

## Discussion Articles

# Assessing Possible Exposures of Ground Troops to Agent Orange During the Vietnam War: The Use of Contemporary Military Records

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### Abstract

**Background.** Potential exposure of ground troops in Vietnam to Agent Orange and 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) remains controversial despite the passage of 30 years since the Vietnam War. Because of uncertainty over the serum dioxin levels in ground troops at the end of their service in Vietnam, attempts have been made to develop a methodology for characterizing exposure of ground troops in Vietnam to Agent Orange and other herbicides based upon historical reconstruction from military records. Historical information is often useful in evaluating and modeling exposure, but such information should be reasonably accurate, complete, and reliable.

**Methods.** This paper reviews the procedures and supporting historical information related to the spraying of herbicides in Vietnam. The historical information is classified into two categories: procedural information and operational information. Procedural information covered the process and procedures followed in spraying herbicides from US Air Force fixed wing aircraft (Operation RANCH HAND) in Vietnam, and included approval procedures for spray missions, the criteria required to conduct a mission, the control exercised by the Forward Air Controller and the Tactical Air Control Center and the characteristics of the equipment used to apply the herbicides. Operational information includes data from the RANCH HAND Daily Air Activities Reports, which included geographic locations of specific spray missions, the amount of herbicide sprayed by a specific mission, reports of battle damage to spray aircraft, reports of fighter aircraft support for aerial spray missions, and any comments, such as reasons for canceling a mission.

**Results.** Historical information demonstrates that herbicide spray missions were carefully planned and that spraying only occurred when friendly forces were not located in the target area. RANCH HAND spray missions were either not approved or cancelled if approved when there were friendly forces in the area designated for spraying. Stringent criteria had to be met before spray missions could be approved. The operational information shows that spray missions for both defoliation and crop destruction were conducted in an extremely hostile environment. Heavy 'fighter suppression' with antipersonnel ordnance was used to minimize the impact of hostile ground fire on RANCH HAND aircraft. Procedures were in place that prohibited movement of troops into sprayed areas immediately after a mission due to the possible presence of unexploded ordnance delivered by fighter aircraft supporting RANCH HAND missions. The optimal nature of the spray equipment and application procedures minimized the possibility of significant spray drift.

**Conclusions.** Few friendly troops were sprayed by fixed wing aircraft during Operation RANCH HAND, which delivered 95% of all defoliants used in Vietnam. Similarly, few troops were sprayed during helicopter or surface-based spray operations, which constituted the remaining 5% of defoliants. Detailed policies and procedures for approval and execution of spray missions ensured that friendly forces were not located in the areas targeted for spraying. Fighter aircraft assigned to accompany each spray mission frequently suppressed much of the hostile fire with bombs and other ordnance. Confirmed clearance of the target area was necessary to avoid friendly casualties. Historical records establish that these policies and procedures were strictly followed. Exposure of troops whether from direct spraying or movement through areas recently sprayed was very unlikely.

The wartime military records of troop positions and herbicide operations are valuable for some purposes, but have specific limitations in exposure reconstruction. The completeness and accuracy of the geographic data (maps used by RANCH HAND and military ground units) were dependent upon the inherent precision of the map, the accuracy with which it depicted surface features, and the completeness and accuracy of the information on which it is based. Navigation by the crew using visual orientation and reference to the map was the only means that aircrew on spray missions had for establishing their locations. A Forward Air Controller independent of Operation RANCH HAND was present at the location of each spray target immediately before and during spraying operations to verify the target location and ensure that friendly forces were clear of the target area. Anecdotal reports of direct spraying of troops in Vietnam likely reflect the RANCH HAND missions spraying insecticide for mosquito control at regular intervals from March 1967 through February 1972.

**Outlook.** The distribution and levels of serum dioxin in RANCH HAND veterans and the US Army Chemical Corps Vietnam veterans (the unit responsible for helicopter and ground-based spray operations) are distinguishable from typical levels in the population decades after the Vietnam conflict. An exposure model similar to that proposed in the 2003 report of the Institute of Medicine's Committee on 'Characterizing Exposure of Veterans to Agent Orange and Other Herbicides Used in Vietnam' was tested in 1988 by the Centers for Disease Control and Prevention and found to be a poor predictor of absorbed dose of TCDD. Military records during the Vietnam War lack the precision to determine that troops were directly sprayed with herbicides during Operation RANCH HAND, especially given the procedures in place to ensure clearance of friendly forces from the target area and the lack of elevated serum levels of TCDD in ground troops judged to have operated in heavily sprayed areas.

**Keywords:** 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD); Agent Orange; historical military records; Operation RANCH HAND; Vietnam

## Introduction

Potential exposure of ground troops in Vietnam to dioxin (2,3,7,8-tetrachlorodibenzo-*p*-dioxin [TCDD]) remains controversial despite the passage of 30 years since the Vietnam War. The distribution and levels of serum dioxin in RANCH HAND veterans (the US Air Force unit responsible for spraying herbicides from fixed-wing aircraft) and the US Army Chemical Corps veterans (the US Army unit responsible for helicopter and ground-based spraying) are distinguishable from typical levels in the population decades later [1,2]. However, studies of ground troops did not find elevated levels of TCDD [3]. The lack of elevated levels of serum TCDD in ground troops suggests that any exposure to Agent Orange was not significant. Uncertainty in the dioxin levels in ground troops at the end of their service in Vietnam led to attempts to develop a methodology for characterizing exposure of ground troops in Vietnam to Agent Orange and other herbicides based upon historical reconstruction of relevant military records [4,5].

Seldom in the scientific literature is there a discussion about the types of historical records that provide a basis for estimating exposure in epidemiological studies. Epidemiologists, especially those involved in occupational and environmental studies, often rely heavily upon historical records to construct exposure assessments. However, the factors bearing on the degree of reliability of historical records are not always documented by investigators in published articles or appreciated by scientists seeking to interpret the results of the studies. One of our intentions in this paper is to assist the scientific community in its use and interpretation of historical data on the Vietnam Conflict. And, more generally, we hope to encourage greater attention to and rigorous analysis of the use of historical data in the investigation of health effects of other potential exposures.

One key element suggesting the absence of significant exposure to ground troops is the adherence to procedures governing the RANCH HAND Operation that ensured that no friendly forces were in the areas targeted for spraying. A full discussion of these procedures and supporting historical data has been absent in the debate on whether ground troops were significantly exposed. Indeed, recent publications have proposed an 'exposure opportunity index' for Agent Orange without verification of the proposed index against serum TCDD levels in ground troops or adequate consideration and presentation of the historical data bearing on the likelihood of significant exposure [4,6]. The purpose of this paper is to review the procedures and supporting historical data related to spraying of herbicides in Vietnam most relevant for the design of future epidemiological studies and the interpretation of the existing body of epidemiological studies of Vietnam veterans. Our analysis of these procedures and data indicates that direct spraying of friendly troops in Vietnam was unlikely.

