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CHAPTER 2

"MASSIVE QUANTITIES OF HERBICIDES WERE APPLIED BY THE UNITED STATES IN A TACTICAL OPERATION DESIGNED TO REDUCE AMBUSHES AND DISRUPT ENEMY TACTICS"

THE MILITARY USE OF HERBICIDES IN VIETNAM

A. L. YOUNG

The introduction of herbicides in 1962 into the armed conflict in Vietnam represented an application of a new technique for modern warfare. Their use in a defensive role was for defoliation. Their use in offensive roles was for crop denial. Today, fifteen years after the last spray mission, these herbicides are at the center of intense scientific debate involving not only medical but also legal, political and ecological issues. This chapter reviews the historical and operational concepts and some potential human exposure considerations involving the military use of herbicides in the Southeast Asian Conflict.

Herbicides Used in South Vietnam

Synthesis technology, efficacy data, and field application techniques were developed for the two major phenoxy herbicides 2,4-dichlorophenoxy-acetic acid (2,4-D) and 2,4-5-trichlorophenoxyacetic acid (2,4,5-T) during World War II at Fort Detrick, Frederick, Maryland (12). Following World War II, the commercial use of these two "synthetic" organic herbicides revolutionized American agriculture. In 1950, more than 4.5 million kilograms (kg) of these materials were used annually for weed and brush control in the United States. By 1960, in excess of 16 million kg were used (13).

In May 1961, the Office of the Secretary of Defense requested the Fort Detrick personnel to determine the technical feasibility of defoliating jungle vegetation in the Republic of Vietnam (7). By early Fall, 1961, 18 different aerial spray test 8 (defoliation and anticrop) had been conducted with various formulations of commercially-available herbicides. The choice of these herbicides was based upon the chemicals that had had considerable research, proven performance, and practical background at that period in time (4). Also, such factors as availability in large quantity, costs and known or accepted safety in regard to their toxicity to humans and animals were considered (12). The results of these tests were that significant defoliation and anticrop effects could be obtained with two different mixtures of herbicides. The first was a mixture of the n-butyl esters of 2,4-D and 2,4,5-T and the iso-butyl ester of 2,4,5-T. This mixture was code-named "Purple." The second "military herbicide was code-named "Blue" and consisted of the acid and sodium salt of cacodylic acid. The colored bands which were painted around the center of the 208-liter drums served as aid to the identification by support personnel (1).

The first shipment of Herbicides Purple and Blue was received at Tan Son Nhut Air Base, Republic of Vietnam, on 9 January 1962. These were the first military herbicides used in Operation RANCH HAND, the tactical military project for the aerial spraying of herbicides in South Vietnam (1). Two additional phenoxy herbicide formulations were received in limited quantities in South Vietnam and evaluated during the first two years of Operation RANCH HAND. These were code-named Pink and Green. By January 1965, two additional military herbicides, code-named Orange and White, had been evaluated and brought into the spray program. Herbicide Orange replaced all uses of Purple, Pink, or Green, and eventually became the most widely used military herbicide in South Vietnam (7). The composition of the three major herbicides in South Vietnam were as follows:

1. Herbicide Orange

Orange was a reddish-brown to tan colored liquid soluble in diesel fuel and organic solvents, but insoluble in water (15). One liter of Orange theoretically contained 510 grams of the active ingredient of 2,4-D and 530 grams of the active ingredient of 2,4,5-T. Orange was formulated to contain a 50:50 mixture of the n-butyl esters of 2,4-D and 2,4,5-T. The percentages of the formulation typically were:

n-butyl ester of 2,4-D	49.49
free acid of 2,4-D	0.13
n-butyl ester of 2,4,5-T	48.75
free acid of 2,4,5-T	1.00
inert ingredients (e.g., butyl alcohol and ester moieties)	0.62

2. Herbicide White

White was a dark brown viscous liquid that was soluble in water but insoluble in organic solvents and diesel fuel (15). One liter of white contained 65 grams of the active ingredient of 4-amino-3,5,6-trichloropicolinic acid (picloram) and 240 grams of the active ingredient of 2,4-D. White was formulated to contain a 1:4 mixture of the triisopropanopamine salts of picloram and 2,4-D. The percentages of the formulation were:

triisopropanolamine salt of picloram	10.2
triisopropanolamine salt of 2,4-D	39.6
inert ingredient (primarily the solvent triisopropanolamine)	50.2

