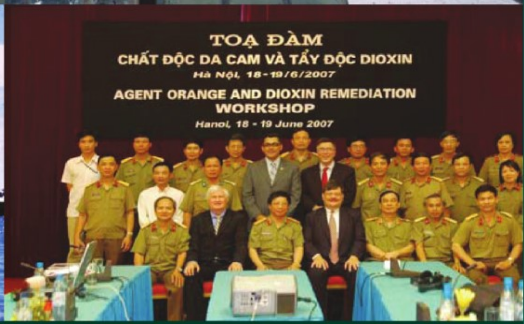

The History, Use, Disposition and Environmental Fate of Agent Orange

Alvin L. Young

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Preface

For almost four decades, controversy has surrounded the tactical use of herbicides in Southeast Asia by the United States military. Few environmental or occupational health issues have received the sustained international attention that has been focused on Agent Orange, the major tactical herbicide deployed in Southern Vietnam. With the opening and establishment of normal relations between the United States and the Socialist Republic of Vietnam in 1995, the time has come for a thorough re-examination of the military use of Agent Orange and other "tactical herbicides" in Southern Vietnam, and the subsequent actions that have been taking place since their use in Vietnam.

The United States Department of Defense has had the major role in all military operations involving the use of tactical herbicides, including that of Agent Orange. This included the Department's purchase, shipment and tactical use of herbicides in Vietnam, its role in the disposition of Agent Orange after Vietnam, its role in conducting long-term epidemiological investigations of the men of Operation RANCH HAND, and its sponsorship of ecological and environmental fate studies. This book was commissioned by The Office of the Deputy Under Secretary of Defense (Installations and Environment) with the intent of providing documentation of the knowledge on the history, use, disposition and environmental fate of Agent Orange and its associated dioxin.

A large body of historical records and other data exist on the use of Agent Orange in Vietnam. Many of these primary historical records are now openly available, and they permit a comprehensive assessment of the procedures and supporting historical data related to spraying of herbicides in Vietnam. An extensive collection of environmental data has been assembled on Agent Orange and its associated dioxin. These data provide insight into the mechanisms of dissipation and degradation as they relate to the distribution and bioavailability of the herbicides and dioxin in the environment, i.e., issues related to human exposure. Procurement records from the United States Air Force and Defense Supply Agency, complemented by records from the Chemical Companies that produced the tactical herbicides, and from the National Institute for Occupational Safety and Health, permit new estimates on both the quantities of tactical herbicides sprayed in Vietnam and on the level of dioxin in those inventories. Lastly, workshops between the United States Department of

Defense and Vietnam's Ministry of National Defence have opened a dialogue on how the two governments can work together to resolve the remaining controversy over Agent Orange and "dioxin hot spots" in Southern Vietnam.

It is hoped that the history and science described in this book can correct many of the misperceptions about the use of tactical herbicides in Vietnam. In particular the science of the degradation of the herbicides and its associated dioxin and historical records, have not yet received the recognition in the debates of the issues that they should. It is my hope that this discussion and this book will make a positive contribution to society's effort to put the Vietnam War behind us and to look to the future relationships between both countries and their peoples.

1 July 2008 Alvin L. Young, Ph.D.

Acknowledgments

First, I want to thank the United States Air Force and the United States Government for giving a young man from the prairies of Wyoming the opportunity to have an exciting career for 40 years in environmental chemistry and toxicology of pesticides and related materials.

For those of us who went to college in the 1960s, the Vietnam War was a major social and political issue. I was a ROTC (Reserve Officer Training Corps) cadet at the University of Wyoming and 1964 was the year of my commissioning and graduation, and it was the year that the War became a national commitment. Because I was a graduate from the College of Agriculture, I was aware of the military's interest in herbicides. Accordingly, I contacted Air University and was given the opportunity to seek a PhD in Herbicide Physiology/Environmental Toxicology at Kansas State University. In 1968, I reported for active duty at Eglin Air Force Base, Florida where I had the opportunity to work closely with the men of Operation RANCH HAND in the evaluation of the aerial spray equipment that was continually being upgraded for use in Vietnam.

I also had the opportunity to conduct the first ecological studies on the dioxin contaminant in Agent Orange. While at Eglin, I began to collect documents on the tactical herbicides Orange, White, and Blue, on their use in Vietnam, and on subsequent studies related to their disposition, environmental fate, and toxicology. During the next 20 years the collection continued to develop as I advanced in my Air Force career. Eventually the size of the collection became large, and I was fortunate in having the interest of the Special Collections Division of the National Agricultural Library, Agricultural Research Service, Beltsville, Maryland. The Air Force School of Aerospace Medicine graciously provided funds to the have the collection (>5,850 documents, reports, articles, photographs, and maps) placed into an electronic database, so that it could support the literature needs of the ongoing Air Force Health Study (the RANCH HAND Epidemiological Study). Thus, my thanks to the National Agricultural Library and to Sarah H. Fugate and Patricia Murphy for establishing "The Alvin L. Young Collection on Agent Orange." The collections is located at the following web site: http://www.nal.usda.gov/speccoll/findaids/agentorange/intro.htm.

The collection at the National Agricultural Library is one of two primary sources for this book. The other primary source is the Armed Forces Pest

Management Board's Literature Retrieval System. The Literature Retrieval System houses more than 150,000 electronically available documents, reports, and books on pests, pesticides, and AFPMB's worldwide studies. The AFPMB's Literature Retrieval System is located at the following web site: http://www.afpmb.org

The unique nature of this book is enhanced through the outstanding photographs and first-hand accounts of all phases of the various tactical herbicide operations and research. Many of the details and photographs of RANCH HAND missions were provided by men who served in Operation RANCH HAND in Vietnam. I am especially indebted to Lt. Colonel Paul F. Cecil, USAF (RET), Ph.D, Military Historian, who provided great assistance in reviewing and commenting on Chapter 3. The other men of Operation RANCH HAND that I wish to acknowledge are Major John "Jack" Spey, USAF (RET); Colonel Ralph Dresser, USAF (RET); Lt. Colonel James Pochurek; and, to the RANCH HAND Vietnam Association. I wish to acknowledge the experience and knowledge shared by men who served as Forward Air Controllers for RANCH HAND missions, especially Colonel Charles "Chuck" Hines, USAF (RET) and Lt. Colonel Leo Tibbitts, USAF (RET). Thanks also to Lt. Colonel Warren Hull, USAF (RET), BSC, for information on Project PACER IVY, and to Major James W. Tremblay, USAF (RET), BSC, who contributed photographs and details on Operation PACER HO. I am grateful for the special scientific expertise of Lt. Colonel Charles "Charlie" E. Thalken, USAF (RET), VC, and Lt Colonel Lorris G. Cockerham, Ph.D., USAF (RET), Colonel Robert Clegern, Ph.D., BSC, USAF (RET), and Colonel William Cairney, Ph.D., USAF (RET) in the conduct of ecological studies at Eglin AFB, Florida, and the Site Monitoring Programs at the Naval Construction Battalion Center, Gulfport, Mississippi, and Johnston Island, Central Pacific Ocean. I wish to give a special thanks to Mr. J. Ray Frank, Frederick, Maryland (formerly with the US Army Chemical Corps, Fort Detrick, Maryland) for many of the photographs included in the book.

I wish to acknowledge the opportunity provided me by Dr. James L. Regens to serve as a Visiting Professor and Senior Fellow with the Institute for Science and Public Policy, Sarkeys Energy Center, The University of Oklahoma, Norman, Oklahoma. Dr. Regens and his Research Associate James T. Gunter encouraged and provided a forum for me to document the history of Agent Orange. Dr. Regens is now Presidential Professor, Occupational and Environmental Health, University of Oklahoma Health Sciences Center, Oklahoma City, Oklahoma. A special appreciation is also given to Dr. Nathan Karch, Exponent, Inc., Washington DC for the many excellent suggestions that contributed to improving the book.

I wish to acknowledge the Program Manager for this project, Mr. Willam J. Van Houten, Environmental Readiness and Safety Group, Office of the Under Secretary of Defense, Washington, DC, and to the Project Manager, Mr. William B. Andrews, Battelle Memorial Institute, Richland, Washington.

It was great pleasure to travel to Hanoi, Vietnam and participate with them in Workshops on “Agent Orange and Dioxin Remediation”.

In conclusion, I wish to acknowledge my colleagues, the men and women who served with honor and distinction in the War in Vietnam. May their sacrifices never be forgotten!

Colonel, USAF (RET) Alvin L. Young, Ph.D.
1 July 2008

Contents

Alvin L. Young Biographical Sketch, 2008

For 40 years, Dr. Alvin L. Young has collected documents, reports, and photographs on the use, disposition, and environmental fate of Agent Orange and other tactical herbicides used in the Vietnam War. He has published or edited four books and more than 70 peer reviewed publications, commentaries, and editorials on the herbicides (and the associated dioxin contaminant) used in Vietnam. He completed his PhD in Herbicide Physiology and Environmental Toxicology at Kansas State University in 1968. He began his Air Force career as a Project Scientist with the United States Air Force in 1968, evaluating both the dissemination characteristics of the Air Force aircraft and the fate of the herbicides used in South Vietnam. In his 21 years with the Air Force (obtaining the rank of Colonel), he was involved with all phases of the Agent Orange Controversy, from test and evaluation of equipment to environmental fate and health impacts. During his years as Associate Professor at the United States Air Force Academy (1971–1977), Colorado Springs, Colorado he conducted studies on the environmental fate of TCDD including studies on the biodegradation of massive quantities of Agent Orange.

From 1977 to 1983, Dr. Young was affiliated with the Epidemiology Division, The School of Aerospace Medicine, Brooks AFB, Texas, and the Environmental Epidemiology Unit of the Department of Veterans Affairs, Washington, DC. His primary responsibilities were the documentation and establishment of exposure assessment protocols for the epidemiological studies of Vietnam veterans. From 1983 to 1987, Dr. Young was assigned to the Executive Office of the President, Washington, DC, where he provided advice to the White House on the issues of Agent Orange and Dioxins. From 1987 to 1997, he was a Science Advisor for the United States Department of Agriculture. From 1997 to 2001, he was the Director, Center for Risk Excellence, United States Department of Energy, Argonne, Illinois. From 2002 through 2007 he was a Visiting Professor and Senior Fellow with the Institute for Science and Public Policy, The University of Oklahoma, Norman, Oklahoma. He currently is President, A. L. Young Consulting, Inc., Cheyenne, Wyoming. His scientific specialty is on the use, toxicology, and human and environmental risks associated with the military herbicides used in South Vietnam, 1961–1972.

Dr. Young has traveled, lectured, attended and sponsored conferences and workshops in 32 countries speaking on issues related to Agent Orange and TCDD, ecological studies, environmental toxicology, and biotechnology. He has served as a Co-editor for four different journals and has more than 300 publications in the scientific literature. He is currently the Editor-in-Chief of the *International Journal Environmental Science and Pollution Research*. He maintains a Special Collection on Agent Orange at the USDA's National Agricultural Library, Beltsville, Maryland, at: http://www.nal.usda.gov/speccoll/findaids/agentorange/index.htm

Chapter 1
Vietnam and the Agent Orange Controversy Revisited

For almost four decades, controversy has surrounded the tactical use of herbicides in Southeast Asia by the United States Department of Defense. Few environmental or occupational health issues have received the sustained international attention that has been focused on Agent Orange and its associated dioxin contaminant. However, the breadth of that controversy has spanned the gamut from alleged military use of chemical weapons, to ecological damage and public health impacts, and to social and political concerns. This spectrum of controversy has represented the crossroads of science and society, i.e., where the significance of the science is "filtered" by the perceptions of the society. Only now that much of the acrimony from that military conflict has subsided can we revisit the military's use of tactical herbicides in Vietnam and the subsequent actions that have occurred since their use. Indeed, today the legacy issues of Agent Orange remain as one of the last contentious issues with the veterans of that war, and between the United States and Socialist Republic of Vietnam.

1.1 Background

Significant confusion has existed about how herbicides were selected by the US Military to be used in the defoliation program in the Vietnam-American War (i.e., the Vietnam War). The belief that commercially available herbicides were simply purchased from US chemical companies and deployed directly to Vietnam was incorrect and contrary to historical records. "Tactical Herbicides" were herbicides and formulations developed specifically by the United States Department of Defense (DOD) to be used in combat operations. The missions to develop tactical herbicides and delivery technologies were assigned to the US Army Chemical Corps, specifically to the Plant Sciences Laboratories at Fort Detrick, Maryland. Fort Detrick evaluated numerous formulations of herbicides for potential tactical use from 1957 through 1967 (Irish et al. 1969; Young 2006). However, the component herbicides that comprised the "tactical herbicides" used in Vietnam were those herbicides

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being developed or already adopted for domestic agricultural use before they were used in Vietnam. Prior to and during their use in Vietnam by the military, the two phenoxy herbicides, 2,4,5-T (2,4,5-trichlorophenxoyacetic acid) and 2,4-D (2,4-diclorophenoxyacetic acid), the major components of Agent Orange, were extensively used in the United States (Bovey 1980a). Prior to the controversy surrounding Agent Orange, an extremely voluminous amount of research data, demonstration, and use experience had been accumulated on all aspects of these two herbicides, from toxicity in animals, to environmental fate, and to weed and shrub control recommendations under field conditions (Young et al. 1978; Bovey 1980b; Lavy 1987).

The herbicide 2,4,5-T was first commercially produced in the United States in 1944 (Hammer and Tukey 1944). The quantity of 2,4,5-T produced and used in the United States, and in world agriculture, increased steadily until 1968–1969, after which a sharp decline in its use occurred. During the period 1961 through 1969, 70 million kg were produced in the United States. Approximately 24 million kg (34.5%) was procured by the United States military for use in Vietnam; almost 36 million kg (51%) were used in domestic herbaceous and woody plant control programs, and the remaining 10 million kg (14.5%) was exported to other countries (Bovey 1980a). The herbicide 2,4-D has long been recognized as one of the safest, non-persisting, and most widely used herbicide worldwide (Lavy 1987). The production and use of 2,4-D greatly exceeded that of 2,4,5-T, and today it is still a major herbicide used in weed control programs. Between 1966 and 1971, 2,4-D was applied annually to almost 23 million hectares of cropland, pastures, and residential lawns in the United States, while 2,4,5-T was annually applied to 607,000 hectares of pastures, rangeland and forests. A mixture of the two herbicides was found to be invaluable for the control of hard-to-kill woody brush and undesirable trees, e.g., honey mesquite (*Prosopis juliflora*) and sand shinnery oak (*Quercus harvardii*). Forestry programs traditionally used 2,4-D and 2,4,5-T in combination to kill competing broadleaf shrubs and trees, thus allowing for conifer release in new plantings of pine and fir trees (Bovey 1980a; Lavy 1987; Newton and Young 2004). The termination of all 2,4,5-T production occurred in the United States after the US Environmental Protection Agency (EPA) issued an Emergency Suspension in 1979 that cancelled all registrations of 2,4,5-T. A Professor of Forestry at Oregon State University noted:

> After 30 years of use without substantial incident and thorough documentation, politics, media bias, and societal concerns eventually destroyed a product with an excellent safety record and an enviable record of benefits to costs (Newton and Young 2004).

Agent White, the second most applied tactical herbicide in South Vietnam contained the two domestic herbicides, 2,4-D and picloram (4-amino-3,5,6-trichloropicolinic acid). As with 2,4,5-T, picloram was a non-selective broadleaf herbicide having a very low toxicity value, and was readily biodegraded by soil microorganisms in soil conditions having adequate moisture, warm temperatures, and high in organic matter (WSSA 1979). Although picloram was readily water soluble, breakdown occurred in UV light and was greatest in clear moving water and on soil and plant surfaces (WSSA 1979). Agent Blue, the third major tactical herbicide used in South Vietnam, consisted of the organic arsenical, cacodylic acid (hydroxydimethyarsine oxide) and its sodium salt (sodium cacodylate). Blue was a contact herbicide that would rapidly defoliate or desiccate a wide variety of plant species, especially grasses and grains, e.g., rice (Hood 1985). The phytotoxic properties of cacodylic acid were quickly inactivated on contact with soil. This organic form of arsenic was considered to have very low toxicity to mammals (Hood 1985). Thus, three (2,4-D, picloram, and cacodylic acid) of the four herbicides contained in the tactical herbicides used in Vietnam are still used commercially in the United States and in world agriculture (WSSA 1979; Bovey and Young 1980; Hood 1985; Lavy 1987). So why so much controversy about the use of herbicides in the Vietnam War?

1.2 The Use of Tactical Herbicides in the Vietnam War

The controversy initially involved the actual deployment of tactical herbicides as a weapon of war in the former Republic of Vietnam (RVN) by the United States Air Force (USAF) and the United States Army (USA). The Biological Laboratories, Army Chemical Corps, Fort Detrick first evaluated tactical formulations in South Vietnam in December 1961 (Brown 1962). From January 1962 to February 1971, the USAF aerially deployed tactical herbicides in combat operations to improve visibility in enemy controlled or contested jungle areas in order to expose infiltration routes, base camps, weapon placements, and storage sites. In addition, with the assistance of the US Army Chemical Corps, tactical herbicides were sprayed along enemy-entrenched lines of communication, transportation routes, around the outside of base perimeters, and for limited but selectively-approved use for crop denial (Fox 1979; Cecil 1986). As developed, tactical herbicides were to be used only in combat operations, not for weed or brush control on military bases and installations. With the full concurrence and support of the Republic of Vietnam (South Vietnam) and the Army of the Republic of Vietnam (ARVN), USAF Operation RANCH HAND was initiated 7 January 1962. Operation RANCH HAND was responsible for the fixed-wing aerial applications from UC-123 aircraft, and applied 95% of the tactical herbicides sprayed in Southern Vietnam (Cecil 1986; Stellman et al. 2003). Helicopters and ground equipment assigned to the US Army Chemical Corps and to Combat Engineers of other Allied Forces sprayed the remaining 5 percent (Young et al. 2004a; see Chapter 3). Figure 1.1 illustrates the results of the first defoliation mission in January 1962 in the South Vietnam.

Fig. 1.1 Results of the first defoliation mission, January 1962, Ca Mau Peninsula, Vietnam (Photograph courtesy of US Army Chemical Corps, Fort Detrick, Maryland)

In should noted that although the United States government terminated all use of tactical herbicides on 31 October 1971, stocks of Agent White and Blue remained at Da Nang Air Base and Bien Hoa Air Base. These stocks were subsequently sprayed by the South Vietnamese Air Force (VNAF) using aircraft given to the VNAF by the 7th Air Force as part of the Vietnamization Program. No records could be found as to the final fate of those stocks, but procurement records indicated how much was sent to Vietnam in late 1970 (Craig 1975; Cecil 1986).

To obtain the quantities of tactical herbicides purchased and used in the Vietnam War, procurement records were obtained from the Defense Supply Agency and the Air Force Logistics Command (the San Antonio Air Materiel Area, Kelly Air Force Base, Texas), and validated with data from the chemical companies that provided the tactical herbicides under Military Specifications (Craig 1975; Product Liability Litigation 1982). Data provided in Table 1.1 represents the most recent data (as of March 2008) and the best estimates of the quantities of tactical herbicides used from 1961 to 1972. The color designation given to the tactical herbicides came from the 7.5 cm (3-in.) color-coded band around the center of the 18-guage steel 208-l (55-gal) drum, not from the color of the liquid herbicide (Craig 1975; see Chapter 2). The quantities of tactical herbicides used in Vietnam are provided in Table 1.1.

The tactical herbicides were also color-coded to facilitate herbicide selection, transportation, and incompatibility issues. Thus the military code names Orange, Blue, White, Pink, Green, and Purple were given to each different military formulation, with Orange being the most widely procured and used (Young 2006). Tactical operations using these tactical herbicides were deployed against the Viet Cong and regular Armed Forces of the Democratic Republic of Vietnam. While Operation RANCH HAND was the USAF military operation

Table 1.1 Estimated quantities of tactical herbicides used in Vietnam, 1961–1972

Tactical herbicide	Commercial components	Number of drums[1]	Number of liters	Years of use
Green[2]	2,4,5-T	365[3]	75,920	1962
Pink[2]	2,4,5-T	1,315	273,520	1961–1963
Purple[2]	2,4-D; 2,4,5-T	12,475	2,594,800	1962–1965
Blue	Cacodylic Acid	29,330	6,100,640	1966–1972
White	2,4-D; Picloram	104,800	21,798,400	1966–1972
Orange[2]	2,4-D; 2,4,5-T	208,330	43,332,640	1965–1970
Total		356,615	74,175,920	

[1] Data based on US Defense Supply Agency and Air Force Logistics Command records (Craig 1975; Young 2006); Data as of March 2008.
[2] These tactical herbicides contained 2,4,5-T herbicide and its associated contaminant, 2,3,7,8-TCDD. Pink was used in the 1964 Thailand tests, but available data indicted last Pink Mission in South Vietnam was in 1963; the Daily Air Activity Reports often confused Purple and Pink.
[3] All herbicide drums sent to Vietnam were of 18-guage steel and held 208 l or 55 gal of product that were applied in concentrated form and not diluted.

responsible for the tactical fixed-wing aerial dispersal of the herbicides, the Army Chemical Corps was responsible for the use of helicopter and ground equipment to deliver tactical herbicides on base perimeters and other selected military targets. Aerial spray systems were specifically developed by the military for fixed-wing and helicopter aircraft (see Fig. 1.2) (Buckingham 1982; Cecil 1986).

Only the US Army Chemical Corps and the US Air Force Logistics Command were authorized to purchase tactical herbicides. However, many commercial pesticides, including herbicides, were used in Vietnam on US and

Fig. 1.2 Three UC-123 aircraft spraying defoliants over the Ashau Valley on 9 May 1967 (Photograph courtesy of J. Ray Frank, Frederick, Maryland)

Allied Bases. These commercial pesticides were purchased under Federal Specifications, and the Armed Forces Pest Control Board regulated their uses (Young 2006; Young et al. 2008).

The Civil Engineering Squadrons assigned to all US and Allied Bases were responsible for acquisition and use of commercial pesticides (see Chapter 2). The Civil Engineering Squadrons in Vietnam were not approved to use the tactical herbicides Orange, Blue, and White. This distinction between tactical and commercial herbicides has been a source of misunderstanding by the public, veterans of the Vietnam War, the Department of Veterans Affairs, and the Vietnamese (Young 2006; Young et al. 2008).

Generally the term "Agent Orange" has been used by the public to describe a group of "Tactical Herbicides" used in combat operations by the US Military and other Allied Forces in the Vietnam War for the suppression and control of vegetation. However throughout the war, military units referred to the herbicides as "Herbicide Orange" or "Herbicide Blue", but the media and critics of the use of these chemicals in military operations (i.e., warfare) called them "Agents" [Cecil 1986]. Hence, in the late 1960s and early 1970s as ecological and public health issues began to receive intense media coverage, "Herbicide Orange" became "Agent Orange". The term "agent" became even more sensational in the media with the recognition in late 1969 that 2,4,5-T was contaminated with a toxic substance known as dioxin, or TCDD (2,3,7,8-tetrachlordibenzo-p-dioxin). In April 1970, as a consequence of concern over potential public health impacts of TCDD in 2,4,5-T herbicide, the government of the United States restricted the herbicide use both in Vietnam and in the United States (DuBridge 1970; MacLeod 1971). In September 1971, the Department of Defense initiated a process (Operation PACER IVY) to return the unused Agent Orange to the United States (i.e., to Johnston Island, Central Pacific Ocean) for final disposition (Young et al. 2004b; see Chapter 4).

1.3 The Disposal of Agent Orange

By the mid-1970s, the focus of the controversy shifted from issues associated with herbicide use to technical concerns about its safe disposal. The major issue involved questions of how best to dispose of the surplus herbicide and the associated dioxin contaminant following the termination of active US involvement in the Vietnam War (Department of Air Force 1974; Thomas et al. 1978). Numerous options for the disposal of Agent Orange were evaluated. However, extensive media and public concern limited the feasibility of most options (Tremblay 1983). In the military operation PACER HO, conducted in the summer of 1977, the USAF disposed of 8.6 million liters of Agent Orange by high temperature incineration at-sea aboard a specially designed incinerator ship (Fig. 1.3) (see Chapter 4) (Tremblay 1983).

Fig. 1.3 The at-sea incineration of Agent Orange near Johnston Island in the Central Pacific Ocean by the *M/T Vulcanus* during Operation PACER HO in August 1977 (Photograph courtesy of USAF OEHL, Brooks AFB, Texas)

1.4 Finding a Resolution to Vietnam Veterans' Health Concerns

Five nations provided combat troops, i.e., Allied Forces, to support the Army of Vietnam, 1962–1973. Australia/New Zealand deployed 46,852 combat troops. The government of Thailand contributed 11,790 military personnel to include Naval, Army, and Air Force units. The Republic of Korea (South Korea) deployed 312,853 combat troops, and the United States deployed 3.2 million military personnel. No figures were available on either the number of troops deployed by the Republic of Vietnam (South Vietnam) as Allied Forces, or the Viet Cong Insurgency Forces or the Democratic Republic of Vietnam (North Vietnam), but the numbers were also in the millions (Young 2002).

In 1977, following the completion of Operation PACER HO, veterans of the Vietnam War began to complain of serious health problems that they believed resulted from exposure to Agent Orange while on duty in Vietnam (Reggiani 1988). The basis for these beliefs were the press reports related to dioxins following the 1976 industrial accident in Seveso, Italy, and the continued concern over the domestic use of 2,4,5-T by the US Environmental Protection Agency (Reggiani 1988). In 1978, with the help of a reporter from the Columbia Broadcasting System, Bill Kurtis, the issue of Agent Orange and its potential impact on veterans' health was presented to the nation in a television documentary entitled "Agent Orange: Vietnam's Deadly Fog" (Kurtis 1978). As Reggiani noted:

> In this way the public became aware of the magnitude of the veterans concerns, and Agent Orange reached the dimensions of a public health problem (Reggiani 1988).

Any attempt by the scientific community to refute this charge simply spread the suspicions within the veteran community. In responding to the documentary, the Council on Agricultural Science and Technology stated:

> ...the program clearly implied that exposure of the veterans to the dioxin in Agent Orange was responsible for some of their current health problems—problems of the type suffered to some degree by persons who were never exposed. Available scientific evidence does not support 20/20's (CBS) allegation (CAST 1978).

As Holden noted in 1979:

> For Vietnam veterans the herbicide has become a symbol for everything that was wrong about the war. The veterans don't want answers in 10 years. They want satisfaction now (Holden 1979).

However, the answers to such questions would require the tremendous commitment of the research establishment and significant Federal funding.

The perceptions that governments have done little to resolve whether Agent Orange, its associated dioxin, or other tactical herbicides were responsible for the many health problems reported in the Vietnam veteran population are not based on the facts. In 1982 and 1983, the Congressional Research Service, Library of Congress, prepared extensive "Issue Briefs" on the actions of the US Government to address "Veterans Complaints Concerning Exposure to Herbicides in South Vietnam" (Smith 1982; Davis 1983). The Veterans Administrations (now the Department of Veterans Affairs) and other Government Agencies in the United States and Australia initiated registries of veterans concerned about Agent Orange, and funded literature reviews, surveys, and epidemiological studies of Vietnam and Vietnam-Era veterans (Hunter 1981; Shepard 1981; Sinclair 1982; Kang et al. 1984; Hood 1985; Lavy 1987; Coombs 1988; CDC 1987, 1988, 1990).

The importance to the Federal Government in resolving veteran health issues was demonstrated in December 11, 1979, when the Executive Office of the President (President Jimmy Carter) directed the establishment of an "Interagency Work Group to Study the Possible Long-Term Health Effects of Phenoxy Herbicides and Contaminants" (the IWG) (Eizenstat 1980). Members of Interagency Work Group (IWG) included representatives from the Departments of Agriculture, Defense, Health and Human Services, Housing and Urban Development, and Labor, and representatives from the Environmental Protection Agency, Veterans Affairs, Office of Management and Budget, Council of Economic Advisors, and Office of Science and Technology Policy. A major issue presented to the IWG was the Congressional interest in having an epidemiological study conducted of ground troops who may have been exposed to Agent Orange during combat operations. Such a study would require the Department of Defense to identify exposed and non-exposed cohorts. In anticipation of such a study, the Department tasked the US Army and Joint Services Environmental Support Group to conduct record searches and identify at least five battalions (over 20,000 potential study subjects) of Army combat personnel who served in III Corps in South Vietnam during the War (del Real 1981). The IWG tracked this activity carefully for two years and in a April 1981 reported to the Assistant to the President for Policy Development that:

> The DOD has searched company-level records of five battalions and has been able to determine that certain units operated in close proximity to areas sprayed with Agent Orange. However, DOD has not been able to identify individuals or even units whose exposure to Agent Orange is or can be documented reliably. The Work Group believes that it is reasonable to presume that military personnel entered sprayed areas. However, a study based on no more than presumed exposure would represent such a serious flaw in scientific design as to be of questionable validity. The Work Group strongly endorses DOD's recommendation that the records search effort by DOD (ESG) be reviewed by outside records search experts to insure that no means of possibly identifying individuals whose exposure to Agent Orange is or can be documented has been overlooked (del Real 1981).

In August 1981, the IWG was expanded and elevated to become the "Agent Orange Working Group" (AOWG) at the Cabinet Council level by President Ronald Reagan. The task assigned to the AOWG was..."to guide and monitor all Federal research into the possible adverse health effects of Agent Orange and similar chemicals on humans, with a particular focus on the health of Vietnam veterans" (HHS NEWS 1981). Secretary of Health and Human Services was appointed Chair of the AOWG, and the Director from the Centers for Disease Control and Prevention (CDC) was appointed Chair of the AOWG Science Panel. The Congressional Office of Technology Assessment and the General Accounting Office were invited to become observers and advisors to the Group. The AOWG undertook a massive effort encouraging, supporting, and monitoring studies conducted by VA, DOD (the Air Force Health Study of RANCH HAND personnel), CDC, other Federal Agencies, and the international community (e.g., Australia and New Zealand) (Davis 1983). Subcommittees were formed to examine the use of TCDD as a bio-indicator of exposure to Agent Orange (Rall 1981), and the Science Panel of the AOWG undertook a comprehensive assessment of the feasibility of conducting the major study of ground troops (Beach 1984). Between 1986 and 1988, the results of many studies conducted by the US Federal Agencies and monitored by the AOWG were reported (Murray 1986; Bowen 1988). A Fact Sheet developed by the AOWG (Bowen 1988) reported on 17 major studies or projects conducted by the CDC (Vietnam Experience Study, Mortality Assessment Study, Selected Cancer Study, and Agent Orange Exposure Study); by the National Institute for Occupational Safety and Health (NIOSH Mortality Study of Production Workers Exposed to Dioxin, and NIOSH Medical Study of Production Workers Exposed to Dioxin); Veterans Administration (Vietnam Veterans Mortality Study, Soft-Tissue Sarcoma Study, Retrospective Study of Dioxins and Furans in Adipose Tissue, Review of Soft-Tissue Sarcoma Cases in VA Patient Treatment File, Specially Solicited Research Projects, Agent Orange Registry, Monograph Series, Literature Review, and Women's Vietnam Veterans Health Study); and, Department of Defense (RANCH HAND Study, i.e., the Air Force Health Study).

Major General John E. Murray, US Army Retired, submitted the most controversial report to the AOWG in May 1986. General Murray, a US Army Records Expert, had been selected and tasked to examine the military records that were collected in anticipation of conducting the large epidemiological study of ground troops (Murray 1986). General Murray conducted a three-month long study of seven battalions that had been identified by the US Army and Joint Services Environmental Support Group. In his Final Report, he noted:

> ...the three-month long pilot study ...did produce invaluable facts that helped to clearly display the complexity of the problem, and to display the lack of preciseness to solve the problem. Accordingly the continuance of the study (i.e., the Ground Troop Study) is NOT recommended (Murray 1986).

Subsequently, Richard Christian, Director of the Environmental Support Group, testified to the Congress (House of Representatives) in July 1986 with the following concluding statement:

> Over the past three years the Military Services have been scrutinized, scrubbed, and critically examined by distinguished groups of experts, such as the National Academy of Science, the Science Panel of the White House Agent Orange Working Group, and most recently the Sub Panel on Agent Orange Assessment. The (military) records do not support continuance of the Agent Orange Epidemiological Study. We are proud of our exhaustive work (Christrian 1986).

The Executive Office of the President subsequently cancelled the Congressionally-mandated Agent Orange Study (Bowen 1988). Thus, in the ten years from 1979 through 1989, the US Federal Departments/Agencies committed vast sums of research funds and scientific expertise in addressing the health issues that were allegedly caused by exposure to Agent Orange (Bowen 1988; Gough 1987). Dr. Michael Gough, the Congressional Office of Technology Assessment concluded after reviewing the studies of the AOWG:

> The likely end of spending hundreds of millions of dollars on chasing after possible health effects of Agent Orange exposure in Vietnam will be results that show no adverse health effects. But for sure, the studies can't prove Agent Orange caused no health effects. It's impossible to prove a negative (Gough 1987).

Thus, the failure to clearly establish "cause and effect", i.e., never confirming that the herbicides had actually caused health problems in Vietnam veterans, resulted in the Congress of the United States and the President taking political action to address veterans concerns by passage of Public Law 102-4, the Agent Orange Act of 1991 (IOM 1994, Young 2002). For the Vietnam veteran, this political route provided a resolution to the debate of whether the government would assume responsibility for any related health impacts that might have been caused by exposure to military herbicides while on duty in Vietnam.

The Agent Orange Act of 1991 established procedures that the Department of Veterans Affairs must follow in deciding whether to create presumptions of service connection for disabilities suffered by Vietnam veterans that may be associated with exposure to Agent Orange or other herbicides in Vietnam. The procedure required that the Department of Veterans Affairs contract with the National Academy of Sciences' Institute of Medicine (IOM) to conduct reviews of the scientific literature on the health effects of exposure to TCDD, Agent Orange, and the other military herbicides (IOM 1994, 1996, 1998, 2000, 2002, 2004, 2006). In accordance with their findings, the Department prepared a list of conditions of disabilities that were "presumed" to be associated with herbicide exposure. For those veterans who served in Vietnam between 9 January 1962 and 7 May 1975, and have one or more of 11 diseases (on the current list), the Department must presume that they were exposed to herbicides and their disease service connected (Young 2002; DVA 2007).

Since the implementation of the Agent Orange Act in 1991, research has continued on the examination of historical military documents, procurement records, and on environmental fate and human studies (Young 2006; Hofmann and Wendelborn 2007; Hatfield Consultants 2007; Cecil and Young 2008). These studies have provided additional understanding of potential human exposure, and the environmental fate and impact of the use of tactical herbicides and TCDD in Vietnam. However, neither the various governments nor the scientific community have been able to resolve the numerous controversies involving the War in Vietnam, including the use of tactical herbicides. In part this may be due to the fact that the Agent Orange Controversy is really an issue that strikes at the fundamental concept of "quality of life"; and hence, science alone cannot resolve the controversy (Palmer 2004; Young 2008). Many veterans of the War returned from Vietnam with apprehensions that were manifested by fear of the unknown about how they were going to re-adjust back into a society that was rapidly changing in its social and economic values (Young 2008). Vietnam and Agent Orange are now public policy issues as well as medical and scientific issues. There are strong public policies favoring our veterans, and rightly so. The government should have acknowledged that many Vietnam veterans do appear to be at risk for a range of diseases and health problems due to the 'Vietnam experience' as a whole. Why focus on Agent Orange instead of on providing treatment and benefit for all these veterans? In hindsight, the government could have been fairer and more generous to all Vietnam veterans with such a program (Young 2004).

1.5 The Return to Vietnam

More than 30 years after its last use by American forces in South Vietnam, the controversy has now shifted primarily to delineating the potential impacts of Agent Orange and dioxin on the environment and people of Vietnam. From 3 to 6 March 2002, a joint United States-Vietnam Scientific Conference on Human Health and Environmental Effects of Agent Orange/Dioxins was held in Hanoi. It was co-sponsored by the US National Institute for Environmental Health Sciences (NIEHS) and the Vietnamese Ministry of Science, Technology, and the Environment (NIEHS 2002; Young 2002). The conference was organized under the auspices of the joint United States-Vietnam Cooperative Research Program on the Health and Environmental Effects of Agent Orange and Dioxin. Experts from throughout the world were invited to attend the conference. The conference had three goals:

- Exchange current scientific information on the health and environmental effects of Agent Orange/dioxin;
- Exchange current scientific information on remediation measures to reduce exposures to Agent Orange/dioxins in humans and the environment; and,
- Examine the current state-of-knowledge and identify future research needs (NIEHS 2002).

Scientists from the NIEHS, US Environmental Protection Agency (EPA), US Centers for Disease Control and Prevention (CDC), and the Vietnamese Ministry of Health held discussions in conjunction with the conference. These discussions were designed to establish a process for guiding research and obtaining funding for studies focusing on human health outcomes from exposure to dioxin, and the environmental and ecological effects of dioxin and Agent Orange. Following the scientific conference and joint discussions, the Director of the NIEHS Division of Extramural Research and Training and the General Director of the National Environmental Agency of Vietnam signed a Memorandum of Understanding outlining a framework for research to guide future joint collaborations. In his comments about the Memorandum of Understanding that was signed by both the U.S. and Vietnamese governments, the Honorable Raymond Burghardt, US Ambassador to Vietnam, stated:

> This agreement and the scientific conference that preceded it mark a new step forward in our relations with Vietnam. It is too soon to predict what the eventual benefits will be, but it is certain that Americans and Vietnamese working together in the pursuit of a common interest can achieve a great deal (NIEHS 2002).

The proposed framework envisioned the preparation and implementation of a broad-based research program that would be conducted in collaboration with Vietnamese and US scientists (Young 2002). However, following government-to-government discussions, the only project to be accepted and implemented by both parties was a project to investigate whether or not the former Tactical Herbicides Storage and Loading Sites in Southern Vietnam constituted a source of dioxin contamination to adjacent communities (Young and Andrews 2005). To initiate this project, the "1st Agent Orange and Dioxin Remediation Workshop" was held in Hanoi, Vietnam in August 2005, and a "2nd Agent Orange and Dioxin Remediation Workshop" was held in Hanoi in June 2007 (See Fig. 1.4) (Young and Andrews 2005; Young et al. 2008).

At the 2nd Workshop, the US Department of Defense presented to Vietnam's Ministry of National Defence (MOD) a special Report prepared by the United States Department of Defense on "The History and Maps of the Former Tactical Herbicide Storage and Loading Sites in Vietnam" (Young and

Fig. 1.4 A Photograph of many of the participants who attended the Agent Orange Workshop in Hanoi, Vietnam on 19 June 2007 (Photograph courtesy of Vietnam's Ministry of National Defence)

Andrews 2006). The Report provided: (1) Detailed information on the quantities of tactical herbicides used or spilled in Southern Vietnam; (2) Detailed information on the types and quantities of dioxins in Herbicide Orange; (3) Maps of the Air Bases used in Operation RANCH HAND and Operation PACER IVY detailing the sites where loading, storage and re-drumming operations had occurred; and (4) An update on remediation and environmental studies. At the request of DOD, the MOD provided: (1) Detailed results from analytical studies conducted in and around Da Nang Air Field; (2) Results of studies on the detoxification of dioxin in soil by an active landfill bioreactor; and, (3) Research data on adsorption efficiency of activated carbon for PCDDs/PCDFs from aqueous solutions. After each presentation, thorough discussions occurred.

Environmental informatics and spatial analysis methods that link various data have been crucial to the integrated assessments for this project. The information and approaches developed to evaluate residual risks from past use of tactical herbicides project are relevant to other ongoing research and remediation activities in Vietnam and other countries. Those efforts include programs for managing environmental dioxins and furans from other sources and managing other persistent organic contaminants (Young et al. 2008). Additional details of the current programs between the US and Vietnam are covered in Chapter 8.

1.6 Methodological Issues in Assessing Impacts

The most intense use of Agent Orange in South Vietnam occurred in the years 1967–1969. That time period coincided with the highest level of combat operations involving US ground forces. At that time, it was not possible for members of the scientific community to conduct thorough scientific field investigations at the sites where herbicides had been repeatedly sprayed, or even at bases where the herbicide operations originated (NRC 1974). Studies initiated under the auspices of the NAS starting in 1971, confronted these difficulties (NRC 1974). Indeed, in the 1974 letter transmitting the final NAS report to the Secretary of Defense and the US Congress, Dr. Phillip Handler, the President of the NAS at the time, noted:

> As we entered upon the task, some of its inherent difficulties were self-evident: appraisal of the effects of herbicide usage, necessarily, had to be taken well after the fact. Since the war in South Vietnam was certainly not conducted as a controlled experiment, valid conclusions might well be seriously constrained by the complexity of actual circumstances, by lack of adequate records or qualified observers on the scene at the time of the spraying program . . . separation of the effects of herbicides from all other aspects of the war would be difficult at best (NRC 1974).

Public discussion and scientific research have proceeded largely on the assumption, rather than a determination, of widespread substantial exposure to tactical herbicides and the associated dioxin to US and Allied Combat Forces and Vietnamese civilians during the Vietnam War. Does sufficient knowledge about the environmental fate of tactical herbicides and dioxin support the conclusion that allied ground troops and Vietnamese civilians could have been contaminated, if not by direct exposure, perhaps by entering previously sprayed areas (Young et al. 2004b)?

To address this question, a recent critical review was published on: "Environmental Fate and Bioavailability of Agent Orange and Its Associated Dioxin During the Vietnam War" (Young et al. 2004b). The findings were summarized:

> In-depth evaluations of the spray systems used to disseminate tactical herbicides in Vietnam showed that they were capable of highly precise applications both in terms of concentrations sprayed and area treated. Research on tropical forest canopies with leaf area indices (a measure of foliage density) from 2 to 5 indicated that the amount of herbicide and associated TCDD reaching the forest floor would have been between 1 and 6% of the total aerial spray. Studies of the properties of plant surface waxes of the cuticle layer suggested that Agent Orange, including the TCDD, would have dried (i.e., be absorbed into the wax layer of the plant cuticle) upon spraying within minutes and could not be physically dislodged. Studies of Herbicide Orange and the associated TCDD on both leaf and soil surfaces have demonstrated that photolyis by sunlight would have rapidly decreased the concentration of TCDD, and this process continued in shade. Studies of "dislodgeable foliar residues" (the fraction of a substance that is available for skin uptake from plant leaves) showed that only 8 percent was present 1 hour after application, and this dropped to 1 percent of the total, 24 hours after application. Studies with human volunteers confirmed that after 2 hours of saturated contact with bare skin, only 0.15–0.46 percent of 2,4,5-T entered the body and was eliminated in the urine. Moreover, serum TCDD levels in veterans claiming direct exposure to Agent Orange while conducting combat operations were no different than of veterans who never served in Vietnam (Young et al. 2004b).

The conclusion of the review was that the prospect of widespread prolonged exposure to TCDD from tactical herbicides in ground troops or Vietnamese civilians in Vietnam entering defoliated areas was unlikely in light of the environmental dissipation of TCDD, little bioavailability, and the properties of the tactical herbicides and circumstances of application that occurred.

