State-of-the-Art: Agent Orange and Dioxin Remediation

2nd Agent Orange and Dioxin Remediation Workshop

Hanoi, Viet Nam, 18–20 June 2007

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DOI: http://dx.doi.org/10.1065/espr2007.10.453

Please cite this paper as: Young AL, Van Houten WJ, Andrews WB (2008): 2nd Agent Orange and Dioxin Remediation Workshop. Hanoi, Viet Nam, 18–20 June 2007 (State-of-the-Art). Env Sci Pollut Res 15 (2) 113–118

1 The Legacy Issue of Agent Orange

The legacy issue of Agent Orange remains as one of the last contentious issues between the United States and Viet Nam from the Vietnam-American War [1]. **Generally the term 'Agent Orange' has been used by the public to describe a group of 'Tactical Herbicides' used in combat operations by the US Military and other Allied Forces in the Vietnam-American War for the suppression and control of vegetation.** The path forward on this issue was first discussed during a US Presidential visit to Viet Nam in 2001 [2]. The plan envisioned the preparation and implementation of a broad-based research program that would be conducted in collaboration with Vietnamese and US scientists [2]. However, following government-to-government discussions, the only project to be accepted and implemented by both parties was a project to investigate whether or not the former Tactical Herbicides Storage and Loading Sites in Southern Viet Nam constituted a source of dioxin contamination to adjacent communities [3]. To initiate this project, the ***1st Agent Orange and Dioxin Remediation Workshop*** was held in Hanoi, Viet Nam in August 2005 [3].

By agreement between the Governments of the United States and Viet Nam, the Workshop was on remediation, not on health issues. Further, the US Department of State (DoS) emphasized that the US Department of Defense (DoD) would not have an active role in cleaning-up any contaminated sites, while the Government of Viet Nam concurred that it would be the responsibility of Viet Nam's Military to cleanup any contaminated sites [3]. With this understanding, the objectives of the 1st Workshop were to: (1) share the scientific and engineering studies conducted in the United States at former Herbicide Orange Storage and/or Loading Sites; (2) open a dialogue with Vietnamese scientists and engineers on how to evaluate the present status of former herbicide storage/loading sites; and, (3) provide guidelines on how to determine the most appropriate use of soil stabilization actions or applications of available remediation technologies [3]. The Workshop was a success, and Viet Nam's Director of the Agency for Science, Technology and Environment, Ministry of National Defence (who was designated as the responsible individual for remediation activities) requested additional information crucial to Viet Nam's study of the former Tactical Herbicides Storage and Loading Sites.

The ***2nd Agent Orange and Dioxin Remediation Workshop*** was held in Hanoi, Viet Nam, 18–19 June 2007. Approximately 40 Vietnamese Military Officers and Civilians and 6 US Participants attended the Workshop (**Fig. 1**). Most of Vietnamese Participants were from Viet Nam's Ministry of National Defence (MOD), primarily from the Agency for Science, Technology and Environment. Major General Nguyen Ngoc Duong, Director, Agency for Science, Technology, and Environment provided introductory comments for the Vietnamese Delegation. Mr. Jonathan M. Aloisi, Deputy Chief of Mission, Embassy of the United States provided introductory comments for the US Delegation. Mr Aloisi introduced Mr. William J. Van Houten, US DoD, Washington, DC, and Dr. Alvin L. Young, Visiting Professor, University of Oklahoma.

At the beginning of the Workshop, Mr. Van Houten presented to Major General Duong from the Viet Nam's Ministry of National Defence a special Report prepared by the United States Department of Defense on ***The History and Maps of the Former Tactical Herbicide Storage and Loading Sites in Vietnam*** [4]. The Report provided: (1) Detailed information on the quantities of tactical herbicides used or spilled in Southern Viet Nam; (2) Detailed information on the types and quantities of dioxins in Herbicide Orange; (3) Maps of the Air Bases used in Operation RANCH HAND and Operation PACER IVY detailing the sites where loading, storage and re-drumming operations had occurred; and (4) An update on remediation and environmental studies. At the request of DoD, the MOD provided: (1) Detailed results from analytical studies conducted in and around Da Nang Air Field; (2) Results of studies on the detoxification of dioxin in soil by an active landfill bioreactor; and, (3) Research data on adsorption efficiency of activated carbon for PCDDs/PCDFs from aqueous solutions. After each presentation, thorough discussions occurred. Because the above Report is not readily available to the public, details of the Report as presented to the Viet Nam's MOD are described below.