The historical information related to herbicide usage in Vietnam can be classified into two categories: procedural and operational information. 'Procedural information' covers the process and procedures followed in spraying herbicides from fixed wing aircraft in Vietnam, and includes approval pro-

cedures for spray missions, the criteria required to conduct a mission, the control exercised by the Forward Air Controller (FAC), and the characteristics of the equipment used to apply the herbicides. 'Operational information' includes the geographic locations of specific spray missions, the amount of herbicide sprayed by a specific mission, reports of battle damage to spray aircraft, reports of fighter support for aerial spray missions, and any comments, such as reasons for canceling a mission.

## 1 Procedural Information

### 1.1 The historical records on Operation RANCH HAND

A large body of historical data exists on the use of Agent Orange in Vietnam. The history of Operation RANCH HAND in Vietnam has been thoroughly documented. The National Archives have unit histories of ground troops stationed in Vietnam from 1964 through 1971. In addition, books have documented the histories of the Vietnam conflict [7,8]. Other primary records include Contemporary Historical Evaluation of Combat Operations (CHECO) reports [9,10] and the Special Reviews of Herbicide Operations [11] and the Military Assistance Command, Vietnam [12]. Many of these primary historical records are now available online through the Special Collection Initiative of the National Agricultural Library, US Department of Agriculture, Beltsville, Maryland <<http://www.nal.usda.gov/speccoll/findaids/agentorange/index.htm>>. The specific web sites for many of these documents are noted with the reference.

### 1.2 Directive 525-1

Overall policy and procedures for herbicide operations in Vietnam were set forth in detailed directives issued by the Military Assistance Command, Vietnam (MACV). These directives were, in turn, based upon specific guidelines provided by the US Departments of State and Defense. The most important of these directives was MACV Directive 525-1 [13,14], which governed all herbicide use by both US and Free World Military Assistance Forces (FWMAF) troops between 1965 and 1970. It was revised periodically by MACV, in consultation with the Departments of State and Defense. The Directive "prescribed policies, responsibilities, and procedures governing the operational employment of herbicides within [South Vietnam]," including all fixed wing, helicopter, and surface-based methods of herbicide application [13,14].

The use of herbicides for defoliation and crop destruction was primarily a Government of Vietnam (GVN) operation that was supported by the US Government. Initial requests for herbicide projects often originated from the GVN, such as those from Vietnamese province officials, and all such requests, regardless of their derivation, had to be approved by a Vietnamese Province Chief in accordance with Directive 525-1. After receipt, requests were referred to the Chief of the Joint General Staff (Chief, JGS), a Republic of Vietnam Armed Forces General Officer who headed a joint Army of the Republic of Vietnam (ARVN)/Republic of Vietnam Air Force (RVNAF) staff in Saigon. Various tactical benefits

and considerations supporting the project were required, and if recommended, the relevant senior US Chemical Corps advisor, who had to endorse the plan's soundness and tactical efficacy, issued the documentation on the project. The JGS request and Chemical Corps recommendation were then forwarded to the US Chemical Operations Division for analysis, staff coordination and evaluation, in light of numerous policy, logistical, technical, and operational considerations and limitations. Disapproved requests were returned to the Chemical Operations Division, which could attempt to obtain clarification or modification from the JGS.

Approved requests were presented, in detail, to the 'MACV 203 Committee.' If approved by the MACV 203 Committee, the plan would then be provided to the US Ambassador and Commander, MACV, for review and consideration. If approved by both, the Chief of Staff, MACV, would forward a letter to the Chief, JGS confirming the decision to proceed with the herbicide project. Thereafter, a coordination meeting was held in the province in which the project was to be conducted, during which the final mission plan was agreed upon. Following the coordination meeting, the Chief of Staff of MACV published an 'operations order' and MACV issued an 'execution' order. The JGS would then requisition the herbicide from appropriate GVN agencies, with ultimate 'releasing authority' residing in the JGS.

Directive 525-1 established detailed 'policies' that formed the foundation of the Directive's procedures governing herbicide use. The policies mandated that (1) defoliation and crop destruction missions were limited to areas of low population; (2) use of US assets for defoliation by fixed-wing aircraft and all crop destruction operations required pre-approval from both Commander, MACV and the US Ambassador (in addition to the approvals required from the GVN); (3) use of US assets to accomplish GVN requests for defoliation by helicopter in support of (i) local base defense, (ii) clearance of small ambush sites and (iii) maintenance of deforested areas, required pre-approval from both the US and GVN; (4) use of US assets to accomplish surface-based spray operations required pre-approval from both the US and GVN; (5) 'care' was to be taken in "planning and executing operations to prevent herbicide damage to rubber trees;" and (6) a "no-spray zone of two kilometers for helicopters and five kilometers for fixed-wing delivery [was to] be maintained around active rubber plantations" [13,14].

All such requests, regardless of type, were required to be detailed and comprehensive. Requests for ground-based defoliation projects, generally transmitted by the Army of the Republic of Vietnam (ARVN) Corps to US Chemical Corps senior advisors, were evaluated based on similar factors to those for fixed-wing projects, and included consideration of whether the default circumstances for clearing were impractical. The default circumstances included hand-cutting, burning or mechanical methods of clearing vegetation [7,8,13].

In light of the elaborate approval matrix dictated by Directive 525-1 and the number of agencies involved, herbicide requests normally took several months to be processed. Critical reviews of the program by outside agencies often cited the "inordinate delays" that impeded timely completion of

the projects [8,9]. Even approved targets occasionally could not be sprayed when scheduled, usually because friendly forces were in the area or a military operation was imminent. In contrast, the 'denial' part of the approval process was executed in a timely fashion. Later, MACV began refusing mission clearances outright "because of high threat," as when intelligence indicated that strong enemy resistance to RANCH HAND airplanes and accompanying fighter aircraft could be expected [7].

### 1.3 Post approval procedures in Operation RANCH HAND

RANCH HAND operations and targeting personnel met weekly with the chemical operations section of MACV to discuss approved requests and schedule post approval survey flights. The survey sorties were necessary to identify actual target locations for the individual missions and to plan optimal attack routes. Survey sorties were flown by single, unescorted UC-123s (the unarmed transport aircraft used for the spray program) manned by the RANCH HAND chief or assistant chief of targeting, a copilot, a navigator from the targeting group, and an Army Chemical Corps officer [8].

After the RANCH HAND reconnaissance flight over the designated area, a coordination meeting was held in the field with the Province Chief, local military commanders, and representatives from MACV, ARVN, the Seventh Air Force and RANCH HAND. Details of target requests, intelligence data, and particulars about the target were worked out. An overlay map of the designated target area was prepared. Following the meeting, formal target requests were prepared and forwarded to Saigon for clearance by ARVN and US authorities [7,8]. After consultation with South Vietnamese military and government officials, final approval authority was assigned to the Commander, MACV, for defoliation targets and to the American Ambassador for crop targets [8].

