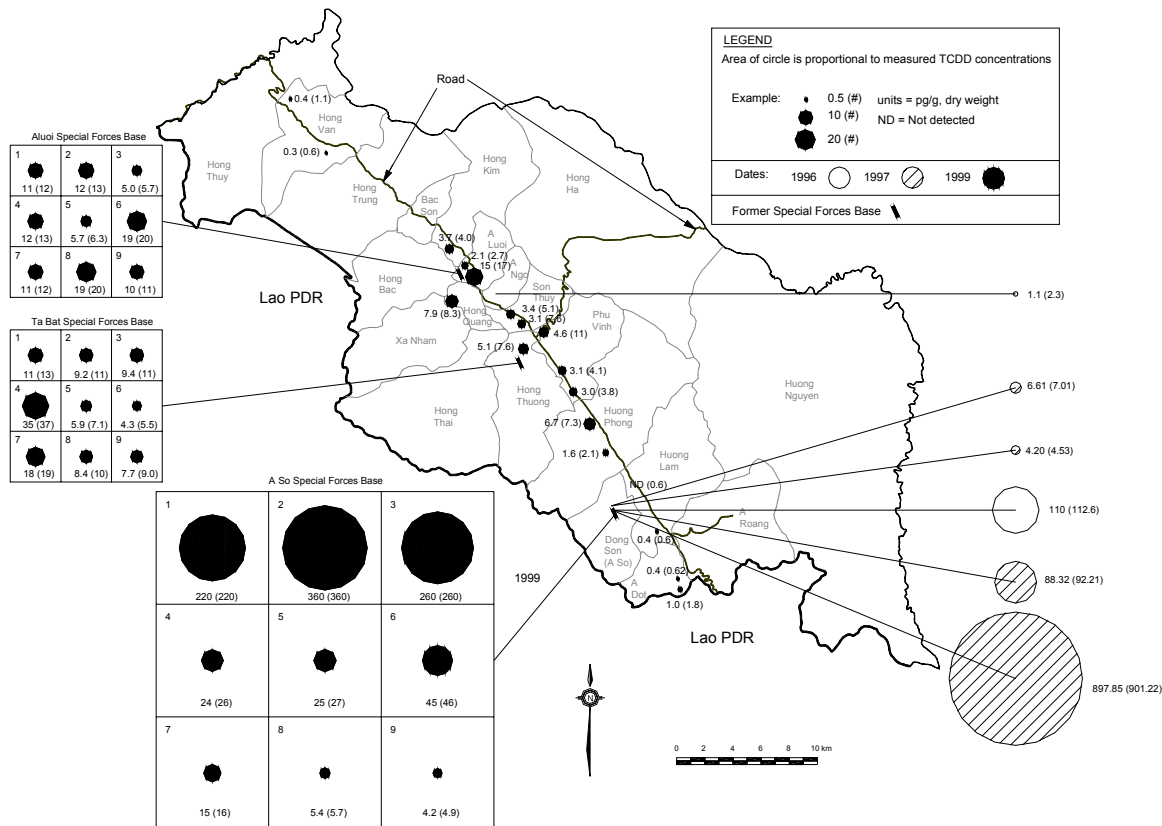


Fig. 2. TCDD (pg/g dry weight) in soils (0-10 cm depth), Aluoi Valley, Viet Nam, 1996-1999; parenthesis enclose Total I-TEQ levels.

3.2 Plant and Animal Tissues

TCDD was not detected in rice, manioc and vegetable oil samples collected from the valley (Fig. 3).

The highest levels of TCDD were detected in fish and duck fat samples from the A So commune (Fig. 3), the highest TCDD level being 82 pg/g in 1999 (Total I-TEQ, 87 pg/g).

Fish fat samples from A So in 1996 and 1997 also yielded elevated levels, 51 pg/g (Total I-TEQ, 53.7 pg/g) and 34 pg/g (Total I-TEQ, 35.4 pg/g), respectively (Fig. 3). Other fish and duck samples from the A So commune were elevated when compared to samples collected from other regions throughout the valley. Fish and duck tissues collected from A So commune, the site of the former Special Forces base, had markedly higher levels of TCDD contamination relative to other communes in the valley.

Total I-TEQ levels in the majority of animal tissues, particularly samples from the A So commune, exceeded the revised World Health Organization (WHO) consumption guidelines^a and, in some instances, the more liberal Canadian threshold^b.