Another question remained, would US and Allied combat ground troops and non-combat Vietnamese (Vietnamese civilians) have been intentionally exposed to tactical herbicides and any associated TCDD? To address this question a critical review was recently published on: "Assessing Possible Exposures of Ground Troops to Agent Orange During the Vietnam War: The Use of Contemporary Military Records" (Young et al. 2004a). The findings were summarized:

> The historical military records do not support the hundreds of examples of anecdotal information by individuals who claimed they were exposed to tactical herbicides and TCDD. Historical records documented that RANCH HAND spray missions were flown at tree top level and consequently were exposed to frequent and intense hostile fire. Therefore, fighter escorts accompanied nearly every tactical herbicide spray missions, often bombing and strafing the spray target to suppress hostile fire and protect the unarmed RANCH HAND aircraft. To prevent "friendly fire" casualties during these missions, military procedures mandated that a Forward Air Controller (FAC) arrive at the spray target in advance of the spray planes and fighter aircraft and direct the mission. The FAC was required to abort the mission unless he could confirm that there were no friendly forces in the area. The records confirmed that 80 percent of all RANCH HAND missions scheduled between 1966 and 1971 were cancelled or aborted because all the conditions required for the conduct of the mission were not met, including absence of friendly forces (Young et al. 2004a).

The conclusion of this review was that through detailed policies and procedures, the circumstances in which spraying of combat troops and non-combat civilians with tactical herbicides in Vietnam was closely managed to minimize this exposure [this is covered extensively in Chapter 3].

How then can the reports by Vietnam War veterans and Vietnamese civilians of repeated sightings of RANCH HAND aircraft spraying Allied Bases and associated Vietnamese communities be reconciled? In late 1966, the United States Air Force was instructed to modify RANCH HAND UC-123 aircraft to an insecticide-spray configuration. Operation FLYSWATTER commenced on 6 March 1967 (Cecil and Young 2008). From that date through February 1972, from one to three UC-123 aircraft and crews were used to spray malathion, an organo-phosphate insecticide, for mosquito and malaria control. The low-flying insecticide-spraying aircraft were commonly called the "Silver Bug Birds" because they normally were not camouflaged. 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 (Fig. 1.5). By 1970, malathion treatment was being applied to 14 airbases and their adjacent South Vietnamese cities, and the re-spray interval had been reduced from every fourteen days to every nine days (Cecil and Young 2008). Between 1966 and 1972, more than 3.5 million liters of malathion

Fig. 1.5 RANCH HAND UC-123 "Silver Bug Bird" Supporting Operation FLYSWATTER

insecticide were sprayed on approximately 6 million hectares of Southern Vietnam (Young et al. 2004a). Thus, anecdotal reports of direct spraying of troops and civilians in Vietnam likely reflected the RANCH HAND missions supporting Operation FLYSWATTER.

1.7 Overview of the Book

As noted earlier, the United States Department of Defense has had the major role in all military operations involving Agent Orange. This included its use in Vietnam, its disposition after Vietnam, its role in conducting long-term epidemiological investigations, or the sponsoring of ecological and environmental fate studies. This book was commissioned by the Department of Defense and is intended to provide a history of the tactical herbicides used in Vietnam, the military operations that occurred using those tactical herbicides, how were the surplus herbicides disposed of after the Vietnam War, and what have we learned of the environmental fate of the Agent Orange and TCDD in the years since the war. Specifically, the Department of Defense requested detailed information on the following:

- Summary of archival information and a detailed overview of the development, transport, handling, storage, and use of tactical herbicides, especially Agent Orange, by the US military in the former Republic of Vietnam during the Vietnam Conflict. The applicability of existing information about transport, handling, storage, and military use of herbicides in Vietnam is to identify potentially contaminated “hot spots” in Vietnam.

- Description of the removal of remaining stocks of Agent Orange from Vietnam and the Naval Construction Battalion Center (Gulfport, MS) and their final disposition using at-sea incineration off Johnston Island in the Central Pacific Ocean.
- A detailed accounting of the amount of tactical herbicides sprayed in the Vietnam War, and a description of the contaminant and the quantities of TCDD that may have been disseminated in Vietnam.
- The results of the environmental fate and ecological impact of the herbicides and the associated dioxin contaminant from studies conducted at Eglin AFB, Florida, from 1969 through 1983.
- The results of residue monitoring programs at Johnston Island and the Naval Construction Battalion Center following site cleanup after Operation PACER HO.
- The results of the US Department of Defense and Vietnam’s Ministry of Defence from the two Workshops held in Vietnam (2005, 2007) on Agent Orange and Dioxin Remediation.

Accordingly, Chapter 2 is a history of the development of tactical herbicides including a background on the sites where the tactical herbicides were tested and evaluated. Chapter 3 provides a detailed description of the military use of tactical herbicides in South Vietnam, including the procedures used by Allied Forces for the approval of defoliation missions, with an emphasis on the transport, handling, storage, and use of Agent Orange and the other tactical herbicides used in South Vietnam during the period from 1961 to 1971. Included in Chapter 3 are the military procedures that would have limited exposure of US and Allied combat troops to the tactical herbicides. Chapter 4 summarizes the removal of Agent Orange in Operation PACER IVY after the termination of its use in Vietnam. It also describes the military’s efforts to find a safe and effective method of destroying the remaining Agent Orange inventories in Operation PACER HO. Chapter 5 describes the new information available on the procurement and use of the tactical herbicides in Vietnam. Included in this discussion are statistical studies of new data on TCDD in 525 samples of Agent Orange and 577 samples of 2,4,5-T that were from production runs from five companies that produced Agent Orange over the years 1964–1969. Chapter 6 is a summary of the ecological and environmental fate studies of Agent Orange and its associated dioxin on Hardstand 7 and Test Area C-52 A, Eglin Air Force Base (AFB), Florida, the sites where the USAF developed and tested the spray equipment used in Operation RANCH HAND and by the Army Chemical Corps in Vietnam. Chapter 7 briefly reviews the residue monitoring studies conducted at the Naval Construction Battalion Center, Gulfport, Mississippi, and Johnston Island in the Central Pacific Ocean, after the destruction of the Agent Orange inventories in Operation PACER HO. Chapter 8 briefly describes the previous research conducted in Vietnam, the 2002

Joint US-Vietnam Conference, the issue of hot spots at the former Allied Air Bases where Operation RANCH HAND and Operation PACER IVY occurred, and the 2005 and 2007 Workshops on Agent Orange and Dioxin Remediation . Included in this chapter is an example of the maps of the seven bases where storage, loading, and re-drumming of tactical herbicides occurred that was presented to Vietnam's Ministry of National Defence in June 2007.

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Chapter 2
A History of the Development and Procurement of Tactical Herbicides

Since 1980, controversy has persisted over the locations at which the Department of Defense (DOD) may have used, tested or evaluated, the herbicides containing 2,4,5-T and its associated dioxin, and "other herbicides" used in the Vietnam War. Adding to the controversy is the confusion by the public, Vietnam veterans, and by the Department of Veterans Affairs as to the distinction between "commercial herbicides" purchased by the DOD and "tactical herbicides" developed by the DOD. Contrary to historical records, many individuals thought that commercially available herbicides were purchased directly from the chemical companies and deployed to the battlefields in Vietnam. However, the use of commercial herbicides was under the jurisdiction of the Armed Forces Pest Control Board (subsequently the Armed Forces Pest Management Board), Forest Glen Station, Walter Reed Army Medical Center, Bethesda, Maryland. The uses and application of commercial herbicides were the responsibilities of the Base Civil Engineers, while tactical herbicides were under the control of special military units (e.g., Army Chemical Corps, and the 7th Air Force's 12th Special Operations Squadron) specifically trained to handle and apply them in hostile military environments. The history of the military development and use of tactical herbicides dates to World War II. The lead agency in developing and testing these tactical herbicides was the US Army Chemical Corps Research Laboratories at Fort Detrick, Maryland. This Chapter describes the development and procurement of the tactical herbicides used in Vietnam.

2.1 Background

In early 2006, the Department of Veterans Affairs (DVA) requested that the Department of Defense provide: "an official compilation of locations and dates outside of Vietnam where the Department used herbicide agents, including Agent Orange, as well as locations and dates where DOD personnel were likely exposed to these agents." The intent of this request was to obtain information

A.L. Young, *The History, Use, Disposition and Environmental Fate of Agent Orange*, DOI 10.1007/978-0-387-87486-9_2,

that may be important in evaluating the merits of many veterans' disability claims. In response to the DVA request, the Office of the Under Secretary of Defense (Installations and Environment) commissioned the report "The History of the US Department of Defense Programs for the Testing, Evaluation, and Storage of Tactical Herbicides" (Young 2006). This report discussed the history of the development of the tactical herbicides, how they differed from commercial herbicides, and where they were tested, evaluated, stored, and used (in the case of Korea in 1968) **OUTSIDE** of Vietnam. Additionally, the report discussed the final disposition of Herbicide Orange after Vietnam. The report contained 32 leaflets identifying different locations or multiple locations involved in same projects (e.g., Leaflet 19 identified 5 locations in Texas), or the multiple use of a specific location (e.g. Eglin Air Force Base, Florida). A total of 40 distinctly different locations were identified. For each leaflet, a description of the activity was provided, an assessment was made of the activity, and where identified, the individuals involved in the project, and sources documented (Young 2006). The Department of Defense was thorough and detailed in the procedures for the safe and efficacious use of tactical herbicides in military operations.

2.2 The Initial Development of Tactical Herbicides

The period of use of tactical herbicides in the Vietnam War, 29 December 1961–31 October 1971, is a story that begins many years before Vietnam. It is really a history of the Department of the Defense's efforts to develop vegetation control methods that would have military applications. In 1943, the Department of the Army contracted the University of Chicago to study the effects of a new series of organic compounds, especially 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-triclorophenoxyacetic acid (2,4,5-T) on cereal grains and broadleaf crops (Irish et al. 1969). From that research came the concept of military applications of small quantities of such compounds to destroy enemy crops. Subsequently, in early 1945, the Army tested 2,4-D and 2,4,5-T formulations at the Bushnell Army Air Field in Florida (Carpenter 1945). That site is now a FUDS (**F**ormerly **U**sed **D**efense **S**ite) location for the Department of Defense. Although not used in World War II, the concept of vegetation control was not forgotten. In 1952, the Department of Army's Chemical Corps Biological Laboratories at Camp Detrick, Maryland, initiated a major program to develop both the aerial spray equipment and herbicide formulations for potential deployment in the Korean Conflict. Again, although not used in the Korean Conflict, the equipment that had been developed and tested, and the formulated chemicals were both stored on the Island of Guam until the end of the Conflict, after which the equipment was sent to Utah and the drums of herbicide were sent to Camp Detrick. Camp Detrick (now Fort Detrick) where the Army Chemical Corps scientists continued working on developing deployment systems and herbicidal materials through the 1950s (Irish et al. 1969).

2.2.1 Previous Research Supporting the Initial Deployment of Tactical Herbicides in Vietnam

The Tactical Herbicide Spray Systems (primarily fixed-wing, helicopter, and truck-mounted sprayers) developed from 1945 to 1959 were available to be tested in Vietnam in late 1961. Their successful use during the period from 8 October 1961 through 18 March 1965 (the Initial Program Development Phase in Vietnam) resulted in the United States Department of Defense approving a major combat role for tactical herbicides from 29 March 1965 to 7 January 1971 (the Operational Phase). The Initial Program Development Phase depended heavily on the limited research into both aerial spray systems and tactical herbicides that the United Army Chemical Corps had carried out from the end of World War II (1945) through 1959. Eight locations were identified and are briefly described below:

1. *Bushnell Army Air Field, Florida, February – April 1945*. The vegetation on a total of 155 hectares (382 acres) were evaluated following aerial applications of a 2% solution of 2,4-D and 2,4,5-T in tributyl phosphate and diesel fuel. The formulations were prepared at Fort Detrick and transported to Bushnell Air Field (Carpenter 1945; Norman et al. 1945; Young 2006).
2. *United States Department of Agriculture (USDA) Research Station, Brawley, California, July–August 1951*. In cooperation with USDA, the Army Chemical Corps evaluated formulations of 2,4-D and 2,4,5-T on small field plots of various agronomic crops in an effort to evaluate the anti-crop effectiveness of small droplet sprays of 2,4-D and 2,4,5-T (Weintraub and Minarik 1952; Young 2006).
3. *Eglin Air Force Base, Florida (Test Ranges 52 and 57), November 1952–April 1953*. In preparation for the potential deployment of anti-crop agents, the Air Force Armament Center evaluated a Large Capacity Spray System (MC-1 Hourglass System) in the B-29, B-50 and C-119 bomber aircraft spraying a mixture of technical normal butyl 2,4-D (50%), technical normal butyl 2,4,5-T (50%) prepared by the Army Chemical Corps. The spray tests were conducted on 3,520 hectares (8,700 acres) from an altitude of 300–600 m, releasing a total of 2,245 l (Acker et al. 1953; Ward 1953; Hanson, 1965; Young 2006).
4. *USDA Experimental Fields, Gallatin Valley, Bozeman, Montana, July–November 1953*. The US Army Chemical Corps evaluated small quantities of various 2,4-D and 2,4,5-T formulations as to their effectiveness as anti-crop agents against wheat. The tests were conducted on approximately 55 hectares of hard red spring wheat (Acker et al. February 1954a; Young 2006).
5. *Area B, Fort Detrick, Frederick, Maryland, June–July 1953*. US Army Chemical Corps scientists evaluated the 3:1 mixture of technical normal butyls of 2,4-D and 2,4,5-T on plots of soybeans and sweet potatoes by simulating tactical operational conditions by spraying from a 6-m tower mounted on a pickup (Acker et al. January 1954b; Young 2006).
6. *Fort Ritchie, Cascade, Maryland, April 1956–September 1957*. The US Army Chemical Corps evaluated 577 potential herbicidal chemicals, including both

phenoxy and arsenical formulations. The chemicals were applied by hand applications to small field plots (Preston et al. 1959; Young 2006).

7. *Dugway, Utah, May 1951–March 1959*. The US Army Chemical Corps and the US Air Force conducted a series of spray tests and evaluations from a variety of platforms including balloons, towers, light aircraft, and jet aircraft with a range of volumes from low volumes to large capacity spray tank volumes. Studies were conducted on the effects of altitude and airspeed on the various potential tactical herbicides (King and Ward 1961; Young 2006).
8. *Fort Drum, New York, May–October 1959*. In the summer of 1959, thirteen drums (2,700 l) of the Herbicide Purple formulation were aerially applied by helicopter to approximately 1,035 hectares of Fort Drum's deciduous forested areas. The US Army Chemical Corps conducted the test and the Herbicide Purple was surplus herbicide manufactured in the 1952 period (Brown 1962; Minarik 1964; Buckingham 1982; Young 2006).

Following the successful tests at Dugway, Utah and at Fort Drum in New York State, the US Army Chemical Corps determined that the capability of deploying tactical herbicides in a combat environment was possible (Buckingham 1982). The tests and evaluation of the herbicides had resulted in the selection of formulations of 2,4-D and 2,4,5-T as defoliants, and of the organic arsenicals as potential anti-crop herbicides, especially against grains (e.g., rice). The selection of the appropriate aircraft and the training of the aircrews would depend upon the mission (Cecil 1986). The role of the Air Force Special Aerial Spray Flight, the Air Force Unit responsible for the aerial spraying of insecticides, and its adoption and modification of the C-123 "Provider" as the aircraft of choice containing the 1,000-gal MC-1 Hourglass Large Capacity Spray Tank and pump systems, has been extensively described (Buckingham 1982; Cecil 1986).

Cecil described the deteriorating situation in Indochina, and the decision by President John Kennedy in May 1961 to jointly establish the United States/Vietnamese Combat Development and Test Center (CDTC) in Vietnam, under the direction of the Defense Department's Advanced Research Projects Agency (ARPA) (Cecil 1986). The first task of the CDTC was to evaluate the use of herbicides to destroy concealing vegetation and enemy food supplies (Project AGILE) (Cecil 1986). To undertake this task in 1961 meant that the men, equipment, and chemicals had to be rushed to Vietnam to take advantage of the growing season, which would end in September or October. As Cecil described it: "...much of the equipment used in the initial tests was 'what was available,' rather than 'what was ideal'" (Cecil 1986).

2.2.2 *The Selection of the First Tactical Herbicides for Use in South Vietnam*

Under Project AGILE, the Department of Army's Biological Laboratories at Fort Detrick, Maryland were given the responsibility to determine the technical feasibility of defoliating jungle vegetation in South Vietnam. The Fort Detrick scientists had been involved in 1957 with tests showing the herbicidal activity of cacodylic acid (an organic arsenical) on rice and grasses, and in the 1959 aerial applications tests with mixtures of 2,4-D and 2,4,5-T at Camp Drum, New York (Darrow et al.1966). As part of Project AGILE, a contract was negotiated in 1962 with the Institute for Defense Analyses, Washington DC to do an in-depth analysis of the available literature on "Chemicals for Control of Vegetation" (Coates and Sharpe 1963). The Institute concluded that the selection of chemicals should be evaluated on the basis of plant physiology (how they physiologically affect the plant); on the basis of health and safety; and, on performance characteristics of commercially available phytoactive chemicals (Coates and Sharpe 1963). The Institute identified five principal military applications for anti-vegetative agents:

- Roadside clearance to reduce ambush,
- Boundary demarcation,
- Vegetation control in depot areas,
- Area denudation to uncover selected targets and to reveal enemy hideouts, and
- Aquatic weed control (Coates and Sharpe 1963).

They reasoned that three distinct phytochemical activities were required, namely the rapid reduction in foliage by desiccation; the systemic herbicidal activity to kill the plants; and residual herbicidal action in the soil to prohibit or retard growth. They concluded that no single herbicidal agent would bring about all three effects; it was essential to consider the use of mixed or formulated herbicides, applied together or successively (Coates and Sharpe 1963).

As a result, the tentative choice of tactical herbicides for use in Vietnam was based upon proven performance in both military and commercial situations, availability in large quantity, costs, and known or accepted safety in regard to their toxicity to humans and animals (Irish et al.1969). Figure 2.1 illustrates the use, extent, and importance of 2,4,5-T herbicide for the control of brush on communication right-of-ways in the US. Simultaneously, the Army Chemical Corps at Fort Detrick were investigating research into the disseminating characteristics affecting aerosol stability (Trout 1962). Studies of the evaporation rate of n-butyl 2,4-D represented the first work of this nature performed on this herbicide. This research provided critical information as to the size of particles that would be required if the aerial spraying of n-butyl formulations of the phenoxy herbicides were to be effective as defoliants (Trout 1962).

On 10 August 1961, as part of Project AGILE, Fort Detrick personnel initiated defoliation tests in South Vietnam (Brown 1962). Stocks (10 drums–1,900 l) of the commercial herbicide "Dinoxol" had arrive on 17 July 1961. It was the first herbicide to be evaluated. It was aerially sprayed using an H-34 helicopter equipped with the HIDAL (Helicopter Insecticide Dispersal Apparatus, Liquid) system. Dinoxol consisted of 20% 2,4-D as the butoxy ethanol ester, and 20% 2,4,5-T butoxy ethanol ester. On 4 September 1961,

Fig. 2.1 Clearing of lines of communication. The effectiveness of 2,4,5-T Herbicide is shown in these two photographs taken in 1959 before and six months after application with a commercial ester formulation of 2,4,5-T (Photographs courtesy of The Dow Chemical Company, Midland, Michigan)

2,025 l of "Trinoxol" (40% 2,4,5-butoxy ethanol ester) arrived and was immediately evaluated (Brown 1962). On 20 November 1961 Pink, Green, and a powdered formulation of Blue (Ansar) arrived. The first shipment of Purple arrived on 9 January 1962 (Brown 1962). Between 10 August 1961 through 3 February 1962, 18 tests were conducted using the six different herbicide formulations. Tests conducted after 9 January 1962 involved the use of modified C-123aircraft deployed to Vietnam under the code name "Operation RANCH HAND" (Brown 1962; Cecil 1986) At the conclusion of the tests, the recommendation was that Purple, Pink, and Green should be used the tactical herbicides of choice for large scale use (Brown 1962).

In 1950, more than 4.5 million kilograms of the phenoxy herbicides were used annually for weed and brush control in the United States. By 1960, in excess of 16 million kilograms were used (Peterson 1967). Thus, it was not surprising that the first tactical herbicides to be used in Vietnam were based on the research, testing, and evaluations of 2,4-D and 2,4,5-T formulations (Crafts 1968).

As noted, the first three tactical herbicides deployed for use in Vietnam were code named Herbicides Purple, Pink, and Green, all of which contained 2,4,5-T.

As noted from Table 1.1, Chapter 1, 365 drums (75,920 l) of Herbicide Green; 1,315 drums (273,520 l) of Herbicide Pink; and 12,405 drums (2,580,240 l) of Herbicide Purple were used in Vietnam from late 1961 through mid-1965 (Young et al. 2008). The fourth tactical herbicide deployed to South Vietnam was a powdered commercial formulation of cacodylic acid (or Ansar 138®).

Herbicide Purple was first formulated in early 1950s in anticipation of use in the conflict in Korea and the possible need for vegetation-control systems. Purple was selected as the agent of choice in 1951, and by 1952 the first spray device, the MC-1 or Hour-glass System was released for prove out and acceptance testing. During 1953 operational capability was completed and the herbicide and spray system was deployed to Guam for anticipated use in the Korean Conflict, although it was never used. At the close of the Korean Conflict (1955) much of the stockpile of Purple was disposed of and the spray units placed in storage (Irish et al. 1969). Purple was approved for military procurement on 27 January 1953 (Department of Army, 1970). Purple was formulated to contain 1.04 kg/l of the active ingredients 2,4-D (510 g/l) and 2,4,5-T (530 g/l) (Darrow et al. 1966). The percentages of the formulation were:

n-butyl 2,4-D 50%
n-butyl 2,4,5-T 30%
iso-butyl 2,4,5-T 20%

Although the records were not complete, it appeared that in 1961 at least a portion of remaining stocks of Purple removed from Guam in 1955 and stored at Fort Detrick were sent to Eglin AFB, Florida, for use in the test and evaluation programs of the spray equipment for use in Vietnam (Young 1974). Subsequent Purple was purchased in FY (Fiscal Year) 1961–FY 1964 (calendar year 1962–1965) for use in Vietnam.

Herbicide Pink was a formulation of 2,4,5-T used extensively in the early RANCH HAND operations (Brown 1962; Collins 1967), and in the defoliation test programs of 1963 in Thailand (Darrow et al. 1966). Pink was formulated to contain 971 g/l active ingredient 2,4,5-T. The percentages of the formulation were:

n-butyl 2,4,5-T 60%
iso-butyl 2,4,5-T 40%

The first mission spraying Herbicide Pink was on 29 December 1961 “(the first use of an approved ‘tactical herbicide.’)” A C-47 aircraft with modified spray equipment was used to spray the herbicide north of Route 15 between Bien Hoa and Long Thanh. Three passes over a test site disseminating a total of almost 200 l of concentrated Pink formulation resulted in a rating of “poor” (Brown 1962). It appeared that the deposition was sublethal, and although the swath was visible in the first week, it failed to develop with time (Brown 1962).

Herbicide Green was a single component formulation consisting of the n-butyl ester of 2,4,5-T. It was used in limited quantities in 1962. Green contained 971grams/liter active ingredient 2,4,5-T [Brown 1962]. After arrival of the Green Herbicide in November 1961, apparently all of it was mixed with Pink or Purple and used in early RANCH HAND missions [Brown 1962: Darrow 1967].

Herbicides Purple, Pink, and Green were shipped to Vietnam (Tan Son Nhut, RVN) in 208-liter drums. To distinguish the herbicides, a 30-cm color-coded band was painted around the center of each drum. Unfortunately, the pink and purple bands were hard to distinguish between each other, especially after they had been stored in the open and in a tropical environment. Consequently, early RANCH HAND mission records frequently misidentified Pink and Purple (Darrow 1967; Cecil 1986). This confusion continued when the HERBICIDE REPORTING SYSTEM, HERBS, was implemented in 1970.

First Herbicide Blue was a powdered form of a commercial formulation of cacodylic acid known as "Ansar 138®". Approximately 6,800 kg of Ansar arrived in Vietnam on 20 November 1961. Water was required to prepare the formulation for spraying (estimated total volume with the 6,800 kg was 95 drums). The first mission of powdered Blue was 29 December 1961 and it was sprayed from a Buffalo Turbine at 10 km/h along a single-track road near an airstrip 6 km from Long Thanh (Brown 1962). The Blue Herbicide caused responses that indicated a relatively rapid desiccation of the foliage to an extent that warranted an aerial release (Brown 1962). The commercial formulation of Ansar 138® was an arsenical herbicide containing 65.6% cacodylic acid, and was manufactured by the Ansul Company, Marinette, Wisconsin.

These four tactical herbicides were used during the period from 29 December 1961 through 18 March 1965 (the Initial Program Development Phase in Vietnam). This period was a time when the aircrews of Operation RANCH HAND had the opportunity to become familiar with the weather and terrain of South Vietnam, and for developing the operational tactics and doctrine (Cecil 1986). It was period for evaluating and upgrading the aircraft and the spray systems that were constantly being developed and tested at Eglin AFB, Florida. It was also a time of deciding how missions would be assigned and how the aircraft and crews would be protected from the increasingly hostile ground fire encountered during the missions. As Cecil noted:

> At the beginning of 1964 the herbicide concept was merely a small adjunct of questionable value to the US effort in Vietnam. By the end of the year the RANCH HAND mission was not only accepted by the military but eagerly sought after, with sortie demands exceeding capacity. While not all questions had been answered, or all problems solved, the foundation for continued development had been laid. Western public comment had been negligible, and the outburst of scientific and lay criticism of the herbicide program was still in the future; 1964 had been a year of development and preparation for continued growth (Cecil 1986).

The role of the United States changed during 1965 from an overt role of training and supplying the South Vietnamese armed forces to a direct combat participation on a major scale (Cecil 1986). This action resulted in the United States Department of Defense approving a major combat role for tactical herbicides, namely the "Operational Phase" of Operation RANCH HAND, a phase that started on 29 March 1965 and ended on 7 January 1971. In anticipation of a potential major operational role for tactical herbicides, the US Army Chemical Corp never faltered in its planning and preparation for that mission.

2.3 The Defoliation Conferences

In 1962, the US Army Chemical Corps' Biological Laboratories at Fort Detrick, Maryland invited "essentially" the entire pesticide industry to Fort Detrick and briefed them on the technical and contract aspects of a Military-Industry Defoliation Program. The intent of this military-industry contract partnership was to "demand of industry its ability, creative ideas, facilities, and the competence of its scientific and engineering disciplines to achieve the results needed in the shortest possible time", i.e., to develop chemicals that could attack vegetation in order to destroy the cover and concealment of enemy combatants in South Vietnam (Hayward 1964). The desired characteristics of an effective defoliant were the following:

- Broad spectrum of activity: the agent should be active on many kinds of plants and vegetation with emphasis on woody species;
- Rapid in action: the physical changes that result in defoliation or leaf abscission must take place within a three-day period;
- Suitable for application with air or ground equipment: Agent should be preferably in liquids of high concentration;
- Nontoxic to man and animals: compounds of moderate or high toxicity may be included in the screening program on the basis that highly favorable candidates may be modified though formulation or other methods to minimize hazards of toxicity;
- Stable in storage: light-sensitive compounds or other unstable chemicals should be examined, since suitable formulations of such compounds that are found to be active may insure stability;
- Effective in low dosages: screening programs have shown a number of synthesized compounds to have high activity as defoliants, desiccants, and herbicides at 112 g/ha;
- Inexpensive: cost should not be a factor in the initial consideration of candidate compounds;
- Readily available or capable of manufacturers: complexity of initial synthesis efforts should not eliminate consideration of a candidate chemical; and
- Noncorrosive: Some of the more active commercially available desiccants require special handling in current application equipment. Proper formulation may eliminate such hazards of corrosive action on equipment (Darrow 1965a).

In late July 1963, Fort Detrick sponsored the First Defoliation Conference. Industrial researchers from American Cyanamid, Ansul Chemical Company, Dow Chemical Company, Ethyl Corporation, FMC Corporation, General

Aniline & Film Corporation, Hooker Chemical Corporation, Monsanto Research Corporation, Pennsalt Chemicals Corporation, and US Rubber Company participated and many of them presented their laboratory, greenhouse, and field studies (as available) of potential candidate defoliants (Mattie 1964). Ansul Company presented their program on the synthesis and preparation of arsinic acids (Ehman 1964). The Dow Chemical Company presented a paper on "Tordon Herbicide for Vegetation Control." describing Dow's results from Tordon (picloram) field studies conducted at Davis, California; at Greenville, Mississippi; and, at Midland, Michigan (Wiltse 1964). Field experiments indicated that as a spray picloram was 4 times was more effective on a kg/liter basis than 2,4,5-T and 2,4-D on a number of woody plants, and as a soil treatment picloram was 8 times more effective on a kg/hectare basis than Fenuron. Moreover, the toxicological studies conducted by Dow indicated that picloram herbicide was safe to handle and presented no hazards to men or animals when used as directed (Wiltse 1964). These data greatly interested the researchers from Fort Detrick.

The following year at the Second Defoliation Conference in August 1964, three research projects involving picloram were presented and discussed. The first project was a presentation by The Dow Chemical Company on the "Effects of Tordon on Crops" (Watson and Barrons 1965). The results showed that picloram was highly injurious when applied to nongraminaceous crops, i.e., such broadleaf crops as manioc and sweet potato, and at doses far below those required for significant yield reductions from 2,4-D and 2,4,5-T. Moreover, soil residual tests confirmed that the effects of piclorm were evident for nine weeks after soil applications (Watson and Barrons 1964). The second research project was a presentation by the Agricultural Research Service, United States Department of Agriculture (USDA) under contract to the Army Chemical Corps, on "Control and Defoliation of Vegetation" (Klingman 1965). This research involved field trials of candidate herbicides including picloram that had been applied to field plots in October 1963 in Livingston and Llano, Texas, and to forest plots in Guanica, Maricao, and Luquilla, Puerto Rico. In Texas and in Puerto Rico, the potassium salt of picloram provided the highest overall defoliation following aerial applications at rates of 2.25 or 2.5 kg/ha (Klingman 1965; Tschirley 1968). Fort Detrick's Crop Division presented the third project. It involved the use of the candidate defoliants on field plots of broadleaf trees on Fort Ritchie and Fort Meade (both in Maryland), and field trials in Georgia (approximately 26 ha of powerline right-of-ways) and Tennessee (approximately 26 ha of Tennessee Valley Authority powerline right-of-ways) (Demaree 1965). The picloram formulations included Tordon (potassium salt), Tordon + 2,4-D, Tordon + diquat, and Tordon + endothal. Excellent results were obtained with Tordon + 2,4-D (subsequently labeled as Tordon 101 containing the triisopropanolamine salt of picloram and 2,4-D) (Demaree 1965).

The first evaluation of "Orange Herbicide" occured in the 1963 field trials at Fort Ritchie, Maryland (Demaree 1965). Herbicide Purple and a liquid formulation of cacodylic acid were also included in these tests (Demaree 1965).

Subsequently, Herbicides Orange and Purple were included in the tests in Georgia, Tennessee, and in field tests in Maryland (Demaree 1965). The Maryland tests were conducted at Aberdeen Proving Grounds, and their purpose was to test the seasonal variations of five different formulations of proposed tactical herbicides, including Herbicides Orange, Purple, picloram (Tordon 101), and cacodylic acid (Phytar 560, subsequently "Tactical Herbicide Blue") (Demaree 1965). While Fort Detrick was conducting these tests in the United States, arrangements were made with the Thai government to conduct some defoliation tests on the Pranburi Military Reservation in Thailand. During the period from April through September 1964, approximately 435 l of Purple, 165 l of Pink, and 60 l of Blue were aerially sprayed on approximately 70 ha of the Pranburi Reservation (Darrow 1965b; Young 2006). The evaluation of these tests 6 months after application confirmed that the 2,4-D/2,4,5-T combinations of butyl esters were superior to other herbicides, although Blue was an effective rapidly acting desiccant (Darrow 1965c).

The Third Defoliation Conference was held in August 1965 and the presentations focused on the successful field trials in Maryland, Georgia, Tennessee, Texas, and Puerto Rico (Mattie and Darrow 1966). The effectiveness of Tordon 101 to kill white pine, short-needle pine, and scrub pine but not damage red cedar or cause permanent damage to ash, hickory, or rhododendron provided amply justification to move this formulation into the category of a "Tactical Herbicide" and to receive the name "Herbicide White" (Young 2006). The consequence of this action removed Tordon 101 from receiving a "Federal Specification" (issued by the General Services Administration) that would have allowed US Air Force, Army, or Navy Installations to purchase the herbicide for use on military lands. Instead, Tordon 101 received a "Military Specification" that allowed the Department of Defense (via the Defense Supply Agency) to directly purchase the herbicide for use **ONLY** in combat operations in South Vietnam. The selection and use of the tactical herbicides were exempt from USDA regulatory oversight, or from the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) (Young 2006).

Of particular importance, the Agricultural Research Service scientists studied the penetration and distribution of herbicide sprays through forest canopies in Texas and Puerto Rico (Tschirley 1968). Although the two areas were widely separated geographically, the forests were similar in terms of structure. The test site in Puerto Rico was typical of moist forest formations. The lowest level of vegetation ranged from 2 to 3 m; the intermediate level had a mean height of 9 m; and, the upper canopy had a mean height of >15 m. In Texas, the forest had a dense and relatively unbroken over-story of post and blackjack oak about 12 m in height. The youpon undercanopy also was dense and relatively unbroken and was about 5 m in height. The volume of spray reaching lower sampling levels varied proportionally with the amount deposited on the top line above the canopy. On the average, about 21% of the spray volume penetrated the upper canopy and about 6% penetrated to the ground level in the experiments conducted in Texas and Puerto Rico (Tschirley 1968).

With the selection of the new "Tactical Herbicides White and Blue", the US Air Force Air Development and Test Center at Eglin AFB, Florida initiated tests evaluating the aerial dispersal characteristics of the herbicide, and its compatibility with the UC-123 aircraft and the AA 45Y-1 Internal Defoliant Dispenser (Flynn 1964). These tests involved the spraying of more than 75 drums of Herbicide White (15,780 l), containing 1,020 kg active ingredient picloram, and 80 drums (16,640 l) of Herbicide Blue containing 6,180 kg of cacodylic acid (Young 1974). Additional tests at Eglin AFB showed that 87% of the herbicide impacted the glass plates on the test array within one minute and within or near the spray swath (Harrigan 1970). The remaining 13% of the herbicide took longer (up to 3 min) to settle due to vortices at the wing tips, drift, or evaporation (Harrigan 1970). Bio-monitoring around the test site confirmed that little lateral movement as spray drift occurred (Young 1974).

Although the decision to accept picloram as a component of a tactical herbicide (Tordon 101 as Herbicide White) occurred in late 1965, the Director of the Fort Detrick Biological Laboratories still had concerns. In a July 20th, 1966 note, Dr. C.E. Minarik stated:

> Picloram, the proprietary component of Tordon 101, is a very active herbicide and in experiments conducted by the Crops Department personnel has proved to be as active as or more active then phenoxy type herbicides on a pound for pound basis.
>
> However, the lack of data on the effectiveness of Tordon 101 mixture, at low volume rates, the higher costs per acre, and its slow response raise doubts as to the advisability of recommending its use on an operational scale in RVN at the present time. Additional R&D is required and is being conducted by Crops Department personnel during the current season. Preliminary results should be available in September 1966 and final results by June 1967 (Minarik 1966).

Thus as directed, the 1966 defoliation tests at Base Gagetown, New Brunswick, Canada involved the evaluation of the Tordon 101 formulation (White), Tordon 22 K (potassium salt of picloram), and formulation M-2993 (a 1:4 mixture of the isooctyl ester of picloram + the propylene glycol butyl ether ester of 2,4,5-T) in various combinations and rates. The tests also included different rates of Phytar 560 (liquid cacodylic acid formulation). In the 1967 tests, picloram was combined with paraquat or diquat. In general, the presence of picloram enhanced the defoliation performance of the 2,4,5-T, the 2,4-D, the paraquat, or the diquat (Demaree and Greager 1968; Demaree and Haws 1968). The 1966 tests at Base Gagetown also included the tactical herbicides Purple and Orange. In 1966, approximately 1 drum (~200 l) of Purple and 1 drum of Orange (~200 l), and a combination of 70% 2,4-D and 30% 2,4,5-T (~190 l) were sprayed on duplicate plots ranging from 9 to 28 l/ha (Demaree and Creager 1968). The 1967 tests at Gagetown involved the spraying of Herbicide Orange at 28 l/ha on duplicate plots for a total of ~ 70 l (Demaree and Haws 1968).

In July 1966, the newly named "Plant Sciences Laboratories" at Fort Detrick initiated a comprehensive short-term project to evaluate desiccants and herbicidal mixtures as rapid-acting defoliants. The tests included 9 different desiccants including the tactical herbicide Blue, and a mixture of systemic herbicides including the two tactical herbicides Orange and White (Darrow et al 1971). The tests were conducted on lands at Fort Gordon near Augusta, Georgia; Fort Chaffee and Fort Smith in Arkansas, and on Forest Service lands in the Apalachicola National Forest near Sopchoppy, Florida (Darrow et al 1971). The results confirmed the choices of Blue, White, and Orange as tactical herbicides. In the 1967 defoliation tests on the Island of Kauai, Hawaii similar observations were obtained (Suehisa et al 1968; Young 2006).

During the three years spanning the three "Defoliation Conferences, ten primary contractors (Table 2.1) supplied 6,535 compounds for the defoliation screening program (Frank 1966). The assay plant used in the "Primary Defoliation Screening" was the 14-day-old Black Valentine bean. To be classed as "active" in the test, a compound had to exhibit herbicidal activity within 14 days after treatment with rates from 0.112 to 1.12 kg/ha.

The "Secondary Defoliation Screening" was conducted on seven species of 2- to 3-year- old seedling trees (Fig. 2.2) (Frank 1966). The hand applicator used in the initial screening test was a specially calibrated hand sprayer (Fig. 2.3).

The goal in these programs was the search for rapid-acting defoliants and desiccants that were active at low rates on all vegetation types (Frank 1966). Desiccants were usually evaluated on grass plots (Fig. 2.4) (Frank 1966).

The next step for the most successful defoliant or desiccant candidates was from the screening programs to the numerous field tests conducted throughout the United States, Puerto Rico, Canada, and Thailand, as previously noted.

Table 2.1 Number and percentage of chemicals from synthesis contracts active in "primary defoliation screening" (Frank 1966)

	Compounds		
Contractor	Number submitted	Number active on beans	% Active
American Cyanamid Company	56	10	18
Ansul Chemical Company	82	45	55
Dow Chemical Company	129	5	4
Ethyl Corporation	1,303	170	1
FMC Corporation	175	59	34
General Aniline & Film Corporation	67	16	24
Hooker Chemical Corporation	128	43	34
Monsanto Research Corporation	2,183	331	15
Pennsalt Chemicals Corporation	2,288	382	17
US Rubber Company	124	20	16
Total	6,535	1,081	

Fig. 2.2 The "Secondary Defoliation Screening" was conducted on 2- to 3-year-old on Norway Spruce, Eastern Hemlock, Chinese Elm, Black Locust, Red Maple, Pin Oak, Scotch Pine, and California Privet (Frank 1966). Photograph of the Seedling Nursery, Fort Deterick, Frederick MD in 1970 (photograph courtesy of A. Young)

Fig. 2.3 A 1970 photograph of the hand applicator used in the initial defoliant screening tests at Fort Detrick. The sprayer was a specially calibrated unit capable of delivery less than 0.1 kg/ha of candidate defoliants (photograph courtesy of A. Young)

Fig. 2.4 The screening at Fort Detrick of rapid acting desiccants was accomplished in small test plots of various grains and grasses (1970 photograph courtesy of A. Young)

2.4 The Major Three Tactical Herbicides Used in Vietnam

All of the field tests and evaluations ultimately resulted in the decision by both the US Army Chemical Corps' Plant Sciences Laboratories, and the US Air Force Logistics Command's San Antonio Air Materiel Area to select and purchase for use in Vietnam the tactical herbicides Orange, White, and Blue (Irish et al. 1969; Craig 1975).

Herbicide Orange was a reddish-brown to tan colored liquid, soluble in diesel fuel and organic solvents, but insoluble in water (Irish et al. 1969]. One liter of Herbicide Orange theoretically contained 510 g of the active ingredient of 2,4-D and 530 g of the active ingredient of 2,4,5-T, for a total of 1.04 kg/l. Herbicide 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 as follows:

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%

Herbicide Orange was first introduced in South Vietnam 1 March 1965 when it was used to defoliate portions of the banks of the Saigon River from the capitol city to the South China Sea (Cecil 1968). In 1986, the demand for and use of Herbicide Orange outstripped the ability of the US Department of Defense to purchase it. Part of the problem was the availability of the n-butyl formulation; hence “Orange II” (two Orange 7.6-cm bands around the drum, while Orange had a single 7.6-cm band; the band width changed from 30 to 7.6 cm with the purchase of herbicides in FY 1964 (Young et al. 1978). The physical, chemical, and toxicological properties of Orange II were similar to those of Orange with the difference being the substitution of the iso-octyl ester of 2,4,5-T in Orange II for the n-butyl ester of 2,4,5-T in Orange. While Orange was formulated to contain 1.04 kg/l active ingredients 2,4-D and 2,4,5-T, Orange II was formulated to contain 0.911 kg/l (510 g/l 2,4-D, and 410 g/l 2,4,5-T) (Department of Army 1970). Thompson-Hayward, Kansas City, Kansas, was the only company to produce Orange II. Approximately 3.6 million liters of Orange II were shipped to South Vietnam during 1968 and early 1969 (Craig 1975).

Herbicide White was a dark brown viscous liquid that was soluble in water but insoluble in organic solvents and diesel fuel (Irish et al. 1969). One liter of Herbicide White contained 65 g of the active ingredient of 4-amino-3,5,6-tricholorpicolinic acid (picloram) and 240 g of the active ingredient of 2,4-D. Herbicide White was formulated to contain a 1:4 mixture of the triisopropanopamine salts of picloram and 2,4-D. The percentages of the formulation were as follow:

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

Limited quantities of “White”, developed by Dow Chemical Company, arrived in Vietnam in December 1965 for evaluation. A mid-1966 shortage of Orange forced the use of large quantities of White by RANCH HAND before the Army Chemical Corps evaluations were completed, although the White was both slower acting and more expensive than Orange (Cecil 1986).

Herbicide Blue was first applied to a powdered cacodylic acid that contained 65% active cacodylic acid and 30% sodium chloride. It was mixed with water in 208-l drums prior to application [Darrow et al. 1966]. Herbicide Blue was a foliage-applied contact herbicide (desiccant) that was first tested by Fort Detrick scientists in 1955–1957 for its effectiveness against rice and other grasses (Department of the Army 1970). In late 1965, the first liquid formulation of sodium cacodylate as Herbicide Blue was procured and sent to Vietnam, and subsequently used in defoliation missions in January 1966 (Department of the Army 1970) The liquid formulation was a commercial product developed by Ansul Company as identified as Phytar 560. The purchase of this formulation with the additional surfactant identified it as “PHYTAR 560G”, and as a tactical herbicide with a “Military Specification” (Young and Wolverton 1970). Herbicide Blue was a clear yellowish-tan liquid that was soluble in water, but insoluble in organic solvents and diesel fuel (Irish et al. 1969). One liter Blue contained 370 g of the active ingredient hydroxydimethyarsine oxide (cacodylic acid). Herbicide 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 as follows:

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

The liquid formulation contained 15.4% of arsenic in the organic pentavalent form, a form of arsenic having low mammalian toxicity and rapidly "inactivated" by the clay and organic matter in the soil (Cullers et al.1976).

As previously noted, colored bands were painted around the centers of the 208-l drums in order to allow support personnel to readily identify the specific herbicide contained in the drums (Irish et al. 1969). Prior to March 1965, a 30-cm band was used. Subsequently, all herbicide drums were marked with a 7.6-cm color-coded band. Storage tanks were similarly color-coded by painting them for identification. Figure 2.5 shows the storing and labeling of Herbicide Orange for shipment to South Vietnam.