Fig. 1: Photograph of many of the participants who attended the Agent Orange Workshop

2 Quantities of Tactical Herbicides Used in Viet Nam

Significant confusion has existed as to how herbicides were selected by the US Military to be used in the defoliation program in Vietnam-American War. The belief that commercially available herbicides were simply purchased from US chemical companies and deployed directly to Viet Nam was incorrect and contrary to historical records. 'Tactical Herbicides' were herbicides developed specifically by the DoD to be used in combat operations. The missions to develop tactical herbicides and delivery technologies were assigned to the US Army Chemical Corps, specifically to the Plant Sciences Laboratories at Fort Detrick, Maryland. Fort Detrick evaluated numerous formulations of herbicides for potential tactical use from 1957 through 1967. The herbicidal formulations used in Southern Viet Nam were purchased under Military Specifications and their use was confined to combat operations. Only the US Army Chemical Corps and the US Air Force Logistics Command were authorized to purchase tactical herbicides. However, many commercial pesticides, including herbicides, were used in Viet Nam on US and Allied bases. These commercial pesticides were purchased under Federal Specifications, and their uses were regulated by the Armed Forces Pest Control Board [4].

The Civil Engineering Squadrons, assigned to all US and Allied Bases were responsible for acquisition and use of commercial pesticides. The tactical herbicides Orange, Blue, and White were not approved for use by Civil Engineering Squadrons on bases in Viet Nam. This distinction between tactical and commercial herbicides has been a source of misunderstanding by both veterans of the Vietnam-American War and the Vietnamese [4].

To obtain the quantities of tactical herbicides purchased and used in the Vietnam-American War, procurement records were obtained from the Defense Supply Agency for the ten Chemical Companies that provided the tactical herbicides under Military Specifications. Data provided in **Table 1** repre-

Table 1: Estimated quantities of tactical herbicides used in Vietnam, 1962–1971[a] [4]

Tactical Herbicide	Commercial Components	Number of Drums	Number of Liters	Years of Use
Green [b]	2,4,5-T	365 drums [c]	75,920 liters	1962
Pink [b]	2,4,5-T	1,130 drums	235,040 liters	1962–63
Purple [b]	2,4-D; 2,4,5-T	12,405 drums	2,580,240 liters	1962–65
Blue	Cacodylic Acid	29,330 drums	6,100,640 liters	1966–71
White	2,4-D; Picloram	104,800 drums	21,798,400 liters	1966–71
Orange [b]	2,4-D; 2,4,5-T	208,330 drums	43,332,640 liters	1965–70
Total		**356,360 drums**	**74,122,880 liters**	

[a] Data based on US Defense Supply Agency records. The term 'used' was intended to account for all herbicides that were sprayed or spilled in Southern Viet Nam during the years indicated
[b] These tactical herbicides contained 2,4,5-T herbicide and its associated contaminant, 2,3,7,8-TCDD
[c] All herbicide drums sent to Viet Nam held 208 liters or 55 gallons of product that was applied in concentration form and not diluted

sent the best estimates of the quantities of tactical herbicides used from 1962–1971. The designation of the color for the tactical herbicide was from the 7.6 cm color-coded band around the center of the 18-guage steel 208-liter (55-gallon) drums, not from the color of the liquid herbicide.

3 Types and Quantities of Dioxins in the Tactical Herbicides

A recent effort was undertaken with the objective of providing a statistically valid measure of the amount of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) contaminant in the 2,4,5-T-containing tactical herbicides shipped and sprayed or spilled in Viet Nam, from 1962 (start of Operation RANCH HAND) to 1972 (completion of Operation PACER IVY). An analytical study of 82 samples of 2,4,5-T herbicide produced from 1968–1971 confirmed that the only readily quantifiable dioxin in 2,4,5-T was the 2,3,7,8-TCDD [3]. Some of the samples contained trace quantities of 1,2,3,7,8-PnCDD, 1,2,3,4,7,8-HxCDD, and 1,2,3,6,7,8 HxCDD, and 1,2,3,6,7,8,9-HpCDD [5].