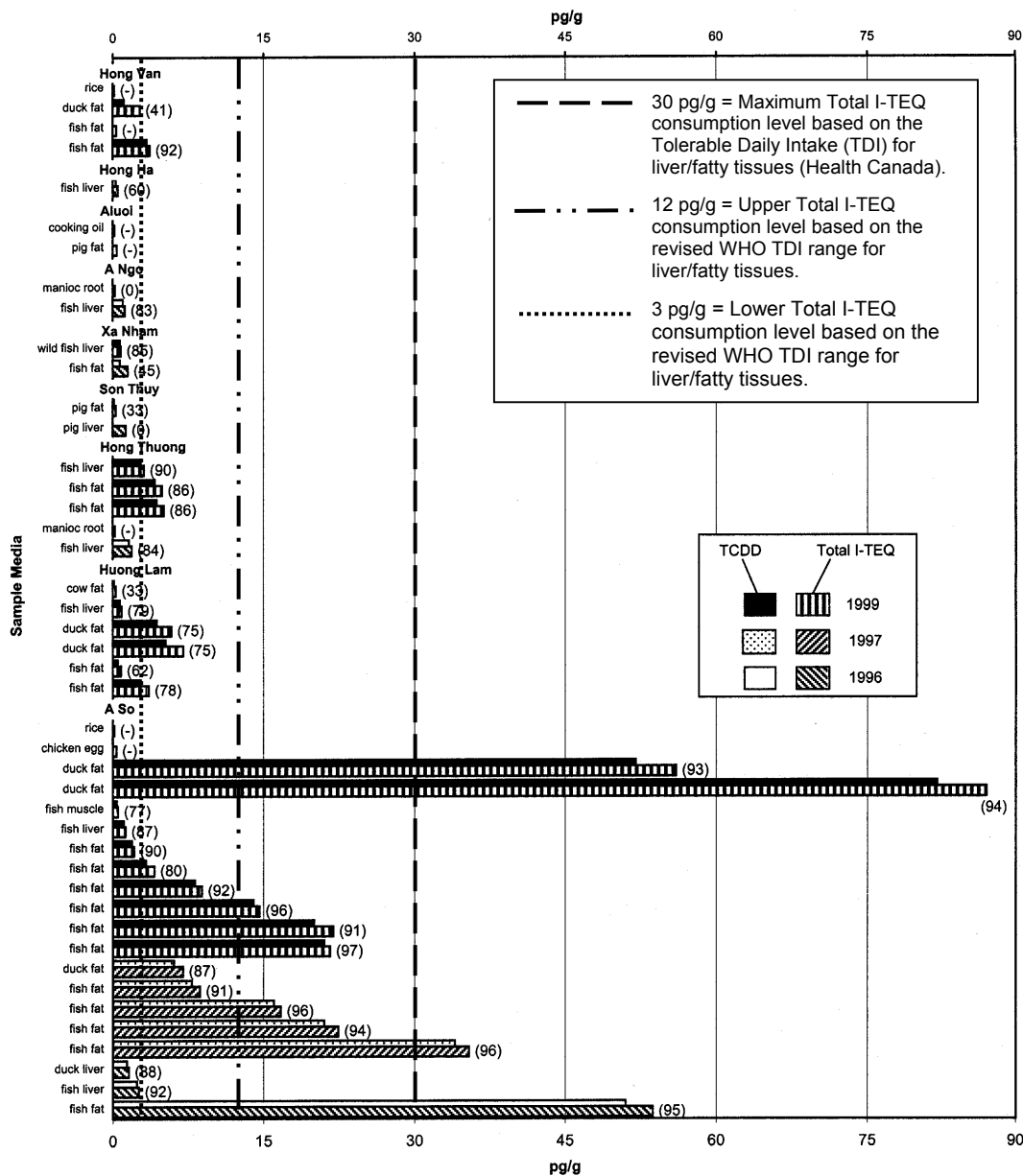


Fig. 3. TCDD and Total I-TEQ in plant (pg/g dry weight) and animal tissues (pg/g wet weight) sampled from Aluoi Valley communes, Viet Nam, 1996, 1997 and 1999. Parentheses enclose percent contribution of TCDD to Total I-TEQ.

^a WHO range of 3-12 pg/g Total I-TEQ based on a revised TDI of 1-4 pg I-TEQ/kg body weight/day (WHO/EURO, 1998 a, b).

^b 30pg/g Total I-TEQ maximum based on a TDI of 10 pg I-TEQ/kg body weight/day (Health Canada, 1996). This guideline is presently under review.