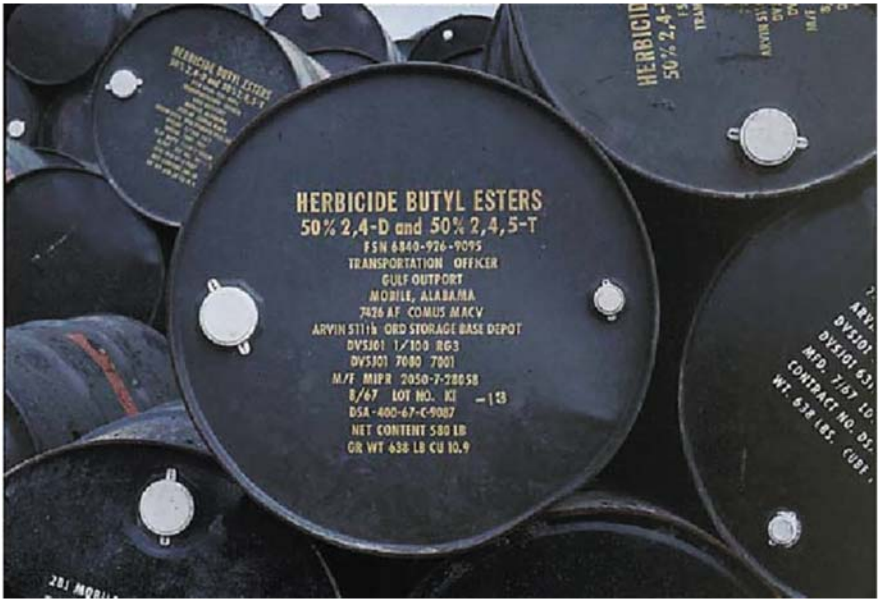

Fig. 2.5 A shipment of Herbicide Orange in 208-l drums. The lid (*top*) of each drum specified the content (Herbicide Butyl Esters of 2,4-D and 2,4,5-T), the Federal Specification Number (FSN), US Port of Embarkation (Mobile, Alabama), destination (ARVN 511th Ordinance Storage Depot, Da Nang, Vietnam), procurement information (including date, 8/67), and net weight. Each of the 11 different companies that manufactured military herbicides packed them in new 208-l 18 gauge steel drums for shipment to Southeast Asia. Each herbicide drum was also marked with a 7.6-cm color-coded band around the center to identify the specific military herbicide (Photograph courtesy of A. L. Young)

2.5 Physical Properties, Handling and Safety Evaluations of the Tactical Herbicides

In anticipation of the deployment of the tactical herbicides, Fort Detrick initiated tests on the physical properties of the normal butyl esters of 2,4-D, 2,4,5-T, and Orange Herbicide (Henson 1965). In the storage, transport, and dissemination of the tactical herbicides the knowledge of such properties as the temperature-viscosity correlation, specific heat, freezing point, surface temperature, thermal conductivity, and flow characteristics are important as to how the materials will be used (Henson 1965). The Physical Sciences Division of the Directorate of Biological Research conducted the study of Orange Herbicide for the above parameters in early 1965. The results indicated that Orange Herbicide would be compatible with the UC-123 RANCH HAND aircraft and both the MC-1 Hourglass, and the A/A45Y-l Internal Defoliant Dispenser Systems as well as with the Helicopter HIDAL Spray System (Boyer and Brown 1964; Henson 1965; Scheidecker 1966). Similar evaluations were conducted for both White and Blue (Irish et al. 1969).

The toxicology of 2,4-D and 2,4,5-T have been determined and re-determined numerous times and extensively published beginning with evaluations in 1954 (Rowe and Hymas 1954). In 1967, the Plant Sciences Laboratories prepared a document on the toxicity of the herbicides in use in Vietnam (Minarik and Darrow 1967). At least three major comprehensive reviews have been conducted on the toxicology and human risks of the phenoxy herbicides (Young et al. 1978; Bovey 1980; Lavy 1987). Comprehensive reviews of the toxicology of cacodylic acid were published in 1965, 1967, and 1985 (Bailey and White 1965; Frost 1967; Hood 1985). A review of the public health implications of the widespread use of picloram was published in 1971 (Johnson 1971). A more comprehensive assessment of the health risks of herbicides in forestry, including picloram, 2,4-D and 2,4,5-T was conducted by Oregon State University (Walstad and Dost 1984). The literature studies conducted by the Midwest Research Institute on the safety and the ecological consequences of the repeated use of herbicides in South Vietnam concluded:

> The possible toxic hazards involved in the aerial spraying of herbicides in Vietnam are of concern to scientists and to the public.... After examining the voluminous toxicity data and the actual rates at which these chemicals have been applied we can make the following observations: (1) the direct toxicity hazard to people and animals on the ground is nearly nonexistent, (2) destruction of wildlife food and wildlife habitat will probably affect wildlife survival more than any direct toxic effects of the herbicides, (3) the application of Orange or White alongside of rivers and canals or even the spraying of the water area itself at the levels used for defoliation is not likely to kill the fish in the water, (4) food produced from land treated with herbicides will not be poisonous or significantly altered in nutritional quality; if residues of a more persistent herbicide such as picloram should carry over to the next growing season it would retard plant growth rather than concentrate some toxic residues in the crop, (5) toxic residues of these herbicides (Orange, White, and Blue) will not accumulate in the fish and mean of animals to the point where man will be poisoned by them, and (6) the primary

ecological change is the destruction of vegetation and the resulting ecological succession in the replacement of this vegetation (House et al. 1967).

The Air Force Armament Laboratory at Eglin AFB, Florida, the Air Force Environmental Health Laboratory, at McClelland AFB, California; the Air Force Occupational and Environmental Health Laboratory, Kelly AFB, Texas; the Plant Sciences Laboratory at Fort Detrick; and, the United States Army Environmental Hygiene Agency, Aberdeen, Maryland, were responsible for determining physical properties, efficacy, toxicology, safe handling procedures, and actions to be taken for spills, environmental contamination, and disposal for all of the tactical herbicides (Young 2006).

The Air Force trained its aircrews for RANCH HAND operations including the handling of the tactical herbicides at Eglin AFB Auxiliary Field No. 9, Hurlburt Field (Cecil 1986). Frequently the training would involve actual spray missions at Eglin's Test Area C-52A, the fully instrumented test array established for the evaluation of the spray equipment by the Air Development Test Center and the Air Force Armament Laboratory (Buckingham 1982). The training of the Army Chemical Corps personnel to handle herbicides was the responsibility of the Army Chemical Corps Training Center at Fort Leonard Wood, Missouri (Irish et al. 1969; Young 2006).

2.6 The Procurement and Management of Tactical Herbicides

2.6.1 Purchase Descriptions for the Tactical Herbicides

In 1962, the responsibility for the management of tactical herbicides was assigned to the United States Air Force Logistics Command (AFLC), and specifically to the Middletown Air Materiel Area (MAAMA), Olmsted Air Force Base (AFB), Pennsylvania (SAAMA 1968). With the implementation of the "Operational Phase of Operation RANCH HAND" in August 1966, the management for tactical herbicides was transferred to the San Antonio Air Materiel Area (SAAMA), Kelly AFB, Texas (SAAMA 1968; Craig 1975). Management responsibilities included the procurement and shipment of all the tactical herbicides sent to Vietnam. Although the United States Army Chemical Corps, and specifically the Plant Sciences Laboratories at Fort Detrick, was responsible for the selection, evaluation, and purchase description of the herbicides, the Product Engineering Branch, Directorate of Aerospace Fuels, San Antonio Air Logistic Command at Kelly AFB was the organization that contracted for the tactical herbicides Orange, White and Blue through the Directorate of Procurement and Production, Defense General Supply Center, Defense Supply Agency, Richmond, Virginia (Irish et al. 1969; Craig 1975; Young 2006).

The Army Chemical Corps had responsibility for the purchase descriptions of the tactical herbicides. The chemical compositions of the tactical herbicides were those that had been selected by the Army Chemical Corps through the years of testing and evaluation. The descriptions were classified as “Military Specifications” and were complete documents that were used when the need for the purchase of a material was confined to a specific military operation (e.g., the herbicides used in tactical operations in Vietnam). “Military Specifications” were noted by the lead identifier; for example:

- MIL-H-51148, Herbicide N-Butyl 2,4,5-Trichlorophenoxyacetate,
- MIL-H-51147, Herbicide N-Butyl 2,4-Dichlorophenoxyacetate.

Under the Purchase Description, additional documents would have included:

- MIL-STD-105, Sampling Procedures and Tables for Inspection of Attributes,
- MIL-I-45208, Inspection Systems Requirements [Department of the Air Force 1974].

In the case of Herbicide Orange as a finished mixture, the Military Specifications would have provided details on the composition (e.g., 50% by volume of MIL-H-51147, and 50% by volume of MIL-H-51148), tolerance range for the composition (e.g., the free acid could not exceed 0.5% by weight), the specific gravity of the composition (1.220–1.242 at 20°C), quality assurance provisions (e.g., Test Methods), and preparation for delivery (e.g., the placing of the orange band around the center of the drum) [Department of the Air Force 1974]. Because Herbicide Orange was a “Tactical Herbicide” purchased under Military Specifications, the contract with the Chemical Company that won the bid for a specific quantity of herbicide had the following note:

> Precaution, IMPORTANT. For procurement of this herbicide for use on lands owned or otherwise managed as military installations, use Federal Specification 0-H-00200. Herbicides procured by this specification (i.e., Military Specifications) must not be diverted to domestic use.

The last purchases of Herbicide Orange procured by the Air Force were under Purchase Description AFPID 6840-1, dated 23 February 1968, and Amendment 1, dated 11 April 1969 (Department of the Air Force 1974). The Purchase Description AFPID 6840-1 contained all of the information noted above, plus the requirement for 18 gauge metal 55-gal (208-l) drums (Specification PPP-D-729) “for shipment of non-corrosive materials” (Department of the Air Force 1974).

The Defense Supply Agency (DSA) procured all tactical herbicides. DSA required the manufacturers to obtain the 55-gal (208-l) drums that met the required specifications and to arrange for all transportation (primarily by rail) of the drums from the chemical companies manufacturing plants to the Port of Embarkation (POE) (Craig 1975). The purchase contracts covered the costs of the herbicide, the drums, and the shipment. The chemical companies were selected on the basis of competitive bids and DSA provided the specifications (those developed by the Army Chemical Corps and refined by the Air Force Logistic Command) required to be met by the manufacture (Craig 1975).

2.6.2 Quantities of Tactical Herbicides Procured

The procurement of the first tactical herbicides (Green and Pink) sent to Vietnam was at the direction of the Army Chemical Corps at Fort Detrick, and purchased by the Department of Army. All of Herbicide Green (n-butyl 2,4,5-T, 365 drums) and 365 drums of Herbicide Pink purchased directly from Dow Chemical Company, Midland, Michigan and airlifted on 13 November 1961 arriving in Saigon (Tan Son Nhut Airport) on 20 November 1961 (Brown 1962; Hanson 1965; Buckingham 1982). In addition, the Department of Army had also procured 15,000 pounds of Ansar 138® (cacodylic acid) from Ansul Chemical Company, Marinette, Wisconsin and this too was airlifted to Tan Son Nhut Airport arriving on 20 November 1961 (Buckingham 1982).

There is much confusion about the surplus herbicide that was manufactured in 1952 and used in aerial spray tests at Eglin AFB, Florida and Dugway Proving Ground in 1952–1953. A note in a letter exchanged between managers at Dow Chemical Company in 1965 stated:

> November 1961: Bid DA-30-070-CML-1636 was for a total of 684,000 lbs. Dow had an inventory of 321,000 lbs of a blend of 75% Normal Butyl Ester of 2,4-D and 25% Normal Butyl Ester of 2,4,5-T which was war surplus, which we had repurchased. We added 160,500 lbs of iso-butyl of 2,45-T to make 481,500 lbs that was sold to the US Army Procurement at a negotiated price of $0.4763 lb. The balance of 203,300 lbs was sold at $ 0.6143 lb (Hanson 1965).

The above note identified the final product as “Purple” (Hanson 1965). As reported in Table 2.2, five companies produced Herbicide Purple and three companies produced Herbicide Pink. White was a proprietary product of Dow Chemical Company and Blue as Phytar 560 G was a product produced by Ansul Chemical Company, but in 1970, the Defense Supply Agency obtained 475 drums of Blue from Diamond Shamrock Company. The procurement records indicated that the Department of Army directly purchased Green, Pink and Purple through 1963. In 1964, the Defense Supply Agency had the responsibility.

The quantities of tactical herbicides in Table 2.2 exceeded the quantities of tactical herbicides reported in Table 1.1 because Table 2.2 includes the Herbicide Orange returned from Vietnam in Operation PACER IVY and the Herbicide Orange that remained in the United States and not shipped to South Vietnam after 1968 (Young et al. 2008). In addition quantities of Purple, Orange, White, and Blue were used in test programs at Eglin AFB, Florida and in test and evaluation programs conducted by the Army Chemical Corps, and in disposition studies conducted in the 1970s (see Table 5.7) (Young 2006).

Table 2.2 The quantities (208-l, or 55-gal, drums) of the six Tactical Herbicides, and the companies that supplied the herbicides from 1961 to 1971 [data obtained from DSA and AFLC Records, with the most recent procurement records obtain March 2008]

	Numbers of 208-l drums of each formulation					
Company	Orange	White	Blue	Purple	Pink	Green
Dow Chemical Company	78,235	105,700		2,840	180	365
Monsanto Company	67,065			7,320	520	
Hercules Inc.	49,945			1,095		
Thompson-Hayward Chemical Company	21,055				400[1]	
Diamond Alkali /Shamrock Company	12,555		475	1,430	620	
US Rubber Company (Uniroyal, Inc)	11,635					
Thompson Chemicals Corporation	7,185				305[1]	
Agrisect Company	1,875			95		
Hoffman-Taff, Inc.	410					
Ansul Chemical Company[2]			29,655			
Total	249,960	105,700	30,130	12,780	2,025	365

[1]This volume was 2,4,5-T remaining at termination of contracts in 1969; some of this 2,4,5-T may have been from Thompson and Thompson-Hayward.
[2]This is PHYTAR 560G, and does not include the 95 drums of ANSAR 138 shipped in 1961 to Vietnam.

2.6.3 Ports of Embarkation

In the contracts negotiated with the various chemical companies that produced the herbicides, a statement was included on where the tactical herbicides were required to be shipped, i.e., to the Port of Embarkation (POE). Prior to 1966, the Middletown Air Material Area (MAAMA), Olmsted AFB, Pennsylvania, had the responsibility for the procurement and management for the tactical herbicides (SAAMA 1968; Craig 1975). In the procurement contracts, MAAMA selected various Ports of Embarkation for shipping the tactical herbicides to South Vietnam. Ports at New Orleans, Baltimore and Seattle were frequently used by the Department of the Army and, subsequently (in 1963) by MAAMA (SAAMA 1968; Craig 1975). After 1966, all shipments of tactical herbicides to Vietnam were the responsibility of SAAMA and were shipped from the Port of Mobile, Mobile, Alabama, or the Outport at Gulfport, Mississippi (Craig 1975).

2.6.4 Management of the Tactical Herbicides

The management of the tactical herbicides was the responsibility of MAAMA (Olmsted AFB, Pennsylvania) until it transferred to SAAMA (Kelly AFB, Texas) in August 1966. The procurement responsibility remained at the Defense General Supply Center at Richmond, Virginia. Research and Development responsibilities for new herbicides were assigned to the Army Chemical Corps at Fort Detrick, while the Air Force Armament Laboratory (AFATL) was assigned the research and development responsibility for equipment support testing (Craig 1975). Within SAAMA, the Directorate of Air Force Aerospace Fuels was assigned the "Program Management" for receiving, storing, shipping, providing transportation, inventory counting, and redistribution and marketing. User management responsibilities dictated a monthly inventory including: open inventory, receipts, disposition, usage, and closing inventory (Craig 1975). Requirements for tactical herbicides used in Southeast Asia were developed by the Army's Chemical Operations Division (J-3), Military Assistance Command, Vietnam (MACV); passed to 7th Air Force of PACAF (Pacific Air Force Command) for coordination; to CINCPAC (Commander in Chief, Pacific Command) for review as required; and to the Joint Chief of Staff and Headquarters, United States Air Force for approval and budgetary processing. SAAMA related these requirements to the mission capability of RANCH HAND, after which the quantity to be procured was determined, the necessary budget allotment obtained, the procurement documents (Military Interdepartmental Procurement Request – MIPR) prepared, and after purchase, the products to be delivered to Vietnam (Craig 1975).

SAAMA based the supply support of tactical herbicides to Southeast Asia on a 180-day (six months) lead-time. This was computed as follows: 60-day supply in Vietnam that represented a 30-day supply at each of the two storage depots, the 20th ARVN (Army of the Republic of Vietnam) Ordnance Depot at Saigon, and the 511th ARVN Ordnance Depot, Da Nang Air Base; 30-day safety level in depot supply, 30 days to process the MIPRs, 15 days production time, and 45 days in the pipeline (i.e., acquisition through shipment) (Craig 1975). Of importance to the purchase and deliverance of the tactical herbicides to Vietnam was the following policy:

> When the drums of tactical herbicides arrived in Vietnam, the ownership was transferred from the United States Air Force to the ARVN. The ARVN had the responsibility for the handling, transport, and storage of the tactical herbicides. In addition, ARVN Commanders, at each of the air bases where the tactical herbicides were shipped, had the responsibility for the final disposition of the empty drums. Thus, the ARVN directed where both full drums of tactical herbicides or the empty drums would be temporarily stored at the air bases where RANCH HAND aircraft were serviced. Most of the personnel involved in the actual handling of the drums of tactical herbicides were ARVN troops assigned to support the RANCH HAND operation (Young and Andrews 2006).

Drummed herbicides were shipped by rail from the manufacturer to the Port of Mobile in standard boxcars. Approximately 128 drums were loaded per boxcar. At the railroad terminal, the drums were loaded on pallets and taken to the pier by forklifts. The ship's crane picked up the drums from the pallets and swung them aboard the ship where they were vertically stacked below deck, normally three high for movement to Vietnam. The Port of Mobile was used because cost and time-wise it was the most economical (Craig 1975). From the Port of Mobile to the Port of Saigon, the time varied from 47 to 52 days (Craig 1975).

2.6.5 Summary of What Defined Tactical Herbicides

The Herbicides coded Purple, Pink, Green, Orange, Blue, and White were developed as “Tactical Herbicides”. The United States Army Chemical Corps’ Plant Science Laboratory at Fort Detrick, Maryland, was responsible for the screening, testing, and evaluating of tactical herbicide candidate formulations at numerous sites throughout the United States, Puerto Rico, Canada, and Thailand. The Plant Sciences Laboratories were also responsible for establishing the “Military Specifications” for those herbicides selected to be used as “Tactical Herbicides”. The ground and aerial spray equipment were developed by the both the Army Chemical Corps and the United States Air Force to support tactical combat military operations in Southeast Asia. The Department of Defense provided the training of aircrews, ground based personnel, and the Army Chemical Corps personnel that had responsibility for handling and spraying of the tactical herbicides. The selection and use of the tactical herbicides were exempt from USDA regulatory oversight, or from the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). In pesticide procurement catalogs the listing of a tactical herbicide was always accompanied by the statement: “This item is for tactical purposes only and not for base type pest control operations” (Adams 1970).

2.7 The Role of the Armed Forces Pest Control Board and Commercial Herbicides

On 17 November 1956, Department of Defense Directive 5154.12 established the Armed Forces Pest Control Board (AFPCB) {subsequently The Armed Forces Pest Management Board (AFPMB)} (AFPCB 1974). The purpose for establishing the AFPCB was to provide oversight of the DOD’s pest management programs on its more than 600 world wide military installations. At the time the Board was established, the Department was using million of pounds of commercial pesticides on these installations. The DOD Directive required that the Board be composed of members from the Army, Navy, Air Force and selected Defense Agencies (a total of 20 members). The Board was also to have 24 liaison members and 25 non-DOD Agency representatives. The Board established 8 Standing Committees: Environmental Impact, Equipment, Quarantine, Medical Entomology, Pesticides, Real Property Protection, Stored Products, and Training, Certification, and Manpower. In August 1961, the Department of Defense, via a

Memorandum of Understanding, established with the USDA a support program that among other responsibilities provided the research, recommendations, and specifications of pesticides that were suitable and met the need for DOD use (Fleck 1961; AFPCB 1974).

The Armed Forces Pest Control Board required all DOD agencies to use pesticide formulations that had "Federal Specifications", with the labeling and use directions approved by the Pesticides Regulation Branch of USDA (now EPA), and in full compliance with the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) (Fleck 1961). As previously noted the "Tactical Herbicides" were required to meet "Military Specifications". There were four distinct "types of specifications". These were: (1) Purchase descriptions; (2) Army, Navy, and Air Force Specifications; (3) Military Specifications; and, (4) Federal Specifications. Purchase descriptions were merely descriptions of the material desired and are used for filling small needs or for materials that are needed on an emergency basis. They were issued by all government agencies and were of a temporary nature. Army, Navy, and Air Force Specification covered items specific to one of these military services (e.g., a biocide for ship hulls). Military Specifications were complete documents and were used when the need for the material was confined to a specific military operation (e.g., the herbicides Orange, White, and Blue used in tactical operations in Vietnam). The AFPCB adopted the policy for the Department of Defense to recommend that any pesticide formulation that had uses in civilian agencies be issued as a "Federal Specification". These types of pesticide were to be issued by the General Services Administration (tactical herbicides were the responsibility of the Defense Supply Agency) (Fleck 1961).

By 1966, the AFPCB strictly controlled the kinds and forms of pesticides available under "Federal Specifications" and on the military supply list (Wickham 1968). New pesticides, before being considered by the Board, had to be recommended by the US Department of Agriculture, the Fish and Wildlife Service, or the Public Health Service, and the proposed use must have been approved by all three of these organizations (AFPCB 1974). In February 1967, the Federal Committee on Pest Control (FCPC) was established. All Federal pest control activities were placed within the purview of the Committee. The Committee was composed of two members from each of the Departments of Agriculture; Defense; Health; Education, and Welfare; and Interior. Before a pesticide was approved for use in the United States, or by a Federal Agency, it had to be reviewed by the FCPC (FCPC 1967). The DOD's "Tactical Herbicides" were exempt from this approval and oversight process. However, all other herbicides used by the Department of Defense were required to meet this approval process. The significance of this action was that herbicides used in 1967–1970 on the more than 600 military installations managed by the Department of Defense required approval by both the AFPCB and the FCPC (after 1970, the registration and oversight of commercially available pesticides was the responsibility of EPA) (Hobson and Donnelly 1994). This requirement applied to all herbicides used in Vietnam that were NOT TACTICAL HERBICIDES.

Thus, herbicides used on Allied Bases in Vietnam around buildings, in equipment storage sites, and along interior roads came under the requirements of the AFPCB. The responsibility for the purchase and application of commercial pesticides on these installations was the Base Civil Engineer, NOT the Army Chemical Corps. The tactical herbicides were NOT approved for these uses. The insecticides used in Operation FLYSWATTER (the aerial application of insecticides to control mosquitoes in Vietnam) were under the Military's Disease Prevention Program and were approved by the AFPMB (Cecil and Young 2008).

With the establishment and functioning of the AFPCB, anytime that a DOD Military Base, e.g., Andersen AFB, Guam, or Osan AB, Korea, requested the use of a herbicide to control plant pests, the selection of the herbicide must have been approved by the Board (Kaufman 1968). Locally purchased pesticides were to be approved by the Command Entomologist. Moreover, the application of the herbicide had to be done by a Board "certified" (trained) applicator, and with equipment that had been approved by the USDA, and under the supervision of the Base Civil Engineer (Kaufman 1968; AFPCB 1977). The Department of Agriculture's Agricultural Research Service (ARS), and the Cooperative State Research Service (CSRS) provided critical support to the development of pesticides that were subsequently recommended and approved for use by the AFPCB (Shepard and Mahan 1965). The Board DID NOT work with the chemical companies that manufactured the pesticides, rather these materials were evaluated by ARS, the various State University Experiment Stations, and the State and Federal Extension Services. AFPCB even depended upon CSRS and its University-based research and extension system to prepare and publish manuals on pesticide use, plans for certification of pesticide applicators, and the disposal of old pesticides and pesticide containers (Shepard and Mahan 1965; Laudani 1967; WGP 1970). The final statements on safety and environment precautions on the use of herbicides that would be commercially available to the military were determined by the agencies of the Public Health Service, and when necessary by the United States Army Environmental Hygiene Agency (Brown 1961; USAEHA 1987).

To ensure that military installations were identifying and controlling pests that were detrimental to military personnel, property, projects, and programs, the AFPCB had a cadre of military and civilian personnel via supporting Agencies and Laboratories (e.g., the Epidemiology Division of the School of Aerospace, Brooks AFB, Texas; USAF Occupational and Environmental Health Laboratory, Kelly AFB, Texas; USAF Environmental Health Laboratory, and the United States Public Health Service) that routinely conducted Pest Surveys, Staff Visits, Training Programs, and Conferences on identifying and controlling pests. Reports of these visits, programs, and conferences were published by the Board and widely circulated to other military installations (Brown 1961; Kaufman 1968; McNeal 1969; NAVFAC 1984).

2.7.1 Summary of the Use of Commercial Herbicides by the DOD

Under the Directives 5154.12 and 4150.7, the Department of Defense gave the Armed Forces Pest Control Board/Armed Forces Pest Management Board the authority to set pest management policy "applicable for all Department of Defense pest management activities in any unit, at any time, in any place, even when conducted by contract operations." The significance of this Directive is that any herbicides used after 1961 on DOD's more than 600 installations must have been approved by the Board, and must have met USDA's regulatory requirements, and all the requirements of FIFRA. The exception to these Directives was the development of the "Tactical Herbicides" sprayed in combat military operations in Vietnam, or by Department of State approval as used in Korea adjacent to the Demilitarized Zone in 1968 (Young 2006).

2.8 Implications of Tactical Versus Commercial Herbicides

Herbicides used in Operation RANCH HAND for defoliation and crop destruction projects, and by the US Army Chemical Corps for vegetation control on perimeters, cache sites, and similar militarily-important targets were classified as "Tactical Herbicides" and were formulated, tested, evaluated, and assigned "Military Specifications" by the Department of Defense. They were not subject to regulatory oversight by the Department of Agriculture, the Armed Force Pest Control Board, or the Federal Committee on Pest Control. However, the insecticides used in Operation Flyswatter were subject to the AFPCB, as were all other pesticides used for control of pests within the boundaries of the military installations in Vietnam.

There were no documents that indicated the herbicides used in Guam, or CONUS military installations were "tactical herbicides", rather, the available documents confirmed that all pesticides used in these locations and other US Department of Defense installations world wide were those commercially available and approved by AFPCB.

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Chapter 3
The Military Use of Tactical Herbicides in Vietnam

The use of herbicides became a new technique in the arsenal for modern warfare when it was introduced into the armed conflict in Vietnam in 1962. "Tactical Herbicides" were used in a defensive role through defoliation. They were also used in offensive roles through crop denial and exposure of enemy weapons caches, transportation routes, and base camps. A large body of historical data exists on the use of tactical herbicides in Vietnam. The history of Operation RANCH HAND in Vietnam has been thoroughly documented in books by Buckingham in 1982 ("OPERATION RANCH HAND: The Air Force and Herbicides in Southeast Asia, 1961–1971"), and Cecil in 1986 ("Herbicidal Warfare: The RANCH HAND Project in Vietnam"). Many of the primary historical records, documents, photographs, slides, and reports are now available online through the Special Collection Initiative of the National Agricultural Library, the Agricultural Research Service, United States Department of Agriculture, Beltsville, Maryland, http://www.nal.usda.gov/speccoll/findaids/agentorange/index.htm.

Almost a decade after the termination of tactical herbicide use in Vietnam, veterans of the Vietnam War expressed concern over the potential impact that the use of tactical herbicides may have had on their health. The unit histories of ground troops stationed in Vietnam from 1964 through 1971, the major period of tactical herbicide use, are housed in the National Archives and have been the subject of intense interest since 1979 when the first epidemiological studies of Vietnam veterans and Herbicide Orange (popularly referred to as Agent Orange) were proposed. Epidemiologists must rely heavily upon historical records to construct exposure assessments. However, factors that were critical to the re-construction of such exposures were not adequately documented in the combative and hostile environment of Vietnam. The procedures governing the use of tactical herbicides, and the supporting historical data, have only recently been recognized as important to the debate on whether ground troops were significantly exposed to tactical herbicides while serving in South Vietnam. This chapter summarizes many of the issues that impact exposure determinations, including the environmental characteristics of South Vietnam, the rationale and procedures for the

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military use of tactical herbicides, the historical and operational concepts of Operation RANCH HAND and, the actual dissemination of tactical herbicides in the Vietnam War.

3.1 Environmental Characteristics of South Vietnam

The environmental characteristics of South Vietnam had a major impact on all facets of American involvement in the war in Southeast Asia. The environmental setting influenced the defense of hamlets, cities, and military bases as well as the conduct of both air and ground offensive operations. The environmental setting's impact came chiefly from the topography, climate, and vegetation of the Republic of Vietnam (Fox 1979).

The Republic of Vietnam (RVN) was a classic example of exposed territory. Its boundaries were extremely lengthy in relation to its size. As a result, infiltration points accessible to enemy forces by land and sea were almost unlimited. South Vietnam extended more than 1,300 km from its northern border at the Demilitarized Zone (DMZ) to its southern border, while its width from east to west varied from 50 to 200 km. Saigon (now Ho Chi Minh City), the Republic's capital, was located less than 60 km from the Cambodian frontier to the west (Fox 1979).

Topography also favored the insurgency forces of the Viet Cong (VC) and the regular Armed Forces (NVA) of the Democratic Republic of Vietnam (hereafter referred to as North Vietnam). Nearly 60% of Vietnam consisted of relatively high mountains and plateaus rising to elevations of 2,500 m. This mountain range, the Annamite Chain, extended southeastward from the border between North Vietnam and the People's Republic of China to form the border between Vietnam and Laos, and further south, between South Vietnam and Cambodia. The mountains and plateaus making up the Annamite Chain terminated at a point in Binh Tuy Province about 80 km northeast of Saigon. Numerous spurs extended to the east and provided broken and rugged terrain in close proximity to almost all of the major cities and allied military installations in the RVN (Cima 1989; Fox 1979). Lowlands with little or no topographical relief comprised the remaining 40% of the country. The lowlands were located primarily in the Ca Mau Peninsula where the land seldom was more than 4–5 m above sea level. In addition, the Ca Mau Peninsula was intersected by numerous waterways. Consequently, almost the entire countryside of South Vietnam offered cover and concealment to enemy troops while presenting major obstacles to observation, penetration, and movement by friendly ground forces. Each of the 10 primary American bases was vulnerable to access by land and/or water by VC and NVA forces (Fox 1979).

Except in the mountains and plateaus of the Annamite Chain (e.g., Pleiku Air Base and the Central Highlands area), high temperatures typically prevailed throughout the year. These high temperatures accompanied by high humidity created a climate that physically stressed military personnel and increased enormously the maintenance requirements for all equipment. The average rainfall was heavy in all regions of South Vietnam, ranging from less than 200 cm near Saigon in the south to more than 325 cm near Da Nang in the north. For most of South Vietnam, the rainy season occurred from the summer through fall (June to November), when an annual average of 10 typhoons from the South China Sea produced even more rainfall. In the Da Nang area, the wettest period lasted from December through January. The heavy rainy season, including periodic monsoons, crippled friendly and hostile military operations alike and marked the yearly low point in VC and NVA attacks (Fuller 1974).

The abundant rainfall and the year-round high temperatures gave much of South Vietnam a 12-month growing season that resulted in luxuriant vegetation. More than 80% of the Republic of Vietnam had a natural cover of rain forests, monsoon forests, and savanna lands. Approximately 57% of the land area of South Vietnam was covered by a diversity of upland (inland) forests, 23% by grasslands or savannas (the Plain of Reeds vegetational type), 18% agricultural and urban lands, and 2% coastal mangrove forests (Westing 1976).

The upland forests were characterized by dense and diverse tree species that varied in height, usually forming two or three rather indistinct strata (storeys) of a multi-canopy jungle dominated by the plant family Dipterocarpaceae, which was represented by at least 30 major species. The upper canopy usually attained a height of 20–40 m. Figure 3.1 is a photograph of a typical double and triple canopy jungle that characterized more than 50% of South Vietnam. One scientist described the upland forests as:

> ...a confusing conglomeration of what appears to be primary forest interspersed with secondary forest in all stages. Moreover, the forests have been subjected over the years and centuries to varying intensities of exploitation for timber, firewood, and miscellaneous products. And of course, many years of war have left their mark as well, in a variety of obvious and subtle ways (Westing 1976).

Reed grasses and shrubs dominated the grasslands and savannas of Vietnam. Especially widespread was tranh grass (*Imperta cylindrical*) that reached a height of 1 to 2 m, while the brush yen-back (*Eupatorium odoratum*) grew densely and to a height of almost 2 m. Widespread was bamboo (*Bambusa arundinacea*), which frequently formed almost impenetrable stands of vegetation that ascended to 12 m (Westing 1976). The height and density of the vegetation in South Vietnam afforded ideal concealment for ambush and infiltration. Figure 3.2 is a photograph of Allied troops on maneuvers in dense savanna vegetation. Figure 3.3 is a quotation from a Field Commander explaining the military significance of the dense and almost impenetrable vegetation where military operations frequently occurred.

Fig. 3.1 The dense inland forests of South Vietnam contained a vast diversity of species. The tree species varied in height, usually forming two and occasionally three rather indistinct strata (storeys). The upper canopy usually attained a height of 20–40 m (Photograph courtesy of J. Ray Frank, Frederick, Maryland)

3.2 The Rationale for Herbicide Use in South Vietnam

The extensive vegetation was a major obstacle to effective base defense. Dense ground cover flourished around all 10 of the major Allied bases, Table 3.1. These ten installations housed the vast majority of aircraft, munitions, and fuels (Fox 1979). They were the center of the US Air Force Logistics Command (AFLC) activities for delivering equipment, supplies and personnel to the war in Vietnam. They also housed the major command elements for the Allied Forces as well as US Air Force, Army, and Marine units. The widespread vegetation hid the enemy, shut off friendly observation and fields of fire, neutralized fencing and other defense barriers, slowed the movement and response of security forces, and nullified detection by sentry dog teams (Fox 1979). The

Fig. 3.2 The grasslands and savannas of South Vietnam were characterized by grasses and shrubs that frequently formed almost impenetrable stands of vegetation and which afforded ideal concealment for ambush and infiltration (Photograph courtesy of J. Ray Frank, Frederick, Maryland)

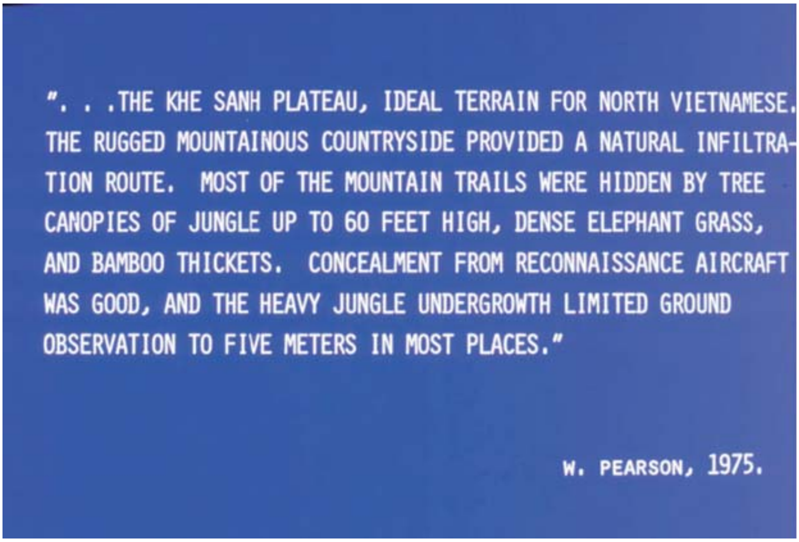


Fig. 3.3 A Department of Defense briefing slide of a quotation from a Combat Field Commander who served in Vietnam during the Vietnam war (Courtesy of Air Force Logistics Command, Wright-Patterson AFB, Ohio)

Table 3.1 Primary Republic of Vietnam air bases used by US and allied forces during the Vietnam war (Fox 1979)

Air base	Urban locations[1]	RANCH HAND base[2]	FLYSWATTER base[3]
Bien Hoa	X	1966–1970	1967–1971
Binh Thuy	X	–	–
Cam Ranh Bay	–	–	1967–1971
Da Nang	X	1964–1971	1967–1971
Nha Trang	X	1968–1969	–
Phan Rang	X	1970–1972	1970–1972
Phu Cat	–	1968–1970	–
Pleiku	X	–	–
Tan Son Nhut	X	1962–1966	–
Tuy Hoa	–	1971–1972	–

[1]Older bases dating from the French regime and that were located in or near population centers.
[2]Bases used for servicing RANCH HAND C-123 aircraft and/or tactical herbicide storage.
[3]Bases used for servicing RANCH HAND C-123 aircraft for insecticide operations (Operation FLYSWATTER).

need to control this noxious vegetation was evident. How to do so was the challenge confronting the American military and its South Vietnamese allies (Brown 1962). A possible solution lay in the example set by British forces in countering an insurgent attempt to overthrow the British-supported Federation government. Facing jungle-concealed guerrilla ambushes, the British Army used local stocks of an n-butyl ester of a 2,4,5-T herbicide (normally kept to control an obligate parasite of rubber trees) as a defoliant to thin the jungle cover along communications routes. Although limited, the British experience would form the basis for future American investigations into herbicidal warfare (Cecil 1986).

In late June 1961, the United States and South Vietnamese Government established a Joint United States/Vietnamese Combat Development and Test Center (CDTC) in Saigon, under the direction of the Defense Department's Advanced Research Projects Agency (ARPA). One of its first tasks was to evaluate the use of herbicides to destroy concealing vegetation and enemy food supplies (Project AGILE) (Cecil 1986). As part of Project AGILE, a contract was negotiated in 1962 with the Institute for Defense Analyses, Washington, DC to do an in-depth analysis of the available literature on "Chemicals for Control of Vegetation" (Coates and Sharpe 1963). The Institute concluded that the selection of chemicals should be evaluated on the basis of plant physiology (how they physiologically affect the plant); on the basis of health and safety; and on performance characteristics of commercially available herbicides/desiccants. The Institute identified five principal military applications for anti-vegetative agents:

- Roadside clearance to reduce ambush,
- Boundary demarcation,
- Vegetation control in depot areas,

- Area denudation to uncover selected targets and to reveal enemy hideouts, and
- Aquatic weed control (Coates and Sharpe 1963).

They reasoned that three distinct phytochemical activities were required, namely the rapid reduction in foliage by desiccation; systemic herbicidal activity to kill the plants; and residual herbicidal action in the soil to prohibit or retard growth. They concluded that no single herbicidal agent would bring about all three effects; it was essential to consider the use of mixed or formulated herbicides, applied together or successively (Coates and Sharpe 1963).

Prior to 1962, a large and useful amount of information about vegetation control, especially woody species control, existed in American agriculture (Bovey and Young 1980). As a result, the tentative choice of tactical herbicides for use in Vietnam was based upon proven performance in both military and commercial situations, on availability in large quantity, upon costs, and on known or accepted safety in regard to their toxicity to humans and animals (Irish et al. 1969). The phenoxy and arsenical herbicides were the apparent chemicals of choice, having been tested and evaluated in numerous locations in the United States and Puerto Rico (Tschirley 1968; Young 2006).

3.3 Combat Tactical Zones

South Vietnam was divided into four Corps Tactical Zones (CTZ), also called Military Regions, and the Special Capital Zone (Saigon area) for purposes of military operations. The four CTZs were identified as I (pronounced as "EYE"), II, III, or IV Corps. Each Corps was an administrative and command area for tactical operations. I Corps was located in the region nearest North Vietnam and hence, adjacent to the DMZ. II Corps encompassed the Central Highlands and III Corps surrounded the Saigon area. IV Corps was in the Ca Mau Peninsula region (Buckingham 1982). Figure 3.4 is a briefing slide of South Vietnam showing the division of the country into Corps Tactical Zones.

Although spraying would occur in most provinces of South Vietnam, certain areas of the country were subject to more intensive spraying than others. Most of the defoliation missions were conducted along transportation routes, over enemy-occupied areas around Saigon, on NVA infiltration routes along the Laotian and Cambodian borders and the DMZ, and on staging areas from which enemy attacks were likely (Cecil, 1986).

Primary target areas for crop destruction missions were in I Corps and along the upland and mountain valleys of II Corps. The areas within III Corps southeast of Saigon known as "Rung Sat" afforded the enemy concealment along the main shipping routes providing access to the Port of Saigon. These areas were also where some NVA infiltrations of troops and supplies terminated in base camps in South Vietnam. As a result, the Rung Sat Special Zone and War Zones C and D were areas that were sprayed repeatedly to reach all levels

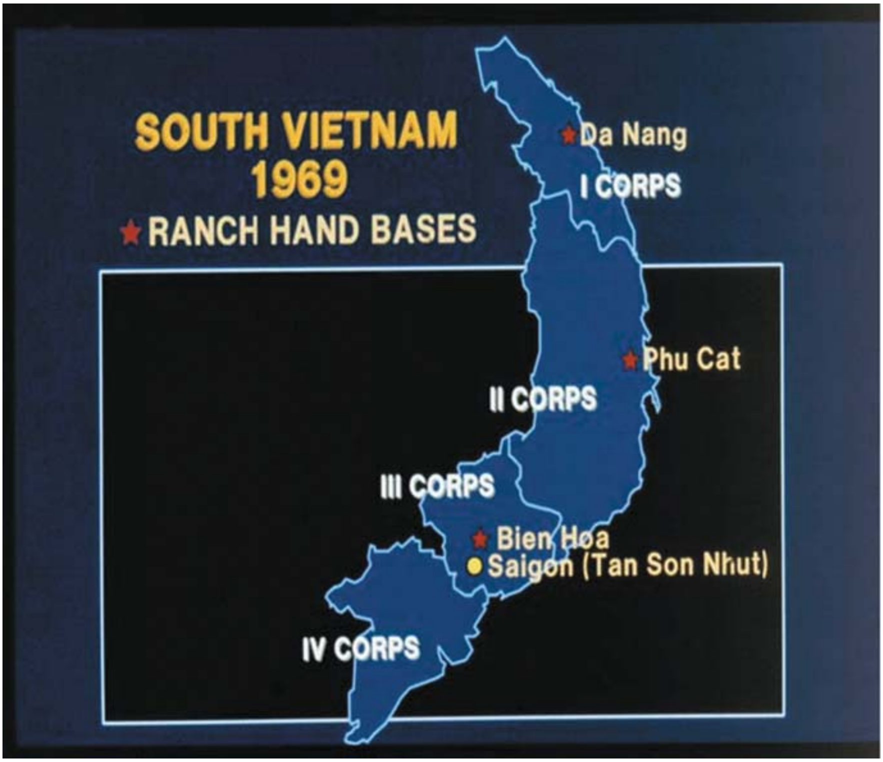


Fig. 3.4 A 1969 Department of Defense briefing slide showing the Combat Tactical Zones and the location of the RANCH HAND bases in South Vietnam (Courtesy of J. Ray Frank, Frederick, Maryland)

of the triple canopy forest and restrict re-growth. In IV Corps, the Makong Delta was a temporary staging area for infiltration into the Ca Mau Peninsula and hence, was the target of defoliation operations (Cecil 1986). As one Army Commander described the challenges that confronted the military units in the Makong Delta:

> Within the patches of jungle bordering rice paddies, the Viet Cong, masters of camouflage, had excellent concealment from air observation. And the dense year-round Mekong undergrowth cut our soldier's vision to little more than the nose in front of his face. If the Viet Cong chose to defend a position rather than slip away after an assault, which they rarely did, they could count on great natural cover (Hackworth 2002).