3. Herbicide Blue

Blue was a clear yellowish-tan liquid that was soluble in water, but insoluble in organic solvents and diesel fuel (15). One liter of Blue contained 370 grams of the active ingredient hydroxydimethyarsine oxide (cacodylic acid). Blue was formulated to contain cacodylic acid (as the free acid) and the sodium salt of cacodylic acid (sodium cacodylate). The

percentages of the formulation were:

cacodylic acid	4.7
sodium cacodylate	26.4
surfactant	3.4
sodium chloride	5.5
water	59.5
antifoam agent	0.5

As previously noted, not all of the herbicides used in South Vietnam were used throughout the entire 10 years (1962-1971) encompassed by the Department of Defense defoliation program. In addition, 2,4,5-T formulations used early in the program are believed to have contained higher levels of the toxic contaminant TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin the time periods shown in Table 1 can be differentiated on the basis of specific herbicides used and the mean dioxin content (15).

TABLE 1 - THE DIFFERENTIATION OF THE THREE TIME PERIODS DURING THE US MILITARY DEFOLIATION PROGRAM IN SOUTH VIETNAM AND MEAN DIOXIN CONTENT

PERIOD	HERBICIDES USED	MEAN DIOXIN CONTENT*
January 1962 -	Purple, Pink, Green	32**
June 1965	Blue	0
July 1965 -	Orange	2+
June 1970	White, Blue	0
July 1970	White, Blue	0
October 1971		

*Found only in 2,4,5-T containing formulations.
**Value based on analyses of five samples.
+Value based on the analyses of 488 samples.

Herbicide Orange was the most extensively used herbicide in South Vietnam (5). Orange accounted for approximately 40.5 million liters of the 67 million liters of herbicide used (Table 2). It was used from mid-1965 to June 1970. However, as noted in Table 2, Orange was not the only 2,4,5-T containing herbicide used in the defoliation program (6). Small quantities of Purple, Pink, and Green, all containing 2,4,5-T were used from 1962 through mid-1965 (5,15). In subsequent sections of this document, the term "Herbicide Orange" will refer to all of the 2,4,5-T containing herbicides

used in Vietnam (Purple, Pink, Green, and Orange).

TABLE 2 - NUMBER OF LITERS OF MILITARY HERBICIDE PROCURED BY THE US DEPARTMENT OF DEFENSE AND DISSEMINATED IN SOUTH VIETNAM DURING JANUARY 1962 - OCTOBER 1971(+)

Code Name	Herbicide	Quantity	Period of Use
Orange	2,4-D; 2,4,5-T	40,295,000	1965-1970*
White	2,4-D; Picloram	21,321,000	1965-1971**
Blue	Cacodylic Acid	4,353,000	1962-1971**
Purple	2,4-D; 2,4,5-T	549,000	1962-1965
Pink	2,4,5-T	46,600	1962-1965
Green	2,4,5-T	31,400	1962-1965
	Total	67,015,400	

+Source: Craig (6).
*Last fixed-wing mission of Orange 16 April 1970; last helicopter mission of Orange 6 June 1970.

**Last fixed-wing mission 9 January 1971; all herbicides under US control stopped 31 October 1971.

The data in Table 2 were obtained by Craig (6) in 1975 from examination of procurement records maintained by the San Antonio Air Logistic Center, Kelly Air Force Base, Texas. The completeness of the records is unknown. A log of herbicide applications was maintained by the United States Military Assistance Command, Vietnam, and these "paper records" became the source documents for the National Academy of Sciences (NAS) 1972-74 study of the effects of herbicides in South Vietnam (5). The NAS computerized these records into the HERBS Tape. The HERBS Tape contained data on approximately 6,100 herbicide missions with an estimated herbicide expenditure of 71,672,760 liters. As noted in Table 2, Craig could only account for procurement documents on 67,015,400 liters. The National Academy of Sciences (5) estimated that their record searches and/or incomplete records accounted for 86% of the RANCH HAND missions. In 1985, the United States Army and Joint Services Environmental Support Group, a joint (Army, Air Force and Navy) military group of military record specialists completed an