3.3 Human Blood

In 1997, TCDD in human blood from A So was males (≥ 25 years of age) 31 pg/g lipid, males (< 25 years of age) 21 pg/g lipid, females (≥ 25 years of age) 11 pg/g lipid, and females (< 25 years of age) 12 pg/g lipid. The number in each pooled sample was 50 individuals. TCDD contribution to Total I-TEQ for these data are 83%, 82%, 77% and 78%, respectively.

In 1999, a total of 556 donors were involved in the whole blood sampling program for the Aluoi Valley in 1999 (Table 1). The highest TCDD level was measured in males ≥ 25 years of age, those inhabiting A So commune (41 pg/g lipid). A So males in the < 25 years of age category had 31 pg/g lipid TCDD. Those individuals (males and females) living on the former base at A So had higher levels of TCDD in their blood, relative to other communes ($p < 0.01$; Student-Newman-Keuls Test; Hicks, 1973). Males, in general, had higher TCDD levels than females ($p = 0.001$). This probably resulted from their higher caloric intake, greater exposure to contaminated soils, and a practice of living off the land when away from home for days. In addition, females may reduce body burdens through lactation.

Table 1. TCDD (pg/g lipid) in pooled whole human blood, Aluoi Valley, Viet Nam, 1999.

Commune and Donor (years of age)	# in Pool	TCDD (pg/g lipid) ^a	Total I-TEQ	TCDD as % of Total I-TEQ
A So				
Males (≥ 25)	48	41	45.9	89.3
Males (< 25)	30	31	35.0	88.6
females (≥ 25)	44	16	18.3	87.4
females (< 25)	41	14	16.6	84.3
Huong Lam				
males (≥ 25)	31	17	25.6	66.4
males (< 25)	33	9.0	19.8	45.5
females (≥ 25)	29	5.3	22.0	24.1
females (< 25)	27	ND	10.0	-
Hong Thuong				
males (≥ 25)	43	21	32.3	65.0
males (< 25)	27	8.6	15.1	57.0
Females (≥ 25)	37	12	24.6	48.8
Females (< 25)	25	7.6	11.5	66.1
Hong Van				
males (≥ 25)	37	ND	5.41	-
males (< 25)	40	NDR	7.67	-
Females (≥ 25)	27	ND	5.95	-
Females (< 25)	37	ND	3.53	-

^a ND = Not detected; for 'Total I-TEQ' calculations, if ND, $\frac{1}{2}$ detection level was used.

NDR = A chromatographic peak was detected but did not meet quantification criteria; for Total I-TEQ calculations, NDR was treated as ND.

Older individuals in 1999 had higher levels of TCDD ($p = 0.019$), given their exposure has been for a longer duration. Younger people (< 25 years of age, born after the war) also had clearly

elevated levels. There was little variation in TCDD levels between the two age categories of females, particularly at A So. This apparent lack of difference may be the result of younger females becoming lactating mothers early in life, while older females are continuing to give birth to children and off-loading TCDD during breast feeding (Schechter *et al.*, 1998; Abraham *et al.*, 1998).

The relatively high percent of TCDD contribution to Total I-TEQs, particularly in samples from the former A So base, indicates Agent Orange involvement in contamination of local foods.

Data from analyses of blood samples collected during the 2001 program, indicate a similar pattern of TCDD contamination (related to age, sex and commune) as that recorded during earlier programs.

3.4 Human Breast Milk

Sixteen primiparous mothers ranging in age from 17 to 28, donated milk at a time when they were breastfeeding infants; infants ranged in age from 20 days to one year (Table 2).

Table 2. TCDD in human breast milk (pg/g lipid) and average daily intake (pg I-TEQ/kg body weight/day) of polychlorinated dibenzodioxins and polychlorinated dibenzofurans by infants from primiparous mothers, Aluoi Valley, Viet Nam, 1999.