### 1.4 Coordinating RANCH HAND spray missions

Once final approval was given for a specific target area (referred to as a target box), the RANCH HAND commander and his targeting officer, together with MACV personnel, determined the most effective mission dates and requested orders to implement the mission. The targeting officer planned individual missions, prepared charts of the target area, and drafted the requests for orders for submission to the US Air Force Tactical Air Control Center (TACC). The day before the mission, TACC coordinated the FAC, fighter and rescue support through the Direct Air Support Center (DASC), and issued an approved mission order [7,8,15,16].

Approved herbicide missions that had passed successfully through the gauntlet of requirements established by directives such as 525-1, still had to pass through additional procedural checkpoints. One of the most important of these checkpoints was the TACC. Before a mission could be executed, TACC, in coordination with the DASC, required clearance from all friendly units in the vicinity of the target area.

This clearance was necessary to ensure that the fighter aircraft supporting the herbicide missions were free to deliver the suppressive ordnance essential to the safe and successful

execution of the RANCH HAND missions. The target area was declared a 'free fire zone,' indicating that the supporting fighter aircraft could freely expend ordnance on any target in the area after clearance from the FAC without fear of injury to friendly forces [7,8,10]. Unfortunately the elaborate spray approval and coordination procedures made it difficult to maintain operational secrecy, and unarmed RANCH HAND aircraft spraying herbicides at low altitudes frequently became targets of hostile fire [8].

### 1.5 Developing the concept of fighter suppression

The procedures followed in the program changed over time. Initially, fighter aircraft were used only if rescue operations became necessary or if opposing forces had fired on the spray aircraft and post-strike actions were undertaken. By late 1963, escort fighter cover was routinely scheduled. RANCH HAND aircraft marked the locations where ground fire occurred by dropping smoke grenades, giving the FAC a visual indicator. The escort restriction was changed after 30 April 1964 when fire from .50-caliber antiaircraft and airburst mortar was encountered in the Mekong Delta south of Ca Mau [9]. The copilot of the lead aircraft was wounded and over 40 holes were found in the aircraft. The revised policy permitted the FAC to use fighter aircraft to prestrike suspected ambush sites. This new tactic was intended to force the enemy to seek cover, reducing the threat to the RANCH HAND aircraft [11,12].

Hostile ground fire was such a hazard to the UC-123 planes that in January 1965, approval was given to prestrike targets with fighter aircraft in advance of impending herbicide missions [17]. From that point forward, close-in fighter support was a vital part of the defoliation program and reduced to some extent the deadly hazards posed to RANCH HAND personnel and aircraft by ground fire from opposing forces.

If a spray target were considered 'cool,' the fighters would fly above the RANCH HAND aircraft and conserve their fuel and ammunition for a more lucrative target [8]. On other targets, a low level 'dry run' by the fighters, in which they delivered no ordinance but simply appraised the opposing forces of their presence, would be sufficient to quell enemy fire temporarily [8]. If a herbicide mission was scheduled against a full-blown 'hot target' in a 'free bomb' or 'free fire' zone, mission planners might request a prestrike of the area. The fighter aircraft supporting RANCH HAND missions would drop Cluster Bomb Units (CBUs), napalm, fire 20-mm guns, or all three [15,16].

Use of fighter aircraft advanced as a tactic during July 1968 into 'heavy suppression' to counter increased ground fire from opposing forces [7]. Frequently, between four and twelve fighter aircraft accompanied the spray planes when RANCH HAND aircraft flew over such targets. When possible, pilots of RANCH HAND and fighter aircraft would meet before the mission to decide on tactics; these would be provided to the FAC who had responsibility for coordinating operations in the target area [15,16]. When heavy suppression was involved, fighters would strike strong points in the target area with 500- or 750-pound bombs two or three minutes before the UC-123s began their spray run. At the start of the spray run, fighters would fly slightly ahead



**Fig. 1:** Three RANCH HAND aircraft spraying at 150 feet above the ground are masked from enemy fire by CBU smoke to the right of the run. Meanwhile a fighter aircraft, barely visible above the hills, has just laid CBU to the left of the planned spray path. This photograph was taken in Northern II Corps in 1967. The photo courtesy of the Plant Science Laboratories, Fort Detrick, MD

of and parallel to the spray planes and drop antipersonnel CBU to force enemy gunners to stay under cover until the spray formation had passed, as shown in Fig. 1 [7]. CBU-12s containing white phosphorus were highly effective in suppressing ground fire due to their lethal anti-personnel effect, and they provided a dense cloud of white smoke to hide the approaching RANCH HAND aircraft.

### 1.6 The critical role of the Forward Air Controller

The role of the FAC was critical to every RANCH HAND mission that occurred after 1964. The Air Force basic work unit was a Tactical Air Control Party (TACP), an autonomous Air Force unit co-located with the US Army. At a minimum, it consisted of an officer, the Air Liaison Officer or the FAC, who was assigned to an Army unit, and the ROMAD (Radio Operator Maintenance Driver), an enlisted member of the TACP who was a mobile (jeep) radio operator [16]. The FAC had major responsibilities for executing the RANCH HAND mission. The FAC flew a small observation aircraft and was the individual most familiar with the Area of Operations (AO). The mission order alerted the RANCH HAND aircraft, the accompanying fighter escort, and the ROMAD who was directed to keep in constant contact with any ground forces (including Special Operation units) that potentially could be near the target box along with other mission information [16].

Usually one or two hours before the RANCH HAND mission, the FAC arrived at the target coordinates to observe the weather and to check if there were observable hostile forces in the area. The FAC, in coordination with the ROMAD and the Direct Air Support Center, ensured that there were no friendly units in the target area [16]. If there were imminent operations or friendly forces in the area, the FAC would cancel the mission or divert the spray mission to an alternate target. This action prevented accidental attack on friendly personnel by the escorting fighters and kept field forces from entering the area too soon after the use of CBU or other heavy suppression munitions [8,16].

About two percent of CBU ordnance used in advance of RANCH HAND missions were duds. The approval procedures for a mission 'cautioned' field commanders not to send friendly troops immediately into areas sprayed because of this unexploded ordnance [8,15,16]. Moreover, about 2-3 weeks were required before defoliation began to improve combat visibility in heavily vegetated areas. Consequently, movement of ground troops immediately into an area sprayed by RANCH HAND aircraft would mean such operations would not have any of the benefit of the defoliation. Thus, movement through sprayed areas soon after spraying would have been unproductive.

As described above, elaborate procedures were developed and implemented, and exhaustive efforts undertaken, to ensure that areas approved for defoliation missions were clear of friendly forces well in advance of the mission start time. The mission order provided the target coordinates, specific radio contact data for the FAC, RANCH HAND formation, and accompanying fighter escort, and served as a warning order to field units that might be near the target. These troop-clearing procedures were strictly observed by the various MACV, TACC, and TACP personnel associated with fighter support missions, as evidenced by the lack of reports of friendly fire casualties associated with suppression of hostile fire against RANCH HAND missions [18,19].