exhaustive search of the military records of the Vietnam era. This unit constructed a data base of 2,394 additional military herbicide missions in Vietnam that were either improperly/incompletely documented in the HERBS Tape or were missions unrecorded. An additional 557 RANCH HAND fixed-wing missions were identified/verified. Of significance, the SERVICES HERBS Tape contain data on helicopter, backpack and other types of ground spraying. When the two tapes (HERBS and SERVICES HERBS) were combined, 8,930 missions were identified and 72,740,400 liters of herbicide were reported (Table 3).

TABLE 3 - HERBICIDE MISSION DATA FROM COMBINING HERBS TAPE (1974) AND THE SERVICES HERBS TAPE (1985), 1961 - 1971 *

Herbicide	Number of Missions	Total Number of Liters
Orange	4,698	44,953,560
White	2,194	20,616,860
Blue	981	4,712,920
Unknown**	965	2,339,460
Other (Purple, Green, etc)	92	117,600
Total	8,930	72,740,400

*Data combine all fixed-wing, helicopter, and ground application missions.
**Records document herbicide mission but do not identify specific herbicide.

Use Patterns of Individual Herbicides

Each of the three major herbicides (Orange, White, and Blue) had specific uses. About 90 percent of Herbicide White was applied in defoliation missions. It was not recommended for use on crops because of the persistence of picloram in soils. Because the herbicidal action on woody plants was usually slow, full defoliation did not occur for several months after spray application. Thus, it was an ideal herbicide for use in the inland forests in areas where defoliation was not immediately required,

with Orange or Blue.

Herbicide Blue was the herbicide of choice for crop destruction missions involving cereal or grain crops. Approximately 50 percent of all Blue was used in crop destruction missions in remote or enemy controlled areas with the remainder being used as a contact herbicide for control of grasses around base perimeters (9).

Approximately 85 percent of all Herbicide Orange was used for forest defoliation and it was especially effective in defoliating mangrove forests. Eight percent of Herbicide Orange was used in the destruction of broadleaf crops (bean, peanuts, ramie, and root or tuber crops). The remaining 7 percent was used around base perimeters, cache sites, waterways, and communication lines.

Table 4 shows the number of hectares sprayed with herbicides in South Vietnam within the three major vegetational categories.

TABLE 4 - THE NUMBER OF HECTARES TREATED IN SOUTH VIETNAM, 1962-1971, WITH MILITARY HERBICIDES WITHIN THE THREE MAJOR VEGETATIONAL CATEGORIES*

Vegetational Category	Hectares Treated**
Inland forest	1,080,970
Mangrove forests	127,750
Cultivated crops	105,260
Total	1,313,980

*Source: National Academy of Sciences, 1974 (5).
**Areas receiving single or multiple coverage.

Certain portions of South Vietnam were more likely to have been subjected to defoliation. Herbicide expenditures for the four Combat Tactical Zones of South Vietnam are shown in Table 5. These data were obtained from HERBS Tape. The distribution of defoliation missions was mapped by the National Academy of Sciences (5) and is shown in Figure 1. Figure 2 is a map of Vietnam identifying the provinces and major cities.

TABLE 5 - HERBICIDES EXPENDITURES IN SOUTH VIETNAM, 1965-1971: A BREAKDOWN BY COMBAT TACTICAL ZONE*

Combat Tactical Zones		Herbicide Expenditure (liters) Orange	White	Blue
CTZ I		8,516,360	1,374,000	1,127,900
CTZ II		9,534,400	2,759,300	1,790,300
CTZ III (includes Saigon)		20,094,600	14,076,400	1,112,800
CTZ IV		4,644,200	1,646,500	234,700
	Subtotals	42,789,500	19,856,200	4,265,700
	Grand Total			66,911,400

*Source: HERBS Tape

In addition to the herbicides, numerous other chemicals were shipped to South Vietnam in 208-liter drums. These included selected fuel additives, cleaning solvents, cooking oils, and a variety of other pesticides. The insecticide malathion was widely used for control of mosquitoes and at least 1,514,000 liters of it was used from 1966 through 1970. In addition, much smaller quantities of lindane and DDT were used in ground operations throughout the war in Southeast Asia. The distribution of the herbicides within Vietnam after their arrival did not occur randomly. About 65 percent was shipped to the 20th Ordnance Storage Depot, Saigon, and 35 percent was shipped to the 511th Ordnance depot, Da Nang.