Commune	Donor Age	Age of Child and Duration of Breastfeeding ^a	% Lipid	TCDD (pg/g)	Total I-TEQ (pg/g)	TCDD as % of Total I-TEQ	Intake ^b Total I-TEQ
A So	22	1 y	5.6	5.5	6.15	89.4	30.1
	20	1 m	4.5	19.0	21.9	86.4	107.3
	18	1 y	4.0	18	18.7	96.3	91.6
	23	5 m	3.3	16	18.8	85.1	92.1
Huong Lam	23	7 m	1.3	12	14.6	82.2	71.5
	19	8 m	3.7	8.3	10.2	81.4	50.0
	28	3 m	3.6	2.9	10.6	27.4	51.9
	21	20 d	1.7	5.8	9.33	62.2	45.7
Hong Thuong	17	5 m	1.6	11	17.2	64.0	84.3
	21	6 m	1.4	8.7	12.6	69.0	61.7
	22	1 y	2.7	7.7	9.73	79.1	47.7
	19	2 m	2.1	11	18.5	59.5	90.7
Hong Van	20	5 m	2.7	3.3	5.07	65.1	24.8
	23	2 m	2.1	2.2	3.85	57.1	18.9
	20	1 m	3.2	5.0	13.2	37.9	64.7
	19	1 m	1.8	1.4	3.0	46.8	14.7

^a y = year, m = months, d = days.

^b Average daily intake via human milk based on a 5 kg infant consuming 700 ml of milk per day with a lipid content of 3.5 % (WHO/EURO, 1989).
Average daily intake = (volume of milk per day in ml)x(% lipid in milk/100)x(concentration of chemical in pg/g)/(infant weight in kg).

The highest levels of TCDD were measured in mothers' milk from the A So commune (19.0 pg/g lipid, 18.0 pg/g lipid, and 16.0 pg/g lipid). Although A So breast milk had the highest levels of TCDD, levels were not statistically different from Houng Lam or Hong Thuong; however, A So levels were significantly higher when compared to Hong Van, the area receiving the least amount of Agent Orange applications ($p < 0.01$; Student-Newman-Keuls Test; Hicks, 1973).

Hong Thuong TCDD levels were significantly greater than those recorded at Hong Van ($p < 0.05$). Hong Lam TCDD levels in breast milk were significantly greater than those recorded at Hong Van ($p < 0.05$).

The lack of apparent difference between some sites may have resulted from the fact that contaminants like TCDD can be eliminated from the body through lactation (Abraham *et al.*, 1998; Raum *et al.*, 1998). The relatively high percent contribution of TCDD to the Total I-TEQ, particularly in milk samples collected from A So, indicate an Agent Orange source for TCDD.

The revised Tolerable Daily Intake (TDI) value set by the World Health Organization (WHO/EURO, 1998a,b), 1-4 pg/g I-TEQ/kg bw/d, are greatly exceeded, particularly in calculations based on breast milk TCDD levels from the A So commune (Table 2). The highest level of exceedance, relative to the revised WHO TDI is the 20 year old mother whose calculated release to her infant is 107.3 pg I-TEQ/kg bw/d. The lowest intake value occurred in Hong Van, 14.7 pg I-TEQ/kg bw/d (Table 2). All breast milk samples from the Aluoi Valley exceeded the WHO TDI for dioxins.

Data from analyses of the 2001 milk samples indicate a similar pattern of TCDD contamination as that recorded in 1999 (i.e., highest TCDD levels in milk from A So mothers).

4.0 Discussion

During the Viet Nam conflict, the US and south Vietnamese military established numerous military installations throughout southern Viet Nam (e.g., artillery bases, communication bases, etc.). Use and storage of Agent Orange on these facilities occurred (US Army documents, 1969, 1970). Ranch Hand spray missions were supplied herbicides from bulk storage facilities (Cecil, 1986). The storage areas for herbicides experienced spills, which prompted recommendations addressing these occurrences (US Army documents, 1969). Recommendations regarding the handling of Agent Orange on storage/dispensing facilities included the construction of drainage ditches, spill ponds, and systems comparable to septic field distribution for spilled herbicides. These action protocols were probably in place at many of the Agent Orange storage centres.

Agent Orange was also sprayed throughout southern Viet Nam, covering approximately 10% of the landmass (IOM, 1994). The two most prominent modes of Agent Orange release to the Vietnamese environment were, therefore, through aerial application and ground activities that occurred in and around various military installations.

Soils, foods and humans in the Aluoi Valley, as evidenced by levels in blood and breast milk, are contaminated with TCDD. However, those environmental samples and human tissues collected from the former US Special Forces base at A So had the highest levels of TCDD contamination,

relative to other former bases (occupied for a shorter period of time), and areas of the valley that received aerial applications of Agent Orange.