Two sources of data were available to calculate the amount of TCDD that may have been present in the 2,4,5-T-containing tactical herbicides used in Viet Nam: (1) Historical records indicated that the United States Air Force Logistics Command collected and analyzed 525 samples from the Herbicide Orange inventories stored at Johnston Island, Central Pacific Ocean (200 samples) and from the Naval Construction Battalion Center (NCBC) in Gulfport, Mississippi (325 samples) [4,6]; and, (2) TCDD data were obtained from 557 archived samples of 2,4,5-T herbicide (1963–1969) from the Dioxin Registry Reports prepared by the US National Institute for Occupational Safety and Health (NIOSH). NIOSH examined five of the Chemical Companies that produced >90% of the Herbicide Orange purchased by the Defense Supply Agency [7].

The frequency distribution of the TCDD data for the Herbicide Orange samples from Johnston Island and NCBC was skewed toward the high concentrations of dioxin, and thus the statistical method employed was a tail-augmented bootstrap method to estimate the mean. This approach resulted in a mean of 1.88 mg/kg (ppm) for the combined inventory of 40,910 drums of Herbicide Orange. As noted, the 557 individual samples of 2,4,5-T from the NIOSH reports spanned the years 1963 through 1969. The mean TCDD concentration, at the 95 percentile, was 1.88 mg/kg **IF** these samples of 2,4,5-T had been used in the production of Herbicide Orange. Thus, these two large data sets gave comparable estimates, confirming that an estimated total amount of the contaminant TCDD in Herbicide Orange used in Southern Viet Nam would have been 105 kg. Samples of 2,4,5-T from early production runs were also available from some of the Chemical Companies that produced Herbicides Green, Pink, and Purple. Statistical analyses of these samples resulted in an estimated (95% confidence level) mean concentration in Pink and Green of 12.2 mg/kg, and 6.1 mg/kg for Purple. The total estimated contribution from these early tactical herbicides was 25 kg. ***The total estimated amount of the contaminant 2,3,7,8-TCDD associated with the 2,4,5-T-containing tactical herbicides used in Viet Nam therefore was 130 kg.***

4 Tactical Herbicide Mapping Project

The purpose of the Viet Nam Tactical Herbicide Project was to gather information on where the United States Air Force (USAF), the Army of the Republic of Vietnam (ARVN), the Army Chemical Corps, or Allied units temporarily stored and maintained inventories of tactical herbicides used in Operation RANCH HAND. Records indicated that the USAF sprayed 95% of the tactical herbicides in Operation RANCH HAND. The remaining 5% was primarily sprayed from helicopters belonging to US Army Chemical Corps (3–4%) and Combat Engineers belonging to Australian, Korean, or ARVN units [8].

In the 'Development Phase' of Operation RANCH HAND (January 1962–March 1965), all tactical herbicides were shipped from the United States to the Port of Saigon (Ho Chi Minh City). The drums were off-loaded and placed on flatbed trucks for transport to the RANCH HAND units at Tan Son Nhut Airport. In the 'Operational Phase' of Operation RANCH HAND (March 1965–January 1971), 65% of the tactical herbicides were shipped to the Port of Saigon for transport to Bien Hoa Air Base, and 35% of the tactical herbicides were shipped to the Port of Da Nang for transport to the air base. When drums arrived in South Viet Nam, the ownership was transferred to ARVN at the 20th Ordnance Storage Depot, Saigon, or at the ARVN 511th Ordnance Storage Depot, Da Nang. Drums of tactical herbicides were distributed from these locations to RANCH HAND operating locations, US Army Chemical Corps operating locations, or to Allied Forces as requested and approved [4,8,9].