### 1.7 Conducting the spray mission

The FAC coordinated both the approaching RANCH HAND aircraft and the accompanying fighter support. If weather conditions in the target were not acceptable (e.g., wind greater than 10 knots, rain, poor visibility), the FAC would cancel the mission or send the aircraft to the alternate target. If the mission was to be executed, the FAC marked the initial point of the target by using a rocket that produced a plume of white smoke [16]. The RANCH HAND aircraft would descend to the appropriate altitude and air speed, and the lead pilot would call 'spray on' at the start of the spray run. All aircraft in the flight would simultaneously turn on their spray systems and would continue spraying until the lead pilot ordered, 'spray off.' If the target area was known to be 'hot' (hostile ground forces present), or if the RANCH HAND aircraft received ground fire, the FAC would direct the fighter aircraft to deliver their ordnance [15] at the appropriate location. If RANCH HAND or escort aircraft were crippled or crashed, the FAC would request air rescue (helicopter) assistance [16].

## 2 Vietnam War Records: Operational Information

### 2.1 Collection and maintenance of records: An overview

The availability of military records from the Vietnam War was dependent upon the quality and quantities of records maintained by the military administrative units responsible for record keeping. Christian and White described the history of records management in Southeast Asia [20]. Army record managers did not have an effective records management program established and operative until 1969. After the war ended, more than 10,000 linear meters of Vietnam War Records were returned to various archive centers in the

US. The records from Vietnam arrived in an assortment of conditions and in many different types of containers because "the troops were fighting a war and were not worrying about such niceties, a price that was paid later in trying to find the records at the centers" [20].

The challenge of using military records to determine troop locations and other data was four-fold [23]. First, many of the records from early in the war may not have been retained because it was only late in the war that all records were prevented from destruction. Second, soldiers on one-year tours barely had time to organize their files before they were transferred and someone else took over. Third, many military records were maintained by Vietnamese civilians and military, for example, the receipt and distribution of herbicides to military units. Last, many of the records created during the period 1961 to 1964 may be of little use because of the nature of the US advisory role and the locations of advisors for those years. Nevertheless, tracking military units through the use of records such as Battalion Daily Journals, Situation Reports, Command Chronologies, Unit Histories, and Morning Reports seemed feasible. In May 1980, the Army's Office of the Adjutant General established a Joint Service Environmental Support Group (later the US Armed Services Center for Research of Unit Records) to reconstruct the movements of combat battalions in Vietnam [20]. They concluded that the military records were created for combat purposes and now "we have to make them work for us in an entirely new and complex manner, [i.e., for epidemiological studies,] never before attempted in the history of records management" [20].

### 2.2 Battle damage to RANCH HAND aircraft and crews

On days with clear weather and relatively unobstructed visibility, the RANCH HAND Aircraft would generally cruise to the target at about 3,000 feet above the ground and then descend rapidly at about 2,500 feet per minute to the 'spray-on point,' in order to reduce their exposure to hostile ordnance [7]. However, if clouds were low and ground-to-air visibility was poor, the aircraft generally would fly a low-level approach to the spray-on point, after which they would begin to disseminate the herbicide [7]. In either case, the aircraft regularly received heavy, sustained automatic weapons fire from opposing forces, who were often alerted to the impending herbicide mission by the sound of the preceding fighter aircraft. The low altitude and slow rate of speed of the UC-123 aircraft, coupled with the open cockpit windows and troop doors, meant that the RANCH HAND crews could clearly hear – and at times see – the weapons being fired at them. The odor of enemy gunpowder often filled the planes [8]. Sufficiently intense ground fire could cause the UC-123s to abandon a target after only one spray pass [7].

Resistance by opposing forces to RANCH HAND operations was so frequent and intense, that during its nine years of operation, RANCH HAND aircraft received more than 5,000 hits, lost nine spray aircraft to hostile fire and had 28 RANCH HAND personnel die in combat [7,8]. While enemy resistance to missions grew in strength over time, even the early RANCH HAND crews were subjected to heavy

hostile fire during herbicide operations. For example, almost half of the aircrew members assigned to Operation RANCH HAND in December 1965 had been wounded at least once, and the aircraft employed during that period sustained a total of nearly 800 hits. One of the older planes, nicknamed 'The Leper Colony,' had been hit 230 times, and its occupants had earned eight 'Purple Heart' medals [8]. RANCH HAND crews had the reputation of being the "most shot-at airmen operating in South Vietnam" [21]. Each year, as the number of RANCH HAND aircraft and sorties increased, so did the number of 'hits' received by the UC-123s from ground fire.

The Viet Cong actually offered a special bonus or bounty to anyone who shot down a RANCH HAND aircraft, and a reward was offered for the capture or death of individual crewmembers [8]. Because of the great hazards posed by enemy fire, modifications were made to the RANCH HAND aircraft, including the installation of specially engineered armor plating in the crew areas and around the fuel tank for the spray pump engine [8]. RANCH HAND crews, in turn, were provided with additional protective equipment, including heavy ceramic flak jackets and specially modified flying helmets equipped with a clear visor that could be lowered to protect the eyes [8]. Used in place of the standard radio headset, the helmet, together with the flak jacket, offered pilots and navigators extra protection from flying shrapnel and glass generated during ground-to-air fire. Twice in December 1965 alone, this additional protection permitted crews to complete runs despite cockpit damage and crew injuries sustained during heavy fire directed at the aircraft. New operational flight tactics also were developed to minimize the RANCH HAND aircraft's 'time on the target' and, therefore, reduce their vulnerability to hostile groundfire [9,10].

### 2.3 RANCH HAND daily air activity reports

Daily Air Activity Reports (DAARs) contained information about the RANCH HAND spraying missions (Fig. 2). Specific daily missions were known as 'lifts' and were designated by alphabetical letters that were also used as part of the formation call sign; that is, the first mission from Bien Hoa Air Base each day was the 'Alpha' lift with the radio call sign 'Cowboy Alpha.' The second mission was the 'Bravo' lift, etc. The earliest morning missions were planned to strike their targets at sunrise, and takeoff times were adjusted according to the distance of the target from the launch base. After returning from the first target, the Alpha crews would re-brief while the aircraft were being serviced and re-launch at 0900 to 0930 hours to another target. This second mission would become 'Charlie' lift. The Bravo crews were also turned around for a second mission and would become the 'Delta' lift. Most missions normally were flown from the RANCH HAND home base at Bien Hoa, with additional sorties from small detachments located at Da Nang and, later, Phu Cat and Nha Trang. During the 'good weather' season in I Corps, the Da Nang detachment might be augmented with additional aircraft to allow four or five missions instead of two. If sufficient aircraft and crews were available, and target approval had been obtained, additional missions were scheduled as 'Echo,' 'Hotel,' 'India,' 'Juliet,' and 'Kilo' lifts. Generally three or four aircraft constituted a