We theorize that the pattern of TCDD contamination recorded in the Aluoi Valley serves as a model for contamination throughout southern Viet Nam. Human exposure, and subsequent contamination through the food chain transfer of TCDD, would be highest in areas of former military installations where significantly higher concentrations of TCDD may be residing in soils, relative to sprayed areas, given the higher loading of TCDD to soils, particularly from herbicide spills. Soils in regions aerially sprayed would not have experienced the same loading of Agent Orange, and therefore TCDD, as military bases.

Schechter *et al.* (2001) sampled near the former Bien Hoa base, and measured very high levels of TCDD in soils (e.g., 1,164,699 pg/g dry weight) and in human blood (e.g., 271.1 pg/g lipid). These levels are probably related to the Agent Orange spill at Bien Hoa in 1970 (US Army documents, 1970), particularly when considering that the soil TCDD contributed 99% of the toxicity to the Total I-TEQ; for blood, TCDD contributed 92% of the Total I-TEQ for the 271.1 pg/g sample. Additional studies near Bien Hoa have recorded a blood TCDD level of 413 pg/g lipid (Schechter *et al.*, 2002). Schechter *et al.* (2001) reported 2 pg/g TCDD in pooled blood from a Ha Noi control group. These data further strengthen our theory.

A review of blood data from Viet Nam (Fig. 4), on the basis of TCDD expressed as a percent of the Total I-TEQ, indicates that the highest percentages (and corresponding Agent Orange responsibility), occur at the former military installations at A So (Aluoi Valley) and Bien Hoa where more comprehensive investigations have occurred.

Studies in the vicinity of the former A So US military base demonstrate that TCDD contamination has spread from soils to humans via the food chain. The soil medium is the ultimate reservoir/source of TCDD, and thereby warrants the term 'hot spot'. The fact that foods, human blood and breast milk in the A So commune also supported the highest dioxin content generates additional 'strata' of hot spots when addressing nutritional and public health issues. These aforementioned hot spot strata (i.e., food and humans) are a direct consequence of the mobilization and migration of TCDD from soil through foods into humans. Results from this study emphasize that former US military bases should be the primary sites on which to concentrate remediation measures, thereby removing them from the TCDD exposure equation of local Vietnamese populations.

As a result of studies in the Aluoi Valley, we recommended the following actions that have been implemented by Vietnamese authorities:

- relocate villagers living on the A So base to avoid further TCDD contamination;
- limit further human settlement on the A So base area;
- deactivate aquaculture ponds on the A So base where fish have been raised for food;