In order to effectively target defoliation or crop destruction missions in all four Combat Tactical Zones, after relocation from Tan Son Nhut to Bien Hoa in 1965, the RANCH HAND squadron established operations locations in three of the four CTZs. A base of operations was not established in CTZ IV because IV Corps targets were readily accessible from Bien Hoa Air Base that was located in III Corps (Cecil 1986). The Combat Tactical Zones and the RANCH HAND bases are also shown in Fig. 3.4.

3.4 Historical Background on Early Spray Missions

The mission of Operation RANCH HAND was unique. It required the development and use of aircraft capable of disseminating large quantities of herbicides at very low attitudes and slow speeds. It required herbicides that were effective against the vegetation encountered in South Vietnam. It also required tactics that had to be designed and implemented on a trial and error basis in order to provide maximum surprise and concealment when approaching targets to minimize hostile ground fire (Clary 1971).

On 10 August 1961, as part of Project AGILE, Fort Detrick personnel initiated defoliation tests in South Vietnam (Brown 1962). Stocks (10 drums – 1,900 liters) of the commercial herbicide "Dinoxol" had arrived by air on 17 July 1961. It was the first herbicide to be evaluated. It was aerially sprayed using a VNAF H-34 helicopter equipped with the HIDAL (Helicopter Insecticide Dispersal Apparatus, Liquid) system. Dinoxol consisted of 20% 2,4-D butoxy ethanol ester, and 20% 2,4,5-T butoxy ethanol ester. On 4 September 1961, 2,025 liters of "Trinoxol" (40% 2,4,5butoxy ethanol ester and 40% 2,4-D-butoxy ethanol ester) arrived and was immediately evaluated (Brown 1962). On 20 November 1961 Pink, Green, and 6,800 kg (95 drums) powdered formulation of Blue (Ansar 138®) arrived. The first sea-lifted shipment of Purple herbicide arrived at the Port of Saigon on 9 January 1962 (Brown 1962). Between 10 August 1961 through 3 February 1962, 18 tests were conducted using the six different herbicide formulations (Brown 1962).

Three of the six United States Air Force (USAF) C-123 aircraft equipped with MC-1 spray tanks (3,785-l capacity) landed at Tan Son Nhut Air Base, RVN at 1,630 h, 7 January 1962 (Brown 1962). The first RANCH HAND herbicide mission was flown on the morning of 12 January 1962. The target for this mission, and the subsequent missions during the first week of operations, was the vegetation on both sides of Route 15 between Bien Hoa and Vung Tau. These missions expended almost 30,000 l of Purple and covered 28 square kilometers (Collins 1967). At the same time, the VNAF helicopters and a Vietnamese C-47 were being used to spray various test chemicals on other crop and jungle targets. Despite the loss of a RANCH HAND C-123 and crew on 2 February 1962, herbicide testing continued. At the conclusion of the tests, the recommendation was that Purple, Pink, and Green should be used as the tactical herbicides of choice for large-scale use (Brown 1962; Cecil 1986).

On 21–23 November 1962, the first crop destruction missions were flown in Phuoc Long Province. The operation, using H-34 helicopters and hand sprayers, destroyed an estimated 300 ha of crops consisting of rice, beans, and manioc. Subsequently, RANCH HAND aircraft completed additional crop destruction projects between November 1962 and March 1963 using Purple and Blue (Warren 1968).

The Pink and Green formulations of 2,4,5-T were received in limited quantities and evaluated during the first years of Operation RANCH HAND (Irish et al. 1969). Pink was used extensively in early RANCH HAND operations as well as in the defoliation test program conducted during 1963 and 1964 in Thailand (Darrow et al. 1966). Green was a single component formulation and was used in limited quantities in 1962 for broadleaf crop destruction, e.g., against manioc (Irish et al. 1969). It has been suggested that the limited amount of Green (365 drums) was generally mixed with Pink, and thus there were no records that specified "Green" only (Cecil 1986).

In March 1965, Herbicide Purple was replaced by "Herbicide Orange", subsequently known as "Agent Orange". Orange was a 50:50 mixture of the n-butyl esters of 2,4-D and 2,4,5-T. These esters were considered "less volatile" than the iso-butyl esters contained in Agent Purple, and hence, less likely to cause damage to non-target vegetation. Agent Orange replaced all uses of Purple, Pink, and Green, and eventually became the most widely used military herbicide in South Vietnam (Darrow et al. 1969). By late 1965 consumption of Herbicide Orange by RANCH HAND was exceeding the production capacity of the American chemical industry and mission cancellations were occurring due to lack of herbicide.

In order to expand production an additional tactical herbicide was developed. The final military herbicide added to the inventory was Herbicide White (Agent White), a formulation of 80% 2,4-D and 20% Picloram. The records on herbicide use indicate that Agent White arrived in the RVN in limited quantities in December 1965 for evaluation. Small amounts of White also were tested in Thailand. The first RANCH HAND missions using White actually occurred in early 1966, as did the liquid formulation of Agent Blue (Phytar 560G, cacodylic acid) (Cecil 1986).

3.5 Use Patterns of Individual Herbicides

Table 3.2 summarizes the military herbicides and their uses during the years 1961–1971 in South Vietnam. Each of the three major military herbicides (Orange, White, and Blue) used after March 1965 had specific applications. About 90% of Agent White was applied in defoliation missions. It was an ideal herbicide for use in the inland forests in areas where immediate defoliation was not required, but where a longer more persistent effect than spraying with "Orange" or "Blue" was desired.

Blue was the herbicide of choice for crop-destruction missions involving cereal or grain crops. Approximately 50% of all Agent Blue applications involved crop-destruction missions in remote or enemy-controlled areas. The remainder was used as a contact herbicide (desiccant) for control of reed grasses

Table 3.2 The major tactical herbicides used by the United States Military in South Vietnam 1961–1971 (NRC 1974; Young and Andrews 2006)

Code name (Herbicide)	Years sprayed	Formulation	Purpose/use
Dinoxol, Trinoxol	1961	2,4-D; 2,4,5-T	Defoliation tests
Purple	1962–1965	2,4-D; 2,4,5-T	General defoliation and destruction of broadleaf crops
Blue	1961–1963; 1966–1972	Cacodylic acid	Rapid defoliation, desiccation of grasses, and rice
Pink	1961–1963	2,4,5-T	Defoliation
Green	1962	2,4,5-T	Crop destruction
Orange	1965–1970	2,4-D; 2,4,5-T	Defoliation, crop destruction
Orange II	1968–1970	2,4-D; 2,4,5-T	Defoliation
White	1966–1972	2,4-D; Picloram	Defoliation

and bamboo around base perimeters (Fox 1979). The internal security concept called for by the US Military and Allied Forces at all major bases involved the preventive perimeter that traced the base boundary line as closely as possible (Fox 1979). Being the first line of defense, it had to detect, report, and engage the enemy as far as feasible from the resources protected. Only in the preventive perimeter area were "defoliants" (i.e., tactical herbicides) used. The Army Chemical Corps used helicopter and ground-based equipment, but as noted:

> Defoliation needs of the 10 primary bases were specific, permanent, and known in advance. Still no ongoing long-term program to satisfy them was ever set up. Instead the job was done piecemeal, with each base handling defoliant requests. Despite the administrative and technical controls, chemical agents remained the single sure way to control vegetation in places where other means could not – notably in the critical perimeter complexes (Fox 1979).

Approximately 85% of all Agent Orange was used for forest defoliation, and it was especially effective in defoliating mangrove forests. Eight percent of Orange was used in the destruction of broadleaf crops (beans, peanuts, ramie, and root or tuber crops). The remaining 7% was used around base perimeters, cache sites, waterways and communication lines (Young 1988). Table 3.3 shows the number of hectares in South Vietnam, based on the major land cover classifications, that was sprayed with herbicides.

Table 3.3 The number of hectares treated in South Vietnam, 1962–1971, with military herbicides within the three major land cover categories (NRC 1974)

Land cover category	Hectares treated*
Inland forests	1,080,970
Mangrove forests	127,750
Cultivated crops	105,260
Total	1,313,980

*Areas receiving single or multiple applications.

3.6 Historical and Procedural Information on Operation RANCH HAND

3.6.1 Deployment of Aircraft

Following World War II, the USAF assumed responsibility for the operations of the Special Aerial Spray Flight (SASF), a military unit that provided control of insect pests through the use of aerial applications of insecticides. Based at Headquarters, Tactical Air Force (TAC) at Langley AFB, Virginia, the unit responded to both military requirements and civil needs during emergencies and natural disasters (Cecil 1986). By 1960, the SASF had conducted more than 1,200 missions in support of national and international control programs for mosquito, black fly, locust, and other pests of public health and economic importance (Cecil 1986).

In early 1960, the Special Aerial Spray Flight phased out the C-47 aircraft and selected the Fairchild-built C-123B "Provider" as its replacement. This high-wing, twin-engine assault transport had excellent low-speed maneuverability, and the high-mounted wings allowed convenient positioning of wing spray booms. More importantly, the large cargo compartment and load capacity were ideal to receive a large spray system for internal carriage. The initial spray system was the Korean War-developed MC-1 Hourglass System, but beginning in July 1965, this spray system was replaced with A/A 45Y-1 Internal Defoliant Dispenser (Fig. 3.5). This modular system consisted of a 3,785-l

Fig. 3.5 USAF photograph of the A/A 45Y-1 Internal Defoliant Dispenser (Photo courtesy of the Air Force Armament Laboratory, Eglin AFB, Florida)

supply tank, 250-gpm pump, and engine, which were all mounted on a frame pallet. An operator's console was an integral part of the unit. Wing booms (3.8 cm in diameter, 6.7 m in length) extended from outboard of engine nacelles toward the wing tips. A short tail boom (7.6 cm in diameter, 6.1 m in length) was positioned centrally near the aft cargo door (Irish et al. 1969). In spray configuration the C-123 aircraft was re-designated as a "UC-123" (Cecil 1986).

Each UC-123 aircraft had a crew of three: the pilot, co-pilot, and flight mechanic (console operator) (Buckingham 1982). The lead aircraft in a formation contained a fourth crewmember, a navigator. The pairing of equipment and aircraft appeared to be ideal. The UC-123 series aircraft became the "work horse" of Operation RANCH HAND. Figure 3.6 is a photograph of the UC-123B RANCH HAND aircraft returning to Phu Cat from a defoliation mission in II Corps. During the peak activity of RANCH HAND operations (1968-1969) as many as thirty UC-123B or UC-123 K (a C-123 modified with two J-57 jet engines in addition to its conventional engines) aircraft were employed (Cecil 1986).

In addition to the RANCH HAND unit (12th Air Commando Squadron), the 315th Air Commando Wing contained four other squadrons of C-123 aircraft that were routinely used throughout South Vietnam (as early as

Fig. 3.6 The UC-123 K "Provider" with its Modular Internal Spray System was the "workhorse" for RANCH HAND. This high-wing, twin-engine assault transport had excellent low speed maneuverability, and the high-mounted wings allowed convenient positioning of wing spray booms. Note the spray boom mounted aft of the cargo door and near the tail of the aircraft (Photograph courtesy of J. Ray Frank, Frederick, Maryland)

December 1961) in support of logistic operations (Cecil, 1986). In addition, starting in 1967, one of the UC-123 aircraft assigned to RANCH HAND was used for insecticide missions under Operation FLYSWATTER (Cecil and Young 2008). A second aircraft was assigned to the FLYSWATTER mission in 1969. These aircraft were used for spraying insecticide for the control of malaria-carrying mosquitoes. The UC-123 aircraft assigned to the insecticide program were not camouflaged. Instead, those aircraft were coated with a silver alodine treatment. The "silver bug birds" were considered "beneficial" by friendly and hostile forces alike and were seldom targets for VC or NVA weapons (Collins 1967; Cecil and Young 2008). The insecticide program is described in more detail later in this chapter.

Table 3.4 describes the various military aircraft used in the dissemination of herbicides and insecticides in South Vietnam. Approximately 4–5% of all herbicides used in South Vietnam were disseminated by helicopter or ground application equipment and was the responsibility of the US Army Chemical Corps (NRC 1974; Irish et al. 1969; Stellman et al. 2003a). 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 H-19, H-34, and the UH-1 series of helicopters, deployed by the US Air Force, Army, and Navy units, generally sprayed the herbicides. The most common spray systems used were the HIDAL and AGRINAUTICS units. These units were installed in or removed from the aircraft in a matter of minutes because they were "tied down" to installed cargo shackles, and aircraft modifications were not required for their use (Young 1988). Each unit consisted of a 760-l tank and a collapsible 9.8-m spray boom. The unit was operated by manual controls to control the flow valve and a windmill brake. Generally, each helicopter had three crewmembers. Figure 3.7 is a photograph of a helicopter readied for a base perimeter spraying with Agent Blue.

3.6.2 Development, Test, and Evaluation of Aerial Spray Systems for Vietnam

The challenges to obtain successful vegetation control in the military conflict in Vietnam required the application of modern science and technology backed

Table 3.4 Military aircraft used in the dissemination of herbicides and insecticides in South Vietnam

Fixed-wing aircraft and helicopters	Camouflaged	Chemical disseminated
UC-123B/UC-123 K*	Yes	All herbicides
UC-123B/UC-123 K "Silver Bug Birds"*	No	Malathion insecticide
Air Force UH-1, Army H-34, UH-1B/UH-1D, Navy H-19	Yes	Orange, Blue, White

* The "B" model was used through early 1968 after which it was replaced by the "K" models, a jet modification (Cecil 1986).

Fig. 3.7 The Military UH-1 series of helicopters generally sprayed the herbicides. The most common spray systems were the HIDAL and AGRINAUTICS units. They could be removed from the aircraft in a matter of minutes. Each unit consisted of a 760-l tank and a collapsible 9.8-m spray boom (Photograph courtesy of the US Army Chemical Corps)

by a cadre of professionally trained men dedicated to the successful completion of a military mission. The Army Chemical Corps had the responsibilities for the ground and helicopter operations and the oversight of the overall ground program. The aerial spray operations of Agent Orange and other tactical herbicides in Vietnam were conducted with highly trained RANCH HAND aircrews using fixed-wing aircraft and aerial spray equipment that had been specifically developed, thoroughly tested, and critically evaluated for their performance and dissemination characteristics. The USAF was responsible for the training of the aircrews, development of aerial tactics for herbicide missions, and development, testing and evaluation of the spray equipment with its associated aircraft. These programs were primarily conducted at Eglin AFB, Florida, and to a much lesser degree at the Pran Buri Calibration Grid in Thailand (Darrow 1965). The development and testing of the herbicides was the responsibility of the US Army at Fort Detrick, Maryland, with the cooperation of the US Department of Agriculture at research stations throughout the United States (Tschirley 1968; Young 2006).

The Eglin AFB Reservation in Northwest Florida served various military uses during the 1960s and 1970s, including the development and testing of aerial spray equipment for disseminating the herbicides used in the Vietnam War. It was necessary for this equipment to be tested under controlled conditions that were as near to those prevalent in South Vietnam as possible. For this purpose, a testing installation was established in 1962 on the Eglin AFB Reservation. Direct aerial application was restricted to an area of approximately 2.6 km^2 within Test Area C-52A. The Test Area covered an area of approximately 8 km^2 and was a grassy plain surrounded by a forest stand that was dominated by pine and oak species (Young 1974). Details of the programs instrumental in the development and testing of aerial spray equipment are provided in Chapter 6. All of the aerial spray equipment used in Vietnam was initially evaluated at the Eglin AFB testing facility, but the need for developing operational parameters and herbicidal effectiveness in a jungle environment prompted the Military Assistance Command, Vietnam (MACV) to develop a test site in Thailand (Darrow 1965; Darrow et al. 1966).

The test program conducted in Thailand during 1964 and 1965 was to determine the effectiveness of aerial applications of Purple, Orange, and other candidate chemical agents in defoliation of upland jungle vegetation representative of Southeast Asia (Warren 1968). The Pran Buri Calibration Grid was located about 260 km southwest of Bangkok, Thailand. The test area or calibration grid was located in a broad valley bordered on the west and partially on the east by precipitous mountain ranges, which rise 90–450 m above the valley. The test area was about 1,600 m long and 5,000 m wide and included about 570 ha of forest. Tests were conducted on duplicate 4-ha plots (Darrow 1965). The value of the Pran Buri Calibration Grid was two-fold. First, it provided a field site to evaluate the performance of the spray system as configured for defoliation missions in Southeast Asia. Second, it was used to evaluate the concentration of applied herbicides (i.e., effectiveness of nine versus twenty-eight liters per hectare) on jungle vegetation that was native to Southeast Asia. These evaluations could be done without the threat of hostile forces (Cecil 1986). Both the hourglass and the AA-45Y-1 spray systems were evaluated successfully in Thailand (Darrow et al. 1966).

Development, testing, evaluation and calibration of the spray equipment were critical to successful vegetation control. Literally hundreds of such tests at various locations occurred between 1962 and 1970 for the UC-123 and helicopter spray systems (Young and Newton 2004). Field tests of the herbicides established a minimum biologically effective ground deposition rate. The goal of the test programs was to match the herbicide, equipment, and aircraft with the operational parameters to obtain the ideal deposition rate. For Agent Orange, the optimum application parameters and spray characteristics of the UC-123 modular internal spray system were as follows: 130 KIAS (knots indicated air speed) at an altitude of 50 m AGL [above ground (or tree-top) level] producing a spray swath of 80 m (plus or minus 6 m) with a mean deposition of 28 l/ha and treating a total area/tank of 130 ha. These parameters allowed the aircraft to be on target for 3.5–4.0 min and resulted in a particle size where 98% were greater than 100 μm (Harrigan 1970). Tests showed that 87% of the herbicide would have impacted the vegetation within 1 min and within the swath width (Klein and Harrigan 1969; Harrigan 1970). Figure 3.8 illustrated

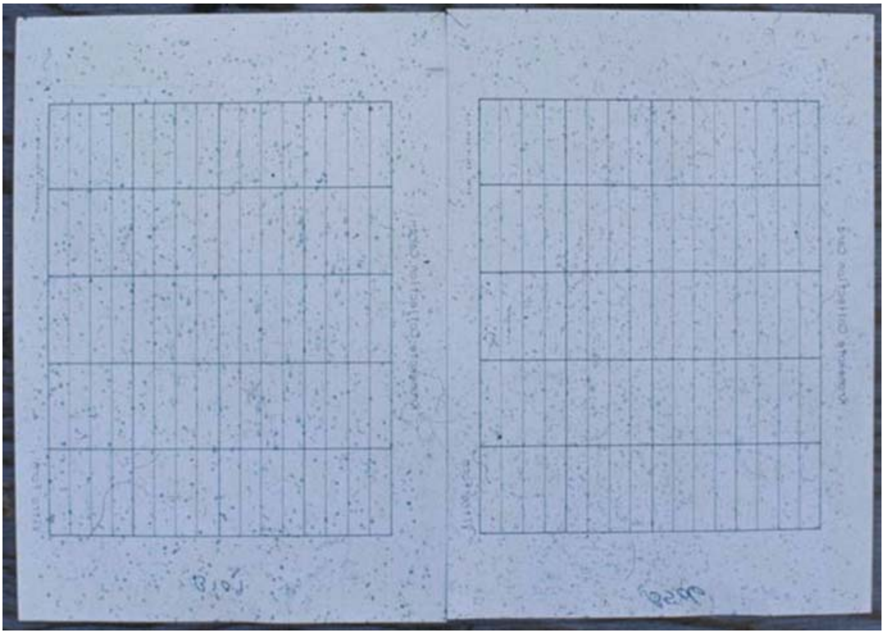


Fig. 3.8 In the test and evaluation of the UC-123 K Modular Internal Spray System at Eglin AFB, Florida, Kromekote cards were employed for physical collection of test material in droplet form. These two cards, each 15 × 20 cm, showed the distribution of particle size and deposition rate when the aircraft was flown at 150 KIAS and 50 m AGL. The Kromekote cards confirmed a deposition rate of 28 l/ha with approximately 98% of the particles greater than 100 μm intersecting the cards (Photograph courtesy of A. L. Young)

the use of Kromekote cards for assessing particle size and distribution. The remaining 13% drifted or volatilized. Similar tests and evaluations provided the optimum parameters for the other herbicides and the helicopter systems (Boyer and Brown 1964).

In October 1961, the newly created Air Force Special Air Warfare Center at Eglin Air Force Base (AFB), Florida was tasked with assisting the Vietnamese Air Force (VNAF) by augmenting their capability through the deployment of three companies of Army H-21 helicopters, a squadron of Air Force C-123 transports, and the loan of 30 T-28 training aircraft. This deployment, under the overall code name FARM GATE, eventually also included the temporary assignment of six C-123 aircraft and four H-34 helicopters for a defoliant spraying program (Cecil 1986). The six aircraft selected for the defoliation operations were quickly modified with the installations of a modular internal spray system, spray booms, and cockpit armor plating (Cecil 1986). The six aircraft departed from Pope AFB, North Carolina on 28 November 1961; a separate operations order using the code name RANCH HAND was not published until the unit's arrival in the Philippines (Cecil 1986).

3.6.3 RANCH HAND Support Activities and Concepts

This section describes the background and mechanics of a "typical" herbicide mission in order to provide some perspective in terms of how herbicides were transported, stored, handled and disseminated in South Vietnam. The following summary of "standard operating procedures" was compiled from the literature and interviews with RANCH HAND aircrews and ground personnel (Craig 1975; Young et al 1978; Buckingham 1982; Cecil 1986; Young 1988, 2006)

1. Each of the 11 different companies that manufactured military herbicides packed them in new ICC 17C 208-l, 18 gauge-steel drums for shipment to Vietnam. Until 1967, lined drums were used only for shipment of Blue. Because of the results of compatibility tests, lined drums were also used to ship White beginning in 1967.
2. Each herbicide drum was marked with a 7.6-cm color-coded band around the center to identify the specific military herbicide. The marking was initially a 30-cm band, but was changed to 7.6 cm in March 1965.
3. Beginning in 1966, the various companies shipped the herbicide by rail to Mobile, Alabama. At the port, the drums were bottom-loaded aboard cargo transport ships. Shipping time from the arrival of the herbicide at the Port of Mobile until it arrived in South Vietnam varied from 47 to 52 days. Figure 3.9 are photographs taken of the arrival of Agent Orange by train, and the subsequent transfer of the drums to a ship at the Port of Mobile.
4. About 10 out of every 10,000 drums shipped were received in a damaged or defective state. This represented a damage rate of 0.1%. About 50% of these damaged drums leaked as a result of punctures or split seams. The damages to the drums were caused by improper loading or because some of the drums were initially defective. Forklifts operated by stevedores also caused punctures. Figure 3.10 is a photograph of a defective drum that was leaking after shipment to Vietnam.
5. About 65% of the herbicide was shipped to the 20th ARVN Ordnance Storage Depot, Saigon, and 35% was shipped to the 511th ARVN Ordnance Storage Depot, Da Nang. Under normal handling procedures, drums were unloaded by Vietnamese stevedores at Saigon and Da Nang from the cargo vessel directly into semi-trailers and were placed in an upright position (See Fig. 3.11). The loaded trailers were then driven by ARVN personnel to the RANCH HAND supply points at Tan Son Nhut (later moved to Bien Hoa), Da Nang, Phu Cat, and Nha Trang air bases.
6. Normally the contents of the drums were transferred into blocked condemned F-6 trailer tanks through a suction hose without removing the full drums from the semi-trailers. Each F-6 trailer tank held 16,300 l or about 78 drums of herbicide. Blocked F-6 trailers were tied to plumbing and pumps so that the herbicide could be delivered to the aircraft by servicing hose without moving the trailers. If blocked F-6 trailers could not accommodate

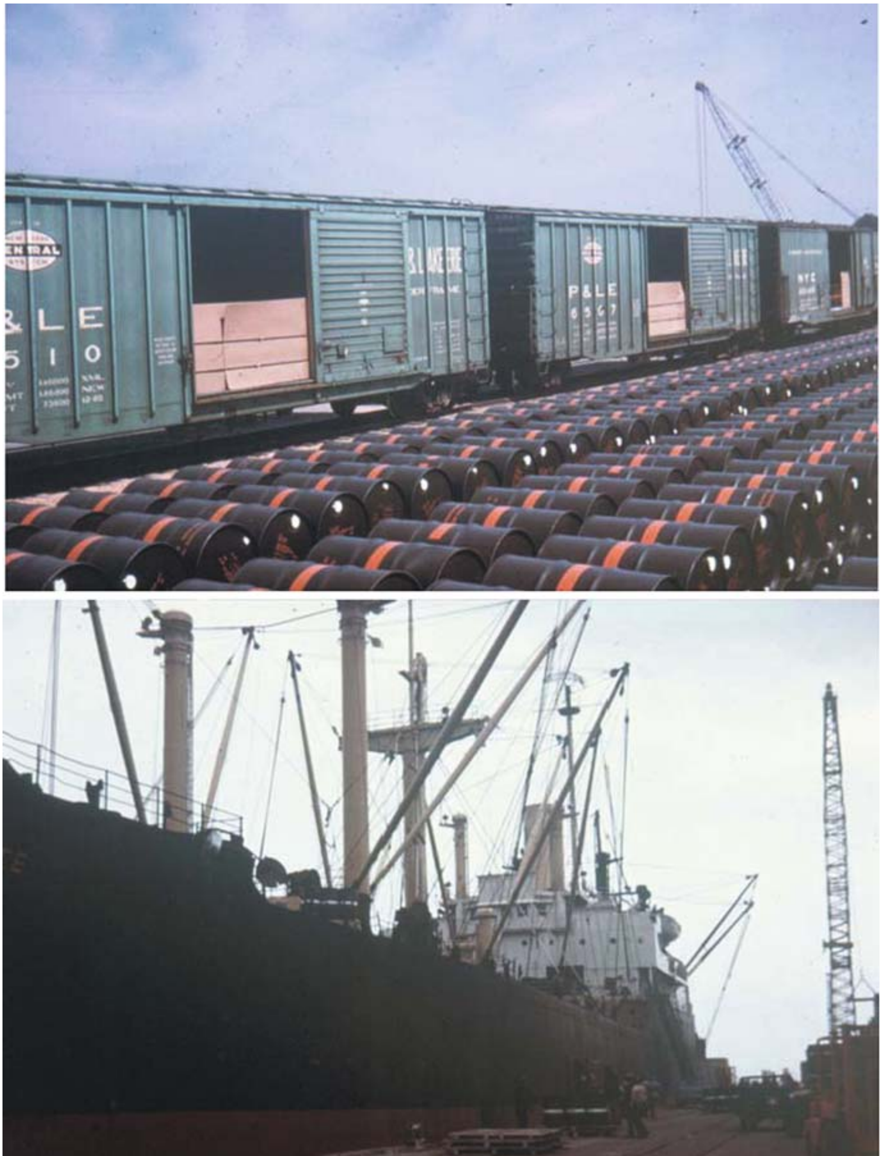


Fig. 3.9 (*Top*) The companies that produced Agent Orange shipped the herbicide in railroad cars to the port at Mobile, Alabama. (*Bottom*) The 208-l drums of herbicide were transferred from rail to a cargo vessel at the port of Mobile for shipment to Vietnam. (Photographs courtesy of Air Force Logistic Command, Kelly AFB, Texas)

Fig. 3.10 Out of every 10,000 drums of herbicide shipped to Vietnam, about 10 of them (0.1%) were received in a damaged or defective state. Leakage from these drums contaminated the docks and the semi-trailers used to haul them to the RANCH HAND bases (Photograph courtesy of Air Force Logistics Command, Kelly AFB, Texas)

the total inventory, the drums were stacked in pyramidal style until needed. During the peak activity of the RANCH HAND operations (1968–1969), contracts were let to construct large above-ground holding tanks at Bien Hoa as part of a hydrant servicing system.

These large color-coded tanks held almost 30,000 gallons (113,550 l) of herbicide. Figure 3.11 is a photograph of semi-trailer loaded with 48 drums of Agent Orange at Bien Hoa Air Base. Figure 3.12 (upper) is a photograph of an F-6 trailers "blocked" near the RANCH HAND flightline at Bien Hoa. Figure 3.12 (lower) is a photograph of the herbicide-servicing row of the Bien Hoa ramp area. Figure 3.13 is a photograph of drums of Agent Orange stacked in "pyramidal style" at Bien Hoa Air Base. Figure 3.14 has photographs taken of the 113,550-l tanks at Bien Hoa Air Base for storage of Agents Orange, White, and Blue, respectively.

7. As previously noted, Orange was insoluble in water, while Blue and White were not. When Blue was mixed with White, a gummy substance consisting of the sodium salt of 2,4-D was formed that clogged pumps, valves, and nozzles. The F-6 trailers and other holding tanks were color-coded to correspond to the drum color-codes and used exclusively for the herbicide to which the code applied.
8. Because of the precipitate formed by the mixing of White and Blue, mission planners had to schedule RANCH HAND aircraft for at least three sorties of Orange Herbicide between changes of load from White to Blue, or visa

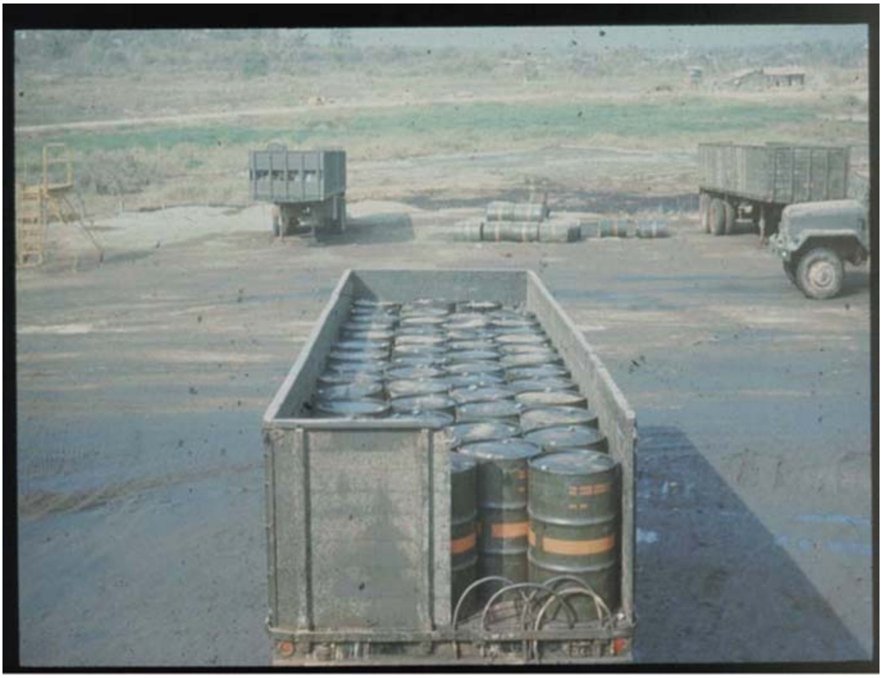


Fig. 3.11 When the Agent Orange was received in South Vietnam the drums were off-loaded directly from the cargo vessel into a semi-trailer. The 48 drums were placed upright and transported to the RANCH HAND units at Tan Son Nhut (1962–1966), Bien Hoa (1966–1970), Da Nang (1964–1971), Phu Cat (1968–1970) or Nha Trang (1968–1969) (Photograph courtesy of J. Ray Frank, Frederick, Maryland)

versa, in order to purge the spray system. Orange was compatible with both Blue and White herbicides. This later created a special problem when the use of Orange was prohibited by American authorities in 1970.

9. The transfer of the herbicides from the 208-l steel drums to storage tanks or aircraft tanks required some precautionary measures. Personnel charged with the supervisory responsibilities of handling the herbicides were to be indoctrinated in appropriate safety precautions including the use of gloves and face shields as needed. Personnel handing the chemicals were to be encouraged to take normal sanitary precautions and to maintain personal cleanliness and to avoid skin and eye contact with the material. Contaminated clothing was to be washed before re-use. Spillage on the skin or in the eyes was to be rinsed copiously with clean water. Despite the above requirements, interviews with numerous former RANCH HAND personnel did not reveal anyone who recalls being briefed on or using any of the required precautionary measures.
10. When the herbicide was pumped from the drums into the F-6 trailers, about 2–5 l remained in the drum. Hence the drums were placed on drain racks and the "drippings" were collected in a pan-type receptacle, re-drummed,

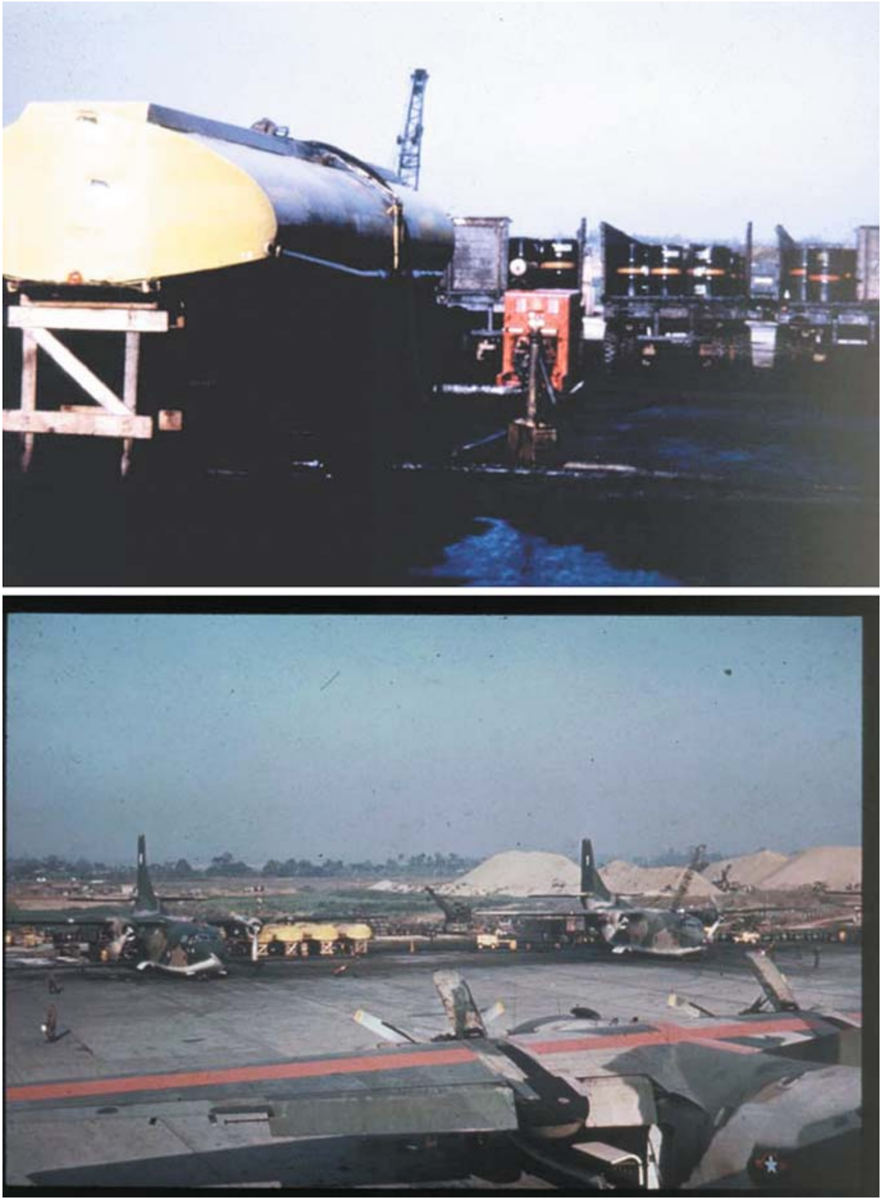


Fig. 3.12 (*Top*) A "blocked" F-6 trailer served as a temporary tank for Agent Orange prior to its loading into the RANCH HAND UC-123 aircraft. The F-6 trailer held 78 drums (29,000 l) of herbicide. The bottom photograph is of the flight line at Bien Hoa Air Base showing the herbicide-servicing row for the RANCH HAND operation. (Photographs courtesy of J. Ray Frank, Frederick, Maryland)

Fig. 3.13 The "pyramidal style" of stacking Agent Orange drums in temporary storage at Bien Hoa Air Base, 1968 (Photograph courtesy of J. Ray Frank, Frederick, Maryland)

and used for spraying base perimeter areas. Figure 3.15 is a photograph of a trailer-mounted drain rack frequently used by the Chemical Corps to collect the "dregs" from herbicide drums for subsequent use for ground-spraying base perimeters.

11. Empty drums were initially given to the South Vietnamese or Free World Military Assistance Forces (primarily Australian or South Korean) for use in construction of defensive positions. The drums were filled with sand, rock, or concrete and used in building bunkers, protective barriers for buildings and check-points. Later American authorities required that empty drums be thoroughly cleaned, punctured, and flattened before being disposed of by burial in landfills.

Fig. 3.14 Photographs of the 30,000-g (113,550-l) above ground tanks constructed at Bien Hoa Air Base in December 1969 for the temporary storage of Agents Orange, White, and Blue, respectively. Each tank was color-coded to identify the herbicide contained. (Photographs courtesy of J. Ray Frank, Frederick, Maryland)

Fig. 3.15 At each of the RANCH HAND Bases trailer mounted drain racks were used to recover the remaining "dregs" of herbicide from the 208-l drums. These dregs were used for perimeter vegetation control (Photograph courtesy of J. Ray Frank, Frederick, Maryland)

12. Surface areas contaminated by spilled herbicides were flushed with diesel fuel or water with diversion of the drainage into settling basins or pits for incorporation into the soil.
13. Within the aircraft, it was not uncommon to have herbicide leakage from around the numerous hose connections joining the spray tank and pumps with the wing and aft spray booms. In hot weather, the odor of herbicide within the aircraft was decidedly noticeable (a frequent term used by the aircrew was "overwhelming"). Periodically, the spray and console were removed (especially with the portable A/A 45Y-1 system) and the interior flushed with surfactant or soap and with water. Because of the corrosive nature of the herbicides (especially Agent Blue), it was also necessary for the aircraft to be painted periodically.
14. Most of the personnel involved in the initial handling of the herbicide were Vietnamese military. However, a USAF flight mechanic or crew chief was responsible for ensuring that the aircraft was properly loaded and the spray system functional. The flight mechanic was also the console operator of the spray system. The pilot, co-pilot and navigator were USAF officers. The flight mechanics, crew chiefs and other ground support personnel were USAF enlisted men. Occasionally a Vietnamese "observer" would accompany the RANCH HAND crew when crop targets were scheduled.
15. For reporting purposes one herbicide "mission" (also referred to as "Lifts") usually consisted of from two to eight aircraft under direction of the mission navigator in the lead aircraft. Each individual aircraft was counted

as a "sortie." An approved area for herbicide operations was called a "Project," with a Project number that reflected the CTZ, whether crop or defoliation project, a sequential identification, and the year of initial approval (for example, Project 4-20-1-66). Within the Project were a number of specific defined "targets." RANCH HAND targeting officers estimated the number of sorties needed to complete the various targets and scheduled the missions/sorties to accomplish the task. Depending on the target size and/or complexity, completion of a single target could take dozens of sorties spaced out over a year or more. Some crop missions were planned against a "target box," which was a large approved area over which the scheduled RANCH HAND aircraft roamed while looking for and spraying ripening crops as discovered. Large, multi-organizational operations were usually labeled with code names, e.g., Pink Rose, Swamp Fox, or Sherwood Forest.

16. The first lift normally took off before sunrise. From a tactical point of view, the arrival of the aircraft at the target area just prior to sunrise permitted the aircraft to approach the target while the jungle floor was still dark. This afforded some degree of protection from enemy ground fire. This also allowed time for the mission to return to base, re-service, and launch on a second lift. From the standpoint of herbicidal action, application by aerial spray was most effective if accomplished prior to 1100 h before temperatures exceeded 85 degrees and winds did not exceed a velocity of 8 knots. This insured the proper settling of the spray on the target area.

3.6.4 Accidental Spills

Spills of herbicides often were a consequence of manual handling of large volumes of materials and the inexperience of the indigenous personnel assigned to load and unload the nearly 500-pound (227-kg) drums. In addition, leaking nozzles on the aircraft spray bars and problems with the transfer plumbing contributed to a constant series of small spills (Cecil 1986). On the other hand, major spills were infrequent until RANCH HAND moved to it's new parking ramp at Bien Hoa. An unsigned US Army Memo dated 15 January 1970 and obtained from the US Armed Services Center for Research of Unit Records, Springfield, Virginia cited two spills involving less than 2,000 l of Orange and White (Young and Andrews 2006). The first spill occurred in December 1969 approximately two weeks after the large 113,550-l herbicide tanks were installed at Bien Hoa Air Base as part of the hydrant servicing system built into the new RANCH HAND flight-line ramp. The memo noted that a leakage was observed in the underground piping system associated with the Agent White tank. The system was shut down and Civil Engineering was notified. After digging up the area, it was discovered that a coupling had broken in the White servicing system. No surface run-off of White occurred, and "all spillage was absorbed in the soil in the immediate vicinity of the break." The Memo also mentioned a spill of less than 2,000 l that occurred during the first week in

February 1970 from the Agent Orange tank servicing system. No other information was provided (Young and Andrews 2006).

On 1 March 1970, in a unsigned US Army Chemical Corps Memo dated 31 March 1970, another underground leak occurred at Bien Hoa Air Base in the 113,550-l Agent Orange Storage Tank (Young and Andrews 2006). The memo indicated that approximately 7,500 gal (28,000 l) had drained into the soil. A dirt dike was immediately constructed to contain the surface runoff (estimated at approximately 400 l). On 7 March, an earthwork dam was constructed downstream of the underground piping system to contain any residue. On 22 March, the following notation was made:

> The local dam has contained all the water and residue. No flow of liquid down the drainage system has occurred. However, the damaged area is now full of water and will not work during the monsoon season. Limited quantities of the water have been flushed over the dam for absorption into the sandy soil in the drainage ditch.

Also on 22 March 1970, the Squadron Flight Surgeon referred the problem to the Bien Hoa Public Health Section. The Bien Hoa Public Health Section determined that the nearest USAF facility capable of testing for 2,4-D and 2,4,5-T was at McCellan AFB, California. Procedures for obtaining water samples were discussed. The memo, however, did not give the results of any water samples, nor provide additional information on further activities related to the spill, other than corrective actions for the piping systems (Young and Andrews 2006). The first quarter 1970 unit history report confirmed the above spills along with other problems with the new underground servicing system. An investigation revealed that vehicular traffic was causing the plastic system couplings to break and leak herbicide. The history report stated that “a program of replacing all plastic 90 degree couplings with steel couplings eliminated” the problem (Cecil 1986).

3.7 MACV Directive 525-1: Herbicide Procedures and Operations

The tactical herbicide program in South Vietnam was a joint United States – Government of Vietnam venture. Since the program carried with it the potential for generating serious political, economic, and psychological counter effects, it was conducted under an elaborate system of policy and operational control extending from the highest levels of both governments through intervening civil and military headquarters all the way down to the province level (Jefferson 1969).