12th ACS DAAR					
A. Date	6 JULY 68	A. Date	6 JULY 68	A. Date	6 JULY 68
B. Lift	HOTEL	B. Lift	INDIA	B. Lift	JULIET
C. Man #/Base of Origin	7-526 DAD	C. Man #/Base of Origin	7-529 DAD	C. Man #/Base of Origin	7-530 DAD
D. Sched/Air/Prod		D. Sched/Air/Prod		D. Sched/Air/Irod	SEE REMARKS
E. Project & #	3/3/3	E. Project & #	3/3/3	E. Project & #	2/3/3
F. UTM Coordinates	enemy Loc	G. UTM Coordinates	Crop	H. UTM Coordinates	base camp
20070200 162200 15700307 06012510 15705540			06022410 094420		
G. Time on Target	0715/0750	G. Time on Target	0640/0700	G. Time on Target	1052/1120
H. Agent: Cals & type	Orange 2900	H. Agent: Cals & type	Orange 2850	H. Agent: Cals & type	Orange 3000
I. Total Flying Time	5400	I. Total Flying Time	3400	I. Total Flying Time	8445
J. Hits	A/0-693 A/0-633 A/0-598	J. Hits	A/0-693 A/0-633 A/0-598	J. Hits	A/0-693 A/0-633 A/0-598
K. UTM of Ground Fire	X/A	K. UTM of Ground Fire	All along the run	K. UTM of Ground Fire	X/A
L. Aborts (No., Cause)	Air X/A Gnd ■ Nx ■ Mx ■ Dx ■ Support ■ Other ■	M. Aborts (No., Cause)	Air X/A Gnd ■ Nx ■ Mx ■ Dx ■ Support ■ Other ■	N. Aborts (No., Cause)	Air X/A Gnd ■ Nx ■ Mx ■ Dx ■ Support ■ Other ■
M. Tgt information			N. Tgt Information		
Temp	326	Temp	227	Temp	277
Wind	210/08 = 10kt	Wind	220/06	Wind	260/10 = 15
Cond	DRY	Cond	DRY	Cond	DRY
I/S	140k	I/S	130k	I/S	140k
O. Remarks:			P. Remarks:		
Spray lift delayed due to FAC working INDIA site, expanded.			Flies did expand.		
GROUP 4 DOWNGRADED AT 3 YEAR INTERVAL					

CONFIDENTIAL  
DECLASSIFIED AFTER 12 YEARS

**Fig. 2:** A Daily Air Activity Report (DAAR) describing three spray missions that occurred on 6 July 1968 in Vietnam

'lift,' although by 1967 the first mission out of Bien Hoa frequently consisted of up to eight UC-123s [8].

Fig. 2 is a photograph of the 12<sup>th</sup> Air Commando Squadron (RANCH HAND) daily record of three missions that were flown from Da Nang Airbase, Vietnam, on 6 July 1968. This record is typical of the daily reports at this time and location. The six aircraft of 'Hotel' and 'India' (missions 7-526 and 7-529) were 'on target' at 0715 and 0640 hours, respectively. The 'Hotel' lift struck as a primary target an enemy line of communications (LOC), while 'India's' primary target was against crops. Both were in the same target box (#1-2-6-66). 'India' took ground fire all along the run damaging all three aircraft. The lead aircraft received 4 hits, the second received 1, and the last aircraft received 8 hits. The attack by 'Hotel' was delayed due to the FAC working the run for 'India.' Fighters expended munitions during both 'Hotel' and 'India' missions. The 'Juliet' lift used the same spray aircraft as 'Hotel,' after they were reloaded with herbicide, with the scheduler anticipating having only two in-commission aircraft available. This explains the 2/3/3 entry for item 'D' which indicates two aircraft scheduled, three launched, and three productive. However, 'Juliet' lift, which was flown against an alternate target of a base camp for opposing forces, encountered extreme turbulence on the ridgelines and called 'spray off' after 50 seconds. Remarks indicate no hits were taken, fighters arrived 30 minutes late,

and no munitions were expended. Since the 'Juliet' lift sprayed for only 50 seconds, the amount of Agent Orange recorded on the form (3,000 gallons) had to be in error, particularly since it was impossible to completely empty the spray tank except by using the emergency dump valve.

The UTM coordinates provided a 'start' and a 'stop' point, but the alphanumeric indicators in the UTM coordinates for the 'Hotel' mission indicated that it did not follow a straight line since there was a third set of coordinates. The 'Hotel' mission was in the mountainous terrain of I Corps, and the flight likely followed the contours of the terrain. The 'India' target was crop destruction, and this possibly required the crews to repeatedly turn on and off the spray system and to make frequent turns, but this is not noted in the UTM coordinates or in the remarks. As a result, the flight paths based literally on the recorded UTM coordinates might at some points have differed by a kilometer or more from the coordinates of the actual flight paths.

Inspection of other DAARs suggests that the DAAR in Fig. 2 is not atypical. The discussion of the DAAR in Fig. 2 indicates both the importance of DAARs as a source of detailed information on RANCH HAND spray operations and also their limitations – limitations that are particularly acute for comparisons of coordinates of spray missions with coordinates from records of military operations. The DAARs provide ample evidence that the detailed procedures and policies for the RANCH HAND missions were strictly observed. The remarks section of many DAARs cite reasons for aborted or cancelled missions, such as due to "friendly forces in the area," "cancelled by ARVN," "sent to alternate by DASC," "cancelled by FAC," etc. All of these elaborate troop-clearing efforts resulted in no documented herbicide-related friendly casualties during the long course of Operation RANCH HAND. However, the DAARs data do permit reliable conclusions that troops on the ground were not directly sprayed during a spray mission.

### 3 The Herbicide Reporting System (HERBS)

In 1970, the US Army's Data Management Agency [22] was tasked to support the Chemical Operations Division (Army Chemical Corps) in developing an Automatic Data Processing system for processing and storing monthly herbicide mission activity data. The result of this effort was the Herbicide Reporting System (HERBS), which was implemented in May 1970. The objectives of the HERBS system were to process the monthly worksheets, prepared by the Chemical Operations Division from information received from the primary data sources (e.g., the Daily Air Activities Report, DAAR); maintain a HERBS mission activity history file, updated monthly; and to produce the monthly update listings and any reports from user requested file inquiries [22]. The HERBS system was used to respond to requests from organizations involved in ecological research, claims investigations, and general inquiries from the Department of Defense and the scientific community [22].

The content of the HERBS system consisted of data from the RANCH HAND spray missions. These data included: the province(s) in which the mission was flown, the mission project

number, the UTM coordinate points covered by the mission with identifying additions to distinguish each UTM point as a start, turn, or stop coordinate, the type of herbicide used, the number of gallons sprayed, the type of mission, the number of hits received during a run, and, the number of aborts attributable to maintenance, weather, battle damage, and other factors [22]. The data were recorded by the field units and forwarded to the Chemical Operations Division.