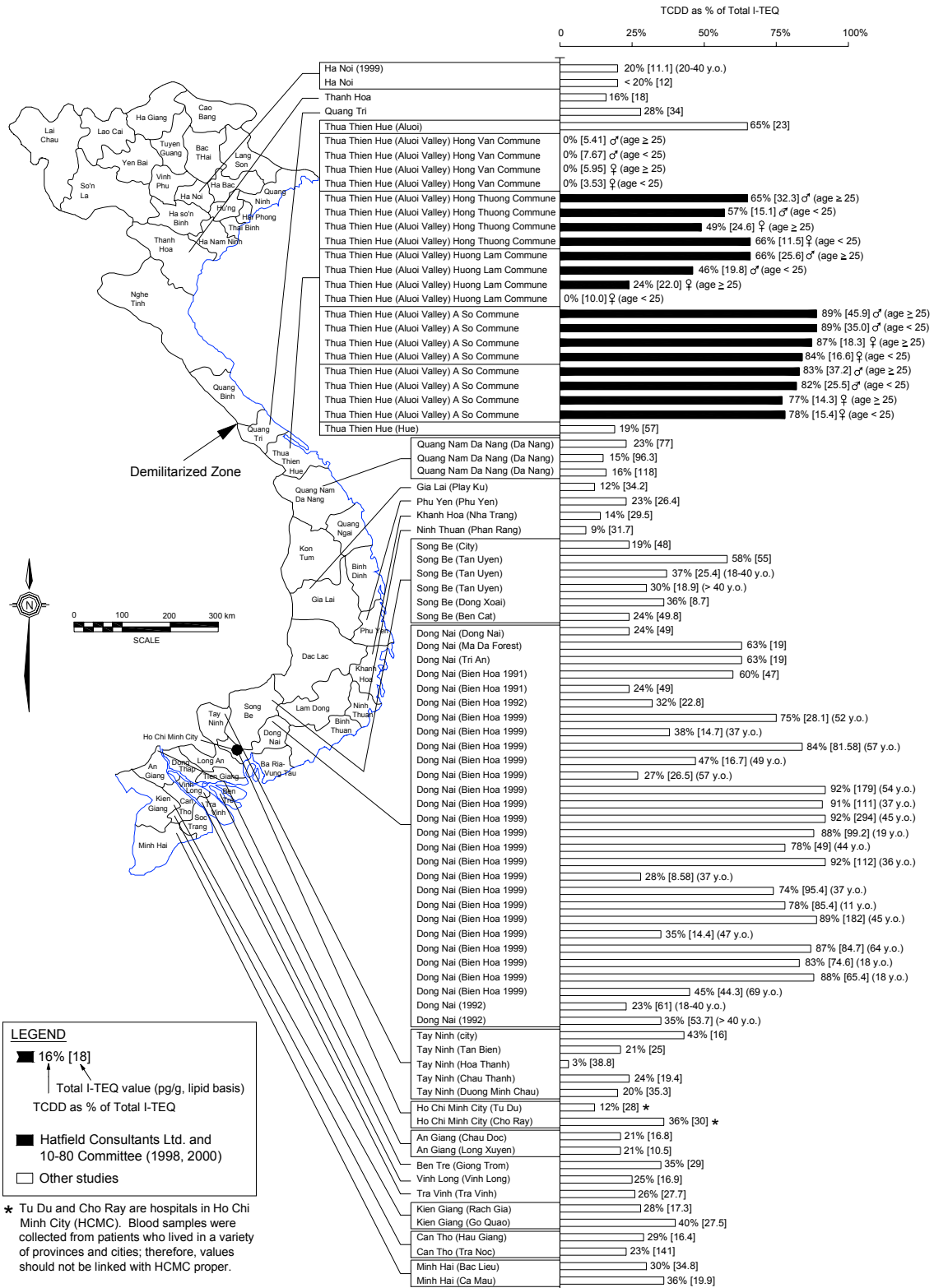


Fig. 4. TCDD as % of Total I-TEQ in human blood from localities in Viet Nam, 1987 to 1999 (Dai *et al.*, 1994, 1995; Schecter *et al.*, 1992, 2001; Schecter, 1994), and 1997 and 1999 (Hatfield Consultants and 10-80 Committee, 1998, 2000; Dwernychuk *et al.*, 2002).

- implement advisories and health protocols regarding potentially contaminated foods (e.g., proper cleaning and peeling of vegetables, discarding fatty tissues and the internal organs of fish and ducks); and
- distribute educational material (e.g., printed and video materials) to Aluoi Valley schools and residents regarding dioxin contamination.

In order to utilize and extend the Aluoi Valley experience to other regions of southern Viet Nam, and address the threat of risk to human health in other potential hot spots, it is further recommend:

- a systematic review of US military archives to determine the location of probable Agent Orange storage/use on bases in southern Viet Nam;
- soils, foods and the human population should be tested, if evidence suggests TCDD contamination in the area;
- crash sites and load-jettison sites of Agent Orange spray aircraft should be investigated;
- assistance be provided to the Vietnamese to implement investigative strategies for identification of potentially contaminated areas; and
- assistance be provided to the Vietnamese to immediately implement health protection measures where TCDD levels are found to be above western standards/guidelines (e.g., monitor aquaculture ponds, discard tissues of fish and ducks that have a high probability of contamination, proper cleaning/peeling of in-ground vegetables, etc.).

The following overview summarizes the unique elements of the joint 10-80 Division/Hatfield Agent Orange studies in Viet Nam:

1. TCDD migration – *confirmed through the food chain*: In a single localized area of Viet Nam, TCDD, originating from use of the defoliant Agent Orange, was followed in its migration from contaminated soils, into the food chain, and into humans. This is the first comprehensive systematic investigation of Agent Orange which has directly quantified TCDD movement within the ecosystem of a small prescribed geographical area of the country.
2. Former military installations – *proven “hot spots”*: Through comparative studies of aerially sprayed lands and three former military bases in the predetermined area of Aluoi Valley, the TCDD “hot spot” theory was proven quantitatively. As a consequence and with the highest priority, research and intervention must be directed at all former military installations where historical records of overt and covert operations reveal the storage and/or use of Agent Orange.