Overall policy for herbicide operations in Vietnam was set forth in directives by the Military Assistance Command, Vietnam (MACV) and based on guidelines from the US Department of State and Department of Defense (Young et al. 2004). The most important of these directives was MACV Directive 525-1, Herbicide Procedures and Operations (MACV 1969). This directive was revised yearly during the peak years of tactical herbicide operations. Most importantly, the uses of all tactical herbicides by United States and Allied Forces in Vietnam were governed by this directive (MACV 1969). The Directive (and Annex K of the Directive) "prescribed policies, responsibilities, and procedures governing the operational employment of tactical herbicides within the Republic of Vietnam," including all fixed wing, helicopter, and surface-based methods of herbicide application (MACV 1968; MACV 1969; Young et al. 2004).

The use of tactical herbicides for defoliation and crop destruction was primarily a Government of Vietnam operation that was supported by the US Government. A complex coordination process was involved in the approval of targets (see Fig. 3.16). Initial requests for tactical herbicide projects could originate either from Vietnamese province officials or Military field commanders, and all such requests had to be approved by the Vietnamese Province Chief in accordance with Directive 525-1 (MACV 1969). As noted in the flowchart (Fig. 3.16), after the request was received it was referred to a coordination meeting of Vietnamese and US officials (usually held in the field) to work out the initial details of the request (Cecil 1986). Various tactical benefits and considerations supporting the project were required prior to the senior US Chemical Corps advisor issuing the documentation on the project.

Project approval requests were presented simultaneously to the MACV 203 Committee and to the Vietnamese JCS 202 Committee (see flowchart), and if both Committees recommended the request, it was sent to the US Ambassador, the Commander of MACV, and to the Government of Vietnam (GVN) for final approval of the Project. The total approval process could take more than a year (Cecil 1986). After final approval the Project package was returned to the MACV Chemical Operations Division for further analysis, staff coordination, evaluation and consideration of policy, logistics, and operational limitations (Young et al. 2004).

Directive 525-1 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 and crop destruction operations required pre-approval from the MACV Commander, the US Ambassador, and the GVN; (3) use of US assets to accomplish GVN requests for defoliation by helicopter in support of local base defense, clearance of small ambush sites and maintenance of deforested areas required pre-approval from both the US and GVN; (4) use of US assets to accomplish ground-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 2 km for helicopters and 5 km for fixed-wing delivery was to be maintained around active rubber plantations" (MACV 1968; MACV 1969).

3.8 Post Approval Procedures in Operation RANCH HAND

RANCH HAND operations and targeting personnel met weekly with the chemical operations section of MACV to discuss active requests and to schedule additional survey flights over proposed areas. The survey missions were necessary to identify actual target tracks and navigational fixes for the individual

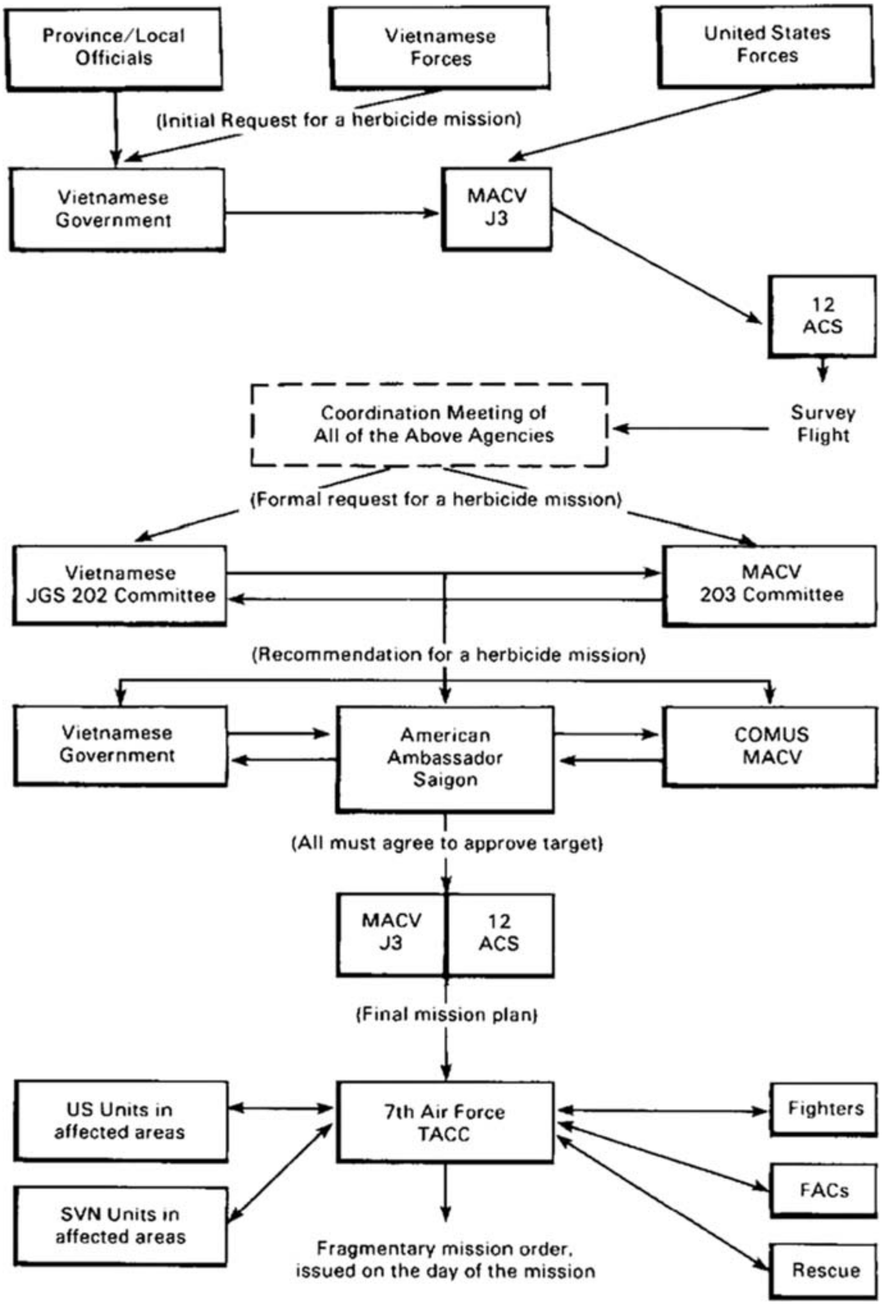


Fig. 3.16 Flowchart of combined United State/Vietnamese tactical herbicide Project approval and directing order system in 1967 (Diagram courtesy of Cecil 1986)

missions and to evaluate the extent and ripeness of crop targets (the optimum time to strike crop targets was just before they were ripe enough for harvesting). The survey flights were flown by single, unescorted UC-123s manned by the RANCH HAND chief or assistant chief of targeting, a pilot, a copilot, a navigator and an Army Chemical Corps officer (Cecil 1986; Young et al. 2004). After the flight specific target details were worked out and a target overlay map of the Project was prepared. Figure 3.17 is an example of a target overlay for a defoliation request (MACV 1968).

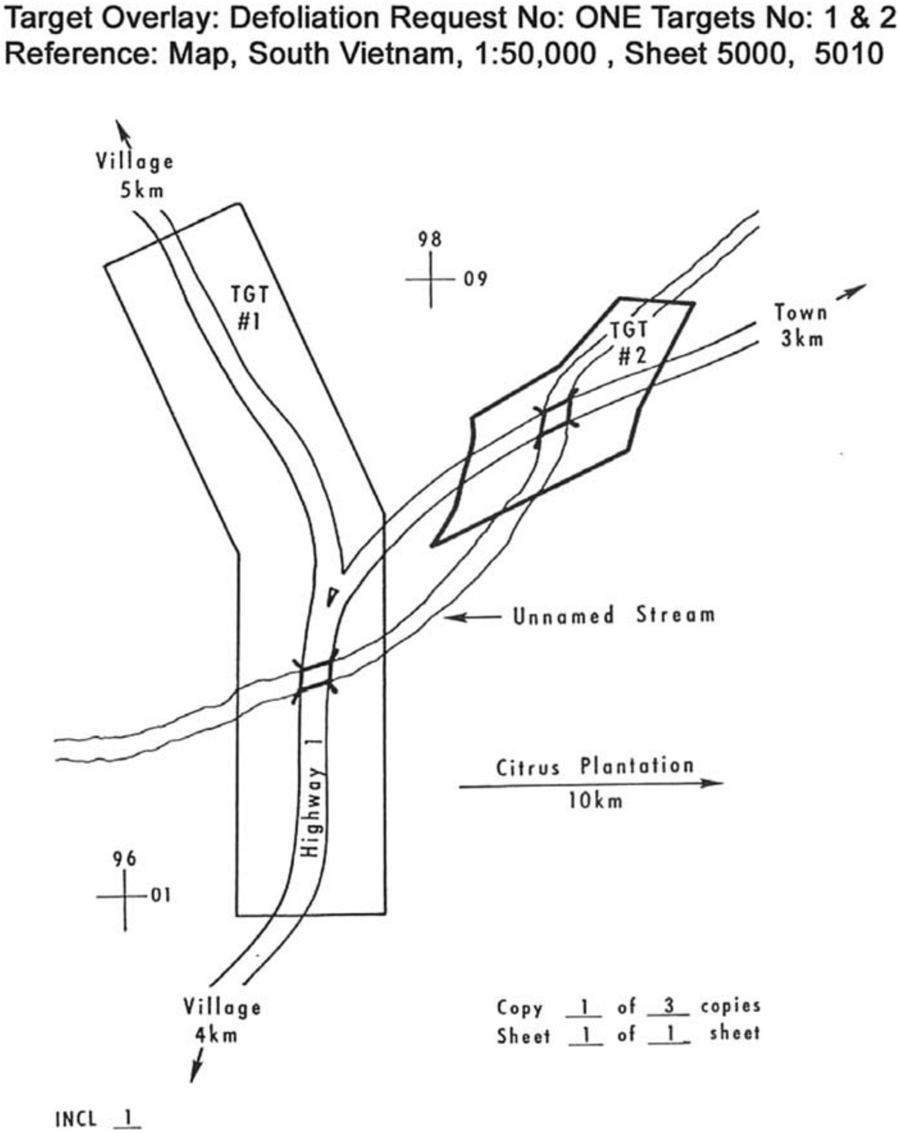


Fig. 3.17 Example of a target overlay (MACV 1968)

3.9 Coordinating RANCH HAND Spray Missions

Once a particular Project area was approved and surveyed it was assigned a priority within the list of approved Projects (by 1965 the number of herbicide requests already exceeded RANCH HAND's capability to complete and new requests were coming in faster than the spray squadron could be expanded). When a Project was selected for accomplishment, the RANCH HAND commander and his targeting officer, together with MACV staff members, determined the most effective mission dates and requested implementing orders. Hostile ground fire was such a hazard to the UC-123 aircraft that fighter escort was mandatory and in January 1965 authorization was given to prestrike spray tracks with fighter aircraft immediately in advance of RANCH HAND formations (Cecil 1986; McConnell 1970).

Fighter support was a vital part of planning and it reduced to some extent the deadly hazard poised to RANCH HAND personnel and aircraft by ground fire from opposing forces. In coordination with the targeting officer the mission navigator determined the amount of fighter support needed for the particular target area, planned the individual missions, prepared necessary mission charts, and drafted the order requests for submission to TACC (Tactical Air Control Center). The day of the mission the mission navigator briefed the aircrews and flew in the lead aircraft to direct the formation. The tactics for an individual target run were first considered during target planning. In selecting the optimum run, the mission navigator weighed such factors as terrain, the size and geometry of the target and restrictions on the approach and departure routes (Jefferson 1969). If possible, the run was planned to be nearly straight and continuous since multiple passes in the same area increased exposure to ground fire. The navigator ensured that the formation would not be boxed in a canyon on mountain runs and that the track went "down-hill" to assist if an engine were lost. He also made judgment on the defenses likely to be encountered, based on past experience in the target area, intelligence briefings and information from the area FAC when available (Jefferson 1969).

The day prior to the mission, TACC coordinated the Forward Air Controller (FAC), fighter and rescue support through the Direct Air Support Center (DASC) and issued the mission order (better known as a "frag" order) (see flowchart, Fig. 3.16). TACC in coordination with DASC sent out warning messages to field forces of the impending mission. All nearby military units had to report that they had no troops in the target area. Any negative response caused the herbicide mission to be cancelled. The target area had to be a "free fire zone", thus assuring the supporting fighter escort they could drop ordnance in the target area with only clearance from the Forward Air Controller (Collins 1967; Buckingham 1982). It also ensured that no friendly military personnel would be present and directly exposed to the herbicide being used (Young et al. 2004).

3.10 Encountering a Hostile Environment

Spray missions for both defoliation and crop destruction were conducted in extremely hostile environments. That was the concept for the use of herbicides – remove the vegetative cover and food sources used by the enemy. The ground fire received by the RANCH HAND aircraft was from enemy troops (Viet Cong and North Vietnamese Army) (Collins 1967). Although the C-123 "Provider" was a tough and dependable aircraft, it was never designed to withstand the harsh combat environment of the RANCH HAND mission in South Vietnam. Significant modifications were made to protect the crew, the spray systems, and the aircraft. The volunteer crews of Operation RANCH HAND had few manuals or guidance documents on how to perform their unusual missions; they learned from day-to-day operations and from their mistakes. Their tactics and strategies were intended to minimize their time at tree-top level while maximizing the effectiveness of the herbicide selected for that target. The refinements to the aircraft and modifications of the tactics and procedures were necessary to minimize aircraft battle damage and crew injury during spray operations (Cecil 1986). The first manual issued by the Tactical Air Command and titled "USAF Special Operations Training Course for UC-123 K Spray Pilot" was issued in January 1972, three months after the RANCH HAND Project in Vietnam had terminated (TAC 1972).

Responding to the increase in battle damage, especially in the cockpit areas, during missions in 1965, RANCH HAND crewmembers began using flying helmets equipped with a clear visor that could be lowered to protect the eyes. Used in place of the standard radio headset while on the spray run, the helmet, together with a flak jacket, offered pilots and navigators extra protection from flying shrapnel and glass. Twice in December 1965 this protection allowed crews to complete runs despite cockpit damage, although it did not prevent them from receiving minor wounds (Cecil 1986). Because of enemy anti-aircraft fire, and at the suggestion of RANCH HAND crews, Doron armor "half moon" cut-outs were installed in front of the instrument panels to provide limited "head-on" protection in the cockpit area. [Doron armor was a highly engineered nonmetallic lightweight armor of laminated fiberglass and nylon.] In addition, an open-topped box, 1 m on each side, constructed of two 1.5-cm thick sheets of Doron armor was installed at the spray operator's position. Sitting in the "box" while on the target run afforded him some protection against ground fire (Buckingham 1982). Armor was also placed around the pump motor fuel tank, and a fire extinguisher was installed nearby to reduce the risk of a ground fire hit causing an internal fire (Buckingham 1982).

In the test and evaluation years of RANCH HAND Operations, the UC-123s had retained the unpainted silver finish of the original aluminum skin, a finish marred only by red-primed skin patches resulting from repair of frequent enemy hits. In January 1966, Air Force Headquarters directed the repainting of all combat aircraft in a camouflage scheme of mottled browns, greens and yellows in irregular patterns. The purpose of the new camouflage color scheme was to make the aircraft harder to see, particularly when dispersed on the ground. However, because of the camouflage, Forward Air Controllers (FACs) and supporting fighters had trouble in distinguishing the spray planes at treetop-level when they did not have their spray turned on. By adding a fluorescent red stripe (in 1967) on top of the wings of the UC-123s, the planes could be spotted more easily by their escorts (Buckingham 1982).

Frequently emergencies occurred which required the crews of the UC-123 to rapidly dump their herbicide load. Such action, for example, had to be taken very quickly when an engine quit – approximately 5,000 kg of herbicide greatly reduced the ability of the remaining engine to keep the aircraft airborne. Hence, in the A/A 45Y-l Internal Modular Dispenser System a 25-cm emergency dump value was installed, replacing the 12.5-cm value previously used. This allowed either the pilots or the flight mechanic to more rapidly empty the entire 1,000-gal (3,785-l) tank (Collins 1967).

In May 1968 RANCH HAND received the first UC-123 K, a re-configured UC-123B. The K-model modifications consisted of the installation of two J-85-17 jet engines to supplement the two radial piston engines, a modulated anti-skid braking system, and a combination stall warning and angle of attack indicator. The additional thrust provided by the jets greatly increased the aircraft's ability to tolerate the loss of an engine, while the extra airspeed and rate of climb reduced vulnerability to ground fire by enabling the spray planes to spend less time at low altitude increasing safety margins during operations over mountainous terrain. To enable the spray delivery system to keep pace with the higher-flying speeds, the UC-123Ks also received a larger spray pump and a flow meter to regulate the deposition rate at a constant three gallons per acre (28 l/ha), regardless of the plane's speed (Buckingham 1982; Cecil 1986).

The tactics used on spray missions varied with target type and depended generally on weather, target terrain, and the amount of ground resistance expected. If the weather was clear, the spray aircraft remained at altitude and then rapidly descended at about 760 m per minute to spray altitude (45 m AGL). If ceilings were low, a low-level approach was made to reach the "spray-on" point. If the target allowed, one long straight run was made. Other tactics included flying a race-track pattern, or a "Plum Tree," which involved making 90–270 degree turns at the end of the first target leg so as to fly a parallel second leg in the opposite direction. If the target was "hot", the spray aircraft made one pass and then diverted to another target for the rest of the mission. In mountainous country, one aircraft flew at a higher altitude, where visibility was greater, and thus was able to "talk" the other spray aircraft along the targeted road or trail. Another technique involved throwing smoke grenades to mark the road before starting the run. The procedure was to then fly from smoke-point to smoke-point (Collins 1967; TAC 1972).

Despite aircraft and system modifications and the continuing efforts to develop tactics that would provide an additional margin of safety, the most effective means of protecting the RANCH HAND aircraft and crews was the supporting role of fighter aircraft. By mid-1964, hostile ground fire became more intense, and the RANCH HAND missions became extremely hazardous. Since the need to assign fighter aircraft to escort and support the defoliation project had not yet been recognized, the spray aircraft were essentially defenseless. Although RANCH HAND aircraft received heavy automatic-weapons fire from the ground with increasing regularity, and as previously noted, it was not until January 1965 that approval was granted to pre-strike targets with fighter aircraft and to provide a fighter escort for the spray aircraft. From that point forward, fighter support was a vital part of the defoliation program and made a significant contribution toward minimizing the effect of ground fire against defoliation aircraft, although it could not entirely eliminate losses of aircraft and crew. Almost half of the aircrew members assigned to RANCH HAND in December 1965 had been wounded at least once and the aircraft had accumulated 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. During its nine years of operation, RANCH HAND aircraft received more than 5,000 hits, lost nine spray aircraft and had 28 RANCH HAND personnel die in Vietnam (Buckingham 1982; Cecil 1986).

3.11 The Critical Role of the Forward Air Controller

The Air Force basic work unit was a Tactical Air Control Party (TACP), and was an autonomous Air Force unit co-located with the US Army. It was comprised at a minimum of an officer, the Air Liaison Officer or the Forward Air Controller (FAC), who was assigned to an Army unit, and the ROMAD (Radio Operator Maintenance Drive), an enlisted member of the TACP who was a mobile (jeep) radio operator. Both the FAC and the ROMAD had radio equipment for UHF (ultra high frequency) and VHF (very high frequency) communications (TASG 1969). The Forward Air Controller had major responsibilities for the executing the RANCH HAND mission. The FAC flew a single-engine observation aircraft (e.g., 0-1/E/F, "Bird Dog"), and was generally based at the nearest Tactical Operations Center (TOC) to the target area, and was the individual most familiar with the Area of Operations (AO), or his Tactical Area of Responsibility (TAOR) (TASG 1969; Boyne 2000). When the FAC received a frag order, he established his "call sign" that would be recognized by the pilot and navigator of the lead RANCH HAND aircraft, the accompanying fighter escort, and with the ROMAD who kept in constant contact with any ground forces (including special operation units) that potentially could be near the target area. Within the Corps Area, e.g., II Corps, the FACs kept their own call signs that were readily recognized by ground troops and pilots (TASG 1969; Harrison 1989; Flanagan 1992).

Usually, one or two hours prior to the RANCH HAND mission, the FAC arrived at the target coordinates and made observations on the weather, landmarks, and if there were observable hostile forces in the area. Since the target area was a “free fire zone”, the FAC, in coordination with the ROMAD, ensured that there were no friendly (allied or US) forces in the target area. If there were any imminent operations or the presence of friendly forces in the area, the FAC would order cancellation, or divert the spray mission to an alternative target. Since CBU ordnance had about a 2% dud rate, it was frequently necessary for ground commanders to deny clearance for movement of friendly troops through the area (Cecil 1986). Hence, the approval procedures for a mission “cautioned” field commanders not to send friendly troops immediately into areas sprayed because of this unexploded ordnance (Harrison 1989; Flanagan 1992). This action prevented accidental attack on friendly forces by the escorting fighters, and kept field forces from entering the area after the use of CBU (cluster bomb unit) or other heavy suppression munitions (TASG 1969; Cecil 1986; Flanagan 1992).

3.12 Executing the Spray Mission

The FAC coordinated with the approaching RANCH HAND aircraft and the arriving fighter support by radio. If the weather in the target area was not acceptable (e.g., wind greater than 10 knots, rain, poor visibility), the FAC cancelled the mission or sent the aircraft to the secondary target. At the last minute the FAC contacted the appropriate Direct Air Support Center (DASC) to insure that the mission was still clear of friendly troops and approved to take place. If the mission was to be executed, the FAC marked the initial point leading to the target by the use of a white phosphorous rocket that produced a plume of white smoke visible through the trees (TASG 1969). The RANCH HAND aircraft descended to the appropriate altitude and air speed and the lead pilot called “spray on” at the start of the spray run. All aircraft in a mission simultaneously turned on their spray systems and continued spraying until the lead pilot called “spray off”. If the target area was known to be a “hot target” (hostile ground force present), or if the RANCH HAND aircraft received ground fire, the FAC could instruct the fighter aircraft to deliver their ordnance at the location where the RANCH HAND aircraft received the ground fire or delay using the fighters until after the spray aircraft safely departed the target area (TASG 1969). The FAC stayed in the target area until the RANCH HAND and fighter aircraft departed the target area. If either the RANCH HAND or fighter aircraft were crippled or crashed, the FAC via the ROMAD requested air rescue (helicopter) assistance (Cecil 1986; Flanagan 1992). Thus the role of the FAC was critical to essentially every RANCH HAND mission that occurred after November 1963.

During July 1968, RANCH HAND developed more fully the tactic called "heavy suppression" to counter increased ground fire over heavily defended targets (Buckingham 1982; TAC 1972). Frequently when RANCH HAND aircraft flew over such targets, between four and twelve fighter aircraft accompanied the spray planes. On the day prior to the mission, the pilots of the RANCH HAND and fighter aircraft would meet and decide on specific tactics. When heavy suppression was involved, fighters would strike strong points in the target area with 500- or 750-pound bombs 2 or 3 min before the UC-123s began their spray run. When the spray run began, fighters would fly slightly ahead of and parallel to the spray planes and drop antipersonnel CBUs to force any gunners on the ground to stay under cover until the spray formation had passed (Buckingham 1982). Figure 3.18 is a photograph showing a fighter aircraft delivering ordnance on a target prior to the arrival of the RANCH HAND aircraft. The fighter aircraft frequently deployed CBU-12s containing white phosphorus that were not only a deadly "heavy suppression" munitions, but one that also provided a "cloud of smoke" to hide the approaching RANCH HAND aircraft.

As previous noted, in 1967 RANCH HAND personnel painted a red identification stripe across the top of the UC-123's wings to help fighter aircraft and forward air controllers see the camouflaged RANCH HAND planes more easily against the background of the South Vietnamese jungle (Buckingham 1982). Figure 3.19 is a photograph of the red stripe on RANCH HAND aircraft.

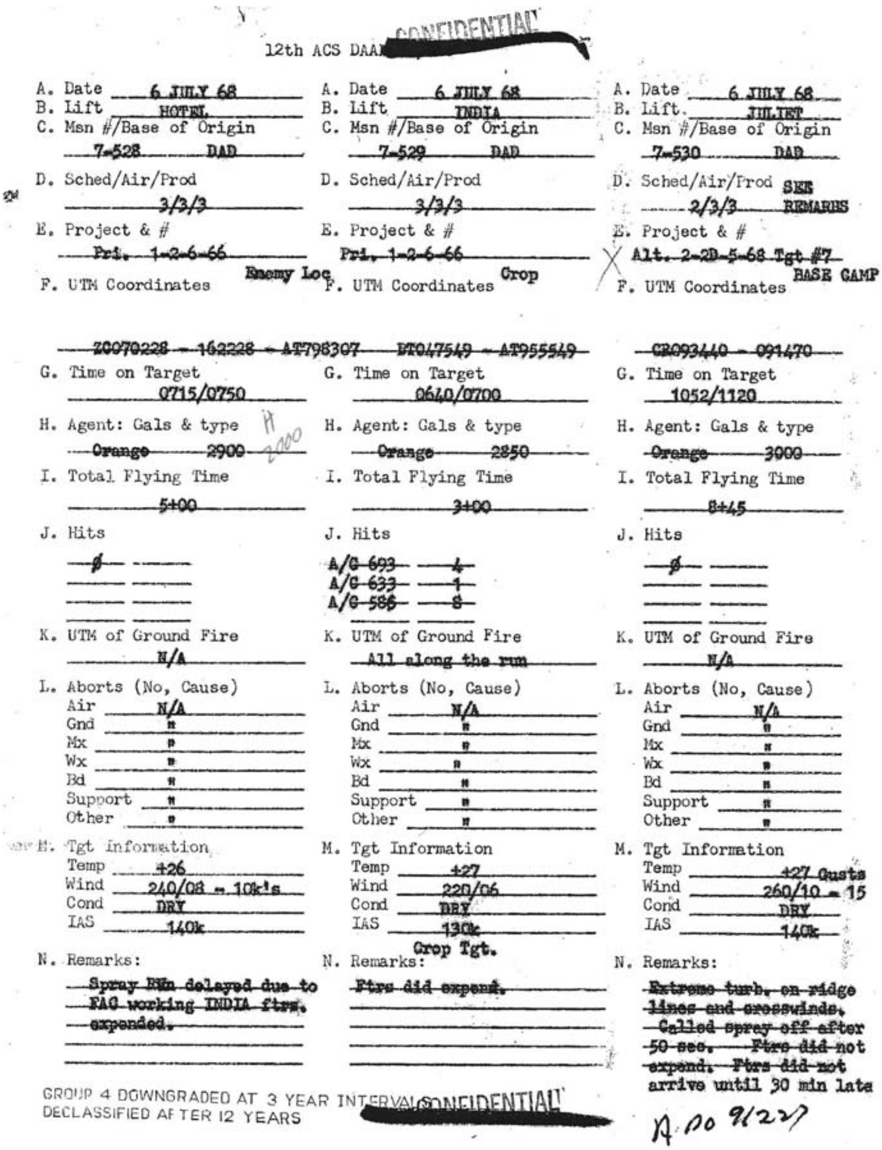
Fig. 3.18 Three RANCH HAND aircraft spraying at 150 feet (45 m) above the ground were masked from enemy fire by CBU smoke to the right of the run. Meanwhile a fighter aircraft, barely visible above the hills, had just laid CBU to the left of the planned spray run. This photograph was taken in Northern II Corps in 1967 (Photograph courtesy of the Plant Sciences Laboratories, Fort Detrick, Maryland)

Fig. 3.19 A photograph of four UC-123 K aircraft "heading down" to the target. Note the bright red band across the upper surface of the wings. This was so FACs and fighters could more easily see the camouflaged RANCH HAND aircraft when at tree-top level. The photograph was taken over II Corps, 23 August 1969 (Photo courtesy of J. Ray Frank, Frederick, Maryland)

3.13 Preparation of the Daily Air Activity Report (DAAR)

The fundamental data on RANCH HAND tactical herbicide operations came from paper records containing data from the missions that were flown (DMA 1970). Figure 3.20 is a photograph of a Daily Air Activity Report (DAAR) describing three spray missions that occurred on 6 July 1968 in Vietnam. The DAAR included the date of the mission, call sign, base of origin, project number, UTM coordinates of the spray track, target type (e.g., enemy line of communication, base camp, crop destruction), type and quantity of herbicide, total flying time, number of hits (from enemy ground fire), reason if mission aborted or cancelled, target information (temperature, wind direction and speed, conditions), indicated air speed while spraying, and any remarks (Cecil, 1986).

During the mission, the lead navigator filled out the initial mission data. The completed pencil copy was then turned over to a clerk-typist who prepared a clean copy for the unit files and a DAAR and electronic message covering all the missions scheduled that day. The electronic DAARs report was sent to the chemical office at MACV Headquarters, where the data was entered into a logbook. Later the logbook entries were transferred to punch cards from which a tape was prepared (the so-called HERBS tape, HERBICIDE REPORTING SYSTEM). Unfortunately, not all information, especially the remarks, was transferred to the punch cards. The data-entry personnel that prepared the punch cards often misinterpreted other logbook entries. As a result the HERBS



CONFIDENTIAL

12th ACS DAA[redacted]

A. Date	6 JULY 68	6 JULY 68	6 JULY 68
B. Lift	HOTEL	INDIA	JULIET
C. Msn #/Base of Origin	7-528 DAD	7-529 DAD	7-530 DAD
D. Sched/Air/Prod	3/3/3	3/3/3	2/3/3 SEE REMARKS
E. Project & #	Pri. 1-2-6-66	Pri. 1-2-6-66	Alt. 2-2D-5-68 Tgt #7
F. UTM Coordinates	Enemy Loc ZC070228 – 162228 – AT798307	Crop BT047549 – AT955549	BASE CAMP CR093440 – 091470
G. Time on Target	0715/0750	0640/0700	1052/1120
H. Agent: Gals & type	Orange 2900 (H 2000)	Orange 2850	Orange 3000
I. Total Flying Time	5+00	3+00	8+45
J. Hits	∅	A/C 693 4; A/C 633 1; A/C 586 8	∅
K. UTM of Ground Fire	N/A	All along the run	N/A
L. Aborts (No, Cause) Air	N/A	N/A	N/A
Gnd	"	"	"
Mx	"	"	"
Wx	"	"	"
Bd	"	"	"
Support	"	"	"
Other	"	"	"
M. Tgt Information Temp	+26	+27	+27 Gusts
Wind	240/08 – 10k's	220/06	260/10 – 15
Cond	DRY	DRY	DRY
IAS	140k	130k	140k
N. Remarks:	Spray Run delayed due to FAC working INDIA ftrs. expended.	Crop Tgt. Ftrs did expend.	Extreme turb. on ridge lines and crosswinds. Called spray off after 50 sec. Ftrs did not expend. Ftrs did not arrive until 30 min late

GROUP 4 DOWNGRADED AT 3 YEAR INT[redacted]NFIDENTIAL
DECLASSIFIED AFTER 12 YEARS

Fig. 3.20 A Daily Air Activity Report (DAAR) describing three spray missions from Da Nang that occurred on 6 July 1968 during the Vietnam War (Courtesy of the Air Force Historical Center, Maxwell AFB, Alabama) tape contains numerous errors. The contents of the HERBS system included the date; the province in which the mission was flown; the project number; UTM coordinates defining the track with additional codes to identify each UTM point as a stop, turn, or start 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. The completeness and accuracy of the data were entirely dependent upon the quality of information obtained from the field units and forwarded to the Chemical Operations Division (DMA 1970; Cecil 2006).

Figure 3.20 is a photograph of a DAAR of the 12th ACS (Air Commando Squadron) daily record of three "missions" from Da Nang Air Base that occurred on 6 July 1968. Individual 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 each day was the "Alpha" lift with the radio call sign "Cowboy Alpha"; the first lift from DaNang was the "Hotel" lift. In 1966 an Air Force wide call-sign directive changed the 315th Wing radio designator from "Cowboy" to "Hades." Typically, show time (arrival time of the aircrews at the mission briefing room) for the Alpha lift was 0430 hours and for the Bravo lift, 0515 hours. These early morning missions were planned to strike their targets at sunrise, and show times were adjusted according to the distance of the target area from the launch base. After returning from the first target, the Alpha crew would rebrief and relaunch at 0900 to 0930 hours to another target. This second mission by this crew would become "Charlie" lift. The "Bravo" crew was also turned around for a second mission and would become the "Delta" lift. As the RANCH HAND unit grew in size with more aircraft and crews available, the average missions grew in size from as few as two sorties to as many as eight and the number of missions expanded from two to four and five. Thus, if sufficient aircraft and crews were available, and target approval had been obtained, additional missions were scheduled as "Echo", "Foxtrot", "Hotel", "India", "Juliet" and "Kilo" lifts (Cecil 1986, 2006).

In the enclosed mission record (Fig. 3.20), notice that "Hotel" and "India" originated from Da Nang (DAD) at 0715 and 0640 and were "on target" at 0750 and 0700 h respectively. Lift "Hotel" had a target that was an enemy line of communication (LOC), while the "India" lift was against a crop target. The "India" lift turned around and became the "Juliet" lift that left Da Nang at 1052 h. Unfortunately the fighter escort arrived 30 min late and when the mission finally got on target extreme turbulence and crosswinds forced "lead" to call "spray off" after 50 s. "Juliet" then diverted to its alternate, an enemy base camp that was Target #7 of Project 2-20-5-68. "Hotel" and "India" were part of the same project but the "Hotel" target was an enemy "line of communication" while crop was the "India" target. Only "India" received ground fire. The lead aircraft received 4 hits, the second (of three) received 1, and the last aircraft over the target received 8 hits. Note that the run for "Hotel" was delayed due to the FAC already working the run for "India". Fighters escorting both "Hotel" and "India" expended munitions. All three missions sprayed Herbicide Orange. Note also that the UTM coordinates indicate that "India" and "Juliet" each flew a spray track of a single straight leg while the "Hotel" mission's spray track was constant, but had two turning points (Cecil 2006).

The DAARS provided both a source of detailed information and ample evidence that the detailed procedures and policies for the RANCH HAND missions were strictly observed (Young et al. 2004). Although the DAARS data do not permit absolute conclusions that troops on the ground were never directly sprayed during RANCH HAND missions, they do frequently cite "friendly forces in the area" and "free fire not authorized" as reasons for aborted or cancelled missions. Table 3.5 is a listing of causal factors of cancellations as taken from DAARS for RANCH HAND missions conducted between January 1967 and December 1970 (Cecil 2006).

As noted in Table 3.5, DAARS were available for 4,488 of the scheduled 5,694 missions from January 1967 through December of 1970. Approximately 52% of all missions cancelled were due to unfavorable weather conditions. Clearly the very narrow range of conditions under which spraying could take place, and the extreme variation in weather conditions over South Vietnam, especially during the monsoon seasons, were the primary cause of the weather related cancellations. Almost 5% of all missions were cancelled because either the FAC or the fighter escorts were not available in the target area. Cancellation

Table 3.5 Data from RANCH HAND Daily Air Activities Reports (DAARs) citing reasons for the cancellation of missions (Cecil 2006)

RANCH HAND target cancellations 1967–1970					
Time Period (Jan.–Dec.)	1967	1968	1969	1970	Total
Scheduled Missions	2030	1697	1542	425	5,694
Missions not checked: DAARS unavailable	611	467	117	11	1,206
Targets cancelled for:					
Weather, general	539	704	600	130	1,973
High temperature or high winds	135	85	112	10	342
Friendly troops in the area	18	39	30	9	96
Not cleared on target by DASC, reason not given	23	6	0	0	29
Not cleared on target by TACC, reason not given	21	68	76	41	206
FAC not available on target	26	46	47	24	143
Fighter escort not available on target	27	12	25	8	72
Cnx by US military field unit	7	10	39	6	62
Cnx by ARVN military field unit	1	7	21	2	31
Due to battle damage or high threat target	19	21	24	2	66
Due to aircraft maintenance malfunction	71	42	63	23	199
Due to other than other above reasons	40	18	29	9	96
Cancelled or not authorized by higher HQ	6	8	34	25	73
Never approved or never scheduled	8	19	12	6	45
Unknown cause	21	50	36	9	116
Totals	962	1135	1148	304	3,549

by various controlling agencies accounted for approximately 10% of the cancellations. Cecil concluded that although the DAARs did not indicate the reasons, it was probably safe to assume that most of these cancellations were the likely result of being unable to obtain fire-on-fire clearances as a result of friendly troops in or scheduled to be in the target area. There was no other logical cause. It should be remembered that the elaborate clearance procedures in place were there for the protection of the spray aircraft and crew, rather than any concern that friendly forces would be harmed by exposure to the tactical herbicides. These procedures also protected friendly troops from the danger of accidental harm from "friendly" fire (Cecil 2006). The fact that a postwar study by the US military indicated that no friendly casualties resulted from RANCH HAND operations also was evidence that regulations requiring a "free fire" area were strictly adhered to (Young et al. 2004).

3.14 Other Herbicide Requests

Defoliating a zone around the outside circumference of an installation/base became the responsibility of the Allied ground commander whose TAOR (Tactical Area of Responsibility) included the base. The desiccant/defoliation (Blue, White, or Orange) request was prepared and documented by the base civil engineer, using a set checklist (Fox 1979). It was then processed through US military channels to the senior US Army headquarters in the Corps Tactical Zone (CTZ). If approved there, it was sent on to the ARVN Commanding General of the same CTZ for military approval and political clearance. Senior US Army advisors affiliated with the Army Chemical Corps at ARVN corps and division level were delegated authority to approve requests in which the dispersal of the tactical herbicides was limited to hand or ground-based power-spray methods (MACV 1968, 1969; Fox 1979). If aerial delivery was desired, the requests could only be approved at the MACV or JCS (Joint Chiefs of Staff) level.

As noted, authorization for herbicide missions by helicopter or surface spraying from riverboats, trucks, and hand-operated backpacks was delegated to the RVN and US authorities at the Corps level, but the responsibility for the actual spraying remained with the US Army Chemical Corps. These operations required only the approval of the unit commanders or senior advisors. "Free-spraying " areas, including the DMZ at the 17th parallel and the first 100 m outside base camps, were also exempt from MACV regulations. This delegation of authority for spraying to the Corps level reduced the lag time that existed from proposal to completion of small defoliation projects conducted around depots, airfields, and outposts (NRC 1974; Collins 1967). Because these helicopter and ground sprays were less rigidly controlled than fixed-wing aerial sprayings, the record keeping of such sprays by the Army Chemical Corps was not as systematic as those of Operation RANCH HAND (IOM 1994).

To clarify, the Base Civil Engineer had responsibility for preparing the requests to the Army Chemical Corps for the spraying of "tactical" herbicides around (outside) the base perimeters. **Within** the military base, the Base Civil Engineer had the responsibility for all pest control programs, this included weed and brush control around base facilities, housing, ditches etc. The pesticides used in these operations were those approved by the Armed Forces Pest Control Board and had GSA-assigned Federal Stock Numbers, and thus could be purchased at the direction of the Base Civil Engineer (AFPCB 1974). All available pesticides that could be purchased by the Base Civil Engineer would have been listed in the Department of Army Supply Bulletins for Pesticides (Lambert 1963). If tactical herbicides were listed in the Supply Bulletins, they would have been accompanied by the following statement: "This item is for tactical purposes only and not for base type pest control operations" (Lambert 1963; AFPCB 1974).

3.15 The Role of the Army Chemical Corps

Although the RANCH HAND unit (i.e., the 12th Air Commando Squadron of the 7th Air Force) had the primary responsibility for tactical herbicide operations in South Vietnam, the Army Chemical Corps staffed the Chemical Operations Branch, US Army, MACV. The MACV Chemical Operations Branch, exercised command supervision, coordination, liaison and control of all US and Allied forces in support of defoliation and chemical crop destruction operations in the RVN, including all aerial herbicide defoliation and crop destruction missions such as Operation RANCH HAND (Warren 1968).

The duties of the Chemical Operations Branch included determining and assessing the quantity of herbicides, including Agent Orange, required for all defoliation and chemical crop destruction missions in South Vietnam. The Branch had supervisory authority over requests for and release/dispensation of all herbicides for use in military operations. This included oversight authority over the promulgation, administration, regulation, and enforcement of rules, guidelines, procedures and directives with respect to the handling, use, and administration of all tactical herbicides. As noted earlier, MACV Directives 525-1 and 525-1, Annex K, Chemical and Herbicide Operation, were the primary directives governing tactical herbicide use and operations in South Vietnam (MACV 1968; MACV 1969).

Twenty-two US Army Chemical Corps units were assigned to South Vietnam during the years between 1965 and 1973 (Thomas and Kang 1990; Dalager and Kang 1997). These units were responsible for the storage, preparation and spraying of tactical herbicides around the perimeters of base camps and aerial spraying from helicopters in Vietnam. Using hand, vehicle-mounted equipment, and helicopters, the Army Chemical Corps conducted spray operations, such as defoliation around Special Forces camps; clearance of perimeters surrounding airfields, depots, and other bases; and small scale crop destruction (Warren 1968; Thomas and Kang 1990). The Army Chemical Corps was responsible for 4–5% of the herbicides applied in South Vietnam. Almost 2,900 men served in the Army Chemical Corps in South Vietnam during the period from

July 1965 to March 1973 (Dalager and Kang 1997). In should be noted that US Army Chemical Corps personnel were also responsible for the storage, handling, mixing, and application of riot control agents (tear gas), and burning agents (napalm). They had the opportunity for exposure to numerous other chemicals used in warfare as well as diesel and jet fuel and other solvents used for equipment cleaning and maintenance (Thomas and Kang 1990).

As previously noted, the first 100 m outside base camps were "free-spraying" areas. Although Army Chemical Corps personnel conducted spray operations, other units, e.g., combat engineers sometimes handled or sprayed herbicides for removal of underbrush and dense growth in constructing support bases. The Chemical Corps was generally called upon to support these operations. Most military bases had vehicle-mounted and backpack spray units available for use in routine vegetation control programs (NRC 1974; Cecil 1986; IOM 1994). More than 100 helicopter spray equipment units were used in the RVN (Young 1988).

The Army Chemical Corps in South Vietnam also used various ground delivery systems 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 windblast with a velocity up to 240 km/h at 280 cubic meters per 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. Under favorable wind conditions, this ground system could effectively spray a swath 75 m in width. The herbicides of choice in these operations were Blue and Orange (Young 1988; Warren 1968). The hand spray units, used on the smallest vegetation-control projects consisted of a backpack type dispenser with a capacity of approximately 11 l.

Commercial herbicides were usually readily available at US installations throughout South Vietnam. These herbicides were used in on-base programs under the control of the Base Civil Engineer, and included Bromacil, Tandex, Monuron, Diuron, and Dalapon (Irish et al.1969). However, it was a common practice that the dregs (remaining 4 to 6 liters in the bottom) from the 208-l tactical herbicide drums were pumped into smaller drums and sent by the Army Chemical Corps to many bases and military camps for control of perimeter foliage (Young et al. 1978). As previously noted, Phu Cat and Nha Trang became "turn around" facilities from mid-1968 through November 1969 for RANCH HAND aircraft. As a result, limited quantities of tactical herbicides were received at these two bases. The dregs from these drums provided an easily accessible supply of herbicides in II Corps (Young and Andrews 2006). However, approval was required for their use, including the use in the "Free-Spray" area (MACV 1968). Figure 3.21 is a photograph an Army UH-1 Helicopter spraying Agent Blue adjacent to the perimeter of an Air Base. Figure 3.22 was a photograph of a modified spray rig mounted in a C-7 spraying Agent Blue on the perimeter at Phan Rang Air Base. Figure 3.23 was a photograph taken of a crop destruction mission carried out by the Army Chemical Corps using a UH-1 Helicopter mounted with the HIDAL Spray System.