#### 3.1 The evolution of the HERBS tape

The evolution of the HERBS Tape has been an on-going process for more than 30 years. Many organizations have examined the original record of missions developed by the Data Management Agency in 1970 [22]. At that time paper records were converted to 'punch cards' and the first tape was compiled for the US Army Chemical Corps. As noted, the basis for records on RANCH HAND in the HERBS file was the Daily Air Activity Reports (DAARs). In April 1971, the MITRE Corporation, at the request of the Defense Communications Agency, conducted the first quality analysis of the HERBS data file [23] and concluded that 2% had missing data, 6% had serious transcription errors or serious measurement errors, 23% of the records had track length (distance sprayed by RANCH HAND aircraft) that was in error by 50%. Statistically, the overall quality of the data was good and by using error curves, track length data could be adjusted to improve the data quality of a record, if it was considered necessary by the analysis [26]. The presumption was that the UTM coordinates provided in the data set were accurate, although as noted above, the precision of coordinates was limited.

The 1974 report by a committee of scientists of the National Academy of Sciences (NAS) on 'The Effects of Herbicides in South Vietnam' [24] noted that the version of the HERBS tape used in their report covered the period August 1965 through February 1971 and listed a total of 6,542 missions. From this total, 880 missions were considered to contain one or more errors; of these 575 were corrected, while the errors in 305 could not be corrected and were omitted from the tape [24]. The NAS committee attempted to document the impact of spraying on forests ecosystems from aerial photographs taken by the military, but this was done on only a small sample of missions [24]. As with the MITRE report, the NAS committee assumed that the spray coordinates were correct but did not verify this by either aerial photographs or ground observations.

In 1986, the Joint Services Environmental Support Group (the joint Army, Air Force and Navy military record specialists, now the US Armed Services Center for Research of Unit Records, CRUR) completed an extensive search of the military records of the Vietnam era [25]. A database of 2,394 additional military herbicide missions in Vietnam, including an additional 557 RANCH HAND missions, was identified. The Services HERBS tape contained data on helicopter, backpack, and other types of ground spraying. When the two tapes (HERBS and Service HERBS) were combined 8,930 missions were identified and 72,740,400 liters of herbicide were reported sprayed [25]. In the course of combining the two tapes, data on battle damage (hits from ground fire) and comments on the use of fighter suppression were

deleted. In 2003, the S-NAS-HERBS was completed, a version of the HERBS tape that combined both NAS and the CRUR databases, plus data from additional review of the records, and imputing data for some missing coordinates [4]. Lathrop [26] concluded that the "map coordinates of the HERBS tapes are largely accurate, but many are inaccurate and based on the guesstimates of RANCH HAND pilots and navigators who were under extreme combat or terrain-flying stress. Straight-line approximations of multi-leg zig-zag patterns can only be viewed as gross approximations of many of the missions in Vietnam. This error source can only be adequately factored into the probabilistic approach (for epidemiological studies) by the use of crude assumptions."

### 3.2 Accuracy of geographic data

Of particular importance is the accuracy of the geographic data (the maps used by the aircrews and ground troops). Electronic navigation aids gave aircrews the relative bearing of their aircraft from a transmitter (always in friendly territory) and in some cases approximate distance, but were incapable of fixing the location of the aircraft with precision. To fix location within one nautical mile (1,850 meters) for a plane 32 kilometers from a TACAN transmitter would have been exceptional. The signals were not ordinarily received at the low altitudes flown on spray missions. Navigation by the crew using visual orientation and reference to a map was the only means that aircrews on spray missions had for establishing their locations. In turn, this was dependent on the inherent precision of a map, the accuracy with which it depicted surface features, and the skill of the individual pilot or navigator.

Early RANCH HAND missions were flown using maps inherited from the French. By 1964–65, maps produced by the US Army Corps of Engineers were available (in most cases based on the French maps and updated with photogrammetric data); the 1:250,000 Joint Operations Graphic series of maps were commonly used. A sample of representative charts [27,28] shows that these guaranteed a horizontal accuracy of *no better* than 120–240 meters. Moreover, the heavy jungle cover in the areas where most RANCH HAND missions were flown made precise navigation difficult. As a general rule, a pilot or navigator could fix his position accurately within the limitations of the map only if he could orient himself by reference to a nearby and clearly visible landmark, such as a prominent and distinctively shaped elevation, the coastline, or a visible inland waterway with a distinctive shape. Such features were available only occasionally. The depiction of man-made features in remote areas – buildings, trails, cultivated areas, etc. – was notoriously unreliable, although aircrews were able to orient themselves relative to friendly aircraft and ground forces with sufficient accuracy to ensure safety and effective coordination. FACs with intimate knowledge of their areas of operation were an essential element in orienting a mission, but were not helpful with precise accuracy relative to the UTM grid [16].

Finally, to compound the problem, ground troops used an entirely different series of maps, typically of 1:50,000 scale. The often severely limited view (due to the dense vegeta-

tion) available to field forces under even the best of conditions made accurate navigation difficult. The fact that ground troops, despite pre-mission warnings, could accidentally enter target areas was the primary reason for the extensive last minute spray cancellation program described earlier. The large number of mission cancellations or diversions documented in the DAARs is ample proof that the program was adhered to.

John Flanagan, a Forward Air Controller, describes the difficulties in tracking locations in the Vietnamese jungles in his book 'Vietnam Above the Treetops' [16]: "This stuff is thick! There are no holes except where the jungle is growing back in some of the grassland area. Some parts of War Zone C had apparently been cultivated at one point. Now the dense elephant grass and bamboo were reclaiming any open area. But 90 percent of the area was double- and triple-jungle canopy."

## 4 Historical Basis for Anecdotal Information

### 4.1 Alternative methods of clearing vegetation

Anecdotal reports by soldiers of exposure to Agent Orange commonly mention cleared, barren landscapes. A widely held misconception is that all clearance of vegetation in Vietnam was accomplished by means of herbicides. That was not the case. Simpler and more direct mechanical methods were frequently used and were often preferred depending on the tactical situation and the terrain. A special unit of US Army Corps of Engineers was created for clearing jungle vegetation by means of a variety of mechanical equipment, ranging from the 'Rome plow,' a large bulldozer equipped with a special tree-cutting blade and an armored cab, to chainsaws, hand axes, machetes, and diesel fuel incineration. Units of the Republic of Korea even used aerial ordnance to clear land [29]. Thus, many cleared areas may have been cleared mechanically rather than with herbicides. Indeed, "Hundreds of thousands of acres of what was formerly 'enemy country' was denuded of jungle through mechanical methods [30]."

Herbicide operations entailed considerable disadvantages, both military and diplomatic. They were politically sensitive, required a cumbersome and time-consuming process of approval to which adherence was strict, and involved considerable cost. Herbicides were often in short supply. Moreover, mechanical clearance was immediately effective, while herbicides required a period of weeks to months to reach maximum military effectiveness, particularly at ground level where multiple layers of dense jungle often shielded the lower canopies from the slow-acting defoliant. Consequently, simpler and more direct alternate methods were developed for removing vegetation, and mechanical land clearance became the favored technique.