Historical records provided information on six major airbases that were used by either the RANCH HAND aircraft (UC-123s) for tactical herbicide operations or for insecticide operations (Operation FLYSWATTER [10]); the latter being under the direction of the US Military Assistance Command, Vietnam's (MACV) Surgeon General's Office [7]. One additional airbase (Tuy Hoa) was identified as part of Operation PACER IVY, the redrumming and return of the remaining stocks of Herbicide Orange to Johnston Island, Central Pacific Ocean [6]. The Air Forces bases in Southern Viet Nam that were used by the United States and Allied Forces for military operations involving tactical herbicides and insecticides are identified in **Table 2**.

5 Distribution of Tactical Herbicides

The preparation of maps of the former US and Allied Air Bases, where tactical herbicides may have been spilled during storage or loading operations, required information on when and how much of the tactical herbicides were destined for a particular airbase. Procurement data on the three major 'tactical herbicides' were obtained from historical records of the Defense Supply Agency and the Air Force Logistics Command (see Table 1). These records provided the yearly quantities of tactical herbicides by manufacturer and port destination (in Viet Nam). Dates were available when the various tactical herbicides were first shipped and deployed in Southern Viet Nam. In addition, the US Army Chemical Corps maintained a record of all defoliation and

Table 2: Air Force Bases in Southern Viet Nam used by US and Allied Forces for tactical operations

Vietnam Air Base	Military Operation [a]			Years [b]
	RANCH HAND	PACER IVY	FLYSWATTER	
Tan Son Nhut	X			1962–1966
Bien Hoa	X	X	X	1966–1972
Da Nang	X	X	X	1964–1972
Phu Cat	X			1968–1970
Nha Trang	X			1968–1969
Phan Rang			X	1970–1972
Tuy Hoa		X		1971–1972

[a] Operation RANCH HAND, 1962–1971 was the USAF Mission to spray herbicides; Operation FLYSWATTER, 1967–1972 was the USAF Mission to spray insecticides to control mosquitoes and malaria; Operation PACER IVY, 1971–1972 was the project to return all remaining stocks of Agent Orange to the United States after April 1970

[b] Time periods encompassing all operations at the specific air base

crop destruction missions conducted by the Chemical Corps and by Operation RANCH HAND. These records were computerized and became known as the Herbicide Reporting System or HERBS Tape. The HERBS tracked all missions from August 1965 through the close of the program in February 1971 [11]. Combining data from all sources, an estimate was made of how much tactical herbicide was shipped and dispersed from RANCH HAND operating locations. These data are provided in **Table 3**.

The PACER IVY re-drumming operation was done by former ARVN troops and overseen by USAF Base Bioenvironmental Engineers at Bien Hoa, Tuy Hoa, and Da Nang. Spills occurred at all three locations during this operation. Approximately 11,000 drums of Herbicide Orange were shipped from Bien Hoa to the Port of Saigon in March 1972; approximately 6,000 drums were shipped from Tuy Hoa to the Port at Cam Rhan Bay; and approximately 8,220 drums were shipped from Da Nang Air Base to the Port of Da Nang. The ship *M/T TransPacific* transported the drums from all three Ports to Johnston Island in the Central Pacific Ocean, arriving in mid-April 1972 [4,6].

6 Construction of Air Field Maps

The Mapping Project provided 'best estimates' on the quantities of tactical herbicides distributed to former Allied air bases in Southern Viet Nam. The Project also identified approximate locations on those air bases where tactical herbicides were stored or where they were loaded on the aircraft used by RANCH HAND, US Army Chemical Corps, or ARVN and used in support of tactical operations. In addition, sites were described where re-drumming of Herbicide Orange occurred in 1971–1972 in support of Operation PACER IVY. Recent satellite images (from QuickBird or Ikonos satellites) were overlaid with the following air fields or sites where herbicides were temporarily stored in support of tactical operations: Tan Son Nhut Airport, and Bien Hoa, Da Nang, Phu Cat, and Nha Trang Air Fields. Routine maintenance and transportation activities in support of Operation PACER IVY also occurred at Bien Hoa, Da Nang, and Tuy Hoa Air Fields. The locations marked on the satellite images represented more area than likely used in the military operations. Thus, increasing the probability that the actual area of use was 'within' the marked area [4].