Fig. 3.21 A photograph of the Army UH-1 Helicopter (shown in Fig. 3.6) spraying Agent Blue adjacent to the base perimeter at Tan Son Nhut Air Base. The presence of tranh grass and other weedy species that grew to a height of 2 m were most easily controlled by the aerial applications of Agent Blue (courtesy of US Army Chemical Corps)

Fig. 3.22 A photograph of the base perimeter of Phan Rang Air Base at the time of aerial application of Agent Blue by the use of a modified spray rig mounted in the cargo bay and door of a C-7. Notice the "in-depth" wire fencing (i.e., two rows consisting of three lines of fence, each 1 m apart). Because the base bordered civilian dwellings, this fence arrangement was intended to keep civilians from inadvertently entering base perimeter areas (photograph courtesy of US Army Chemical Corps)

Fig. 3.23 A photograph of a US Army Chemical Corps UH-1 Helicopter conducting a crop destruction mission in II Corps, August 1969 (Photograph courtesy of J. Ray Frank, Frederick, Maryland)

3.16 Herbicide Operations in the Individual Combat Tactical Zones

Providing support for RVN, US, and Free World Military Assistance Forces was a major responsibility of the RANCH HAND operation (Warren 1968; Collins 1967; Clary 1971; Buckingham 1982; Cecil 1986). Five nations (the United States, Australia, New Zealand, the Republic of Korea, and Thailand) committed most of the combat troops deployed to support the RVN from 1962 to 1973. The United States deployed 3.2 million military personnel to Southeast Asia during the Vietnam War. US Forces were deployed throughout South Vietnam (Young 2001). The United States Marine Corps (USMC) was primarily located in I Corps, while US Army units were deployed in each of the CTZs and conducted most II, III, and IV Corps military operations staged by American troops. Australia and New Zealand jointly deployed approximately 46,850 combat troops, and they were primarily located in III Corps. The Republic of Korea (ROK) contributed approximately 312,850 combat troops, and they were primarily located in the coastal areas of II Corps (Larsen and Collins 1975; Young 2002). Thailand also provided a small contingent of 11,790, in addition to making several air bases available for US use. The Thailand units were primarily located in III Corps.

The vast majority of missions involving Agents Orange and White occurred in late 1967 through June of 1969 and were targeted in the northern provinces bordering Laos and Cambodia (I and II Corps). The greatest number of missions was flown on targets in Kontum Province. The plans for these missions were outlined in an August 1966 Report on "Chemical Defoliation of the Ho Chi Minh Trail" (IDA 1966). The requirements for those missions were so great that in mid-1968, RANCH HAND began using turn-around facilities at Phu Cat and Nha Trang. Those two bases in II Corps were used as reserving points for fuel and herbicides. The RANCH HAND squadron's UC-123s would take off from Bien Hoa Air Base in III Corps on their first mission of the day against targets in northern areas of II Corps, and after spraying, land at Nha Trang. With their fuel and herbicide replenished, they would then spray another target before returning to Bien Hoa. The UC-123s from Da Nang would re-service for fuel and herbicide at Phu Cat before returning to targets on the Ho Chi Minh Trail after which they would return to Da Nang (Cecil 1986).

Infrequently, and at the request of RVN province chiefs and local commanders, RANCH HAND aircraft sprayed targets on Route 1 and the railroad in Phu Yen Province (II Corps). These actions reduced ambushes against train and road convoys between Tuy Hoa and Qui Nhon (Buckingham 1982). Figure 3.24 was photograph of a mission of four aircraft (four sorties) spraying Highway 1 south of Qui Nhon. Figure 3.25 was a photograph of a single aircraft (sortie) spraying vegetation along the east side of Highway 1 south of Tuy Hoa in Phu Yen Province. Figure 3.26 was a photograph of a defoliated section of Highway 19 between An Khe and Pleiku.

Fig. 3.24 A photograph of four UC-123B aircraft (four sorties) spraying Highway 1 south of Qui Nhon. This photograph was taken on 14 December 1963. The tactical herbicide was Purple and it was disseminated at a rate of 14 l/ha (Photograph courtesy of the Plant Sciences Laboratory, Fort Detrick, Frederick, Maryland)

Fig. 3.25 This photograph of a RANCH HAND UC-123B aircraft spraying vegetation along the east (in this N/S oriented view) side of Highway 1, south of Tuy Hoa in Phu Yen Providence in early 1965. Note the west side of the highway had been previously sprayed (Photograph courtesy of Plant Sciences Laboratory, Fort Detrick, Frederick, Maryland)

Fig. 3.26 A photograph of the effects of RANCH HAND defoliation missions flown in the spring of 1967 near Highway 19 between An Khe and Pleiku. The herbicide was likely White because of the vegetation type found in the An Khe Pass area (Photograph was taken on 31 October 1967, courtesy of J. Ray Frank, Frederick, Maryland)

Although defoliation missions in II Corps were primarily confined to areas adjacent to the Laos and Cambodia borders, crop destruction missions were frequently conducted in Binh Dinh, Kontum, and Khanh Hoa Provinces. For example, in August 1965, forty sorties were flown against crop targets in Binh Dinh and Kontum Provinces, and in September 1965, 67 sorties were flown against crop targets in Binh Dinh, Kontum, and Khanh Hoa Provinces. In 1967, numerous missions against crop targets occurred west of Highway 1 between Tuy Hoa and Qui Nhon, and between Phu Cat and Quang Ngai (Buckingham 1982; Cecil 1986). The tactical herbicide of choice was Agent Blue.

Larsen and Collins (1975), in discussing South Korean pacification efforts conducted in II Corps, noted that ROK forces were against using defoliants to destroy rice crops. The ROK military units furnished external defense and fire support for four air bases in II Corps: Phu Cat (ROK Capital Division), Tuy Hoa (ROK 28th Regimental Combat Team), and Cam Ranh Bay and Phan Rang (30th Regiment, ROK 9th Division). All four of these bases were located next to settlements. The concentrations of civilian dwellings afforded the enemy an absolute tactical advantage since they provided cover and concealment up to the threshold of each base (Larsen and Collins 1975). These conditions also seriously restricted defense forces by prohibiting or limiting free fire zones and the placement of exclusion areas (e.g., land mines) around base perimeters (Fox 1979). Thus, precautions to restrict inadvertent entry by civilians into base perimeters were limited to "in-depth" fencing and vegetation control.

At air bases, clearing approaches to the base was the first order of business. This meant defoliating a zone around the perimeter of the installation, an area outside the USAF's accepted base security/defense responsibility. It became the task of the Allied ground commander whose TAOR was confined to the base. As noted, in the cases of Phu Cat, Tuy Hoa, Cam Ranh Bay and Phan Rang, the ROK was assigned responsibilities for external defenses of those bases (Fox 1979).

The mangrove habitat, scattered primarily along the southern coastline of South Vietnam, occupied approximately 500,000 ha of inhospitable and seemingly impenetrable swamp (Westing 1984). However, the VC forces found it to be a safe haven from Allied forces; and, hence it was a target for vegetation control. The most intensive defoliation treatments of mangrove were applied in the Rung Sat Special Zone (III Corps), an area that surrounded the shipping channel into Saigon. Defoliation of the mangrove was started in 1966, but most of the defoliation flights were made after June 1967. A block of about 460 km^2 had been treated by the end of January 1967 (Tschirley 1969).

Members of the Australian Army Training Team Vietnam (AATTV) were first deployed to Vietnam in 1962, and were located throughout South Vietnam as part of the Advisory effort. In 1965, the First Royal Australian Regiment (1 RAR) was deployed to an area adjacent to the Bien Hoa Air Base. This began the buildup of Australian and New Zealand Forces in South Vietnam (Sinclair 1982). In 1966, the First Australian Task Force (1 ATF) deployed to Nui Dat

(Phuoc Tuy Province in III Corps), while an Australian Logistic Support Group was located at Vung Tau (also in Phuoc Tuy Province). The Australian Forces saw the defoliation program as “an important measure in helping to deprive the enemy of the advantages that he enjoyed through the use of natural vegetation for cover in Vietnam’s tropical environment” (Sinclair 1982). When the 1 ATF was in place in the Phuoc Tuy Sector, requests for defoliation by RANCH HAND aircraft involved more than 62 targets. Most of the early sorties were with Agent Orange, but after October 1967, Agent White became the predominant herbicide used in Phuoc Tuy (Sinclair 1982; Cecil 1986). At both Nui Dat and Vung Tau, extensive aerial insecticide spraying programs were conducted by UC-123 insecticide aircraft (Operation FLYSWATTER) and by Australian aircraft (Sinclair 1982).

Targets in IV Corps were some of the first locations for spraying herbicides in South Vietnam. Early RANCH HAND missions were flown during March 1962 against targets in the Ca Mau Peninsula. The Ca Mau peninsula was a temporary staging area for VC infiltration into the Mekong Delta and for attacks on local shipping and RVN naval patrol craft along the peninsula’s streams and canals (IOM 1994). In June 1963, eight sorties dispensed 27,200 l of herbicide on 46 km on the Ca Mau Peninsula (Buckingham 1982). Defoliation operations in 1967 and early 1968 aided military operations conducted by the Army’s 9th Infantry Division by improving observation within formerly heavily forested jungle (US Army 1972).

Only recently has it been possible to assemble data from the Defense Supply Agency, the Air Force Logistics Command, and in some cases verification from the Chemical Companies, on the quantities of tactical herbicides disseminated in Vietnam during the Vietnam War (Young et al. 2008). These data are provided in Table 3.6. Differences in quantities of herbicide disseminated and areas treated in South Vietnam varied among individual sources (USAF Memorandum 1964; Irish et al. 1969; NRC 1974; Craig 1975; Young et al. 1978; Westing 1976, 1984; IOM 1994; Stellman et al. 2003a). Further discussion of both the quantities of herbicides and the estimated amount of dioxin disseminated in Vietnam are discussed in Chapter 5.

Table 3.6 Estimated quantities of tactical herbicides used in Vietnam, 1961–1972 based on defense supply agency and air force logistics command records (data as of March 2008)

Tactical herbicide	Commercial components	Number of drums	Number of liters	Years of use
Agent Green	2,4,5-T	365	75,920	1962
Agent Pink	2,4,5-T	1,315	273,520	1961–1963
Agent Purple	2,4-D; 2,4,5-T	12,475	2,580,240	1962–1965
Agent Blue	Cacodylic Acid	29,330	6,100,640	1962; 1966–1972
Agent White	2,4-D; Picloram	104,800	21,798,400	1966–1972
Agent Orange	2,4-D; 2,4,5-T	208,330	43,332,640	1965–1970
Total		356,615	74,175,920	

3.17 The Preparation, Accuracy, and Use of the Military Records

As noted in the previous section, the data available on the use of herbicides in Vietnam is dependent upon the quality and quantities of records maintained by the administrative units that had responsibility for record keeping in Vietnam. Christian and White provided an excellent overview of battlefield records management and its relationship with Agent Orange (Christian and White 1983). They noted that there were 12,000 linear meters of Vietnam War records that were returned to various archive centers in the United States. They reported that 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" (Christian and White 1983). In addition, some records may not have been returned at all.

The challenge facing retrieval of records pertaining to Agent Orange was three-fold (Christian and White 1983). 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 frozen to prevent their destruction. Secondly, soldiers on one-year tours barely had time to organize their files before they were transferred and someone else took over. Moreover, Vietnamese personnel did some of the records maintenance. Lastly, although it can be ascertained that the use of herbicides began in 1961, data for the period 1961–1964 was of little use because of the nature of the advisory role and the locations of the advisors for those years. As was noted:

> To use military records, created for combat purposes in an entirely new and complex manner, e.g., for epidemiological studies, may not be accomplished within the capabilities of the existing records (Christian and White 1983).

In 1970, The United States Army's Data Management Agency, DMA was tasked by MACV to support the Chemical Operations Division by developing an Automatic Data Processing system for processing and storing herbicide mission activity data (DMA 1970). The result of this effort was the HERBICIDE REPORTING SYSTEM (HERBS Tape), which was designed and implemented in May 1970. The objective of the HERBS system was to process the worksheets prepared by the Chemical Operations Division from information received from the primary data sources (e.g., RANCH HAND Operations and Army Chemical Corps Projects); maintain a HERBS mission activity history file updated monthly; and to produce the monthly update listings and any reports resulting from user requested file inquires (DMA 1970). Indeed, MACV used the HERBS system to respond to requests from organizations involved in ecological research, claims investigations, and general inquiries from the Department of Defense and the scientific community (DMA 1970). The National Research Council of the National Academy of Sciences subsequently used these computer-generated tapes to construct maps of crop destruction and defoliation missions throughout South Vietnam (NRC 1974).

The content of the HERBS system consisted of data from the missions that were flown. This included the province(s) in which the mission was flown; the mission project number; the universal transverse mercator points (UTM) covered by the mission with identifying additions to each UTM point as a stop, turn, or start coordinate; the type of agent 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 (DMA 1970). The completeness and accuracy of the data were entirely dependent upon the quality of information obtained from the field units and forwarded to the Chemical Operations Division and on the accuracy with which this information was then recorded (Cecil 1986).

In April 1971, the MITRE Corporation, at the request of the Defense Communications Agency, reported the results a data quality analysis of the HERBS data file (Heizer 1971). On the basis of the data quality analysis, the following statements were made:

(a) 97 out of the 5,157 records (2%) in HERB 01, a cleaned-up version of the HERBS system tape, have missing data;
(b) 304 out of 5,157 records (6%) have serious transcription errors or serious measurement errors; and,
(c) 1,161 of the 5,060 (23%) records that do not have missing data, have track data that results in track length (distance sprayed by RANCH HAND aircraft) that is in error by 50%.

Statistically, the overall quality of the data was good and by using error curves, track length and track data could be adjusted to improve the data quality of a record, if it was considered necessary by the analyst (Heizer 1971). The presumption by the author (and the Chemical Operations Division) was that the UTM coordinates provided in the data set were accurate, but that the analyst didn't understand how to interpret the material. The National Research Council in 1974 (NRC 1974), the US Army and Joint Services Environmental Support Group in 1986 (ESG 1985), and Stellman et al in 2003 (Stellman et al. 2003b) did subsequent updating of the HERBS tape. Interestingly, neither the Stellman's 2003 version of the HERBS Tape (S-NAS-HERBS), nor their publications contain any data or references to ground fire hits or battle damage. When records contained only a single coordinate, they "developed schemata to impute likely flight paths for many of the fixed-wing missions". Moreover, many of the UTM coordinate data were taken from the RANCH HAND project planning documents, rather than from the DAARs. Thus, in many cases they apparently recorded where missions were to occur, rather than where missions may have actually occurred (Stellman et al. 2003b). Furthermore their interpretations of the database show a woeful lack of understanding of RANCH HAND procedures and reporting.

3.18 Other Sources of Herbicide Consumption Data

Some researchers have used the HERBS data to argue that much more herbicide was dispensed over the Vietnamese countryside than reported by the US military (Hatfield 2000). The implication was that military authorities made unauthorized clandestine purchases of herbicide for ulterior purposes. Fortunately, the historical records of the RANCH HAND unit are available in the annexes of the quarterly historical reports of the 315th Air Commando Wing (later redesignated 315th Special Operations Wing, and then 315th Tactical Airlift Wing). These records reported the total amount of tactical herbicide actually issued from the herbicide supply depots. Although not broken down by herbicide type in the historical reports, these contemporary records provided usage comparison data with which to validate the data in Table 3.6.

To insure that transcription errors in the HERBS Tape did not contaminate comparisons to contemporary unit historical reports, Cecil randomly selected 15 months in which to do a line-by-line comparison of the HERBS Tape entries versus available original DAARs and to correct any errors in the entries (Cecil 2006). In addition, the revised HERBS Tape was expanded to include previously un-entered original mission information concerning the lift designator (thus identifying the base the mission launched from); the time-on-target; target number within the project; the number of sorties originally scheduled, sorties added, sorties actually launched, and sorties which effectively sprayed on target; spray track lengths to the nearest 0.1 km; type and cause of both primary and alternate target aborts; mission flying hours; number of ground fire hits on mission aircraft; and any amplifying entries from the "Remarks" section or elsewhere on the DAAR. So valuable did the revised database appear that Cecil expanded the comparison project to include the entire fixed-wing portion of the HERBS Tape. This corrected and amplified database has been referred to as the "RANCH HAND Revised" (RHR) Tape (Cecil 2006).

For the reader's information the corrected RHR Tape quantities are compared in Table 3.7 to the total herbicide expended by month from the RANCH HAND stocks as listed in the historical reports for the 15 selected months. In all cases the expenditure of herbicide on the RHR Tape exceeded the amount actually disbursed from stocks, validating the assumption that the DAAR practice of reporting fixed standardized amounts dispensed per plane resulted in over-reporting of herbicide dispensed (Cecil 2006).

The excess reported quantity varied from a high of 7.0% in February 1967 to a low of 0.8% in April 1970 and was obviously strongly influenced by the extent of activity by the RANCH HAND unit. The 2.60% average reported excess seemed reasonable and there was no anticipated reason to expect it that it would not be valid for the non-sampled months from 1965 to 1971 (Cecil 2006). The results, however, made the daunting task of comparing the entire HERBS Tape entries against available original DAARs for the complete 1965–1971 period seem worthwhile.

Table 3.7 Comparison of data (in liters) from selected months of the RANCH HAND Revised Tape (RHR) to monthly data from the RANCH HAND Historical Reports (Cecil 2006)

Date	RHR tape	Historical report	Excess(+/−)
Jan 1967	1,637,777	1,564,491	+ 73,286
Feb 1967	1,473.017	1,381,864	+ 91,153
Mar 1967	1,292,339	2,247,103	+ 45,236
Jul 1967	1,675,021	1,650,041	+ 24,980
Sep 1967	1,549,520	1,516,776	+ 32,744
Jul 1968	1,613,152	1,558,643	+ 54,510
Oct 1968	1,090,577	1,068,118	+ 22,459
Jan–Mar 1969[1]	4,757,878	4,684,540	+ 73,339
Oct 1969	1,472,146	1,435,617	+ 36,529
Jan–Mar 1970[1]	2,390,581	2,356,516	+ 34,065
Apr 1970	428,508	425,102	+ 3,407
Total	19,380,516	18,888,810	+ 491,706

[1] Unit historical report was for quarter only, not broken down into separate months.

Other sources for error between procurement and consumption would have included the inevitable spillage involved in transferring the herbicides from the shipping drums to the bulk storage facilities and in servicing of aircraft. Residual chemical left in the drums after transfer to the bulk storage tanks was partially recovered by using drum drain racks. This amount of herbicide was reportedly used in some perimeter foliage control programs and thus may have been inadvertently counted twice by the accountability records. Undoubtedly some theft of herbicide and/or unpurged drums also took place. In addition, HERBS Tape quantity data for helicopter and ground equipment operations could not be validated, but it would be surprising if it were any more accurate than the fixed-wing data. These unverified entries accounted for 2,823,246 l of the total herbicide dispensed in Vietnam in 1965–1971. When added to the corrected RHR Tape fixed-wing amounts, the total herbicide dispensed comes to 69,619,850 l versus the procurement data of 71,231,680 l estimated in the Table 3.6 for Orange, White and Blue. The variances in individual herbicide amounts can possibly be explained by the failure of personnel to accurately report or transcribe which herbicide was used, a discrepancy noted in the 15-month sample check referred to earlier. However, 610,690 l of White arrived in Vietnam in 1971 and was not accounted for in Table 3.8, a yearly comparison.

As previously noted Cecil compared the total herbicide issued by RANCH HAND against the total amounts shown dispensed in the HERBS Tape by year (see Table 3.8) (Cecil 2006). As noted earlier sampling and comparison with original DAARs have shown the HERBS data to have significant errors and omissions.

As Table 3.8 indicated, annual over-reporting of herbicide dispensed by fixed-wing was as much as 4.45% and averaged 2.57%. This supports Cecil's

Table 3.8 A by-year comparison between quantities of tactical herbicides reported on the HERBS Tape and data from RANCH HAND unit quarterly historical reports (in liters)

Year	HERBS Tape	RH Historical Rpt	Excess
1965 (after 18 Mar)[1]	1,887,122	1,839,944	+47,178
1966	9,940,260	9,842,066	+98,194
1967	19,124,209	18,436,802	+687,408
1968	17,971,385	17,563,924	+407,462
1969	16,487,705	16,147,802	+339,903
1970	3,345,413	3,202,669	+142,744
1971	7,192	7,192	+/− 0
Total	68,763,286	67,040,398	+1,722,888

[1]1965 data does not include Purple herbicide sprayed prior to 19 March 1965.

earlier random sampling finding (Cecil 2006). Adding the RANCH HAND total to the Blue, White, and Orange herbicides reportedly sprayed by ground units and helicopters gave a total of 69,763,622 l, which compared favorably with the computed 69,511,840 l noted earlier. Although the "unknown" entries for fixed-wing operations was proportionally included in the RANCH HAND adjustment, what could not be explained were the entries under "ground" and "helicopter" codes for 100,022 "unknown" liters since there are no other data sources with which to compare and correct those entries. Even more puzzling are the 366,958 l the HERBS Tape claims were sprayed by "Unknown" type equipment. Without these "unknowns" procurement and disposition records can be reasonably correlated. Contemporary reports indicate that herbicides were dispensed by fixed-wing, helicopter and ground equipment only. {NOTE: the additions of 69,763,622 + 100,022 + 366,958 = 70,841,292 l versus the procurement data in Table 3.6 of 71,231,680 l for Orange, White and Blue.} Stellman et al. apparently chose to accept their HERBS Tape data as opposed to the procurement records; however, they did not address the question of "unknown" herbicides or "unknown" delivery equipment (Stellman et al. 2003a, b).

Overall it appears that the discrepancy involved in the question of herbicides procured versus herbicides dispensed or destroyed is one of records maintenance. Record keeping by the United States military in Vietnam was complicated by both the interface with South Vietnamese allies in joint or mixed operations and by the precipitate manner that terminated the war effort and resulted in the rapid pullout of Allied forces. Large numbers of records were either lost or trashed as American units left Southeast Asia. This makes the reconstruction of particular events in the combat zones difficult, if not impossible, especially when using records reconstituted and "reconstructed" 15–25 years later. The second major problem, that of entries spraying "unknown" herbicides and of entries using "unknown" equipment to do the spraying, may also be one of inaccurate records maintenance, but there is no alternate source of information available with which to positively confirm or deny these entries (Cecil 2006).

3.19 The Accuracy of Geographic Data

As noted, the HERBS tape documented how much herbicide was sprayed. Where the herbicide was sprayed was identified by one or more six-digit UTM coordinates. The lead navigator had the task of planning, verifying and reporting the coordinates of a RANCH HAND mission. In the early years through mid-1965, the 1:250,000 maps used for navigation were often those prepared by the French, as was the language on the charts, although they were updated with photoreconnaissance grammetric data (Young et al. 2004).

Electronic 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 m) for a plane 32 km from a TACAN transmitter would have been exceptional (Young et al. 2004). Moreover, TACAN signals were not received at the low altitudes flown by RANCH HAND aircraft during a spray mission so the crew used visual orientation and, obviously, the instructions from the Forward Air Controller (Young et al. 2004).

The lead navigator and pilot had responsibility for documenting the mission coordinates, the type and volume of herbicide sprayed, and any ground fire they received. Unless these were specific reasons not to (i.e., aborted or alternate target), they reported "as planned" the UTM coordinates and volume sprayed (Spey 2003). Buckingham (1982) reported that the RANCH HAND navigators did their best to accurately report the location of their missions. For example, spraying targets in the mountain regions of I Corps and II Corps was a difficult job, even when the crews had accurate maps of the targeted roads and trails (Buckingham 1982). It was some times impossible to follow the roads and trails at the desired spray altitude of 45–50 m. RANCH HAND developed three techniques for spraying these roads and trails:

(1) One UC-123 would fly ahead of and higher than the plane delivering the herbicide. An effective tactic where the road or trail was clearly visible from an altitude of about 450 m, the lead aircraft would follow the road from its higher vantage point, and guide the spray aircraft. After one UC-123 had delivered its load of herbicide, the two aircraft switched roles so that the former lead would spray. Initially one flight of two aircraft would cover a 30-km length of road with one defoliated strip. In about a week, discoloration, easily visible from the air, marked the strip. RANCH HAND aircraft would then return and spray each side of the road, following the previously sprayed strip and widening the defoliated area to the required 250 m on both sides of the road.

(2) When the road or trail was not clearly visible from any altitude, except for brief glimpses, the spray aircraft would first fly over the road or trail and throw out smoke grenades at intervals where they could see the road or trail.

With the jungle canopy in some places reaching 50–60 m, it took about 1 min for the smoke to rise to visible height. The RANCH HAND aircraft would then connect the columns of smoke with a strip of herbicide. This second method took a great deal more time than the first, and it was not as accurate. However, it did have the advantage of reducing the risk from enemy anti-aircraft fire, since both aircraft were flying at a very low altitude.

(3) The third, and least effective, technique RANCH HAND developed was not used unless the target absolutely required it. Using time and a heading from a known topographic feature, a navigator guided the spray planes over the target. Accuracy suffered because roads and trails were not always exactly where they were placed on the maps used by the navigator. This method, however, required the least amount of time over the target, and it was therefore the safest to use in the case of roads and trails with known gun emplacements (Buckingham 1982).

John Flanagan, a Forward Air Controller for many RANCH HAND missions, described the difficulties in tracking locations in the Vietnamese jungles in his book "Vietnam Above the Treetops":

> 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 (Flanagan 1992).

3.20 Alternate Methods of Clearing Vegetation

Anecdotal reports by soldiers of exposure to tactical herbicides commonly mention cleared, barren landscapes (Young et al. 2004). A widely held misconception was that all clearance of vegetation was accomplished by means of tactical herbicides. Simpler and more direct methods were frequently used, and a special unit of the 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 chain saws, hand axes, machetes, and even diesel fuel incineration (Ploger 1974; Young et al. 2004). Figure 3.27 was a photograph of a US Army Corps of Engineers Rome plows clearing vegetation in III Corps.

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...This 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 (Ploger 1974).

Fig. 3.27 A photograph of US Army Corps of Engineers using Rome plows to clear vegetation in III Corps, Vietnam (Photograph courtesy of J. Ray Frank, Frederick, Maryland)

3.21 Insecticides and Operation FLYSWATTER

The deployment beginning in 1965 of major US combat forces into South Vietnam found them unprepared for the disease-ridden conditions they encountered. Despite the weekly use of prophylactic choroquine-primaquine pills, 5–50% of American soldiers coming off early field actions developed malaria (Kiel 1968). Compounding the threat to Allied troops in South Vietnam was the discovery of chloroquine-resistant *Plasmodium falciparum* carried by the anopheles mosquito (Kiel 1968). The only course of action was to implement effective control programs for the mosquito. Although both the Navy and the Army experimented with low volume dispersal of malathion insecticide, an organo-phosphate insecticide, the use of helicopters did not adequately contain the spread of malaria. In late 1966, Headquarters USAF directed the modification of one of the UC-123 herbicide-spray planes to an insecticide-spray configuration to counter the anopheles mosquito. The selected aircraft had to be washed of all herbicide, stripped of its camouflage, and equipped with finer orifice spray nozzles needed for insecticide work (Cecil and Young 2008). The ability of the UC-123 to cover large areas (up to 6,500 ha) made it the ideal aircraft for base and urban area treatment. Operation FLYSWATTER commenced on 6 March 1967. Under control of the MACV Surgeon General's

Office, the mission was supported at Bien Hoa by the US Army's 20th Preventive Medicine Unit, and at Da Nang by the US Navy Preventive Medicine Unit located on the USMC base (Cecil 1986; Cecil and Young 2008).

From March 1967 through February 1972, first one and later two UC-123 RANCH HAND aircraft were used to spray initially 57% malathion, but later 95% malathion, for mosquito and malaria control (MACV 1970; Cecil and Young 2008). As noted earlier, the insecticide-spraying aircraft could be distinguished from the herbicide-spraying aircraft because they were not camouflaged. Figure 3.28 has photographs of the "Silver Bug Birds" as they were commonly called. The aircraft routinely sprayed insecticide over military bases and Vietnamese cities, as well as over areas where military operations were in progress or about to commence (Young et al. 2004).

By 1970, routine 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 (Cecil 1986). The major military bases that received insecticide applications are listed in Table 3.9 (Collins 1967; Cecil 1986; Fox 1979). The frequent anecdotal reports of UC-123s directly

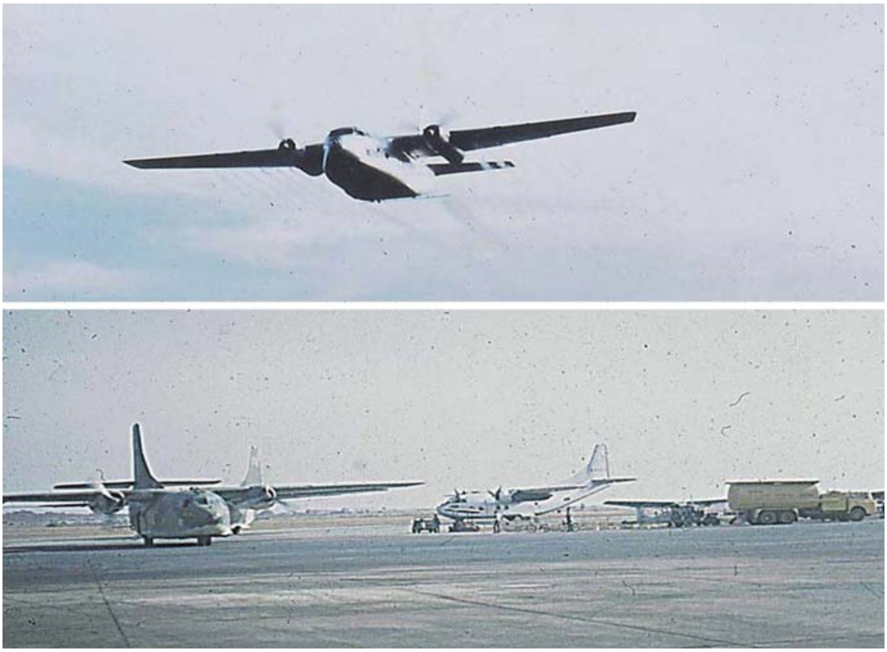


Fig. 3.28 Photographs of "Silver Bug Birds" which were RANCH HAND UC-123 aircraft dedicated to the spraying of malathion insecticide for mosquito control. Each aircraft could spray more than 6,000 ha and routinely treated 14 bases and their adjacent Vietnamese cities every nine days. Re-servicing was available at the air bases at Cam Ranh Bay, Bien Hoa and Da Nang (Photographs courtesy of J. Ray Frank, Frederick, Maryland)

Table 3.9 Major US and allied forces bases receiving insecticide applications

Base	Province	Corps	Base	Province	Corps
Da Nang	Quang Nam	I	Qui Nhon	Binh Dinh	II
Bien Hoa	Bien Hoa	III	Nha Trang	Khanh Hoa	II
Pleiku	Pleiku	II	Cam Ranh Bay	Khanh Hoa	II
Quang Tri	Quang Tri	I	Phan Rang	Ninh Tuan	II
Tan Son Nhut	Capital Special Zone		Binh Tuy	Binh Tuy	III
Phu Cat	Phu Yen	II	Vung Tau	Phouc Tuy	III
Tuy Hoa	Phu Yen	II	Nui Dat	Phouc Tuy	III

spraying troops in Vietnam with herbicides likely reflect the RANCH HAND mission of frequently spraying insecticide for mosquito control in the hours around dawn and again near sunset (Young et al. 2004).

In August and September 1969, a group of scientists from the Plant Sciences Laboratory, Fort Detrick visited numerous locations in I Corps around the city of Da Nang in response to claims by Vietnamese farmers that their crops had been injured by indiscriminate spraying of herbicides (Darrow 1969). The following two notes were taken from their trip report:

> The group then visited a Catholic Church in the hamlet Cam He. The priest claimed that their crops were killed by herbicide spray planes. His description of the planes as silver indicated that he had seen the insecticide spray planes used for mosquito control. Careful inspection showed that slight herbicide damage was evidence on papaya and mango trees. The damage was probably caused by fumes from empty drums of agent ORANGE which were kept less than 20 feet from damaged plants. Sensitive weeds in close proximity also had herbicide symptoms. No evidence of damage caused by aerial applications of herbicides was noted (Darrow 1969).

> On 30 August the group visited a vegetable growing area at An Hai, east of Da Nang City. The growers were washing off all of the vegetable plants to prevent herbicide damage. This procedure was instituted after the people had seen a silver spray plane fly over, supposedly spraying herbicide. The plane was the mosquito control spray plane which was spraying the insecticide malathion. Several small beds of seedling lettuce were damaged by a damping off plant pathogen but no herbicide damage was observed on any of the vegetable crops in the area (Darrow 1969).

The best estimate of the total volume of malathion that was sprayed in South Vietnam between 1966 and 1972 was 3.5 million liters (Cecil 1986; Cecil and Young 2008). Westing similarly estimated that 3 million kg of malathion were sprayed on approximately 6 million hectares of South Vietnam (Westing 1984).

3.22 Termination of Herbicide Use

The concept of using chemical herbicides to alter the combat environment in the Vietnam War was new, particularly in its broad scope and in light of the extensive tropical vegetation that faced Allied troops. The history of warfare is one of innovation and discovery as the participants continually find new and more effective weapons with which to exact mayhem upon each other. The unique weapon involving herbicides was different only in that the primary goal was to improve combat visibility so that allied troops could effectively cope with the jungle guerrilla warfare. The question of amounts of expendable supplies used to accomplish this goal was one for the logisticians at major headquarters, not the soldiers in the field. It should come as no surprise that the daily activity reports were more general than exact and that the individuals involved were more concerned with those things directly involving their health and well being. The young men of RANCH HAND who daily flew slow, unarmed, and unarmored transport planes at tree-top level while subject to enemy ground fire were more concerned with how well they placed their herbicides on the assigned targets than upon the exact amounts dispensed. This is not to disparage the important work of those concerned with procurement and movement of supplies, but to recognize the priorities placed on record keeping by those in the front lines (Cecil 2006).

On 13 September 1971, because of emerging scientific evidence indicating that dioxin was teratogenic (i.e., causing birth defects in laboratory mice) and that Agent Orange was contaminated with dioxin, Secretary of Defense Melvin Laird ordered all remaining stocks of Agent Orange (and Orange II) in Vietnam returned to the United States as quickly as possible after the US Embassy negotiated a formal transfer of title from the RVN Government. On 31 October 1971, all tactical herbicide activities under US control were terminated, with insecticide operations for mosquito abatement continuing by the USAF and US Army into 1972. The removal of all remaining Orange in South Vietnam by the 7th Air Force was completed in April 1972 (Operation PACER IVY) when approximately 5.2 million liters (25,220 drums) were off-loaded on Johnston Island in the Central Pacific Ocean. Operation PACER HO (Herbicide Orange), the destruction of the Herbicide Orange using at-sea incineration, was conducted from June through August 1977. Chapter 4 describes Operation PACER IVY and Operation PACER HO.

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Chapter 4
Removal from Vietnam and Final Disposition of Agent Orange

The use of the tactical herbicide "Agent Orange" by the United States Military in South Vietnam was discontinued on 19 April 1970. On 13 September 1971, Department of Defense Secretary Melvin Laird ordered all remaining stocks of Agent Orange (and Orange II) in the Republic of Vietnam (RVN) returned to the United States as quickly as possible after the US Embassy negotiated a formal transfer of title from the RVN Government. On 31 October 1971, all herbicide activities under US control were terminated. Operation PACER IVY, the removal of all remaining Orange Herbicide in South Vietnam, was completed on 28 April 1972 when approximately 5.2 million liters (25,220 drums) were off-loaded on Johnston Island in the Central Pacific Ocean. Operation PACER HO, the destruction of the Agent Orange by at-sea incineration, was conducted from May through September 1977. This Chapter describes the removal of Agent Orange from South Vietnam, its subsequent storage and maintenance, and its final disposition.

4.1 Background

In the fall of 1969, a report prepared by the National Institutes of Health (NIH) and subsequently published in *Science* (Courtney et al. 1970) presented evidence that the commercial herbicide 2,4,5-T was a teratogen in mammals (i.e., causing birth defects). These NIH results concluded that 2,4,5-T could cause malformed pups and stillbirths in mice. Subsequent studies revealed that the teratogenic effects resulted from a toxic contaminant in the 2,4,5-T, identified as 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) (Reggiani 1988).

In response to this report, Deputy Secretary of Defense David Packard directed the Joint Chiefs of Staff to ensure that Agent Orange would be sprayed only in remote areas that were away from Vietnamese civilian populations pending a decision by the appropriate government agencies about whether 2,4,5-T could remain on the US domestic market (Young et al. 1978; Buckingham 1982). The Deputy Secretary of Defense did, however, authorize

A.L. Young, *The History, Use, Disposition and Environmental Fate of Agent Orange*, DOI 10.1007/978-0-387-87486-9_4,

continuing the normal use of Agents White and Blue with the stipulation that "... the large-scale substitution of these two military herbicides for Agent Orange must not occur" (Buckingham 1982).

In early April 1970, the Department of Defense (DOD) was notified that the Secretary of Health, Education and Welfare (HEW), the Secretary of the Interior (DOI), and the Secretary of Agriculture (USDA) planned to release a joint statement on the morning of 15 April announcing the immediate suspension of all uses of 2,4,5-T herbicide, except for registered applications on non-crop lands such as ranges and pastures (MacLoed 1971). Secretary of Defense Melvin R. Laird, after discussions with the Director of Defense Research and Engineering, and with the Joint Chiefs of Staff, followed the lead of HEW, DOI, and USDA on 15 April and announced that "The Department of Defense will temporarily suspend the use of 2,4,5-T in all military operations pending a more thorough evaluation of the situation" (JCS 1970).

The RANCH HAND Operations Office, Bien Hoa Air Base in South Vietnam received notification of the prohibition against further use of Agent Orange on 19 April 1970 (JCS 1970). Because Agent Orange was no longer available, all defoliation missions previously planned for this herbicide shifted to Agent White. On 9 May 1970, after exhausting the existing stocks of Agent White at Bien Hoa, Da Nang and Phu Cat Air Bases, RANCH HAND flew its last defoliation mission of the war. Stocks of Agent Blue continued to be used for crop destruction targets. New stocks of Agent White arrived in October 1970 (Buckingham 1982). The last RANCH HAND herbicide mission of the war was sprayed on a crop target in Ninh Thuan Province on 7 January 1971. All use of tactical herbicides under US control was terminated on 31 October 1971 (Buckingham 1982). However, in the first Quarter of 1971 RANCH HAND crews stationed at Phan Rang Air Base trained VNAF crews to fly the UC-123 K aircraft that were then transferred to the Vietnamese Air Force via the Vietnamization Program, thus allowing VNAF crews to continue expending the remaining stocks of Agents Blue and White throughout 1971 and 1972 [310th TAS 1971].

In a 13 September 1971 Memorandum from DOD Secretary Laird to the Chairman, Joint Chiefs of Staff dated the subject of "Disposition of Herbicide Orange" was addressed:

> I have recently considered the issues associated with the stocks of herbicide ORANGE in both RVN (Republic of Vietnam) and CONUS (Continental United States). I have decided that all stocks of ORANGE will be returned to CONUS as quickly as practicable for disposition. All stocks, both RVN and CONUS with unacceptable levels of impurities will be incinerated. Options for possible use of remaining stocks would be considered.
>
> A Joint State/Defense message has been prepared requesting the US Embassy negotiate with GVN (Government of Vietnam) for the return to US control of all stocks of herbicide ORANGE in RVN.
>
> Upon US assumption of control over all herbicide ORANGE in RVN, you are requested to take necessary action for its quick return to CONUS. Coordination

should be effected with OASD (I&L) (Office of the Assistant Secretary of Defense for Installations and Logistics) (Laird 1971).

In a 14 September 1971 Memorandum from the MACV Headquarters to the American Embassy in Saigon, the Secretary of the Joint Staff wrote the following:

> Reference is made to SECSTATE message DTG 102302Z September 1971 which announced the decision to return all in-country stocks of herbicide ORANGE to CONUS and request US Embassy negotiate with the Government of Republic of Vietnam for the return to US Control of all RVN stocks of herbicide ORANGE.
>
> We have learned that approximately 22 ammunition ships are either in port or will arrive during the period September – October 1971. These ships will become available for backloading starting week of 27 September 1971. If reacquisition negotiations could be completed and stocks returned to US control by that time, this available transportation could be utilized to expedite return of herbicide ORANGE to CONUS.
>
> Your comments on the above proposal would be appreciated (Crockett 1971).

Based on these two memoranda, DOD initiated Operation PACER IVY, the removal of Agent Orange from Vietnam to Johnston Island in the Central Pacific Ocean, as an alternative to taking the Herbicide to the Continental United States. PACER is a USAF term referring to logistical movements; **IVY** presumably was selected as an abbreviation for inventory (**I**n**V**entor**Y**) to refer to the stocks of Agent Orange. Operation PACER IVY began in September 1971 and was completed with the transfer of the remaining stocks of herbicide to a storage area on Johnston Island in April 1972. Over the next five years, various options were explored for the disposition of the stocks on Johnston Island as well as the stocks remaining at the Naval Construction Battalion Center (NCBC) located in Gulfport, Mississippi (Department of Air Force 1977; Miller 1980). Operation PACER HO (the destruction of Agent Orange by at-sea incineration) was initiated at Gulfport, Mississippi, in May 1977 and completed at Johnston Island in September 1977 (Tremblay 1983). A key issue in assessing the potential for "hot spots" persisting in Vietnam today was the initial levels of TCDD contamination measured in the two inventories (NCBC and Johnston Island) and what residual concentrations remained at the two sites (Young and Andrews 2005).

4.2 Operation PACER IVY

The archiving of records including memoranda, reports, and photographs relating to the conduct of Operation PACER IVY was the responsibility of 7th Air Force. The Alvin L. Young Agent Orange Collection (http://www.nal.usda.gov/speccoll/findaids/agentorange/search.htm) located at the National Agricultural Library in Beltsville, Maryland, provided a number of relevant memoranda, messages, and reports. However, the most valuable primary sources of historical information were a daily journal provided by Richard C. Carmichael, the USAF

Bioenvironmental Engineer assigned to oversee the operation at Da Nang Air Base, and an oral interview with Warren Hull, the USAF Bioenvironmental Engineer (subsequently referred to as the Hull Interview (Hull 2002)) who was responsible for the operation at Tuy Hoa Air Base. Photographs, maps, and notes were included in the journal (subsequently referred to as the Carmichael Journal that was titled as PROJECT PACER IVY, DA NANG AFLD, VIETNAM, 23 DEC 71 – 21 JAN 72 (Carmichael 1972)).

The question of "ownership" of the remaining stocks of military herbicides was an issue that complicated initiating Operation PACER IVY. The US Embassy's General Counsel worked with the Government of Vietnam and arranged the legal transfer of ownership of the herbicide from the Republic of Vietnam to the United States so the unused Agent Orange could be returned to the United States (Buckingham 1982).

Once the US reacquired ownership of the unused herbicide, responsibility for removing the remaining stocks of Agent Orange from Vietnam was assigned to units of the 7th Air Force based in South Vietnam. Support for and oversight of the activity was assigned to the Bioenvironmental Engineer, who was a member of the Air Force Biomedical Science Corps, at each storage facility. The first challenge was to ensure that all of the remaining inventory of Agent Orange could be located. Second, once located, existing stocks would be moved to central locations where they could be relabeled and, as necessary, repackaged for shipment to the United States. Coordination with the RANCH HAND units at Bien Hoa, Phu Cat and Da Nang as well as with the Army Chemical Corps was essential in locating and removing the remaining inventory of herbicide.