3. Exposure of US military personnel – *highly probable*: Present-day hot spots on former military installations would indicate that these areas were ‘hot’ during the conflict. Consequently, any soldier/personnel serving on a military base where Agent Orange was stored and/or sprayed had the potential to be exposed to dioxin.
4. TCDD standards exceeded – *immediate intervention required*: Hatfield has demonstrated that in hot spots, TCDD levels in soils and food exceed international standards and guidelines which are used to protect human health; therefore, in proven hot spots we state emphatically that no additional research on human health is required to facilitate intervention to protect local inhabitants.
5. Mitigation strategy – *recommended and implemented*: As a consequence of quantifying TCDD levels in the environment and humans living in a specific area of Viet Nam, a mitigation strategy was recommended and implemented to protect human health. The intervention strategy has wide applicability and serves as a model for all of southern Viet Nam.

Acknowledgements

We gratefully acknowledge the following for their financial and/or in-kind support during our investigations: Canadian International Development Agency (CIDA), Environment Canada, The Canadian Space Agency, Revenue Canada, Forest Inventory and Planning Institute (Ha Noi), Thua Thien Hue Peoples’ Committee and Department of Health, Thua Thien Hue Department of Planning and Investment, Ministry of Science Technology and Environment, Aluoi District Peoples’ Committee, local peoples’ committees in the communes of Aluoi District, local police, military and citizens of Aluoi valley.

We are also grateful to Mr. Gerd Willkommen, who worked with our field crews during soil sampling to clear for unexploded ordnance.

References

- Abraham, K., Papke, O., Gross, A., Kordonouri, O., Wiegand, S., Wahn, U., Helge, H. 1998. Time course of PCDD/PCDF/PCB concentrations in breast-feeding mothers and their infants. *Chemosphere* 37, 1731.
- Cecil, P.F. 1986. *Herbicide Warfare: the RANCH HAND Project in Viet Nam*. Praeger, New York, 290 p.
- Dai, L.C., Minh, D.Q., Quynh, H.T., Thom, L.H., Thuy, L.B. 1994. Remarks on the dioxin levels in human pooled blood from various localities of Viet Nam. p. 5-15. In: H.D. Cau *et al.* (eds.). *Herbicides in War – The Long-term Effects on Man and Nature*. 2nd International Symposium, Ha Noi, 1993. Ha Noi: 10-80 Committee, Hanoi Medical School. 476 p.

- Dai, L.C., Thuy, L.B., Minh, D.Q., Quynh, H.T., Thom, L.H. 1995. Remarks on the dioxin levels in human pooled blood from various localities in Viet Nam. *Organohalogen Compounds* 26: 161-167. [15th International Symposium on Chlorinated Dioxins and Related Compounds].
- Dwernychuk, L. Wayne, Cau, H.D., Hatfield, C.T., Boivin, T.G., Hung, T.M., Dung, P.T., Thai, N.D. 2002. Dioxin reservoirs in southern Viet Nam – A legacy of Agent Orange. *Chemosphere* 47, 117-137.
- Hatfield Consultants and 10-80 Committee. 1998. Preliminary assessment of environmental impacts related to spraying of Agent Orange herbicide during the Viet Nam war. Volume 1: Report; Volume 2: Appendices. Hatfield Consultants Ltd., West Vancouver, BC, Canada; 10-80 Committee, Ha Noi, Viet Nam.
- Hatfield Consultants and 10-80 Committee. 2000. Development of Impact Mitigation Strategies Related to the Use of Agent Orange Herbicide in the Aluoi Valley, Viet Nam. Volume 1: Report; Volume 2: Appendices. Hatfield Consultants Ltd., West Vancouver, BC, Canada; 10-80 Committee, Ha Noi, Viet Nam.
- Health Canada. 1996. Values presently used by contaminants toxicology section. food directorate, Ottawa, Canada.
- Hicks, C.R. 1973. *Fundamental concepts in the design of experiments*. Hold, Rinehart and Winston, Toronto, 349 p.
- IOM (Institute of Medicine). 1994. *Veterans and Agent Orange - Health effects of herbicides used in Viet Nam*. National Academy Press, Washington, D.C., 812 p.
- IOM (Institute of Medicine). 2001. *Veterans and Agent Orange - Update 2000*. National Academy Press, Washington, D.C., 604 p.
- NATO (North Atlantic Treaty Organization). 1988. *International Toxicity Equivalent Factor (I-TEF) method of risk assessment for complex mixtures of dioxins and related compounds. Pilot study on international information exchange on dioxins and related compounds. Committee on the Challenges of Modern Society. #176, 26 p.*
- Raum, E., Seidler, A., Schlaud, M., Knoll, A., Webling, H., Kurtz, K., Schwartz, F.W., Robra, B-P. 1998. Contamination of human breast milk with organochlorine residues: A comparison between East and West Germany through sentinel practice networks. *Epidemiol Community Health* 52, 50S.
- Schechter A., Papke, O., Ball, M., Cau, H.D., Dai, L.C., Ming, N.Q., Quynh, H.T., Phuong, N.N.T., Phiet, P.H., Chi, H.K., Vo, D.T., Constable, J.D., Spencer, J. 1992. Dioxin and dibenzofuran levels in blood and adipose tissue of Vietnamese from various locations in Viet Nam in proximity to Agent Orange spraying. *Chemosphere* 25, 1123-1128.