Military Aircraft and Vehicles Used in the Dissemination of Herbicides

Numerous aircraft were used in the air war in Vietnam, but only a few of these aircraft were used for aerial dissemination of herbicides. The "work horse" of Operation RANCH HAND was the C-123, "Provider." This cargo aircraft was adapted to receive a modular spray system for internal carriage. The module (the A/A 45 Y-1) consisted of a 3,785 liter tank pump, and engine which were all mounted on a frame pallet. An operator's console

was an integral part of the unit, but was not mounted on the pallet. Wing booms (3.8 cm in diameter and 6.7 m in length) extended from outboard engine nacelles toward the wing tips. A short tail boom (7.6 cm in diameter, 6.1 m in length) was positioned centrally near the aft cargo door. Each aircraft normally had a crew of three men: the pilot, co-pilot (navigator), and flight engineer (console operator). During the peak activity of RANCH HAND operations (1968-1969), approximately 30 UC-123K aircraft were employed. However, many other squadrons of non-RANCH HAND C-123 aircraft were routinely used throughout South Vietnam in transport operations.

The control of malaria and other mosquito-borne diseases in South Vietnam necessitated an extensive aerial insecticide application program in order to control these vector insects. from 1966 through 1972, three C-123 aircraft were used to spray malathion, an organophosphate insecticide. These aircraft could be distinguished from the herbicide-spraying aircraft because they were not camouflaged. These aircraft routinely sprayed insecticide adjacent to military and civilian installations, as well as in areas where military operations were in progress, or about to commence.

Approximately 10 to 12 percent of all herbicides used in South Vietnam was disseminated by helicopter or ground application equipment. Generally, helicopter crews were not assigned to herbicide spray duties on a full-time basis and rotated the spraying duties with other mission requirements. The military UH-1 series of helicopters, deployed by the Air Force, the Army, and Navy units, generally sprayed the herbicides. The most common spray systems used were the HIDAL and AGRINAUTICS units. These units were installed in or removed from the aircraft in a matter of minutes because they were "tied down" to installed cargo shackles and aircraft modifications were not required for their use. Each unit consisted of a 760-liter tank and a collapsible 9.8 m spray boom. The unit was operated by manual controls to control the flow valve and a windmill brake. Generally, each helicopter had three crew members.

A summary of the aircraft used in herbicide and insecticide operations is shown in Table 6.

TABLE 6 - MILITARY AIRCRAFT USED IN THE DISSEMINATION OF HERBICIDES AND INSECTICIDES IN SOUTH VIETNAM

Aircraft	Camouflaged	Chemical Disseminated
UC-123/UC-123K	Yes	All Herbicides
UC-123K	No	Malathion
Helicopter		
Air Force UH-1 Army UH-1B/UH-1D,H-34 Navy H-19	Yes	Orange, Blue

Various ground delivery systems were also used in South Vietnam for control of vegetation in limited areas. Most of these units were towed or mounted on vehicles. One unit that was routinely used was the buffalo turbine. It developed a wind blast with a velocity up to 240 km/h at 280 m^3/minute volume. When the herbicide was injected into the air blast, it was essentially "shot" at the foliage. The buffalo turbine was useful for roadside spraying and applications of perimeter defenses. The herbicides of choice in these operations were Blue and Orange.

Mission Concepts

The objectives of the defoliation and anticrop programs in South Vietnam have been thoroughly reviewed by Huddle (11) and others (2,3,5,7). It is the objective of this section to elaborate only on the background and mechanics of a "typical" herbicide mission that would have influenced the degree of exposure to herbicides by aircrew and/or ground personnel. The following scenario of events or "standard operating procedures" has been compiled from the literature and interviews by Young et al (15), and is captured in photographs in Figures 3 through 22.