According to a contemporaneous history of the land clearing operations in Vietnam, "engineer methods of land clearing gained wide acceptance as among the most effective tactical innovations of the war" and was considered to be of the Army's "most effective weapons" [30]. The units, often referred to as 'Jungle Eaters' or 'Land Barons' were described as the "key elements in successful operations aimed at penetrating enemy strongholds, exposing main infiltration routes, de-

nying areas of sanctuary, and opening major transportation routes to both military and civilian traffic [31,32]."

On average, a land clearing company cleared 60–80 hectares of 'medium jungle' each day, although the rate could vary depending on terrain, weather, maintenance requirements and hostile action. For example, Army engineers in support of Operation PAUL BUNYAN managed to clear jungle at a rate of 240 hectares per day. During the first six months of the Operation, the unit cleared a total of 2,025 hectares of double and triple canopy jungle [33].

As noted by a military historian, "from a strategic standpoint, the cumulative effects of land-clearing operations in Vietnam had a decided impact as the enemy was forced increasingly to adjust to the disappearance of his operational bases or to interdiction of connecting trails . . ." Mechanical clearing was also the preferred method for clearing fire zones around bases, camps, and landing areas. The greatly improved capability of allied forces to operate through vast areas once concealed by dense jungle "... represented dramatic progress, not only in a strict military sense but also in terms of pacification and economic development [30]."

#### 4.2 RANCH HAND insecticide operations

In the CDC study published in 1988 [3], a substantial portion of Vietnam veterans (25%) reported having experienced direct exposure to Agent Orange by RANCH HAND aircraft. As noted, it was highly unlikely that the RANCH HAND aircraft were spraying Agent Orange. Instead, it was *highly likely* that the aircraft was spraying insecticide.

In late 1966, Headquarters USAF recommended the modification of one of the RANCH HAND UC-123 aircraft to an insecticide-spray configuration [8]. Operation FLYSWATTER commenced on 6 March 1967 [8,9].

From March 1967 through February 1972, from one to three UC-123 RANCH HAND aircraft and crews were used to spray malathion, an organo-phosphate insecticide, for mosquito and malaria control [34]. The low-flying insecticide-spraying aircraft were commonly called the 'Silver Bug Birds' because they normally were not camouflaged [8]. These RANCH HAND aircraft routinely sprayed insecticide over military and civilian installations, as well as in areas where military operations were in progress, or about to commence [8,9,10,34]. By 1970, malathion treatment was being applied to 14 bases and their adjacent South Vietnamese cities, and the re-spray interval had been reduced from every fourteen days to every nine days [8,32]. Between 1966 and 1972, more than 3.5 million liters of malathion insecticide were sprayed on approximately 6 million hectares of South Vietnam [8,35].

#### 5 Conclusions

Through detailed policies and procedures, the circumstances in which spraying could occur were carefully controlled, and as a result, spraying of troops with Agent Orange in Vietnam was highly unlikely. The historical documentation details these policies and procedures and the evidence that they

were followed. Even after RANCH HAND had launched on an approved mission, the FAC or other control agencies would cancel mission if there were friendly forces in the target area. In addition, the often heavy application of 'fighter suppression' to minimize the ground fire from opposing forces [7,8,9] suggested the absence of friendly forces. The stringent criteria for spray missions, such as meteorological conditions, and the empirically studied and highly optimized nature of the equipment and application procedures minimized the possibility of significant spray drift [36].

Spray missions for both defoliation and crop destruction were conducted in a hostile environment. This was an unavoidable reality since the herbicides were used to deprive opposing forces of vegetative cover and food sources in areas in which they were active. RANCH HAND aircraft and their FAC and fighter escorts were routinely subjected to ground fire from Viet Cong and North Vietnamese forces [7,8,9]. Air Force fighters expended massive quantities of bombs and ammunition in close support of RANCH HAND aircraft conducting spray missions [7]. On many missions, fighter aircraft preceded the spray planes on the target deploying antipersonnel ordnance (CBU and other fragmentation bombs) [15,16]. Perhaps the most telling evidence of hostile forces in spray areas was the losses in RANCH HAND. Despite intense fire suppression by Air Force fighters, RANCH HAND lost nine aircraft and 28 crewmembers in combat [7,8].

If friendly forces had been present on or near the spray paths, the military records would have reflected numerous casualties due to 'friendly fire,' but there is no indication that this occurred. The wartime military records of troop positions and herbicide operations are valuable for some purposes, but are not sufficiently accurate to permit a reliable conclusion that a particular herbicide mission passed over a specific military unit, especially since procedures were followed which ensured that friendly forces were cleared from the target area before the mission could proceed. Reliance on wartime military records of the Vietnam Conflict of troop positions and herbicide operations to estimate an opportunity for exposure needs to consider the procedural and operational details for mission approvals that make apparent the clearing of friendly forces when spraying occurred. This conclusion is confirmed by the lack of reports of 'friendly fire' casualties and the lack of elevated serum TCDD levels in ground troops who served in heavily sprayed areas of Vietnam [3].

