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CRITERIA FOR ESTIMATING EXPOSURE LEVELS OF MILITARY PERSONNEL TO DIOXIN AND HERBICIDE ORANGE DURING THE VIETNAM WAR

Any attempt to determine exposure levels of military personnel to Herbicide Orange and its associated dioxin must be predicated on events that occurred at least ten years ago. Since there were no routine occupational or environmental sampling programs associated with the handling or dissemination of the herbicides in South Vietnam, a quantitative determination of exposure can only be subject to speculation. In addition, since specific no-effect criteria for comparison with actual or derived values do not exist, the calculation of theoretical exposure levels might provide data in the absence of a means to assess their significance. The approach taken in this document is to develop data points for determining "relative" exposures to Herbicide Orange and TCDD. The population at risk certainly did not include all military personnel who served in South Vietnam. Moreover, within the military population at risk, the range in magnitude of exposure must have been great. Therefore, it is important to evaluate those factors which would have influenced the potential for a given individual to be "at risk" and those which would have influenced the magnitude of that exposure. The following factors for determining relative exposures are proposed:

Time

When was the individual in South Vietnam?

Duty

What job(s) did the individual perform?

Exposure

What was the situation at the time of exposure?

What aircraft/vehicle was involved in the exposure?

How did the exposure occur?

Each of these questions will be discussed and available data will be provided in order to evaluate the magnitude of exposure.

I. WHEN WAS THE INDIVIDUAL IN VIETNAM?

This issue of time is very important. Not all of the herbicides used in South Vietnam were used throughout the entire ten years (1962-1972) encompassed by the Department of Defense (DOD) defoliation program. In addition, 2,4,5-T formulations used early in the program are believed to have contained higher levels of dioxin (TCDD) 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*

PERIOD	HERBICIDES USED (Code Names)	MEAN DIOXIN CONTENT** (parts per million)
January 1962 - June 1965	Purple, Pink, Green	~32 +
	Blue	0
July 1965 - June 1970	Orange	~ 2 ++
	White, Blue	0
July 1970 - ~~April 1972~~ October 1971	White, Blue	0

* Source: Young et al(3)

** Found only in 2,4,5-T containing formulations

+ Value based on the analyses of 5 samples

++ Value based on ~~[illegible]~~ 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 ~~April~~ June 1970. However, as noted above and 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 - ~~February~~ 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	

* Source: Young et al[3]

** Last fixed wing mission of Orange, 16 APR 70; last helicopter mission of Orange 6 JUN 70.

*** Last fixed wing mission 7 JAN 71; All herbicides under U.S. Control stopped 31 Oct 71.

II. WHAT JOB(S) DID THE INDIVIDUAL PERFORM DURING HIS TOUR(S) IN SOUTH VIETNAM?

There were relatively few military operations that involved the handling of herbicides by military personnel. It is, thus, appropriate to examine both the functions, or jobs, where individuals would have been at risk, and to estimate the size of the population at risk.

a. Populations at Risk

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.

b. Population Estimates

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 one hundred 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 ten percent of South Vietnam was sprayed with herbicides, and most of this area was contested and/or controlled by enemy forces. An estimated frequency of occurrence for selected exposure scenarios is given in Table 3.

TABLE 3. Estimated Frequency of Events Where Military Ground Personnel May Have Been Exposed to Herbicide Orange

EVENT	FREQUENCY
Direct application of Herbicide on ground troops	~~Unique~~ RARE
Ground troops moving into area treated within 24 hours	~~Rare~~ SELDOM
Ground troops entering a defoliated area (one month or more after herbicide application)	Frequent

Discussions with a RANCH HAND aircrew members confirmed that in at least one instance in 1967, direct application of herbicide onto a Marine patrol did occur. The basic concept for the major use of the defoliation program, i.e., the use of chemicals to remove foliage to enhance visibility, supports the contention that it was unlikely that troops would be in areas to be treated, or would move into the areas immediately after treatment since the desired effect would not be evident until three to six weeks after the herbicides were applied. However, the occurrence of the first two scenarios in Table 3 cannot be ruled out.

III. WHAT WAS THE SITUATION AT THE TIME THE INDIVIDUAL WAS EXPOSED?

There are a number of exposure scenarios in which an individual was more likely to have been significantly exposed to a specific herbicide or even another pesticide, including:

1. Guards at a base perimeter.
2. An individual at a Special Forces camp in the inland forest.
3. An individual on combat patrol in the Rung Sat Special Zone.
4. An individual repairing contaminated aircraft.
5. A supply clerk or depot aide handling drums of chemicals.

These different situations could have exposed individuals to varying amounts of different herbicides and insecticides since the use patterns of the chemicals herbicides differed markedly.

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 two percent was used around base perimeters, cache sites, waterways, and communication lines.

Table 4 shows the number of acres in South Vietnam within the three major vegetational categories.

TABLE 4. The Number of Acres Treated in South Vietnam, 1962-1972, With Military Herbicides Within the Three Major Vegetational Categories.

VEGETATIONAL CATEGORY	ACRES TREATED*
Inland forests	2,670,000
Mangrove forests	318,000
Cultivated crops	260,000
Total	3,248,000

* Areas receiving single or multiple coverage. Source: NAS Westing (1)

Certain portions of South Vietnam were more likely to have been subjected to defoliation. Herbicide expenditures for the four military regions of South Vietnam are shown in Table 5. These data were estimated by Westing and total volume is not in agreement with the actual procurement data displayed in Table 2, because volume was calculated on spray line data and estimated area treated).