- Schechter A., Ryan, J.J., Papke, O. 1994. Elevated dioxin blood levels in Russian chemical workers and their children following maternal exposure. *Chemosphere* 29, 2361-2370.
- Schechter, A. 1998. A selective historical review of congener-specific human tissue measurements as sensitive and specific biomarkers of exposure to dioxins and related compounds. *Environmental Health Perspectives* 106, 737.
- Schechter, A., Dai, L.C., Papke, O., Prange, J., Constable, J.D., Matsuda, M., Thao, V.D., Piskac, A.L. 2001. Recent dioxin contamination from Agent Orange in residents of a southern Vietnam city. *J. Occup. Environ. Med.* 43, 435-443.
- Schechter, A., Pavuk, M., Constable, J., Dai, L.C., and Papke, O. 2002. A follow-up: high level of dioxin contamination in Vietnamese from Agent Orange, three decades after the end of spraying. *J. Occup. Environ. Med.* 44, 218-220.
- Stanton, S.L. 1985. *Green Berets at war: U.S. Army Special Forces in southeast Asia, 1956-1975.* Ivy Books, New York, 383 p.
- Stellman, J.M., Stellman, S.D., Christian, R., Weber, T., and Tomassallo, C. 2003. The extent and patterns of usage of Agent Orange and other herbicides in Vietnam. *Nature* 422, 681-687.
- US Army documents (declassified). 1969. Accidental herbicide damage at Nha Trang, Bien Hoa, Phu Cat and Saigon military bases. Department of the Army. The US Army Center of Military History, Fort Lesley J. McNair DC, 20319-5048, USA.
- US Army documents (declassified). 1970. Agent Orange spills on the Bien Hoa military base. Department of the Army. The US Army Center of Military History, Fort Lesley J. McNair DC, 20319-5048, USA.
- US Army documents (declassified). 2001. Action reports and memoranda regarding the A Shau Valley, Viet Nam. Authority NND 931713/903562, National Archives, Washington, DC.
- Westing, A.H. 1984. Herbicides in War: past and present. In: Westing, A.H. (Ed.). *Herbicides In War, The Long-term Ecological and Human Consequences.* Stockholm International Peace Research Institute. Taylor and Francis, London and Philadelphia, pp. 3-24.
- WHO/EURO (World Health Organization/European Regional Office). 1989. Levels of PCBs, PCDDs and PCDFs in breast milk: Results of WHO-coordinated interlaboratory quality control studies and analytical field studies (Yrjanhaiki, EJ, Ed.). *Environmental Health Series Report #34.* Copenhagen: World Health Organization Regional Office for Europe, 92 p.

WHO/EURO (World Health Organization/European Regional Office). 1998a. WHO revises the Tolerable Daily Intake (TDI) for dioxins. World Health Organization European Centre for Environment and Health; International Programme on Chemical Safety. Organohalogen Compounds 38, 295.

WHO/EURO (World Health Organization/European Regional Office). 1998b. Assessment of the health risk of dioxins: re-evaluation of the Tolerable Daily Intake (TDI). Executive Summary. World Health Organization, European Centre for Environment and Health; International Programme on Chemical Safety. WHO Consultation, May 25-29, 1998, Geneva, Switzerland, 22 p.

WHO/EURO (World Health Organization/European Regional Office). 2001. Interlaboratory quality assessment of levels of PCBs, PCDDs and PCDFs in human milk and blood plasma. Website: <http://www.who.dk/document/e70039.pdf>. Accessed June 12, 2001.

Zumwalt, Jr., E.R. 1990. Report to Secretary of the Department of Veterans Affairs on the association between adverse health effects and exposure to Agent Orange. U.S. Dept. of Veterans Affairs; Declassified Document. May 1990. 37 p.