At the Workshop, the presentation of the of seven large Satellite Image Maps by Mr. Van Houten included a 'table walk around' activity where Professor Young explained the information on the 1 meter x 1.25 meter colored maps (**Fig. 2**). Each of the satellite images had a resolution of one meter, and was pan-sharpened, multi-spectral, and geo-referenced to geographic coordinates [4]. A joint DoD–MOD discussion of each map revealed that MOD had mis-identified many objects on the maps that were not related to tactical herbicide operations.

Table 3: Quantities of tactical herbicides (Number of 55gal/208L drums) at former US/Allied Air Bases in Southern Viet Nam

Location	Transient [a]			Temporary [b]
	Orange	White	Blue	Orange
Tan Son Nhut	57,300	17,000	4,200	(14,075 drum Purple, Pink, Green) [c]
Bien Hoa	98,000	45,000	16,000	(11,000) [d]
Da Nang	52,700	29,000	5,000	(8,220) [d]
Phu Cat	17,000	9,000	2,900	
Nha Trang	9,000	4,800	1,100	
Tuy Hoa				(6,000) [d]
Totals	**~234,000**	**~104,800**	**~29,200**	**(25,220)**

[a] Transient refers to stocks sent to the base and deployed in combat operations

[b] Temporary refers to Herbicide Orange stocks stored and re-drummed in Operation PACER IVY

[c] Early 'Tactical Herbicides' used from January 1962–March 1965

[d] Removed from Viet Nam to Johnston Island in Operation PACER IVY

Fig. 2: Photograph of Professor Young discussing with Viet Nam's Ministry of Defense the Satellite Image Maps showing the location of former tactical herbicide storage and loading sites in southern Viet Nam

7 The Issue of Hot Spots

Tactical herbicides sent to Viet Nam were either used as intended for vegetation control, unintentionally spilled during handling, or removed from Vietnam for disposition when use of the material was ended (Operation PACER IVY). The science of the environmental fate of TCDD supported the expectation that the TCDD aerially applied with Herbicide Orange would have photodegraded on the surface of the vegetation (or as vapor in the air) within a few hours of application [12]. However, once the TCDD moved with the herbicide beneath the soil surface (colloidal movement), as in the case of spills, the TCDD could persist for decades [13]. This provided context for the issue of hot spots and why the aerial applications were of little potential significance.

In the Report **The History and Maps of the Former Tactical Herbicide Storage and Loading Sites in Vietnam,** the DoD suggested that the sites of greatest interest for potential hot spots were at the locations where Operation PACER IVY had occurred. As previously noted, on 15 April 1970, the US DoD suspended all uses of Herbicide Orange in Viet Nam. The remaining Orange Herbicide stocks were placed in temporary storage at Da Nang and Bien Hoa Air Bases (now Air Fields). In addition, the US Army Chemical Corps also stored small quantities of tactical herbicides at Special Forces Camps, e.g., in the Aluoi Valley [4]. Small quantities were also located at the Air Bases at Phu Cat and Nha Trang. On 15 September 1971, the 7th Air Force directed that all stocks be consolidated at Bien Hoa, Tuy Hoa, and Da Nang Air Bases. Under the PACER IVY project, remaining stocks of Herbicide Orange were re-drummed and returned to the continental United States. All remaining Herbicide Orange stocks in III and IV Corps were consolidated at Bien Hoa Air Base, those in II Corps were consolidated at Tuy Hoa Air Base, and those in I Corps were consolidated at Da Nang Air Base [4].