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## References

- [1] The Air Force Health Study – Final Report (2002): Air Force Research Laboratory, Brooks City-Base, Texas. Prepared by SAIC. Available at <<http://www.brooks.af.mil/AFRL/HED/hedb.afhs.html>>
- [2] Kang HK, Dalager NA, Needham LL, Patterson DB, Matanoski GM, Lees PS (2001): Health Status of US Army Chemical Corps Vietnam Era Veterans Relative to Current Serum Dioxin Concentrations. *Organohalogen Compounds* 54, 392–395
- [3] Centers for Disease Control and Prevention (CDC) (1988): Serum 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin in US Army Vietnam-era Veterans. *JAMA* 260 (9) 1249–1254
- [4] Stellman JM, Stellman SD, Weber T, Tomasallo C, Stellman AB, Christian R (2003): A Geographic Information System for Characterizing Exposure to Agent Orange and Other Herbicides in Vietnam. *Environ Health Perspect* 111, 321–328
- [5] Stellman JM, Stellman SD, Christian R, Weber R, Tomasallo C (2003): The Extent and Patterns of Usage of Agent Orange and Other Herbicides in Vietnam. *Nature* 422, 681–687
- [6] Institute of Medicine (2003): Characterizing Exposure of Veterans to Agent Orange and Other Herbicides Used in Vietnam. Final Report of the Committee on the Assessment of Wartime Exposure to Herbicides in Vietnam. National Academy Press, Washington, DC
- [7] Buckingham WA (1982): The Air Force and Herbicides in Southeast Asia 1961–1971. Office of Air Force History, United States Air Force, Washington, DC <<http://www.nal.usda.gov/speccoll/findaids/agentorange/text04154.pdf>>
- [8] Cecil PF (1986): Herbicidal Warfare: The RANCH HAND Project in Vietnam. Praeger Special Studies, Praeger Scientific, New York
- [9] Collins CV (1967): Herbicide Operations in Southeast Asia, July 1961–June 1967. HQ PACAF, Directorate, Tactical Evaluation, CHECO (Contemporary Historical Evaluation of Combat Operations) Report, 11 October 1967 <<http://www.nal.usda.gov/speccoll/findaids/agentorange/text/03116.pdf>>
- [10] Clary JR (1971): RANCH HAND: Herbicide Operations in SEA. CHECO (Contemporary Historical Examination of Current Operations) Report 167, 13 Jul 71 1971, HQ PACAF, Directorate of Operations Analysis, CHECO/CORONA HARVEST Division. Department of the Air Force, Washington, DC (Notes from microfilm) <<http://www.nal.usda.gov/speccoll/findaids/agentorange/text/03140.pdf>>
- [11] Warren WF (1968): A Review of the Herbicide Program in South Vietnam. Scientific Advisory Group Working Paper No.10–68, August. Commander in Chief, Scientific Advisory Group, FPO San Francisco, CA <<http://www.nal.usda.gov/speccoll/findaids/agentorange/text/03121.pdf>>
- [12] Military Assistance Command, Vietnam (1968): The Report on the Herbicide Policy Review, Prepared for the United States Embassy, Saigon, South Vietnam <<http://www.nal.usda.gov/speccoll/findaids/agentorange/text/03120.pdf>>
- [13] MACV (1969): Directive 525-1, Herbicide Procedures and Operations (revised 15 February 1966, revised 22 November 1967, revised 15 December 1968, revised 12 August 1969), US Military Assistance Command Vietnam, APO San Francisco, CA
- [14] MACV (1968): Directive 525-1, Annex K, Chemical and Herbicide Operations: SOP to FFORCEV 011808Feb68, US Military Assistance Command Vietnam, APO, San Francisco, CA
- [15] 504<sup>th</sup> Tactical Air Support Group (1969): Standards/Evaluation and Information Files for FACs. Pacific Air Command, April 1969
- [16] Flanagan JF (1992): Vietnam Above the Treetops: A Forward Air Controller Reports. Praeger Publishers, New York, NY
- [17] McConnell AF (1970): Mission: RANCH HAND. *Air University Review* 21 (3) 89–94 <<http://www.nal.usda.gov/speccoll/findaids/agentorange/text/00159.pdf>>
- [18] MACV (1968): Friendly Casualties from Friendly Fires. Vietnam Lessons Learned No.70, 17 October 1968, U742V5no 70. Available from the US Army Military History Institute <<http://www.carlisle.army.mil/usamh/bibliographies/ref>>
- [19] Shrader CR (1982): Amicide: The Problem of Friendly Fire in Modern War. US Army Combat Studies Institute, Ft Leavenworth, KS. Available from the US Army Military History Institute: <<http://www.carlisle.army.mil/usamh/bibliographies/ref>>
- [20] Christian R, White JP (1983): Battlefield Records Management and Its Relationship with the Agent Orange Study. *Chemosphere* 12, 761–769
- [21] Butz JS Jr (1966): Tactical Airpower in 1965 – The Trial by Fire. *Air Force and Space Digest*, March 1966
- [22] Data Management Agency (1970): Command Manual for Herbicide Reporting System (HERBS), Document No. DAR U07, Military Assistance Command, Vietnam, APO, San Francisco, CA <<http://www.nal.usda.gov/speccoll/findaids/agentorange/text/00170.pdf>>
- [23] Heizer JR (1971): Data Quality Analysis of the HERB 01 Data File. MITRE Technical Report 5105, 21 April 1971, MITRE Corporation, Washington, DC <<http://www.nal.usda.gov/speccoll/findaids/agentorange/text/00175.pdf>>
- [24] National Research Council (1974): The Effects of Herbicides in South Vietnam, Part A – Summary and Conclusions. Committee on the Effects of Herbicides in South Vietnam, National Research Council, National Academy of Sciences, Washington, DC <<http://www.nal.usda.gov/speccoll/findaids/agentorange/text/00181.pdf>>
- [25] US Army & Joint Services Environmental Support Group (1985): Services HERBS Tape – A Record of Helicopter and Ground Spraying Missions, Aborts, Leaks, and Incidents. NTIS Document ADA 229879, Springfield, VA <<http://www.nal.usda.gov/speccoll/findaids/agentorange/text/00109.pdf>>
- [26] Lathrop GD (1988): The Epidemiology of Agent Orange and Its Associated Dioxin. In: Young AL, Reggiani GM (eds), *Agent Orange and Its Associated Dioxin: Assessment of a Controversy*. Chapter 5, 91–114. Elsevier Publishers, New York, NY
- [27] Joint Operations Graphic (Air) Sheet NC 48-6, LONG XUYÊN, VIETNAM; CAMBODIA (US Army Corps of Engineers: coastal hydrography, 1970; all other map features, 1965–72; data compiled, December 1972), depicting the area around Kon Tum and Dak To in the Central Highlands of South Vietnam. Accuracy as related to control of map (that is relative to the geographic reference grid): Horizontal position within 410 feet
- [28] Joint Operations Graphic (Air) Sheet ND 48-8, ATTAPU, LAOS; KAMPUCHEA; VIETNAM (US Army Corps of Engineers: photogrammetric data 1953–59; printed 11–65), depicting the Mekong River watershed immediately south of the Cambodian border. Accuracy as related to control of map (that is relative to the geographic reference grid): Horizontal position within 820 feet
- [29] Korean Armed Forces in Vietnam (1973): Vietnam War: Comprehensive Research. Headquarters of the Korean Armed Forces in Vietnam
- [30] Ploger RR (1974): Vietnam Studies: US Army Engineers (1965–1970). Department of the Army, Washington, DC
- [31] Wolfe M (1971): US Army Engineer Command, Vietnam. *Castle Courier* 6 (10) May 17, 1971
- [32] Anonymous (1971): Land Barons Clean Jungle. *The Army Reporter* 7 (7) February 15, 1971
- [33] Anonymous (1968): Engineer Brigade Operation Clears 50,000 Acres. *The Army Reporter* 4 (2) January 13, 1968
- [34] MACV (1970): Aerial Dispersal of Insecticides. Directive 40-10, 23 March 1970, HQ United States Military Assistance Command, Vietnam (MACV), APO, San Francisco, CA <<http://www.nal.usda.gov/speccoll/findaids/agentorange/text/00221.pdf>>
- [35] Westing AH (1976): Ecological Consequences of the Second Indochina War. Stockholm Peace Research Institute, Almqvist & Wiksell International, Stockholm, Sweden
- [36] Young AL, Giesy JP, Jones PD, Newton M (2004): Environmental Fate and Bioavailability of Agent Orange and Its Associated Dioxin During the Vietnam War. *ESPR – Environ Sci & Pollut Res* 11 (6) 359–370 <DOI: <http://dx.doi.org/10.1065/espr2004.10.222>>

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