In a recent 2006 Report "The History and Maps of the Former Tactical Herbicide Storage and Loading Sites in Vietnam," the DOD suggested that the sites of greatest interest for potential hot spots were at the locations where Operation PACER IVY had occurred (Young 2006). As previously noted, on 15 April 1970, the US DOD suspended all uses of Agent Orange in Vietnam. The remaining Agent Orange stocks were placed in temporary storage at Da Nang and Bien Hoa Air Bases (now Air Fields). In addition, the US Army Chemical Corps also stored small quantities of tactical herbicides at Special Forces Camps, e.g., in the Aluoi Valley. Small quantities were also located at the Air Bases at Phu Cat and Nha Trang. On 15 September 1971, the 7th Air Force directed that all stocks be consolidated at Bien Hoa, Tuy Hoa, and Da Nang Air Bases. Under the PACER IVY project, remaining stocks of Herbicide Orange were re-drummed and returned to the US control at Johnston Island. By December 1971, all remaining Agent Orange stocks in III and IV Corps were consolidated at Bien Hoa Air Base, those in II Corps were consolidated at Tuy Hoa Air Base, and those in I Corps were consolidated at Da Nang Air Base (Carmichael 1972; Cecil 1986; Hull 2002; Young 2006). Figure 4.1 is a crash map for Da Nang Air Base, Vietnam. The sites were labeled for the de-drumming/re-drumming operations and the storage area associated with Operation PACER IVY (Carmichael 1972) (additional information on PACER IVY and map locations can be found in Chapter 8).

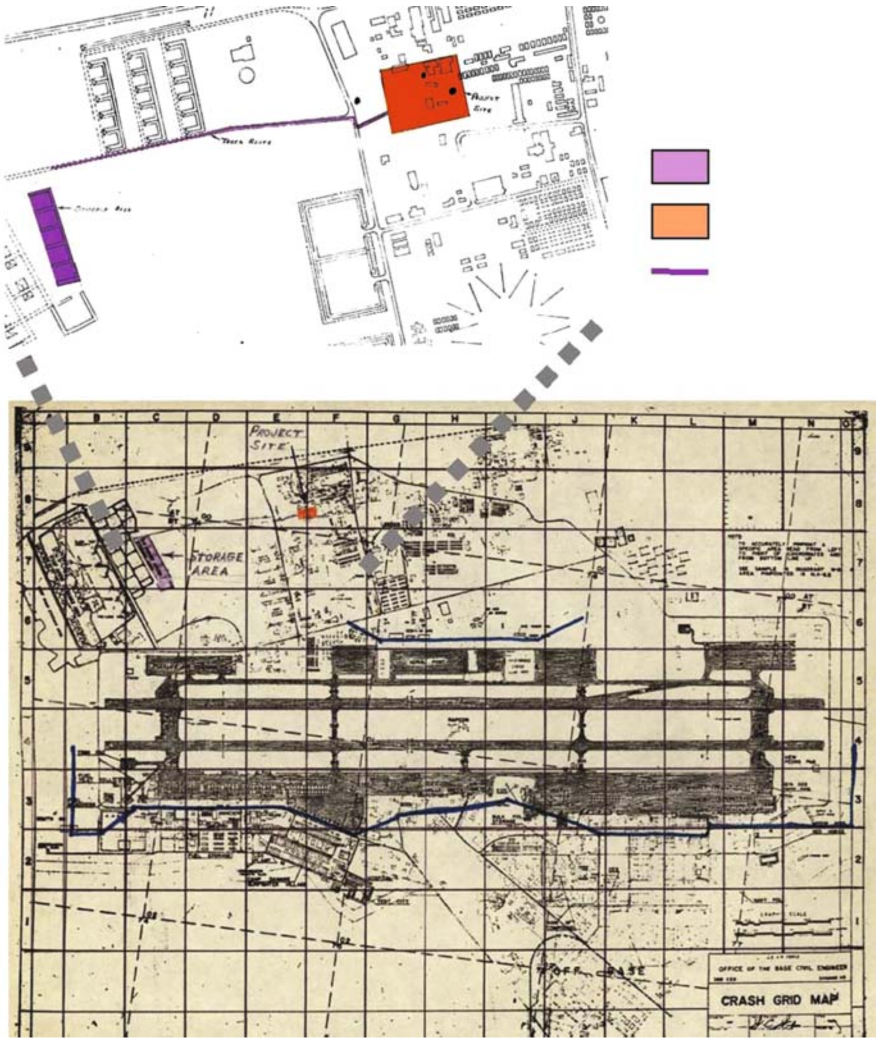

Fig. 4.1 Crash Map for Da Nang Air Base, Vietnam. The De-drumming/Re-drumming Operations Area, Storage Area, and transportation route between the two areas are indicated by the orange and purple polygons, December 1971 (Carmichael Journal 1972)

In his journal, Carmichael noted that the project to clean, re-label, and, when necessary, repackage the Agent Orange for shipment began at Da Nang Air Base, Vietnam on 23 December 1971. Similar operations occurred at Tuy Hoa Air Base and Bien Hoa Air Base during the same time period (Hull 2002). Figure 4.2 was a photograph taken on 29 December 1971 of drums of Agent Orange in storage at Da Nang prior to the de-drum/re-drum operations. It is worth noting the deteriorating condition of the drums and the apparent spill on the ground near the drums.

Fig. 4.2 Photograph of damaged and leaking Agent Orange drums, Da Nang Air Field, 29 December 1971 (Carmichael Journal 1972)

Figure 4.3 was a photograph taken on 30 December 1971 of the entire herbicide storage area at Da Nang. Included in this inventory were 8,220 drums of Agent Orange/Orange II, and an unspecified number of drums of Agent White (Fig. 4.4) and Agent Blue (Fig. 4.5). Both Agent White and Agent Blue were subsequently segregated from the Agent Orange and were left under the control of the RVN Government. A well for water was marked "contaminated water" and is shown in the foreground of Fig. 4.3. Carmichael had the

Fig. 4.3 Photograph of the Main Herbicide Storage Area at Da Nang Air Field, 30 December 1971; inventory included more than 8,000 drums of Agent Orange/Orange II (Carmichael Journal 1972)

water sampled. It was found to contain herbicide, and the well was placed "off limits" to US and RVN personnel."

Both Hull and Carmichael noted that the activities to prepare the Agent Orange for shipment from South Vietnam to Johnston Island in the Central

Fig. 4.4 Drums of Agent White in storage at Da Nang Air Field, December 1971 (Carmichael Journal 1972)

Fig. 4.5 Drums of Agent Blue in storage at Da Nang Air Field, December 1971 (Carmichael Journal 1972)

Pacific Ocean were overseen by Chinese contractors. Hull believed that a firm in Hong Kong received the contract to conduct the ground operations. Local Vietnamese women performed much of the actual labor, although the task of de-drumming and re-drumming was left to the Vietnamese military. The use of women was common practice at the time; Hull noted that Vietnamese women were routinely hired by the RVN Government to support cleanup operations on military installations throughout South Vietnam. As noted above, the heavy work of transferring the herbicide from one drum to another as well as was the transport of drums to the piers for loading on ships was left to South Vietnamese military personnel.

Hundreds of women were estimated to have been involved in the various operations at each of the three sites. In the interview with Hull, he explained that he had verbally expressed concern to the contractor because the boots, aprons, and gloves issued to the Vietnamese women were too large for them to wear. As a result, many of the women wore sandals and handled the herbicides without gloves. Figure 4.6 was a photograph of Vietnamese women moving, labeling, and inspecting Agent Orange Drums for shipment by truck from Da Nang Air Base to the port area of Da Nang during February 1972 (Carmichael 1972).

The Carmichael Journal provides a valuable chronology of the steps involved in handling the Agent Orange for shipment to Johnston Island. For example, Carmichael noted in his journal that 2000 new barrels arrived at Da Nang Air Base on 13 January 1972. He recorded in his journal for that day:

Fig. 4.6 Vietnamese women involved in Operation PACER IVY, Da Nang Air Field, February 1972 (Carmichael Journal 1972)

> The transfer process has begun. As the pictures show (Figs. 4.7 and 4.8), the herbicide is being poured from one barrel to another. This appears to be working quite well. There was little spillage noted. The Project seems to be progressing well (Carmichael 1972).

These photographs confirmed that South Vietnamese military personnel were responsible for the actual transfer of the liquid herbicide to new drums.

Fig. 4.7 Operation PACER IVY Project at Da Nang Air Field. South Vietnamese soldiers provided the support for de-drumming and re-drumming Agent Orange, January 1972 (Carmichael Journal 1972)

Fig. 4.8 Transferring Agent Orange from damaged drums to new drums. South Vietnamese soldiers provided support for the re-drumming operation, Da Nang Air Field, 13 January 1972 (Carmichael Journal 1972)

The drums at all three locations that were declared "unusable" were further destroyed by using picks to punch additional holes in the tops and bottoms (Fig. 4.9). These drums were then sent to a local landfill to be buried. "Usable" drums were steam cleaned and provided to the RVN Air Force (Fig. 4.10) (Carmichael 1972).

Carmichael noted that more than 4,000 empty drums remained after the re-drumming operation. This suggests that approximately 50% of the inventory was shipped from South Vietnam in its original packaging and 50% was re-drummed. The source of the empty drums required for the re-drumming operation was never specified. Photographs of the inventory at Johnston Island confirmed that many of the 208-l drums were re-used drums that had contained a variety of different petroleum products.

On 7 March 1972, Carmichael noted that the drums at Da Nang Air Base were loaded on trucks and that a convoy of those trucks transported nearly 8,220 drums of Agent Orange to the pier at Da Nang (Fig. 4.11). The cargo ship, the *M/T TransPacific*, arrived at Da Nang on 10 March 1972. The ship departed the Port of Da Nang on 15 March and docked at Cam Ranh Bay to load the drums from Tuy Hoa Air base. From there it sailed to the port of Saigon to load Agent Orange on board from Bien Hoa Air Base. The ship departed Saigon on 1 April 1972 and arrived at Johnston Island, Central Pacific Ocean approximately 18 days later (Department of the Air Force 1974). The best estimate of the individual sources for the inventory was that 11,000 drums were from Bien Hoa, 6,000 drums from Tuy Hoa, and 8,220

Fig. 4.9 Empty Agent Orange drums identified as non-reusable were further damaged by punching holes in the tops and bottoms, and then disposed of in a local landfill, Operation PACER IVY, Da Nang Air Field, 18 January 1972 (Carmichael Journal 1972)

drums from Da Nang, for a total of 25,220 drums of Agent Orange (Carmichael 1972; Hull 2002). In the San Antonio Air Materiel Area history, Phu Cat Air Base not Tuy Hoa is identified as the base where II Corps drums were collected and re-drummed (Craig 1975). This error in location was likewise used by Vietnamese Officials in remediation discussions in 2005 (Young and Andrews 2005).

On 28 March 1972, 7th Air Force Headquarters at Tan Son Nhut Air Base sent a message with the subject HERBICIDE ORANGE REMOVAL to the Commander, Da Nang Airfield, RVN. The message stated the following:

1. Reference recent removal of Herbicide Stocks from your Installation, understand contractor departed prior to complete clean up of staging area; TMO (Transportation Management Office) requested Base Fire Dept assist in scrubdown.
2. Request inspection of area by Base Bioenvironmental Engineer for adequacy of clean up with advise of complete action asap. Please provide any additional assistance as necessary to satisfy environmental requirements, advise labor resources contributed and we will request contract adjustment accordingly (Carmichael 1972).

Carmichael recorded that the contaminated wooden pallets were burned (Fig. 4.12), but other cleanup was not accomplished. In his 3 April 1972 letter in response to the above request, Carmichael, on behalf of the Base Commander, replied:

Fig. 4.10 Usable empty Agent Orange drums were steam cleaned and provided to the Vietnamese Air Force (VNAF), Operation PACER IVY, Da Nang Air Field, 15 January 1972 (Carmichael Journal 1972)

1. The final storage area for Herbicide Orange was inspected on 3 April 1972 by Captain Carmichael, Base Bioenvironmental Engineer.
2. The results of this inspection showed that the spilled Herbicide Orange has become impregnated in the asphalt covering of this area resulting in the following:

   a. Complete clean-up is impracticable.
   b. Further clean-up would now do little to alter the environmental impact of this project.
   c. Deterioration of the asphalt covering has occurred, much of which could have been prevented by prompt clean-up (Carmichael 1972).

Hull (2002) reported a similar situation when he noted that the de-drumming area and storage site at Tuy Hoa had been heavily contaminated with Agent Orange. The sandy soil quickly adsorbed the liquid and no attempt was made to clean or decontaminate the area.

The *M/T TransPacific* arrived at the pier at Johnston Island on 18 April 1972. The approximately 25,220 208-l drums were off-loaded from the ship and placed in temporary storage on the northwest corner of the Island (Fig. 4.13). The unloading of the ship was completed on 28 April 1972. Approximately 50% of the stocks had required re-drumming in South Vietnam before they were transported to Johnston Island (Carmichael 1972; Hull 2002). In the 1974 Final

Fig. 4.11 On 7 March 1972, truck convoys began transporting drums of Agent Orange from Da Nang Air Field to the Port at Da Nang City in support of Project PACER IVY (Carmichael Journal 1972)

Fig. 4.12 Ash and wood residue from burning Agent Orange contaminated pallets, Da Nang Air Field, 3 March 1972; no additional clean up was conducted and Project PACER IVY was terminated (Carmichael Journal 1972)

Fig. 4.13 The Agent Orange inventory from Vietnam consisted of approximately 25,220 208-l drums pictured here at Johnston Island, Central Pacific Ocean, May 1972 (Photograph courtesy of Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

Environmental Impact Statement on the Disposition of Agent Orange, the Johnston Island inventory was listed as containing 26,689 208-l drums in storage (Department of the Air Force 1974). Prior to Operation PACER HO, Battelle Columbus Laboratories noted that the Orange Herbicide stored on Johnston Island represented 25,000 drums (Thomas et al. 1978). Moreover, Battelle estimated a loss of approximately 455 drums of Herbicide Orange during storage, maintenance and PACER HO operations (Thomas et al. 1978). The final total of drums of Agent Orange processed in Operation PACER HO in July-August 1977 was 24,795. Thus, a rough estimate of 25,250 drums was calculated by Battelle to have been delivered to Johnston Island in April 1972. The estimate of 25,220 by Carmichael and Hull is validated. Operation PACER IVY officially ended once the drums from South Vietnam were placed in storage at Johnston Island and limited cleanup activities at Da Nang, Tuy Hoa and Bien Hoa, were completed.

4.3 Storage and Maintenance of Agent Orange in the United States

In August 1966, the United States Department of the Air Force consolidated the responsibility for the management of all tactical herbicides (used in Vietnam) under the Directorate of Air Force Aerospace Fuels, San Antonio Air Materiel Area (SAAMA), San Antonio, Texas. One action that resulted from this consolidation was the selection of the Port of Mobile, Mobile, Alabama for the port of embarkation of all tactical herbicides procured and shipped to Vietnam. Thus, all of the producers of Agent Orange, Agent White, and Agent Blue were instructed by the Defense Supply Agency (the procuring agency) to ship the tactical herbicides in 55-gal drums and by rail to the Port of Mobile. As the tactical herbicide inventory began to build up in Vietnam (primarily at the Air Bases at Bien Hoa and Da Nang) in 1968, SAAMA temporarily discontinued shipment from the Port of Mobile in order "to avoid exposing large quantities of herbicides to possible damage by enemy action." Since the Port of Mobile was routinely used as the port of embarkation, SAAMA arranged for the tactical herbicides to be temporarily placed in storage at the Port. However, it was recognized that additional temporary shortage would be needed (SAAMA 1968; Young 2006).

On 26 June 1968, SAAMA negotiated with the Naval Construction Battalion Center (NCBC), Gulfport, Mississippi to receive and store additional drums of tactical herbicides, Moreover, the NCBC outside storage area was about two miles from the Gulfport Outport Docks. By December 1968, 66,700 drums had been moved to NCBC. Over the next eight months (in 1969) drums were again being shipped to Vietnam out of both the Outport at Gulfport and from the Port of Mobile (Craig 1975). On 17 August 1969, Hurricane "Camille" hit the Gulfport, Mississippi area with winds in excess of 200 miles per hour. There were 17 railroad cars on the Gulfport Docks containing 1,700 drums of herbicide that were withdrawn to NCBC area before the storm hit. However, there were 1,466 drums of Orange and Blue in the berthing area awaiting loading and shipment to Vietnam. These drums were scattered throughout the port area and into the water by the hurricane (Craig 1975; Miller et al. 1980).

Of the 1,466 drums, 412 were recovered and shipped to Vietnam. The remainder were dredged from the Gulf by the personnel of the Army Corps of Engineers and piled in the Commercial Port Area at Gulfport. On 2 October 1969, the Air Force Logistics Command directed the Eastern Area Military Traffic Management and Terminal Services to furnish labor, hoses, and heavy equipment for the re-drumming of the remaining inventory. SAAMA furnished new drums, marking and shipping instructions. The Army Corps of Engineers (Gulf Detachment) disposed of the contaminated soil and empty damaged drums. The re-drumming operations were completed on 7 November 1969 (Craig 1975). After the completion of the operation, Port Officials and Air Force Logistic Command personnel determined that 171 drums of Herbicide Blue and 74 drums of Herbicide Orange/Orange II were missing from the inventory and despite recovery efforts, they were never found. The issue of these "lost drums" was the subject of a Freedom of Information Request to the Air Force Logistics Command, Wright-Patterson Air Force Base, Ohio, and a subsequent newspaper article in The Sun/The Daily Herald, Biloxi, Mississippi, 11 March 1985 (Miller et al. 1980).

By the time Operation PACER IVY was initiated, approximately 15,280 drums of Agent Orange were already in storage at NCBC (Fig. 4.14). In addition, the USAF had 705 drums of 2,4,5-T esters at Kelly AFB, Texas,

Fig. 4.14 In 1968, the Agent Orange inventory that was placed in storage at the Naval Construction Battalion Center (NCBC), Gulfport, Mississippi consisted of 15,280 208-l drums. Much of the inventory was initially located at the Port of Mobile, Alabama, and subsequently moved to the NCBC later in the year (Photograph courtesy of AFLC, Kelly AFB, Texas)

and 129 drums of Agent Orange at Eglin AFB, Florida. When the inventory from Vietnam was placed in storage on Johnston Island, this brought the total inventory to more than 8.5 million liters of Agent Orange that needed to be disposed of properly (Tremblay 1983).

The USAF faced the challenge of how best to dispose of the remaining Agent Orange. Any disposal method had to address the effectiveness of destroying the dioxin “impurities” in the Agent Orange. In a 31 May 1972 Memorandum to the Secretary of Defense, Secretary of the Air Force Robert Seamans, Jr., addressed the subject of “Disposition of Herbicide Orange”:

> In your memorandum of 13 September 1971, you directed that all stocks of Herbicide Orange in Southeast Asia be returned as quickly as practicable for disposition. Removal of stocks from Southeast Asia (1,387,045 gallons) (52.5 million liters) has been accomplished by relocation to Johnston Island. There are an additional 863,000 gallons (32.7 million liters) of Herbicide Orange that had already been stored at Gulfport, Mississippi.
>
> Your memorandum also directed that all stocks with unacceptable levels of impurities will be incinerated. For the past several months, we have been doing research, both in-house and by contract, on various methods of disposition. These include:
>
> (1) Commercial Incineration in CONUS
> (2) Construction of an Incinerator on Johnston Island
> (3) Chemical Fractionation (The separation of the TCDD from the phenoxy herbicides)

> (4) Deep Well Injection
> (5) Soil Biodegradation (The degradation of the herbicide by soil microorganism)
>
> Each of these alternatives is being carefully researched to determine environmental effects, public relations implications and relative costs. Each is considered a viable alternative. Sufficient data will be available by late June 1972, to choose the most effective of these in terms of costs and environmental effects.
>
> A sixth alternative has also become apparent which could be cheap, fast, and humanitarian as well. We have been informally approached by the Government of Brazil regarding donation or sale of Herbicide Orange. The product would be diluted and repackaged for use to improve rangeland to control jungle growth along highways in the interior and Amazon areas. The repackaged and diluted product would be applied by hand rather than indiscriminately sprayed. We have determined that export of the product to countries where its use is lawful would be consistent with the US policy on pesticides and other herbicides not authorized for domestic US uses.
>
> Since your memorandum of 13 September 1971 directs disposition by incineration of Herbicide Orange with unacceptable levels of impurities (which for all practical purposes is our total stock), and in view of the various other options available as disposition methods, I request your approval to effect disposal of our Herbicide Orange stocks by whichever means are determined to be both safe and economical, including consideration of sale or donation to foreign governments for bonafide agricultural uses. The specific method chosen will of course, be coordinated with your staff and other interested agencies such as the Environmental Protection Agency, Department of Agriculture, and state and local environmental protection organizations (Seamans 1972; Department of Air Force 1972).

The option to store the herbicide indefinitely was unacceptable, although the Air Force thought that the disposition of the herbicide could be accomplished, if not in a matter of months, certainly within two to three years. Those time estimates were too optimistic. It actually took the USAF almost six years to dispose of the remaining stocks of Agent Orange (Department of Air Force 1977). While the approximately 42,000 208-l steel drums containing the Agent Orange were deemed to be in good to excellent condition in May 1972, the structural integrity of the original 208-l drums progressively deteriorated. As a result, extensive maintenance and re-drumming operations were active at both storage sites. External corrosion due to exposure to salty sea air, expansion-contraction caused by temperature changes, and frequent handling continually reduced the structural integrity of the steel drums. Compounding the problem of structural degradation was the fact that there was no available method for easily examining a drum and accurately predicting when it would begin to leak or when it was degraded to the point that re-drumming was required. From 1972 through mid-1977, approximately 10,500 drums required re-drumming. About 10,000 (40%) were re-drummed at Johnston Island, and 500 (3%) were re-drummed at NCBC. At Johnston Island, re-drumming operations averaged about 29 drums per week with a peak of 97 drums in a one-week period (Department of Air Force 1977).

Because of the deteriorating condition of the drums, the Johnston Island inventory required continual maintenance. Figure 4.15 was a photograph of the

Fig. 4.15 Agent Orange inventory, Johnston Island, May 1975; note the presence of spills (Photograph courtesy of A.L. Young)

inventory in May 1975. Many of the drums were no longer recognizable with the orange "band" around the center of the drums, although efforts were made to continue labeling new drums as "HERBICIDE BUTYL ESTERS" (Fig. 4.16, photographed in August 1974). Note also in Fig. 4.15, the spills

Fig. 4.16 The drums of Agent Orange re-located from South Vietnam were labeled as "Herbicide Butyl Esters" (Photograph courtesy of A.L. Young)

Fig. 4.17 A leaking drum of Agent Orange, 1974 at NCBC, Gulfport, MS. The leak occurred on the "rib" of the drum on the underneath side (toward the ground); A policy was implemented to periodically rotate the drums, thus preventing or minimizing this type of leak (Photograph courtesy of A.L. Young)

that occurred from the leaking drums. The soil of the atoll was crushed coral and the herbicide was slowly absorbed into the calcium matrix. Agent Orange was insoluble in water and the leaching into the coral was generally confined to the top 15 cm of soil (Thomas et al. 1978).

Figure 4.17 was a photograph taken in 1974 of a leaking Agent Orange drum at the Naval Construction Battalion Center. The leak occurred in the "rib" of the drum on the underneath side (toward the ground); consequently the drums at both sites were periodically rotated. This slowed the erosion from the outside but increased the number of leaks due to ruptures from physically handling the drums (Craig 1975).

Figure 4.18 was a photograph taken in October 1973 of the de-drum/re-drum facility constructed on Johnston Island. Figure 4.19 is a photograph of the de-drumming and rinsing operation at the Naval Construction Battalion Center in April 1975. A full-time crew was needed to maintain oversight of the inventories. This was a contractual operation at both Johnston Island and the Naval Construction Battalion Center. From 1 July 1971 through 30 September 1976 the cost for re-drumming, environmental monitoring, and "housekeeping" (rotating the drums and maintaining the facilities and fences) at both NCBC and Johnston Island was $2.47 million (Department of the Air Force 1977). Figure 4.20 was a photograph of the Johnston Island "fenced" Agent Orange inventory in August 1974, while Fig. 4.21 was a photograph taken in 1976 showing the continual deterioration of the drums. Figure 4.22 was a photograph taken in 1974 of the Agent Orange inventory at the Naval Construction Battalion Center. Note that the NCBC inventory had been removed from pallets and placed on wooden

Fig. 4.18 De-drum/Re-drum Facility at Johnston Island, October 1973; approximately 10,000 drums were required to be re-drummed during the years from 1972 through mid-1977 (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

Fig. 4.19 De-drumming and rinsing operation of an Agent Orange drum at Naval Construction Battalion Center, Gulfport, MS, April 1975; a full-time crew was required to maintain oversight of the inventories at NCBC and Johnston Island (Photograph courtesy of AFLC, Kelly AFB, Texas)

Fig. 4.20 The "fenced" Agent Orange inventory at Johnston Island in August 1974; although, Johnston Island was both "remote" and "secure," the Agent Orange inventory was "off limits" to military and civilian employees stationed on the Island (Photograph courtesy of A.L. Young)

dunnage. Both inventories would remain essentially intact as shown in the two photographs until Operation PACER HO was initiated in May 1977 (Young et al. 1978).

Fig. 4.21 Agent Orange inventory, Johnston Island, 1976; note the continued deterioration of the drums (Photograph courtesy of A.L. Young)

Fig. 4.22 Photograph of the Agent Orange inventory in 1974, at the Naval Construction Battalion Center; the inventory was initially stored upright on pallets, but the drums were subsequently placed on their sides on wooden dunnage (Photograph courtesy of AFLC, Kelly AFB, Texas)

4.4 Operation PACER HO

4.4.1 Selection of At-Sea Incineration and Discussion of Alternative Methods

In 1972, a draft environmental statement proposed destruction of the Agent Orange stocks by a commercial land-based incinerator facility in the United States (Department of the Air Force 1972). Public comments to this draft statement led the Air Force to continued studies on incineration, as well as additional alternative disposal methods. From 1972 through 1974, various techniques of destruction and recovery of the Agent Orange were investigated. Destructive techniques investigated included soil biodegradation, high temperature incineration, deep-well injection, burial in underground nuclear test cavities, sludge burial, and microbial reduction. Techniques to recover a useful product included use, return to manufacturers, fractionation, and chlorinolysis. Of these techniques, only high temperature incineration was sufficiently developed to warrant further investigation. The other methods were rejected because of several considerations, including long lead-times for development with no assurance of success, the lack of industrial interest, and the likelihood of obtaining public acceptance (Department of Air Force 1977; Young 2006).

In December 1974, the Air Force filed a final environmental impact statement with the Council on Environmental Quality on the disposition of Herbicide Orange by destruction aboard a specially designed incineration vessel in a remote area of the Pacific Ocean, west of Johnston Island (Department of Air

Force 1974). The US Environmental Protection Agency (EPA) held a public meeting in February 1975 to consider an ocean incineration permit application submitted by the USAF in accordance with the Marine Protection, Research and Sanctuaries Act of 1972 as amended, 33 U.S.C. 1401 *et seq* (USAF 1977). During this meeting, public testimony was presented that suggested that Agent Orange could be reprocessed and the material used in the commercial area. The EPA in response to the public comments requested that the Air Force investigate the feasibility of reprocessing the herbicide as a means of disposition prior to making a decision to destroy the herbicide via incineration (EPA 1975).

As a result, the USAF undertook an investigation into the feasibility of reprocessing Agent Orange. Pilot plant-level studies were conducted from the fall of 1975 to July 1976 on selective activated carbon adsorption of TCDD from the herbicide. This reprocessing method was shown to be technically and environmentally feasible. However, a technically feasible and environmentally acceptable method of safely disposing of the TCDD-laden activated carbon was not demonstrated. The USAF concluded in February 1977 that the option of reprocessing was not feasible, timely, or cost effective since a technique for the ultimate disposal of the activated carbon was not currently available or anticipated in the foreseeable future (Young et al. 1978). The Air Force immediately submitted to EPA a Final Amendment to the 1974 Final Environmental Statement on the Disposition of Orange Herbicide by At-Sea Incineration (Department of Air Force 1977).

On 9 March 1977, the USAF requested reconvening the EPA public hearings. Following the public hearing held on 7 April 1977, the EPA issued a research permit to the USAF and Ocean Combustion Services, B.V. (OCS) (EPA 1977). The permit authorized the transport of the Herbicide Orange from NCBC to a designated site in the Pacific Ocean for the purpose of at-sea incineration in accordance with the provisions of the Marine Protection, Research, and Sanctuaries Act of 1972, as amended.

The vessel contracted for the at-sea incineration was the Dutch-owned *M/T Vulcanus*, a ship registered in Singapore and previously used in the North Atlantic Ocean and the Gulf of Mexico to destroy chlorinated hydrocarbon wastes (Wastler et al. 1975). Three herbicide loadings were required to incinerate the total stocks of Agent Orange: one from Gulfport, Mississippi, and two from Johnston Island (Young et al. 1978). The incineration of the NCBC inventory (loaded at Gulfport) represented a trial burn that was followed by an EPA-sponsored public hearing to review the scientific results of the incineration destruction efficiencies (CMR 1977; Walsh 1977; Tremblay 1983).

4.4.2 Operation PACER HO

The preparation for Operation PACER HO began immediately after EPA issued the permit for the destruction of Agent Orange by at-sea incineration. It required the dedication and coordination of military and civilian personnel from numerous Federal and State agencies and from military installations in Texas, Mississippi, Alabama, Florida, Ohio, Hawaii, Utah, Georgia, Oklahoma, and California. The Air Force Logistics Command, Wright-Patterson AFB, Ohio, was designated as the "responsible agent" for the disposition of Herbicide Orange. In early April 1977, the San Antonio Air Logistics Center prepared and released "Programming Plan 75-19 for the Disposal of Herbicide Orange" (Air Force Logistics Command 1977). The Programming Plan documented and assigned responsibilities and provided authority for the time-phased actions necessary to dispose of 8.5 million liters of Agent Orange by at-sea incineration. The three major functions detailed in the plan included (1) De-drumming operations at Gulfport, Mississippi, and Johnston Island; (2) Environmental monitoring at Gulfport and Johnston Island; and, (3) Disposal by incineration on a ship at sea in a remote area off Johnston Island.

The plan included personnel requirements, medical and environmental surveillance, emergency protocols, public relations coordination, and technical guidance for all of the engineering and transportation requirements (Air Force Logistics Command 1977). The schedule called for briefings to be held for local authorities and the media on 29 April 1977, and for all "Operating Personnel" to be on-site at the Naval Construction Battalion Center on 1 May 1977. Operation PACER HO commenced on 2 May 1977. The schedule called for all actions to be complete at Gulfport within 38 days at which time the operation would shift to Johnston Island, with final activities including at-sea incineration, to be completed by day 123. Indeed, the Operation was conducted as planned (Tremblay 1983). Figure 4.23 was a photograph of the media event scheduling the "kick-off" of Operation PACER HO that occurred on 29 April 1977 at the Naval Construction Battalion Center, Gulfport, Mississippi. The Operation was completed on 5 September 1977 at Johnston Island.

In the remaining section of this chapter, a brief overview will be provided on pertinent activities of the Operation. Details of Operation PACER HO were published in six major source documents:

- Land Based Environmental Monitoring at Johnston Island – Disposal of Herbicide Orange (Thomas et al. 1978);
- At-Sea Incineration of Herbicide Orange Onboard the *M/T Vulcanus* (Ackerman et al. 1978);
- Chapter II. Disposal of Herbicide Orange. IN: The Toxicology, Environmental Fate, and Human Risk of Herbicide Orange and Its Associated Dioxin (Young et al. 1978);
- Land Based Environmental Monitoring at the Naval Construction Battalion Center, Gulfport, Mississippi: Disposal of Herbicide Orange (Doane 1979a);
- Land Based Environmental Monitoring for 2,4-D, 2,4,5-T and Dioxin in Support of the U.S. Air Force Herbicide Orange Disposal Operations (Tremblay et al. 1980); and,
- The Design, Implementation, and Evaluation of the Industrial Hygiene Program Used During the Disposal of Herbicide Orange (Tremblay 1983).

Fig. 4.23 Media briefing at "Kick-Off" of Operation PACER HO, on 29 April 1977, at the Naval Construction Battalion Center, Gulfport, Mississippi; press from all over the United States was present (Photograph courtesy of USAF OEHL, Brooks AFB, Texas)

4.4.3 Description of Land-Based Operations

The operations at both storage sites were similar in many ways. At both sites, the 208-l drums of Agent Orange were transported short distances from their storage location to a centralized facility. The herbicide was drained from the drums and transferred to the *M/T Vulcanus*. Following emptying, the drums were rinsed with diesel fuel, and subsequently crushed. The residual liquid from rinsing the empty drums was combined with the herbicide and transferred to the ship for later incineration at sea (Thomas et al. 1978; Doane 1979a)

4.4.4 Operations at the Naval Construction Battalion Center

The centralized de-drumming facility at the NCBC was a temporary, enclosed facility with a ventilation system capable of providing 57 air changes per hour through in-line activated charcoal filters (Doane 1979a; Tremblay 1983). Within this facility were four identical processing lines, each manned with a crew and each assigned to a specific activity, Fig. 4.24. Each line consisted of a self-closing entry door to admit full drums; a roller conveyor along which drums were moved in an upright position; a position equipped with a heavy duty electrically operated de-heading cutter; a suction wand to remove the greatest portion of the herbicide from the de-headed drum; a spray device beneath the conveyor over which the de-headed and emptied drum was inverted and rinsed

Fig. 4.24 The De-drum crew in the De-drum Facility for Operation PACER HO, Naval Construction Battalion Center, Gulfport, Mississippi, 24 May–10 June 1977 (Photograph courtesy of USAF OEHL, Brooks AFB, Texas)

with diesel fuel; a commercial, heavy-duty crusher; and a self-closing exit door through which the crushed drums were passed (Doane 1979a; Tremblay 1983).

Following de-heading of the drum (Fig. 4.25), the contents were removed by the suction wand, leaving approximately 11 l of liquid in the drum. The drum was then manually inverted, and the remaining herbicide was collected in an open trough beneath the conveyor. Each drum was permitted to drain into the same trough for a minimum of five minutes after which it was sprayed with 7.5 l of diesel (Fig. 4.26), allowed to drain while still inverted for a minimum of two minutes, and then crushed end-to-end to approximately one-third its original volume. The rinsed and crushed drum was then passed through the exit door and stacked with all other crushed drums (Fig. 4.27) (Doane 1979a).

The liquid herbicide from the suction wands, and the herbicide and diesel fuel rinsing liquid from the below-grade open trough, were pumped to 37,800-l capacity rail tank cars. The rail cars were moved along a rail spur approximately 3.2 km to a dockside location where the herbicide was transferred to the incinerator ship, the *M/T Vulcanus* (Fig. 4.28) (Doane 1979a).

A total of 15,470 drums of Agent Orange were processed in this fashion at the Naval Construction Battalion Center between 24 May 1977 and 10 June 1977. Two 8-h shifts of approximately 55 men each accomplished the de-drumming/transfer operations. The men were military personnel from Kelly AFB, Texas; Hill AFB, Utah, Robins AFB, Georgia; Tinker AFB, Oklahoma; and McClellan AFB, California (Fig. 4.29) (Young et al. 1978). All of the workers were provided daily changes of freshly laundered work clothes, and the men working

Fig. 4.25 Removing drum lids and contents (Agent Orange) being removed by a suction wand, Operation PACER HO, Naval Construction Battalion Center, Gulfport, Mississippi 24 May–10 June 1977 (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

within the de-drum facility were provided protective clothing including cartridge respirators, face shields, rubber aprons and rubber gloves. With only a few exceptions, the men rotated through all jobs involved in the de-drumming and transfer operations. All personnel were given detailed pre-operational and post-operational physical examinations (Calcagni 1979).

Air, biological (tomato plants), and other environmental monitoring were conducted throughout the entire operation. The Brehm Laboratory, Department of Chemistry, Dayton, Ohio, provided the analytical services for the air, water, and sediment samples collected for herbicide and TCDD residues at the NCBC and the wharf (OEHL 1977). Figure 4.30 was a photograph of a tomato plant slightly damaged by herbicide vapor. It was located approximately 200 m downwind from the de-drum facility. As expected, the levels of 2,4-D and 2,4,5-T were significantly (45–150 times) lower (e.g., the highest value for 2,4-D was 186 $\mu g/m^3$ and for 2,4,5-T it was 168 $\mu g/m^3$) than were found within the De-drum Facility (Doane 1979b). The

Fig. 4.26 Draining and rinsing Agent Orange drums, Operation PACER HO, Naval Construction Battalion Center, Mississippi, 24 May–10 June 1977 (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

Fig. 4.27 Crushed Agent Orange drums, July 1977, in storage at the Port of Gulfport (Outport) near the Naval Construction Battalion Center, Mississippi following Operation PACER HO (Photograph courtesy of USAF Occupational and Environmental Laboratory, Brooks AFB, Texas)

Fig. 4.28 During the operation at Naval Construction Battalion Center in June 1977, the Agent Orange was transferred to rail cars and moved to the Port at Gulfport, Mississippi where it was loaded onboard the Incinerator Ship, *M/T Vulcanus* (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

Fig. 4.29 Military personnel from six military bases in the US provided the manpower for Operation PACER HO, Naval Construction Battalion Center, May - June 1977 (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

Fig. 4.30 Pictured here was a tomato plant slightly damaged by herbicide vapors. It was located approximately 200 m downwind from the De-drum Facility at the Naval Construction Battalion Center, during Operation PACER HO, 26 May 1977 (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

detailed results of these monitoring programs and the industrial hygiene analyses are available in the references (Young et al 1978; Tremblay 1983).

The crushed drums were sold to a smelter. All of the solid waste, including the wooden dunnage, and contaminated clothing and protective gear were subsequently disposed of in an approved landfill at the National Space and Technology Laboratory in Bay Saint Louis, Mississippi (Doane 1979a). The soil and adjacent drainage ditches at the former storage site on the Naval Construction Battalion Center were contaminated with herbicide and TCDD (Fig. 4.31) (Young et al. 1978). Soil, sediment and biological monitoring programs were put in place in August 1977. These monitoring programs were continued for ten years, until a final decision was made to physically decontaminate the site in 1987 (Cook and Haley 1991). The results from these monitoring programs on the fate of the herbicide and TCDD are the subjects of a subsequent chapter [see Chapter 7].

Within the storage at NCBC, the responsibility for re-drumming operations was the San Antonio Air Materiel Area (SAAMA 1968). The external corrosion due to salty sea air, expansion-contraction caused by temperature changes, and handling of the drums continually reduced the structural integrity of the steel drums. Hence, a full-time crew was contracted to maintain oversight of the NCBC Herbicide Orange inventory. From 1972 through mid-1977, 500 drums (~3%) of the inventory were re-drummed at NCBC (Miller et al. 1980). An estimated 160 drums of herbicide were spilled or lost via leakage at NCBC before and during PACER HO (Doane 1979a). Further information on the NCBC site is described in the residue and monitoring studies in Chapter 7.

Fig. 4.31 Photograph of an Agent Orange spill that occurred during Operation PACER HO at the Naval Construction Battalion Center, Gulfport, Mississippi June 1977 (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

4.4.5 Operations at Johnston Island, Central Pacific Ocean

The centralized de-drum facility at Johnston Island was a temporary, open facility consisting of a concrete pad, roof, and moveable canvas walls to exclude rain (Fig. 4.32). This open facility was located adjacent to the Herbicide Orange storage site on the northwest end of Johnston Island. Nearly constant easterly winds ranging from 4.8 to 9.5 m per second provided natural ventilation and carried released vapors away from occupied areas (Thomas et al. 1978). The east one-third of the facility contained pumps and a drive through for fuel trucks that were used to transport the de-drummed herbicide to the pier. Full drums of herbicide were transported to the De-drum Facility in sets of four using forklifts equipped with specially designed clamps (Fig. 4.33). The drums were placed on the inclined metal racks in four groups of 12 drums each. The de-drumming crew handled independently sets of 12 drums (Thomas et al. 1978).

Once a set of 12 drums was on the rack and the forklifts withdrawn, a crew member would punch a vent hole near the top of each inclined drum to allow the crew's supervisory personnel to check the contents. Any drums found to contain other than Agent Orange were removed from the line and held for further testing. Three or more closely spaced holes were then punched in the bottom of each drum and the contents were drained into the open troughs. The drums were handled using techniques similar to those used at the NCBC:

Fig. 4.32 Agent Orange De-drum Facility, Johnston Island, Operation PACER HO, July–September 1977 (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

Fig. 4.33 Removing Agent Orange drums from the Johnston Island inventory, Operation PACER HO, August 1977 (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

Fig. 4.34 Drum crushing Operation, PACER HO, Johnston Island, July-September 1977 (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

they were allowed to drain, rinsed twice with diesel fuel that was also drained into the open troughs, transported to a nearby drum crusher (Fig. 4.34), crushed one drum at a time along the longitudinal axis, removed, banded 30 drums at a time, and stacked together near the crusher (Fig. 4.35) (Thomas et al. 1978). The herbicide and rinsing liquids from the drums flowed into the two open troughs to a below-grade sump. The material was pumped from this sump into modified fuel tankers and transported in 11,340-l lots to dockside where the material was pumped aboard the *M/T Vulcanus* (Fig. 4.36) (Thomas et al. 1978).

A total of 24,795 drums of herbicide were processed in this fashion between 27 July and 23 August 1977. Two 10-hour shifts of approximately 50 men each were used. The workers were civilian employees of a contractor engaged to perform the de-drumming operations (Thomas et al. 1978). USAF officers monitored all operations (Tremblay 1983). As at NCBC, all workers were provided daily changes of freshly laundered work clothes, and men working within the de-drum facility were provided protective clothing consisting of cartridge respirators, face shields, rubber aprons, and rubber gloves and boots. Unlike at NCBC, men on each crew remained in the same job through the de-drumming and transfer operations. A requirement for employment was pre- and post-operational physical examinations similar to those given to the workers at NCBC (Calcagni 1979).

Fig. 4.35 Crushed Agent Orange Drums, Johnston Island, August 1977 (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

Fig. 4.36 Transfer of Agent Orange from an F-6 Trailer to the *M/T Vulcanus*, Operation PACER HO, Johnston Island, August 1977 (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

4.4.6 Land-Based and Shipboard Air Monitoring Programs

Both environmental and occupational monitoring was accomplished at each land site and aboard the *M/T Vulcanus*. Essentially, the same equipment, methods and procedures were used at both NCBC and Johnston Island. All sampling at NCBC was accomplished by members of the USAF Occupational and Environmental Health Laboratory (USAF OEHL), Brooks AFB, Texas (Tremblay 1983). Sampling at Johnston Island was conducted by Battelle Columbus Laboratories, Columbus, Ohio (Thomas et al. 1978). Shipboard sampling was accomplished by TRW, Inc. personnel and members of USAF OEHL (Ackerman et al. 1978). In general, the industrial hygiene sampling program at each of the land sites consisted of daily air samples of the de-drum facilities with rapid analysis (within 24 h) for 2,4-D and 2,4,5-T. Samples collected for analysis of TCDD were analyzed after-the-fact. Pre-operational and post-operational background sampling was also accomplished. Environmental monitoring programs were also conducted (Doane 1979a; Thomas et al. 1978).