1. Each of the 11 different companies that manufactured military herbicides packed them in new ICC 17C 208-liter 18 gauge steel drums for shipment to Southeast Asia. Until 1967, lined drums were used only for shipment of Blue. However, because of the results of compatibility tests, lined drums were also used to ship White beginning in 1967.

2. Each herbicide drum was marked with a 7.6 cm color-coded band around the center to identify the specific military herbicide. This marking was initially a 30 cm band, but was changed to a 7.6 cm band in March 1966.

3. Shipping time from the arrival of the herbicide at a US port until it arrived in South Vietnam varied from 47 to 52 days.

4. About 10 out of every 10,000 drums shipped were received in a damaged or defective state. This represented a damage rate of 0.1 percent. About 50 percent of these damaged drums leaked as a result of punctures or split seams. These were caused by improper loading and defective drums. Forklifts operated by stevedores also caused punctures. Redrumming was accomplished at the ports.

5. About 65 percent of the herbicide was shipped to the 20th Ordnance Storage Depot, Saigon, and 35 percent was shipped to the 511th Ordnance Storage Depot, Da Nang. Under the normal handling procedures, drums were unloaded at Da Nang and Saigon from the cargo vessel directly into semi-trailers and were placed in an upright position. The trailers were driven to the various units of the 12th Air Commando Squadron (primarily at the bases of Da Nang, Phu Cat, or Bien Hoa) for disposition.

6. Normally the contents of the drums were transferred into blocked F-6 trailer tanks through a suction tube without removing the full drums from the semi-trailers. Each F-6 trailer held 16,300 liters or about 78 drums of herbicide. If blocked F-6 trailer tanks could not accomodate the total inventory, the drums were stacked in pyramidal style until needed.

7. The transfer of the herbicides from the 208-liter steel drums to storage tanks or aircraft tanks required some precautionary measures. Personnel charged with the supervisory responsibilities of handling the herbicides were indoctrinated in appropriate safety precautions including the use of gloves and face shields as needed. Personnel handling the chemicals were encouraged to "take normal sanitary precautions and to maintain personal cleanliness and to avoid skin and eye contact with the material. Contaminated clothing were to be washed before re-use. Spillage on the skin or in the eyes was to be rinsed copiously with clean water.

8. When the herbicide was pumped from the drums into the F-6 trailers about 2 to 5 liters remained in the drum. Hence the drum was placed on a drain rack and the "drippings" were collected from many drums in a pan-type receptacle and used for spraying base perimeter areas.

9. Empty drums were generally given to the military forces (Vietnam, U.S. and Free World Military Assistance Forces) for use as barriers in defensive positions. The drums were filled with sand or concrete and used in the construction of bunkers or in foundations for runways and barbed wire perimeters.

10. Surface areas contaminated by spillage of the herbicides were flushed with diesel fuel or water with diversion of the drainage into settling basins or pits for incorporation into the soil.

11. The F-6 trailers were tied to plumbing and pumps so that the herbicide could be delivered to the aircraft without moving the trailers.

12. As previously noted, Orange was insoluble in water, while Blue and White were not. When Orange was mixed with either Blue or White, a gummy substance formed. The F-6 trailers were therefore color-coded to correspond to the drum color-codes and used exclusively for the herbicide to which the code applied.

13. The aircraft spray tanks, positioned in the center of the airplane, and the spray system were purged before the type of herbicide carried was changed. Particular attention had to be given to sequences

involving Blue and White. A mixture of these two herbicides resulted in the formation of a precipitate consisting of the sodium salt of 2,4-D.

14. Most of the personnel involved in the actual handling of the herbicide drums were Vietnamese. However, a USAF flight mechanic or crew chief was responsible for insuring that the aircraft was properly loaded and the spray system functional. A flight mechanic was also the console operator for the spray unit. The pilot and co-pilot were officers while the flight mechanics, crew chiefs and other ground support personnel were enlisted men.

15. For record keeping purposes a herbicide "mission" consisted of several aircraft; if only one aircraft was used the operation was termed a sortie. All missions within a target formed a project.