Of the 130 kilograms of TCDD estimated to have been present in the tactical herbicides used in Viet Nam, it was likely that at least 96 to 98% of the TCDD was aerially sprayed over the jungles and mangrove swamps of Viet Nam [12]. A recent re-analysis and update of the HERBS Tape indicated that approximately 344,000 drums of tactical herbicides were sprayed, compared with approximately 356,400 deployed in Vietnam (~ 96%) [4]. Thus, only about 2 to 4% of the dioxin from Herbicide Orange (estimated at 105 kg) would have remained in hot spots, which is estimated at about 2 to 4 kilograms. This is a very different picture than previously visualized in Viet Nam [14]. Similar handling losses occurred with the 25,220 drums of Herbicide Orange that were removed from Vietnam in 1972 and sent to Johnston Island. During five years of storage, more than 10,000 leaking drums were re-drummed before Operation PACER HO (the disposition of Herbicide Orange by at-sea incineration) in 1977 [15]. PACER HO destroyed 24,795 drums indicating that about 2 percent of the herbicide had spilled in the storage area from 1972 to 1977 [15].

A point of confusion is the fate of the TCDD contained in the 96 to 98% of tactical herbicides sprayed over the jungles and mangrove swamps of Viet Nam. The 15-year ecological research program conducted at Eglin Air Force Base in Northwest Florida, 1969–1984 [16], and the dioxin research reported on the Ma Da Forest in 2007 [17], provided results indicating that a substantial preponderance of 2,3,7,8-TCDD was degraded by sunlight immediately after application of the 2,4,5-T-containing tactical herbicides. Thus validating the importance of focusing attention on any remaining hot spots in Southern Viet Nam.

The issue of hot spots has been extensively covered in recent studies conducted in Viet Nam [14]. Limited analytical data collected during the past two years from Da Nang Air Field and Bien Hoa Air Field were presented by MOD at the Workshop. Soil and sediment samples from the Da Nang Air Field perimeter areas averaged ~ 40 pg/g or 40 ppt. Six samples (0.7–365 ng/g, ppb, mean 95 ppb) were collected beneath the tarmac where RANCH HAND loading operations had occurred. Five samples from an area identified by MOD as a former storage area ranged from 0.1 to 100 ppb, mean of ~45 ppb. Nine samples of sediments from a lake on the Da Nang Air Field averaged ~2.3 ppb. The MOD has proposed a clean-up standard of 1 ppb. However, as noted by MOD during the Workshop, this standard is a US Environmental Protection Agency standard and may or may not be applicable to the situation at Da Nang Air Field. MOD also reported human samples collected in the Da Nang Community by Hatfield Consultants, West Vancouver, British Columbia, Canada [14]. The samples contained numerous dioxins, furans, and PCBs suggesting numerous sources of contamination probably including Herbicide Orange. Professor Young noted that the levels of 2,3,7,8-TCDD in soil and sediment samples on the Da Nang Air Field were generally consistent with TCDD residues reported for both former Herbicide Orange Storage Sites on Johnston Island and at Gulfport, Mississippi [13].

Although the sites sampled by MOD at Da Nang were not associated with the locations where Project PACER IVY occurred, MOD recognized the importance of the PACER IVY locations. The MOD presentations at the Workshop focused on their research sponsored or conducted by their scientists and engineers at Da Nang Air Field [14,18,19]. The seven maps presented to the MOD by DoD provided potentially new sites for hot spots. However, the designation of other former herbicide handling and storage locations as hot spots where spills may have occurred remains to be determined, but warrant further investigation as a precautionary measure.

Environmental informatics and spatial analysis methods that link various data have been crucial to the integrated assessments for this project. The information and approaches developed to evaluate residual risks from past use of tactical herbicides project are relevant to other ongoing research and remediation activities in Viet Nam and other countries. Those efforts include programs for managing environmental dioxins and furans from other sources and managing other persistent organic contaminants.

8 Follow-on Activities

At the conclusion of the presentations, and with the signing of formal Minutes, both the Governments of the United States and Viet Nam agreed to continue sharing information, remediation experiences, and best scientific practices for the purpose of promoting and understanding the legacy of Agent Orange and its associated dioxin. Both the United States and Viet Nam recommended that the next activities should include:

- Joint program involving sampling, surveys and analyses of potentially contaminated sites at the other Air Fields identified for MOD at the Workshop.
- Joint program to develop scientifically credible remediation programs 'based on risk,' as required.

Acknowledgement. Funding for Workshop and Conference Report from US Army Research Office, Research Triangle Park, North Carolina, USA, Contract # DAAD19-02-D-001.

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