TABLE 5. US Herbicides Expenditures in South Vietnam, 1962-1972: A Breakdown by Region*

REGION	HERBICIDE EXPENDITURE (gallons)		
	ORANGE	WHITE	BLUE
Military Region I			3,249,300
Military Region II			4,013,800
Military Region III			10,130,500
Military Region IV without Saigon			1,720,300
Subtotal	Total		19,113,900

* Source: Westing (2)

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 quantitites of Lindane and DDT were used 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.

IV. WHAT MILITARY AIRCRAFT/VEHICLE WAS INVOLVED IN THE EXPOSURE?

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/UC-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 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), approximately 30 C-123/UC-123 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 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 pesticide operations is shown in Table 6. Ground crews that maintained these aircraft were also at risk for exposure to the herbicides and insecticides.

TABLE 6. US Military Aircraft used in the Dissemination of Pesticides in South Vietnam*

AIRCRAFT	CAMOUFLAGED	Chemical DISSEMINATED
C-123/UC-123	Yes	All Herbicides
C-123	No	Malathion
Helicopter		
Air Force UH-F		
Army UH-1B/UH-1D	Yes	Orange, Blue
Navy UH-1E		

* Source: Young et al[3]

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 ft^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 on perimeter defenses. The herbicides of choice in these operations were Blue and Orange.

V. HOW DID THE EXPOSURE OCCUR?

As previously noted, the population at highest risk was the RANCH HAND group since these individuals were exposed to herbicides on a daily basis. Non-RANCH HAND support personnel who handled herbicides and performed secondary level maintenance were also at risk. Beyond these limited populations, the likelihood of other individuals being heavily exposed to herbicides was significantly less. 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.

As previously discussed, the use of Herbicide Orange in South Vietnam was for the purpose of denying the enemy the cover of dense jungle foliage. The areas normally sprayed were remote, unpopulated, forested areas where very few, if any, US military personnel would be located and the exposure to direct spray of Herbicide Orange would have been unlikely. In addition, 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 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 exposures 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 C-123 aircraft and the characteristics of the spray itself.

Generally, herbicide was sprayed in the early morning or late afternoon to minimize the effect of air inversions on particle dispersion.

TABLE 7. Pertinent Chemical and Physical Characteristics of Herbicide Orange

Formulation Concentrated	(8.6 lb ai/gal)[a]
Water Insoluble	Density = 1.28
Vapor Pressure	3.6×10^{-4} mm Hg at 30°C
NBE[b] 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	

[a] Pounds active ingredient (2,4-D and 2,4,5-T) per gallon

[b] 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	150 ft
Tank volume	1,000 gal
Spray time	3.5-4 min
Particle size:	
< 100μ 1.9%	
100-500μ 76.2%	
> 500 21.9%	
87% impacted within 1 min	
13% drifted or volatilized	
Mean particle volume	0.61μℓ
Spray swath	260 ±20 ft
Mean deposition	3 gal/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. Young et al[3] have conducted an indepth review of the environmental fate of Herbicide Orange and TCDD. The following is a summary from that report:

". . . Available data indicate that the vast majority of the phenoxy herbicides would impact forest canopy, the intended target. Rapid uptake (e.g., within a few hours) of the ester formulations of 2,4-D and 2,4,5-T would occur. Most of the herbicide probably would undergo rapid degradation (weeks) within the cellular matrix of the vegetation. However, some of herbicide may remain unmetabolized and would be deposited on the forest floor at the time of leaf fall. Soil microbial and/or chemical action would likely complete the degradation process.

"Herbicide droplets that impacted directly on soil or water would probably hydrolyze rapidly (within hours). Biological and nonbiological degradative processes would further occur to significantly reduce these residues. Some volatilization of the esters of 2,4-D and 2,4,5-T would occur during and immediately after application. The volatile material most likely would dissipate within the foliage of the target area. Photodecomposition of TCDD would minimize the amount of biologically active volatile residues moving downwind of the target area.

"Accumulation of phenoxy herbicides in animals may occur following ingestion of treated vegetation. The magnitude of this accumulation would likely be at nontoxic levels. Herbicide residues in animals would rapidly decline after withdrawal from treated feed.

"Most TCDD sprayed into the environment during defoliation operations would probably photodegrade within 24 hours of application. Moreover, recent studies suggest that even within the shaded forest canopy, volatilization and subsequent photodecomposition of TCDD would occur. Since translocation into vegetation would be minimal, most TCDD that escaped photodegradation would enter the soil-organic complex on the forest floor following leaf fall. Soil chemical and microbial processes would further reduce TCDD residues. Bioconcentration of the remaining minute levels of TCDD may occur 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 accumulate in these animals would have a biological effect.

"The environmental generation of TCDD from 2,4,5-T residues, through thermal or photolytic processes, would be highly unlikely and of no consequence. . . ."

VI. CONCLUSIONS

While a precise determination of herbicide exposure cannot be achieved,

might
the five factors discussed in this document ~~will~~ permit both a characterization and a relative estimate of the magnitude of the exposure. In the preparation of a total exposure for a given individual, answers to the five questions must be determined for each exposure incident, and a summary exposure estimate developed.

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