16. Aircraft takeoffs were normally before sunrise. From a tactical point of view, the arrival of the aircraft at the target area just prior to sunrise permitted the aircraft to approach the target from the direction of the rising sun. This afforded some degree of protection from enemy ground fire. From the standpoint of herbicidal action, application by aerial spray was most effective if accomplished prior to 0800 hours while inversion conditions existed, in the absence of precipitation, and while the wind was calm or not exceeding a velocity of 8 knots. This insured the proper settling of the spray on the target area.

17. Within the aircrafts, it was not uncommon to have herbicide leakage from around the numerous hose connections joining the spray tank and pumps with the wing and aft spray booms. In hot weather, the odor of herbicide within the aircraft was decidedly noticeable. Periodically, the spray tank and console were removed (especially with the portable A/A 45Y-1 system) and the interior flushed with surfactant or soap and with water. Because of the corrosive nature of some herbicides, it was necessary for the aircraft to also be repainted periodically.

18. In the 1966 through 1968 period, more than one sortie per day was often common. For example, during the first six months of 1968,

the 24 UC-123B aircraft assigned to RANCH HAND averaged approximately 39 sorties per day.

Exposure Considerations: Applications and Environmental Parameters

There were relatively few military operations that involved the handling of herbicides by military personnel. A review of operations involving Herbicide Orange in South Vietnam from January 1962 to April 1970 revealed that there were essentially three groups of military personnel potentially exposed to Herbicide Orange and its associated dioxin contaminant. These three groups were:

1. "OPERATION RANCH HAND" personnel actively involved in the defoliation program. This group included aircrew members and maintenance and support personnel directly assigned to the RANCH HAND squadrons.

2. Personnel assigned to selected support functions that may have resulted in exposure to Herbicide Orange. This group included, for example, personnel who sprayed herbicides, using helicopters or ground application equipment; personnel who may have delivered the herbicides to the units performing the defoliation missions; aircraft mechanics who were specialized and occasionally provided support to RANCH HAND aircraft; or, personnel who may have flown contaminated C-123 aircraft, but were not assigned to RANCH HAND (e.g., during the Tet Offensive, all RANCH HAND aircraft were reconfigured to transport supplies and equipment, and were assigned to non-RANCH HAND squadrons).

3. Ground personnel who may have been inadvertently sprayed by defoliation aircraft or who, during combat operations, may have entered an area previously sprayed with Herbicide Orange.

The total number of US military personnel exposed to Herbicide Orange is not known. Approximately 1,250 RANCH HAND personnel were exposed in direct support of the defoliation operations; however, there are no data on the number of non-RANCH HAND personnel who may have been exposed. The actual number of people may be in the thousands since at least 100 helicopter spray equipment units were used in South Vietnam, and most

military bases had vehicle-mounted and backpack spray units available for use in routine vegetation control programs. The number of military ground personnel who may have inadvertently been sprayed with Herbicide Orange during combat operations is not known. Approximately 10 percent of South Vietnam was sprayed with herbicides, and most of this area was contested and/or controlled by enemy forces. Most areas sprayed were remote, unpopulated and forested (14). Because of the dense canopy cover, the target of the defoliation operation, the amount of herbicide penetrating to the forest floor would have been small. The exposure of personnel could have occurred by essentially three routes:

1. Percutaneous absorption and inhalation of vapors/aerosols by direct exposure to sprays.

2. Percutaneous absoprtion and inhalation of vapors by exposure to treated areas following spray application, and

3. Ingestion of foods contaminated with the material.

The chemical and physical characteristics of Herbicide Orange and the spray, as it would have occurred following dissemination from a C-123, are important factors in assessing relative exposure to the herbicides and TCDD.

Table 7 reviews the pertinent chemical and physical characteristics of Herbicide Orange. Table 8 reviews both the application parameters of the spray system used in the UC-123K aircraft and the characteristics of the spray itself. Generally, herbicides were sprayed in the early morning or late afternoon, so as to minimize the effects of air movement on particle dispersion.

