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DEVELOPMENT OF AN EXPOSURE INDEX FOR AN EPIDEMIOLOGIC STUDY OF
GROUND TROOPS EXPOSED TO AGENT ORANGE DURING THE VIETNAM CONFLICT

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Epidemiologic studies have been proposed of veterans exposed to Agent Orange during the period 1965-1970 of the Vietnam Conflict. These studies are predicated on the identification of cohorts obtained from objective evaluations of their likelihood of having been exposed to Agent Orange during their military duties in South Vietnam. Since the military records available on the Vietnam Conflict were never extended for epidemiologic investigations, there were no data available on personnel exposed to the herbicides or the magnitude of these exposures. Nevertheless, a relative exposure index may be developed based upon those factors that would have influenced the likelihood of exposure to herbicides, namely, the herbicide formulations, methods of application, routes of exposure and environmental fate of the herbicides and the associated dioxin contaminant 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD).

Historical Background

Synthesis technology, efficacy data, and field application techniques were developed for the two major phenoxy herbicides, 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) during World War II at Fort Detrick, Frederick, Maryland. Following World War II, the commercial use of these two "synthetic" organic herbicides revolutionized American agriculture. In 1950, more than 10 million pounds of these materials were used annually for weed and brush control in the United States. By 1960, in excess of 36 million pounds were used.

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. By early fall, 1961, 18 different aerial spray tests (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. 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. 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 55-gallon drums served as aid to the identification by support personnel.

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. 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. The composition of the three major herbicides used 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. One gallon of Orange theoretically contained 4.21 pounds of the active ingredient of 2,4-D and 4.41 pounds 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. One gallon of White contained 0.54 pounds of the active ingredient of 4-amino-3,5,6-trichloropicolinic acid (picloram) and 2.00 pounds of the active ingredient of 2,4-D. White was formulated to contain a 1:4 mixture of the triisopropanoamine salts of picloram and 2,4-D. The percentages of the formulation were:

triiisopropanolamine salt of picloram	10.2
triiisopropanolamine 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. One gallon of Blue contained 3.10 pounds 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 or "dioxin") than did the formulations used in the later years. The three time periods

shown in Table 1 can be differentiated on the basis of specific herbicides used and the mean dioxin content.

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

Period	Herbicides Used (Code Names)	Mean Dioxin Content (parts per million)*
January 1962- June 1965	Purple, Pink, Green Blue	~32** 0
July 1965- June 1970	Orange White, Blue	~ 2+ 0
July 1970- October 1971	White, Blue	0

*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. Orange accounted for approximately 10.7 million gallons of the total 17.7 million gallons 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. Small quantities of Purple, Pink, and Green, all containing 2,4,5-T were used from 1962 through mid-1965. 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 GALLONS 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	10,646,000	1965-1970*
White	2,4-D; Picloram	5,633,000	1965-1971**
Blue	Cacodylic Acid	1,150,000	1962-1971**
Purple	2,4-D; 2,4,5-T	145,000	1962-1965
Pink	2,4,5-T	123,000	1962-1965
Green	2,4,5-T	8,200	1962-1965
	Total	17,705,200	

*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.

Use Patterns of Individual Herbicides

Each of the three major herbicides (Orange, White, and Blue) had specific uses. Ninety-nine 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, but where it did occur it would persist longer than if the area were sprayed 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.

Ninety 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 (beans, peanuts, ramie, and root or tuber crops). The remaining 2 percent was used around base perimeters, cache sites, waterways, and communication lines.

Table 3 shows the number of acres sprayed with herbicides in South Vietnam within the three major vegetational categories.

TABLE 3. THE NUMBER OF ACRES TREATED IN SOUTH VIETNAM, 1962-1971, WITH MILITARY HERBICIDES WITHIN THE THREE MAJOR VEGETATIONAL CATEGORIES

Vegetational Category	Areas Treated*
Inland forest	2,670,000
Mangrove forests	318,000
Cultivated crops	260,000
Total	3,248,000

*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 4. These data were obtained from the HERBS tape (a computer listing of all herbicide missions in South Vietnam from 1965 through 1971). Total volume is in close agreement with the actual procurement data shown in Table 2.

TABLE 4. US HERBICIDES EXPENDITURES IN SOUTH VIETNAM, 1962-1971:
A BREAKDOWN BY COMBAT TACTICAL ZONE*

Combat Tactical Zones	Herbicide Expenditure (gallons)		
	Orange	White	Blue
CTZ I	2,250,000	363,000	298,000
CTZ II	2,519,000	729,000	473,000
CTZ III (includes Saigon)	5,309,000	3,719,000	294,000
CTZ IV	<u>1,227,000</u>	<u>435,000</u>	<u>62,000</u>
Subtotals	11,305,000	5,246,000	1,127,000
Grand total			<u>17,678,000</u>

*Source: HERBS tape

In addition to the herbicides, numerous other chemicals were shipped to South Vietnam in 55-gallon 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 400,000 gallons of it were 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 two-engine aircraft C-123/UC-123 called the "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 1,000-gallon 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 (1.5 inches in diameter, 22 feet long) extended from the outboard engine nacelles toward the wing tips. A short tail boom (3 inches in diameter, 20 feet long) 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), 33 UC-123K aircraft were employed. The "U" designated modification for aerial spraying and the "K" designated modification with jet boosters. 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 1967 through 1972, three UC-123K 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 system used was the AGRINAUTICS unit. This unit was installed in or removed from the aircraft in a matter of minutes because it was "tied down" to installed cargo shackles and aircraft modifications were not required for its use. The unit consisted of a 200-gallon tank and a collapsible 32-foot 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 5.

TABLE 5. US MILITARY AIRCRAFT USED IN THE DISSEMINATION OF HERBICIDES AND INSECTICIDES IN SOUTH VIETNAM

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

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 150 mph at 10,000 ft³/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.

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 US 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 1,200 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 by RANCH HAND aircraft, or who may have entered areas recently 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. 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 absorption 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 UC-123K, are important factors in assessing relative exposures to the Herbicides and TCDD.

Table 6 reviews the pertinent chemical and physical characteristics of Herbicide Orange. Table 7 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 6. PERTINENT CHEMICAL AND PHYSICAL CHARACTERISTICS OF HERBICIDE ORANGE

Formulation Concentrated	(8.6 lb ai/gal)*
Water Insoluble	Density = 1.28
Vapor Pressure	3.6×10^{-4} mm Hg at 30°C
NBE** 2,4-D : 1.2×10^{-4}	
NBE 2,4,5-T : 0.4×10^{-4}	
TCDD : 1×10^{-7}	
Viscous	40 centipoises at 20°C
Noncorrosive to metal	
Deleterious to paints, rubber, neoprene	
Long shelf life	

*Pounds active ingredient (2,4-D and 2,4,5-T) per gallon. ..

**NBE - Normal Butyl ester

TABLE 7. APPLICATION PARAMETERS AND SPRAY CHARACTERISTICS OF THE UC-123K/AA 45 Y-1 INTERNAL SPRAY SYSTEM

Aircraft speed	130 KIAS*
Aircraft altitude	150 feet
Tank volume	1,000 gallons
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 min	
13% drifted or volatilized	
Mean particle volume	0.61 microliters
Spray swath	260 \pm 20 feet
Mean deposition	3 gallons/acre
Total area/tank	340 acres

*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 the the vast majority of the phenoxy herbicides would have impacted forest canopy, the intended target.