TABLE 7 - PERTINENT CHEMICAL AND PHYSICAL CHARACTERISTICS OF HERBICIDE ORANGE+

Formulation Concentrated		1 Kg ai/liter*
Water Insoluble		Density - 1.28
Vapor Pressure		3.6 x 10^{-4} mm Hg at 30 °C
NBE** 2,4-D	: 1.2 x 10^{-4}	
NBE 2,4,5-T	: 0.4 x 10^{-4}	
TCDD	: 4.68x 10^{-7}	
Viscous		40 centipoises at 20°C

Noncorrosive to metal
Deleterious to paints, rubber, neoprene
Long Shelf life

+Source: Young et al, (15,16)
*Kilograms active ingredient (2,4-D and 2,4,5-T) per liter.
**NBE - Normal Butyl ester.

TABLE 8 - APPLICATION PARAMETERS AND SPRAY CHARACTERISTICS OF THE C-123 MODULAR INTERNAL SPRAY SYSTEM

Aircraft speed	130 KIAS*
Aircraft altitude	50 m
Tank volume	3,785 liters
Spray time	3.5-4 minutes
Particle size:	
100 microns: 1.9%	
100-500 microns: 76.2%	
500 microns: 21.9%	
87% impacted within 1 minute	
13% drifted or volatilized	
Mean particle volume	0.61 microliters
Spray swath	80±6 meters
Mean deposition	28 liters/hectare
Total area/tank	130 hectares

Source: Darrow et al, (8) and Harrigan (10).
*Knots indicated air speed

Ground combat forces normally would not have been expected to have entered a previously treated area for several weeks after treatment, during which time numerous environmental factors would have reduced the potential for exposure to military personnel. An indepth review of the environmental fate of Herbicide Orange and TCDD concluded that the vast majority of the phenoxy herbicides would have impacted forest canopy, the intended target (15). The proposed scenario was as follows:

Rapid uptake (e.g., within a few hours) of the ester formulations of 2,4-D and 2,4,5-T would have occurred following aerial application. Most of the herbicide probably would have undergone rapid degradation (weeks) within the cellular matrix of the vegetation. However, some of the herbicide may have remained unmetabolized and would have been deposited on the forest floor at the time of leaf fall. Soil microbial and/or chemical action would likely have completed the degradation process. Herbicide droplets that impacted directly on soil or water would have hydrolyzed rapidly (within hours). Biological and nonbiological degradative processes would have further occurred to significantly reduce these residues. Some volatilization of the esters of 2,4-D and 2,4,5-T would have occurred during and immediately after application. The volatile material most likely would have dissipated within the foliage of the target area. Photodecomposition of TCDD would have minimized the amount of biologically active volatile residues moving downwind of the target area.

Accumulation of phenoxy herbicides in animals may have occurred following ingestion of treated vegetation. The magnitude of this accumulation would have rapidly declined after withdrawal from treated feed.

Most TCDD sprayed into the environment during defoliation operations would have probably photodegraded within 24 hours of application. The TCDD that escaped photodegradation would probably have entered the soil-organic complex on the forest floor following leaf fall. Soil chemical processes would have further reduced the bioavailability of the TCDD residues. Bioconcentration of the remaining minute levels of TCDD may have

occurred in liver and fat of animals ingesting contaminated vegetation or soil. However, there are no field data available that indicate that the levels of TCDD likely to have accumulated in these animals would have had a biological effect.

Report on Exposure Assessment by the Agent Orange Working Group

In 1981, the President of the United States established the White House Agent Orange Working Group (AOWG). While the AOWG does not conduct any research, it is charged with being the overall coordinator, clearinghouse, and evaluator of the Federal research effort. In January 1986, the AOWG directed its Science Panel (a panel of senior scientists from ten Federal agencies) to review pertinent information on veteran exposure to Agent Orange and/or its associated dioxin, to examine additional pilot data developed by the U.S. Army and Joint Services Environmental Support Group, and to evaluate the feasibility of a scientifically valid epidemiologic study where the cohorts were selected on the basis of military records. The conclusions of the AOWG Science Panel were reported (16), and are quoted below:

> The Science Panel concluded that the U.S. Army's Environmental Support Group has sought and obtained all military records pertinent to the use of herbicides in Vietnam. The environmental Support Group staff is trained and qualified to have expertly reviewed and abstracted the records appropriate to exposure assessment.
>
> From a thorough review of these military records, it appears that considerable misclassification of the individual's exposure status is possible; i.e., we found no way, based on military records, to verify an individual's exposure to herbicide or dioxin. Two issues were specifically recognized as influencing the degree of misclassification:
>
> a. Unit Dispersion - On a substantial number of days, personnel in combat units eligible for the Agent Orange Study were not located together as a unit, rather they were dispersed geographically up to 20 kilometers on the same day.
>
> b. Incomplete Records - The most complete records for herbicide applications in Vietnam are the "HERBS TAPES," records of the missions of OPERATION RANCH HAND. These tapes, originally computerized by the National Academy of Sciences in the early 1970s, were supplemented recently by the SERVICES HERBS TAPES which provide additional data on perimeter applications (including

helicopter and ground application missions). Expert opinion suggested that an unknown, but apparently large proportion of firebase perimeter spray operations were never recorded. The degree to which these "unrecorded" operations may have influenced exposure is unknown.

After extensive review of military records during the past two years, it was apparent that the majority of veterans had never been within two kilometers of a sprayed area within a week of herbicide application. Additional pilot data reviewed at this time confirmed this finding, and the paucity of clearly exposed combat veterans makes it questionable whether a sufficient number can be assembled to conduct an epidemiological study of the type originally designed.

It is clear from the available data that health studies designed to assess the effects of Agent Orange and its associated dioxin can be done on more appropriate populations than those identified through military records; e.g., industrial workers and commercial herbicide applicators.

Recent advances in analytical chemistry may make it feasible to identify chemical (e.g., 2,3,7,8-TCDD) or biological (DNA adducts) markers that will permit a more reliable exposure assessment.

RECOMMENDATION: This Science Panel recommends that any study of ground troops, which is dependent upon military records for the assessment of exposure to herbicides, not be conducted without an additional method to verify exposure.

Conclusions

The documentation on the use of herbicides in the military conflict in Southeast Asia from 1962 through 1971 is extensive. Nevertheless, the records were never intended to serve as the basis for health studies or litigation activities. Health studies of the effects of the phenoxy herbicides are difficult enough under conditions of normal agricultural use, but they become more complex when conducted with cohorts briefly exposed more than two decades ago under conditions of war in a tropical environment.

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LIST OF FIGURES

Figure 12. Slide 10. The A/A 45Y-1 Internal Defoliant Dispenser was a moduler spray system for internal carriage in the C-123 aircraft. The module consisted of a 3.785-liter tank, pump, and engine mounted on a frame pallet. An operator's console was an integral part of the unit but was not mounted on the pallet.

Figure 13. Slide 11. The RANCH HAND C-123 aircraft had spray booms mounted under each wing and behind the cargo door. Each wing boom was 6.5m in length and mounted with 16 nozzles.

Figure 14. Slide 12. A typical RANCH HAND Crew consisted of a pilot and Co-pilot (officers) and a flight mechanic (enlisted) who served as a console operator for the spray unit.

Figure 15. Slide 13. A typical RANCH HAND mission consisted of 3-5 aircraft.

Figure 16. Slide 14. RANCH HAND Aircraft timed the arrival of the aircraft at a target site just prior to sunrise, thus, permitting the aircraft to approach the target from the direction of the rising sun. This afforded some degree of protection from enemy ground fire.

Figure 17. Slide 15. Defoliation missions along canals and roadways wre common targets. The photograph shows a defoliated area associated with a canal.

Figure 18. Slide 16. The inland forests of Vietnam were defoliation mission targets aimed at dislocating enemy forces. This "swath" was defoliated by at least a five-aircraft formation spraying a distance of almost 13 Km. The herbicides of choice for such an operation were either White or Orange.

Figure 19. Slide 17. The U.S. Army's UH-1 helicopter was ideal for base perimeter spraying of herbicides.

Figure 20. Slide 18. The typical spray system for helicopters consisted of a 750-liter tank, spray boom and windmill pump.

Figure 21. Slide 19. Helicopter spraying Agent Blue on the tall elephant grass on a base perimeter.

Figure 22. Slide 20. Military personnel in a area defoliated by herbicides. Typically, personnel did not enter a defoliated area until the effects of defoliation were apparent and visibility within the area was significantly enhanced.