The results of the environmental and occupational monitoring programs have been published (Thomas et al. 1978; Young et al. 1978; Tremblay 1983). All available data indicated that there were no adverse environmental impacts on air, water, or land resources at either land site or at the designated ocean burn site as a result of land-based de-drumming, transfer operations, and at-sea operations. The results of the occupational monitoring programs revealed that under the worst case noted (de-drum facilities), the levels of 2,4-D and 2,4,5-T vapors were well below the TLV (Threshold Limit Value) for each of these materials. The levels detected were at least two and in most cases three orders of magnitude below the TLVs (the time-weighted TLV for either 2,4-D or 2,4,5-T was (10,000μg/m^3) (Tremblay 1983). TCDD was not detected in any air samples (Young et al. 1978).

4.4.7 Brief Description of Shipboard Operations

The *M/T Vulcanus*, converted in 1972 from a bulk carrier, was designed to carry approximately 3,500 cubic meters of liquid wastes. Two high temperature incinerators were installed on the aft of the vessel. Depending upon the characteristics of a given waste, the ship incinerators operated up to 25 metric tons per hour. The normal incinerator operating flame temperature was 1,500°C; and normal incinerator residence time was 1.0 s (Wastler et al. 1975).

During the Agent Orange disposal operations, the ship conducted three burns. Average rate of incineration was 15 metric tons per hour. Flame temperatures ranged from 1,375°C to 1,575°C. The results of incinerator stack sampling revealed that the TCDD destruction efficiency exceeded 99.87% for each of the three burns. The destruction efficiencies for 2,4-D and 2,4,5-T exceeded 99.999% (Ackerman et al. 1978).

4.4.8 The Termination of Operation PACER HO

The last drum of Agent Orange to be processed at Johnston Island was on 23 August 1977 (Fig. 4.37). The first loading on the ship had occurred at Gulfport; the second loading of the ship was 27 July–5 August; and, the third and final loading occurred on 17–23 August (Thomas et al. 1978). The *M/T Vulcanus* conducted incineration burns 13–25 July, 7–16 August, and the final burn 24 August–3 September (Ackerman et al. 1978). When the ship returned to Johnston Island on 3 September, a final rinsing of the on-board tanks with diesel fuel occurred. This was incinerated as the ship returned to The Netherlands. As the ship prepared to leave Johnston Island, a final photograph was taken to document the event (Fig. 4.38). Over the next few weeks, the wooden dunnage and pallets, contaminated clothing, rags, sorbent materials, etc were incinerated on the island and the ash buried. Fourteen drums of Agent Blue were found within the inventory (Thomas et al. 1978). These were sent to a military base in the Continental United States to be used in on-base weed control programs. The more than 36,000 crushed drums were disposed of through sale to a smelter company. The former Agent Orange site was shown in Fig. 4.39, as it looked on 1 September 1977. A residue monitoring program for 2,4-D, 2,4,5-T, and TCDD was put in place in late September 1977 (Young et al. 1978). The results from that program are a subject that will be covered in Chapter 7.

On 3 September 1977, the following message was sent from the Project Officer for Operation PACER HO, USAF Colonel S.A. Morrow, to the Commanding General of the Air Force Logistics Command (General Rogers) at Wright-Patterson AFB, Ohio:

Fig. 4.37 Final drum of Agent Orange, Project PACER HO, 23 August 1977, Johnston Island (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

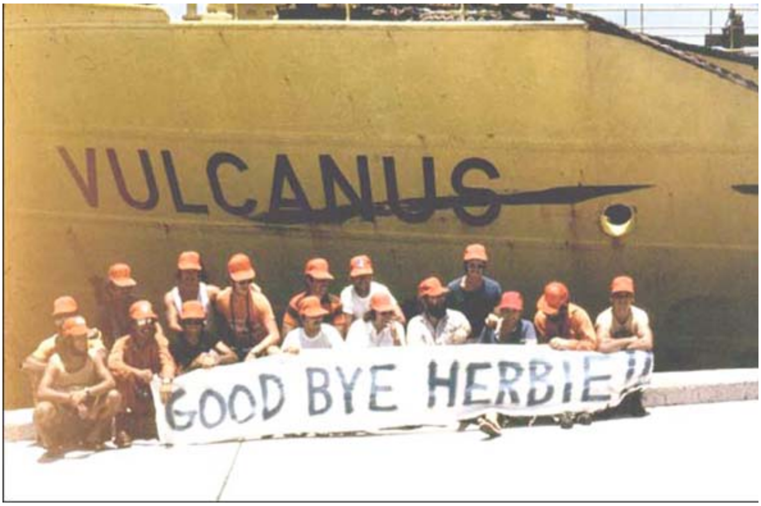

Fig. 4.38 Farewell to Agent Orange, completion of Operation PACER HO, Johnston Island, 5 September 1977 (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

Fig. 4.39 A Photograph of the Johnston Island Agent Orange Storage Site taken on 1 September 1977 After completion of Operation PACER HO; In the background are the approximately 35,000 crushed drums prepared for shipment to a smelter; a residue monitoring program for the site was initiated on 25 August, 1977 (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

It is my privilege as director of the PACER HO operations to inform you that at 032150z Sept 77 (3 September 1977, 9:50 pm local time) the ship Vulcanus completed incineration of the last of Herbicide Orange. All air force stocks at Gulfport and Johnston Island have now been removed and destroyed. All phases of the operation to date, Gulfport, Panama Canal Transit, Johnston Island and ocean incineration have been completed without minor or major incidents of any kind and well within all restrictions, tolerances, and time schedules imposed. This was achieved through the dedication and professional skills of some 500 technical, scientific and cooperating (military, civilian, and contractual) contributing to the various phases of the project. Action now is continuing in the final phase of cleaning of the ship and phase out of the Johnston Island operation

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Chapter 5
Agent Orange and its Dioxin Contamination

Much of the concern over the widespread military use of tactical herbicides in South Vietnam, especially the use of Agent Orange, stemmed from the dioxin (2,3,7,8-tetrachlorodibenzo-*p*-dioxin, TCDD) contaminant in the 2,4,5-T herbicide. Our awareness of its toxicity, persistence in biological tissue, and environmental fate now spans at least 35 years. In that span of time, thousands of articles have been published on TCDD making it not only a chemical of intense regulatory interest but also one of the most researched molecules worldwide. The Department of Defense (DOD) has expended hundreds of million dollars in the conduct of the Air Force Health Study, on the disposal of Agent Orange (Operation PACER HO), and on the numerous remediation and environmental monitoring programs conducted at the former sites where Agent Orange was stored in Mississippi and Johnston Island. This chapter explores the history of Agent Orange and its dioxin contaminant. It also describes the analytical studies on the quantities of TCDD contained in the 2,4,5-T herbicides and the subsequent Agent Orange production, and the conflict that exists between science and social concern.

5.1 The Significance of the Dioxin Contaminant in Agent Orange

It is likely that the expenditures related to the development and use of tactical herbicides by the Department of Defense will however be dwarfed by the costs that will eventually be incurred by the United States Department of Veterans Affairs (DVA) on the Congressionally-mandated Agent Orange Act of 1991. This act established procedures that the DVA must follow in deciding whether to create new presumptions of service connection for disabilities suffered by Vietnam veterans that may be associated with exposure to Agent Orange and other herbicides in Vietnam (IOM 1994). For the DVA, the determination of whether a disease (currently eleven) should be service connected is not based on determination of causation or proof of exposure, nor is it based on studies of veterans who served in Vietnam. Rather, it is based on whether the evidence, as

A.L. Young, *The History, Use, Disposition and Environmental Fate of Agent Orange*, DOI 10.1007/978-0-387-87486-9_5,

judged following periodic reviews of the scientific literature by the National Academy of Sciences' Institute of Medicine, is sufficient to conclude there is a positive association (IOM 1994). In making the final decision on whether an association exists, the Secretary of DVA must apply the standard, as mandated by Congress and the courts, that any resolution of doubt favor the Vietnam veteran (IOM 1994; Young 2002).

Vietnam, Agent Orange, and its associated dioxin are intense societal, emotional, legal, and public policy issues as much as medical and scientific issues – perhaps more so. There are strong societal concerns and public policies favoring our veterans, and rightly so. But our scientific principles ought not favor or disfavor anyone. However, as scientists, we cannot ignore the societal, emotional, or legal issues influencing public policies, because in today's environment those policies shape the research agenda (and hence funding), and if we are not careful, may affect even the research results (Young 2004, 2008).

Thus, it is appropriate to ask the question "How did we get ourselves into this situation?" This Chapter explores the history of Agent Orange and its dioxin contaminant and the conflict that exists between science and social concern.

5.2 Formation of the TCDD Contaminant

Polychlorodibenzo-*p*-dioxins may be contaminants of any of the chemical products that use chlorophenols in the manufacturing process (Young 1980). The presence of 2,3,7,8-TCDD (and its concentration) was dependent upon the industrial process used in the manufacture of the basic chlorophenol, in this case, the production of sodium 2,4,5-trichlorophenate. The most common industrial process that was used for the production of 2,4,5-T herbicide is shown in Fig. 5.1.

The process of making 2,4,5-trichlorophenate by the hydrolysis of hexachlorobenzene was a process developed by Dow Chemical Company and was known as the "Dow Process" (Plimmer 1973). The reaction temperatures during the Dow Process had to be carefully maintained. If the temperature of the hydrolysate rose above the normal 180°C, an exothermic reaction occurred after any residual solvent, e.g., glycol, was removed by distillation. This reaction, attributed to the decomposition of sodium-2-hydroxethoxide, started at a temperature of 230°C and continued to 410°C. The heat generated by this reaction assisted in the formation of TCDD through the dimerization of two molecules of sodium trichlorophenate (Plimmer 1973; Young 1980). The rapid temperature increase in the reaction vessel, results in a pressure increase; failure to release this pressure resulted in the Seveso accident of 1976 (Reggiani 1988). In this case, the dimerization resulted in a 1% yield of 2,3,7,8-TCDD (Reggiani 1988).

The capability for accurately assessing the levels of TCDD in herbicide formulations did not exist in the years during the use of Agent Orange in

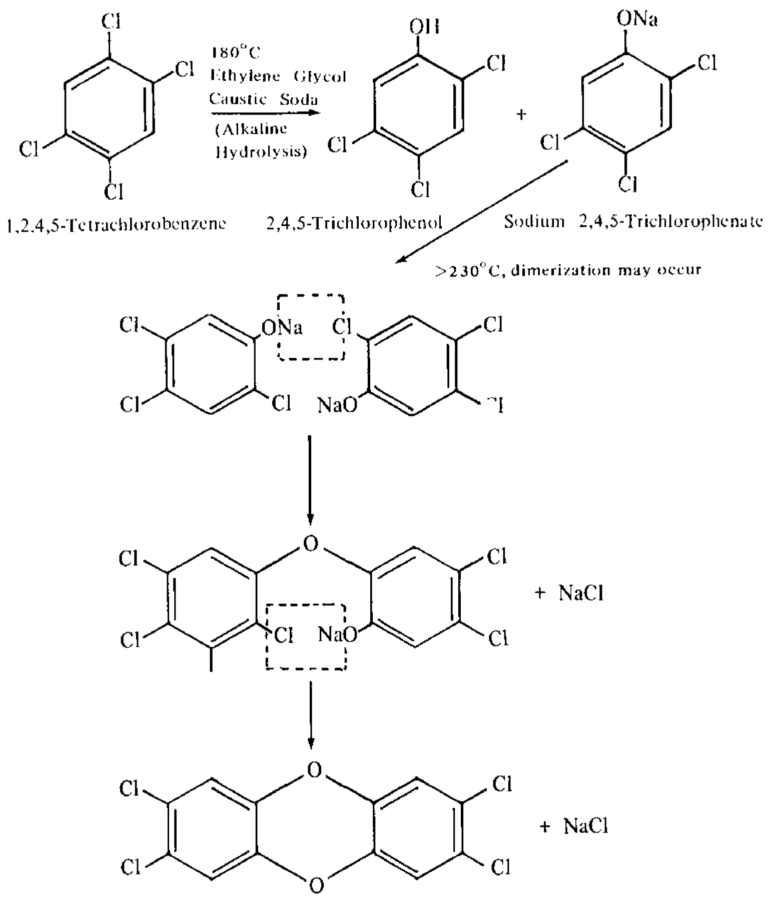

Fig. 5.1 Formation of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin by the alkaline hydrolysis and subsequent dimerization of sodium 2,4,5-trichlorophenate (Young 1980)

Vietnam. Furthermore, no mention was made in the early scientific literature that dioxins might occur as contaminants in the commercial chlorinated phenols until 1959 (Julia and Baillarge 1953). In 1962, the first description of the acnegenic potency of TCDD was published in the article: "A technique for testing acnegenic potency in rabbits, applied to the potent acnegen 2,3,7,8-tetrachlorodibenzo-p-dioxin" (Jones and Kizek 1962). It is interesting to note that much controversy surrounded the preparation, properties, and identification of high purity samples of 2,3,7,8-TCDD that could be used as standards for analytical studies. The National Cancer Institute (NCI) took the lead in preparing purified standards, conducting studies of the chemistry, and searching for possible sources for human exposure. The NCI 4-volume publication "Evaluation of the Carcinogenic, Tetragenic, and Mutagenic Activities of Selected Pesticides and Industrial Chemicals" was released in 1967 (NCI 1967).

Dr. Warren Crummett (a Dow Analytical Chemist) reported that the analytical limit of detection of 2,3,7,8-TCDD in herbicide formulations was 1 ppm in 1965, but the procedure for doing this analysis required rigorous cleanup and purification of the analyte, often using the rabbit ear test to validate TCDD (Crummett 2002). It was not until late 1969 that 2,3,7,8-TCDD could be positively identified and quantified in herbicide formulations by the use of gas chromatography-mass spectroscopy (Crummett 2002). Subsequently in 1970, they were able to confirm levels of 0.050 ppm with some consistency. However, it was not until 1974 that Dow Analytical Services was able to detect 0.001 ppm in ester, amine, and acid formulations of 2,4,5-T herbicide (Crummett 2002). Buser of Switzerland reported the same level of detection that same year, indicating the global search that was occurring for methods of detection of the dioxins and furans (Buser and Bosshardt 1974). By 1975, the ability to detect TCDD in biological tissues and in other environmental samples had reached the limit of 10 parts-per-trillion, ppt (picograms/gram), but the cost of doing one analysis exceeded $1000/sample (Young 1980). Today the capability to detect 0.01 ppt of various dioxins and furans is common. However, as Crummett noted:

> Chemists seeking to measure small numbers of molecules will continue to develop more sensitive and specific instrumentation for doing so. Eventually, they will reach the ultimate limit – single molecule detection. And what will that mean in a practical sense? Nothing, of course! But as a point of interest, it may mean that at least one molecule of every substance that has ever existed in nature will be present in a glass of drinking water (Crummett 2002).

In 1972, the United States Agricultural Research Service published data on the analysis of additional samples of 2,4,5-T herbicide (Woolson et al. 1972). Of 42 samples of 2,4,5-T, 22 samples contained less than 0.5 ppm TCDD. Of the 20 samples containing more than 0.5 ppm of TCDD, 15 were obtained for the yearly survey of one manufacturer. The samples were from 1966 to 1970, with four samples usually collected each year. There was a 10-fold drop in TCDD content by this manufacturer between 1968 and 1969. However, their technical grade 2,4,5-T still contained 2–3 ppm of TCDD in 1970. The 1970 technical samples from another manufacturer contained less than 0.5 ppm (Woolson et al. 1972). Technical grade 2,4,5-T manufactured as a formulation for use in agricultural products, typically contained 90–92% 2,4,5-T (as the acid) and 8–10 % impurities; suggesting that the sample noted above, when made into a commercial form of 2,4,5-T herbicide, probably contained between 1 and 1.5 ppm TCDD (Bovey 1980). Edmunds et al. (1973) subsequently reported on 55 samples of butyl and octyl esters of 2,4,5-T from lots manufactured in the late 1960s and early 1970s. The mean concentration of TCDD in the 55 samples was 0.31 ppm.

In 1971, in a report on 2,4,5-T prepared by the President's Science Advisory Committee (MacLeod 1971) obtained data on TCDD levels in technical grade 2,4,5-T from one manufacturer for samples analyzed from 1958 to 1969. These data were provided in Table 5.1.

Table 5.1 The history of TCDD concentrations, ppm, in technical grade 2,4,5-T acid manufactured by one company (MacLeod 1971)

Parts-per-million, ppm, 2,3,7,8-TCDD in Technical Grade 2,4,5-Tmanufactured by one company	
1958	11
1959	11
1960	8
1961	5
1962	10
1963	11
1964	12
1965	5–32
1966	3–18
1967	1–25
1968	1–25
1969	<1

The data in Table 5.1 represented only one of the seven major companies that produced 2,4,5-T for use in formulating Agent Orange. All seven companies simultaneously provided 2,4,5-T commercial formulations for US and international agriculture (WSSA 1969). Both the demand for 2,4,5-T for military and commercial uses increased during the period 1965–1970, at the same time that improvements were occurring in the industrial process and in the analytical methodology for the detection of the TCDD in the herbicide formulations.

5.3 Establishing Agent Orange and its Contaminant as a Major Public Health Issue

The relationship between TCDD and Agent Orange first became a matter of public concern in the fall of 1969 when the results of a study commissioned by the National Institutes of Health to the Bionetics Research Laboratories of Bethesda, Maryland, became known (Bionetics 1968; Reggiani 1988). A portion of that report described the teratogenicity of 2,4,5-T in laboratory mice was subsequently published in Science Magazine in 1970 (Courtney et al. 1970). However, in June 1969 reports that Herbicide Orange had produced birth defects in humans had already appeared in Vietnamese newspapers (MacLeod 1971). A subsequent analysis of the 2,4,5-T used by Bionetics revealed that the cause of the toxicity was the TCDD contaminant and that 2,4,5-T in itself was not teratogenic (Reggiani 1988; Crummett 2002). The members of the scientific community that had been asked to examine the Bionetics data and the reports coming out of Vietnam concluded that the use of 2,4,5-T represented a potential risk to human health that outweighed the benefits of its use domestically, or by the Department of Defense in Vietnam (Nelson 1969; DuBridge 1970).

In 1970, the United States Congress directed the Secretary of Defense to request that the National Academy of Sciences (NAS) conduct studies assessing the ecological and biological impact of the military use of herbicides in Vietnam (NRC, 1974). A committee of the National Research Council (NRC) published their report "The Effects of Herbicides in South Vietnam" in February 1974 (NRC 1974). Due to insufficient data it had not been possible to assess the potential impact of TCDD in Vietnam. For the next decade, studies funded by the US Federal Government and other governments on the toxicity, sources, environmental fate, and human risks of TCDD were debated and published in hundreds of forums (Young and Reggiani 1988; IOM 1994; Young 2002). The public was bombarded by stories of the horror of dioxin (see Fig. 5.2).

A large volume of toxicological data on 2,4,5-T and 2,4-D were available during the final years of US involvement in Vietnam, but woefully inadequate toxicological and environmental data on TCDD. Although scientists in 1969 had recognized that TCDD as acutely toxic and teratogenic (birth deforming) in laboratory animals, no studies were available on the effects of chronic, long-term, low-level exposures in lower mammalian species. Furthermore, numerous occupational exposures to TCDD were reported during the industrial production, but epidemiological studies were not available despite documented exposures as early as 1949 (Young et al. 1978).

Reggiani (1988) described how the issue of TCDD and Agent Orange was refocused for the public:

> In 1978, with the help of a reporter from the Columbia Broadcasting System, Bill Kurtis, the issue of Agent Orange and its potential effects on human health was presented to the nation in a television documentary entitled "Agent Orange: Vietnam's Deadly Fog". In this way the public became aware of the magnitude of the veteran's concern, and Agent Orange reached the dimensions of a public health problem. Thus,

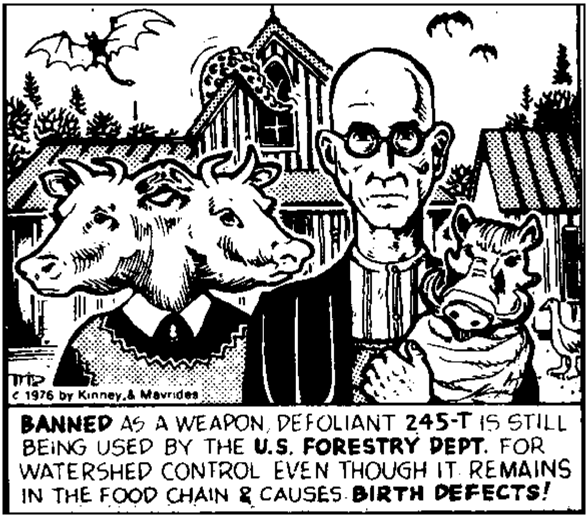

Fig. 5.2 A cartoon critizing the US Forest Service for its continued use of 2,4,5-T herbicide. Published by *The Daily Utah Chronicle*; Thursday, May 20, 1976, page 3

the public turned its attention to the scientific and policy decisions the government had taken or intended to take regarding this matter (Reggiani 1988).

In response to the documentary and numerous inquiries from Vietnam veterans, the United States Air Force's Occupational and Environmental Health Laboratory (OEHL), Brooks Air Force Base, Texas published as a technical report a comprehensive review of "The Toxicology, Environmental Fate, and Human Risk of Herbicide Orange and Its Associated Dioxin" (Young et al. 1978). The significance of the document was that both historical and scientific analyses were available in a single publication on the tactical herbicides used in Vietnam and the dioxin contaminant. Of particular value was the assessment of how much herbicide had been procured and disseminated in Vietnam, and how much of the TCDD contaminant had likely been disseminated with the 2,4,5-T herbicide.

Once the public was alerted to the controversy surrounding Agent Orange, it was only a matter of time before the US Congress and the Executive Office of the President expressed interest in taking action. Indeed, the importance to the Federal Government in resolving veteran health issues and addressing the potential risks of dioxin were demonstrated in December 11, 1979, when the Executive Office of the President (President Jimmy Carter) directed the establishment of an "Interagency Work Group to Study the Possible Long-Term Health Effects of Phenoxy Herbicides and Contaminants" (Eizenstat 1980). Members of Interagency Work Group (IWG) included representatives from the Departments of Agriculture, Defense, Health and Human Services, Housing and Urban Development, and Labor, and representatives from the Environmental Protection Agency, Veterans Affairs, Office of Management and Budget, Council of Economic Advisors, and Office of Science and Technology Policy. In August 1981, the IWG was expanded and elevated to become the "Agent Orange Working Group (AOWG)" at the Cabinet Council level by President Ronald Reagan. The task assigned to the AOWG was..."to guide and monitor all Federal research into the possible adverse health effects of Agent Orange and similar chemicals on humans, with a particular focus on the health of Vietnam veterans" (Bowen 1988). Secretary of Health and Human Services was appointed Chair of the AOWG, and the Director of the Centers for Disease Control was appointed Chair of the AOWG Science Panel. The Congressional Office of Technology Assessment and the General Accounting Office were invited to become observers and advisors to the Group.

The AOWG undertook a massive research effort encouraging, supporting, and monitoring studies conducted by VA, DOD (the Air Force Health Study of RANCH HAND personnel), the Centers for Disease Control and Prevention (CDC), other Federal Agencies, and the international community (e.g., Australia and New Zealand) (Davis 1983). Subcommittees were formed to examine the use of TCDD as a bio-indicator of exposure to Agent Orange (Rall 1981), and the Science Panel of the AOWG undertook a comprehensive assessment of the feasibility of conducting the major study of ground troops (Beach 1984).

The major issue facing all of the government-supported research was the confirmation of exposure to the phenoxy herbicides and the associated TCDD. The 1988 study released by the CDC compared levels of serum TCDD in 646 US Army veterans who served as ground troops in the most heavily sprayed regions of Vietnam with those of 97 Vietnam-era veterans who had not served in Vietnam (CDC 1988). The distribution of TCDD levels were ‘nearly identical’ in the two groups, both having means and medians of about 4 ppt, which was well within the range of background at that time (CDC 1988). The CDC concluded that neither military and spraying records nor self-reported history of exposure could reliably identify high or low exposure groups, and “most US Army ground troops who served in Vietnam were not heavily exposed to TCDD, except perhaps men whose jobs involved handling herbicides” (CDC 1988). These results were consistent with other studies and so clear cut that a planned epidemiological study of ground troops and Agent Orange was discontinued as infeasible (Young 2004).

Subsequent publications by Buckingham (1982), Cecil (1986), and Young and Reggiani (1988) provided more insight into the details of Operation RANCH HAND. Publications by Westing (1976, 1984) provided appraisals of the ecological impact of the use of herbicides in Southeast Asia. All of these publications became the primary sources of information on Agent Orange and RANCH HAND for the National Academy of Sciences’ Institute of Medicine’s publication in the 1994 on “Veterans and Agent Orange: Health Effects of Herbicides Used in Vietnam” (IOM 1994).

Disregarding the eight years of research conducted by the Federal Agencies in the United States, and the conclusion based upon that science, the Congress moved to find a “political solution” to Agent Orange (Hanson 1987). The Congressionally-mandated (and signed by the President) Agent Orange Act of 1991, Public Law 102-4, established procedures that the Department of Veterans Affairs (DVA) must follow in deciding presumptive compensation; that is, whether to create new presumptions of service connection for disabilities suffered by Vietnam veterans that may be associated with exposure to Agent Orange and other herbicides in Vietnam. The procedures required that the DVA contract with the National Academy of Sciences’ Institute of Medicine to conduct reviews every two years of the scientific literature on the health effects of herbicides and TCDD (IOM 1994). In response to the DVA, the IOM noted in its first report:

> Controversy has surrounded the study of Agent Orange since the first questions of herbicide-related health effects in Vietnam veterans were raised more than 20 years ago. In the course of its work, the Committee heard allegations of scientific misconduct and claims of government conspiracy to suppress information on health effects, as well as serious disagreements among scientists about the interpretation of laboratory and clinical data. The Committee was not charged with investigating or resolving these controversies, and it did not attempt to do so... Although the conclusions and recommendations presented here will not end the controversy surrounding this issue, it is the

> Committee's hope that this report will crystallize the current scientific information on this important topic and prompt further research to answer the remaining questions being asked by veterans and their families, the Department of Veterans Affairs, and Congress (IOM 1994).

The Academy's Institute of Medicine has now issued seven comprehensive reports (IOM 1994, 1996, 1998, 2000, 2002, 2004, 2006). In accordance with their findings, DVA has prepared a list of conditions that are presumed to be service connected based on herbicide and/or TCDD exposure (DVA 2007). The issue of whether a veteran was actually exposed to Agent Orange, and presumably dioxin, is irrelevant for establishing presumption. For any veteran who served in Vietnam between 9 January 1962 and 7 May 1975, and has one of the eleven diseases on that list, DVA must presume that they were exposed to herbicides (and associated TCDD) and their disease is service connected (DVA 2007).

5.4 Composition of Agent Orange and Associated Contaminants

In order to determine the quantity of TCDD that may have been present in the 2,4,5-T containing tactical herbicides, data on the TCDD contamination of the 2,4,5-T stocks used in formulating Agent Orange must first be gathered. Herbicide Orange was procured from numerous chemical companies. The USAF procured Orange under Purchase Description AFPID 6840-1, dated 23 February 1968, and Amendment 1, dated 11 April 1968. The Orange Purchase Description containing the changes and additions of Amendment I was published in the Final Environmental Statement on the "Disposition of Orange Herbicide by Incineration (Department of Air Force, 1974). Since the most recent purchase description for "Herbicide Orange" was dated 11 April 1968, no reference was made of the TCDD contaminant. Table 5.2 was the procurement specification for Herbicide Orange.

As part of the sampling protocol for TCDD analyses, the Air Force wanted to know how closely the military specifications had been met, and what other chemical compounds were present. Table 5.3 provided a summary of the results from analyzing 12 randomly selected drums from one lot of drums that was part of the Agent Orange Inventory at the Naval Construction Battalion Center (NCBC), Gulfport, Mississippi. These samples were taken from Agent Orange produced by Dow Chemical Company (Dow Lot 10, or assigned number, ASN, 10). The data from these samples were presumably representative of the approximately 6,950 drums of Dow product in storage at NCBC in 1973. The average concentration of 2,3,7,8-TCDD in this lot was subsequently found to contain $\leq$0.05 ppm.

As noted for Tables 5.2 and 5.3, at the time that Orange Herbicide was procured for use in South Vietnam, TCDD was **NOT** recognized as either a contaminant or as an issue of quality control. Moreover, it was not until

Table 5.2 The Military Procurement Specification for Herbicide Orange (Department of the Air Force 1974)

1. SCOPE: this purchase description prescribes requirements for a herbicide identified as Orange. The material is used as a systemic growth regulator to kill and defoliate vegetation.
2. Applicable documents:
   PPP-D-729, drums: metal 55-gal, for shipment of non-corrosive material.
   MIL-H-51148, herbicide N-butyl 2,4,5-trichlorophenoxyacetate.
   MIL-H-51147, herbicide N-butyl 2,4-dichlorophenoxyacetate.
   MIL-STD-105, sampling procedure and tables for inspection of attributes
   MIL-I-45208, inspection systems requirements
3. Requirements
   3.1 Materials. The herbicide shall be composed of the following two ingredient materials.
      a. N-butyl 2,4,5-trichlorophenoxyacetate
      b. N-butyl 2,4-dichlorophenoxyacetate
         3.1.1 The ingredient materials shall meet the following specifications:
            a. Specification MIL-H-51148, N-butyl 2,4,5-trichlorophenoxy-acetate, except free acid will be 0.5% by weight.
            b. Specification MIL-H-51147, N-butyl 2,4-dichlorophenoxyacetate except composition (purity) shall be 98% minimum by weight, acid equivalent shall not be less than 79.0% nor more than 80.0% and free acid shall be 0.5% maximum by weight.
   3.2 Finished mixture (Orange)
         3.2.1 Composition
            a. 50% by volume N-butyl 2,4,5-trichlorophenoxyacetate
            b. 50% by volume N-butyl 2,4-dichlorophenoxyacetate
         3.2.2 Tolerance. Tolerance range for amount of each composition ingredient contained in the final mixture will be ± 1.5% including the precision allowance for the analytical method used.
            a. Range for N-butyl 2,4,5-trichlorophenoxyacetate is 48.5–51.5% by volume.
            b. Range for N-butyl 2,4-dichlorophenoxyacetate is 48.5–51.5% by volume.
         3.2.3 Free acid. A maximum of 0.5% by weight.
         3.2.4 Total acid equivalent (as 2,4-D acid)
            90.0% minimum by weight.
            94.0% maximum by weight.
         3.2.5 Specific gravity.
            1.275–1.295 at 20° / 20°C
         3.2.6 Color. A clear reddish brown color.
         3.2.7 Weight per gallon.
            10.70 ± 0.08 lbs at 20°C (55 gal will weigh 584.10–592.90 pounds on a 20°C basis).

recently that other dioxins or furans became of importance to the biomonitoring of human populations (Schecter et al. 2003; Sexton et al. 2004). In an analytical study of 83 samples of 2,4,5-T herbicide produced from 1968 to 1971, the only readily quantifiable dioxin in 2,4,5-T was the 2,3,7,8-TCDD (see Table 5.4). Some of the samples contained trace quantities of 1,2,3,7,8-PnCDD; 1,2,3,4,7,8-HxCDD; 1,2,3,6,7,8-HxCDD; and, 1,2,3,6,7,8,9-HpCDD (Young and Andrews 2006).

Table 5.3 A 1973 characterization of Agent Orange produced by Dow Chemical Company and in the inventory at NCBC, Gulfport, MS (Fee et al. 1975)

Average concentration (relative % by weight)[1]	Compound
0.30	Butanol
0.10	Toluene
0.03	Xylenes, Ethylbenzene
0.05	Butyl Chloride
0.12	Dichlorophenol
0.57	Peak D
0.23	Trichlorophenol
0.16	Butoxydichlorobenzene
0.16	Butoxytrichlorobenzene
46.87	Butyl dichlorophenoxyacetate
44.62	Butyl trichlorophenoxyacetate
1.38	Butyl monochlorophenoxyacetate
2.68	Butyl methoxydichlorophenoxyacetate
0.42	Butyl (bis-dichlorophenoxy) acetate
0.29	Octyl dichlorophenoxyacetate[2]
0.42	Octyl trichlorophenoxyacetate[2]
0.33	1,1-dibutoxy-2-trichlorophenoxyethane
1.27	Unidentified compounds
100.00	*Sum*

[1] The data represent the average concentration found in 12 samples.
[2] Tentative identification based solely on gas chromatographic retention time.

To confirm that 2,3,7,8-TCDD was the principal congener of interest in blood serum, a study was conducted on 9 individuals who routinely sprayed 2,4,5-T herbicide (Smith et al 1992). Table 5.5 provided the data on lipid-adjusted serum levels of dioxins and furans from the nine applicators and their matched controls.

Table 5.4 The dioxin congeners in 83 Samples of 2,4,5-T acid produced by one manufacturer from 1968 to 1971 (Young and Andrews 2006)

Dioxin congeners (parts-per-million, ppm) in 2,4,5-T acid			
Congener	Analyzed	No. non-detected	Range of positive samples
2,3,7,8-TCDD	47	26	0.5–0.8 μg/g
PnCDD	3	2	0.17
HxCDD	11	3	0.16 ± 0.10
HpCDD	11	10	0.20
OCDD	11	9	0.40 ± 0.11

Table 5.5 Levels of PCDD and PCDF congeners in lipid-adjusted serum of nine 2,4,5-T applicators and nine matched controls (Smith et al. 1992)

Average level, ppt ± SE, § not detected		
PCDD/PCDF congener	2,4,5-T applicators	Matched controls
Dibenzodioxins		
TCDD	53.3 ± 16.1	5.6 ± 1.1
1,2,3,7,8-PnCDD	12.4 ± 1.1	8.8 ± 0.7
1,2,3,4,7,8-HxCDD	6.8 ± 0.5	5.7 ± 0.4
1,2,3,6,7,8-HxCDD	28.6 ± 5.1	23.3 ± 4.9
1,2,3,7,8,9-HxCDD	9.9 ± 0.9	8.2 ± 0.6
1,2,3,4,6,7,8-HpCDD	121.9 ± 28.5	119.4 ± 18.4
OCDD	788.6 ± 82.3	758.7 ± 92.8
Dibenzofurans		
2,3,7,8-TCDF	1.6 ± 0.3	1.7 ± 0.3
1,2,3,7,8-PnCDF	<2.1§ ± 0.2	<2.0§ ± 0.2
2,3,4,7,8-PnCDF	8.0 ± 0.9	7.4 ± 0.8
1,2,3,4,7,8-HxCDF	5.4 ± 0.3	5.1 ± 0.5
1,2,3,6,7,8-HxCDF	5.5 ± 0.4	5.6 ± 0.6
1,2,3,7,8,9-HxCDF	<0.8§ ± 0.1	<0.8§ ± 0.1
2,3,4,6,7,8-HxCDF	<1.1§ ± 0.4	<1.7§ ± 0.2
1,2,3,4,6,7,8-HpCDF	14.2 ± 0.7	16.0 ± 2.3
1,2,3,4,7,8,9-HpCDF	<1.6§ ± 0.1	<1.9§ ± 0.3

5.5 Estimates of Quantities of Tactical Herbicides Procured by the Defense Supply Agency

For years there have been many estimates published on the quantities of tactical herbicides purchased by the Defense Supply Agency from the various chemical companies for use in South Vietnam from January 1962 through October 1971. Differences in quantities of tactical herbicides disseminated and areas treated in South Vietnam varied among individual sources (Collins 1967; Irish et al. 1969; NRC 1974; Westing 1976; Young et al. 1978; Stellman et al. 2003). The differences were attributable to varying assumptions about the quantity expended on each mission, the number of missions, the loss of herbicide during the de-drumming and re-drumming of the residues, and the amount of herbicide spilled on the tarmac and in storage sites in Vietnam. In addition, the estimates varied because of reliance upon data that may have been uncertain, incomplete, or based on differing underlying assumptions, e.g., various revised HERBS Tapes. Only recently has it become possible to search and obtain actual procurement data from various record repositories (National Archives, Washington DC; Air Force Logistic Command at Kelly AFB, Texas and Wright-Patterson AFB, Ohio; Air Force Historical Research Center, Montgomery, Alabama;

and from the 1982 Pre-Trial Statements in Re: "Agent Orange" Product Liability Litigation). The best estimates of procurement data for Agent Orange taken from the above sources and for the nine chemical companies contracted with the Defense Supply Agency to manufacture the tactical herbicide were assembled in Table 5.6.

As noted in Table 5.6, the first production of Agent Orange was in Fiscal Years (FY) 1963. Fiscal Year 1963 was from 1 October 1962 through 31 September 1963. The Army Chemical Corps first used Orange in the tests and evaluations conducted in Texas and Puerto Rico beginning in March 1963 (Young 2006). The Air Force first used Orange in the tests and evaluation of the MC-1 and A/A 45Y-1 Spray Systems at Eglin AFB, Florida in Fiscal Year 1964 (1 October 1963–31 September 1964) (Young 2006). The first use of Herbicide Orange in South Vietnam was in March 1965 (Cecil 1986). Monsanto Company provided the majority of Agent Orange for use in South Vietnam in FY 1965 (1 October 1964–31 September 1965), but after 1965 five companies provided Orange to the Air Force Logistics Command (AFLC) for shipment and use in South Vietnam. The "history" of use of the tactical herbicides was provided in Table 5.7. Certainly not all of the tactical herbicide produced by the various manufacturers went to Vietnam.

Table 5.6 Orange productions and shipment of estimated number of drums from the nine chemical companies with contracts to the Defense Supply Agency, Fiscal Years 1963–1969

Company	1963	1964	1965	1966	1967	1968	1969	Number Drums
Dow			5,465	3,720	32,115	36,935		78,235
Monsanto	15	1,085	15,490	9,960	18,520	20,875	1,120	67,065
Hercules			6,005	12,885	14,505	16,550		49,945
Thompson-Hayward					5,875	15,180		21,055
Diamond Alkali				1,000	4,920	6,595	40	12,555
UniRoyal				1,635	8,180	1,820		11,635
Thompson					2,985	3,365	835	7,185
Aggrasit							1,875	1,875
Hoffman-Taff							410	410
Gallons	825	59,675	1,482,800	1,606,000	4,790,500	5,572,600	235,400	
Drums	15	1,085	26,960	29,200	87,100	101,320	4,280	249,960[1]
Liters	3,120	225,680	5,607,680	6,073,600	18,116,800	21,074,560	890,240	

[1]To obtain the estimated number of gallons, multiply the number of drums times 55; to obtain the estimated number of liters, multiply the number of drums time 208.

Table 5.7 History of the use and disposition of the tactical herbicides procured by the Defense Supply Agency for the US Army Chemical Corps and the US Air Force Logistics Command

Estimated number of drums of tactical herbicides							
	Orange	White	Blue	Purple	Pink	Green	Blue[1]
Total procured	249,960	105,700	30,130	12,780[2]	2,025[3]	365	95
Test programs							
Eglin	345	75	80	285			
Others[4]	60	15	20	15	2		
Thailand				5	3		
Korea, 1968[5]	380		625				
Hurricane[6] Camille, 1968	75		170				
Disposal options	180	810[7]					
NCBC	15,370				705[3]		
Johnston Island	25,220						
Vietnam	208,330	104,800	29,235	12,475	1,315	365	95

[1] The first "Blue" produced in 1961 and shipped to Vietnam was a powdered formulation. In subsequent tables, the 95 drums of Ansul 138® were added to the total of liquid Blue, Phytar 560G, to bring the total of Blue used in Vietnam to 29,330 drums.
[2]Questions remain as to the total production of Purple, especially as to the source of Purple used at Eglin AFB, Florida. One source indicated that the Purple used at Eglin was manufactured in 1953–1954 (Young and Newton 2004).
[3] The tactical herbicide that was identified as "Pink" by AFLC (Craig 1975), was actually 2,4,5-T formulations remaining after AFLC terminated contracts in FY 1969 for the procurement of Orange II. The 705 drums were shipped to Kelly AFB, Texas awaiting final disposition.
[4] "Others" refer to the various test and evaluation programs conducted by the Army Chemical Corps throughout the United States, Puerto Rico and Canada (Young 2006).
[5] In 1968, the Department of State requested that AFLC provide tactical herbicides for the control of vegetation adjacent to the Demilitarized Zone in Korea (Young 2006).
[6] In 1968, Hurricane Camille destroyed 75 drums of Orange and 170 drums of Blue (Young 2006).
[7] Approximately 810 drums from the final procurement of White Herbicide from Dow Chemical Company in 1971 were not shipped to South Vietnam, but directed by the Armed Forces Pest Management Board to be sold as "Tordon 101" for use by Base Civil Engineers (Craig 1975; Young 2006).

5.6 The Initial Analysis of Dioxin Contamination in the Agent Orange Inventory

5.6.1 Sampling the NCBC and Johnston Island Inventories of Agent Orange

The most controversial issue associated with Agent Orange has been the concentration of the "unacceptable levels of impurities." The procurement specifications provided no information on potential impurities, including 2,3,7,8-TCDD. The Herbicide Orange returned from South Vietnam to Johnston Island in 1972 (Operation PACER IVY) was stored until a decision was made by

AFLC for its final disposition. However, before a decision could be made about the method of disposing of the Agent Orange, data on the level of the dioxin contamination was required. Because of the extraordinary toxicity of 2,3,7,8-TCDD and its association with 2,4,5-T herbicide, it was one of the earliest dioxin isomers available in sufficient quantity to be used as an analytical standard (Tiernan 1983). Mass spectrometry was selected as the method for the detection and quantification of TCDD in Agent Orange (Hughes et al. 1975).

In 1973, the USAF assigned responsibility for characterizing the dioxin concentrations in the Agent Orange Inventories to the Environmental Health Laboratory at Kelly AFB, Texas, and the Aerospace Research Laboratory at Wright-Patterson AFB, Ohio (Fee et al. 1975; Department of Air Force 1974). The Environmental Health Laboratory at Kelly AFB later became the Air Force Occupational and Environmental Health Laboratory (OEHL) and was located at Brooks AFB, Texas. OEHL was subsequently given the responsibility for conducting Operation PACER HO (Thomas et al. 1978). The analytical team at the Aerospace Research Laboratory that characterized Agent Orange and its associated dioxin subsequently became the Brehm Laboratory, part of the Department of Chemistry at Wright State University in Dayton, Ohio (OEHL 1977). As an academic institution, it supported many of the analytical requirements for Operation PACER HO (Tiernan 1983).

Two different types of sampling procedures were used to obtain Agent Orange samples for characterization and analyses. Because of re-drumming operations in Operation PACER IVY, and the continual maintenance requirements, the Agent Orange Inventory at Johnston Island could not be separated into identifiable processing lots. Therefore, two hundred separate samples were collected to represent the entire population (of drums). It was assumed that these 200 samples were a random representative sample of the Johnston Island Agent Orange inventory (Department of Air Force 1974).

Figure 5.3 is a photograph of a Bioenvironmental Engineer from the Environmental Heath Laboratory sampling an Agent Orange drum at Johnston Island in October 1973. The samples at Johnston Island were sent to the Analytical Services Laboratory of Dow Chemical Company in Midland, Michigan, for analyses of 2,3,7,8-TCDD (Department of Air Force 1974). Dow Analytical Services was used because only a few analytical laboratories were capable of handling large numbers of samples of liquid herbicide for TCDD analyses in 1973 (Young 1980).

Unlike Johnston Island, the samples of Agent Orange taken at the Naval Construction Battalion Center could be grouped to represent concentrations of TCDD in stocks supplied by certain manufacturers (Department of the Air Force 1974). Initially, 6–12 samples were taken to represent each manufacturer's stocks (later more than 80 samples were taken to characterize the stocks).

Figure 5.4 is a photograph of a team of Bioenvironmental Engineers from the Environmental Health Laboratory inspecting the NCBC inventory. Note

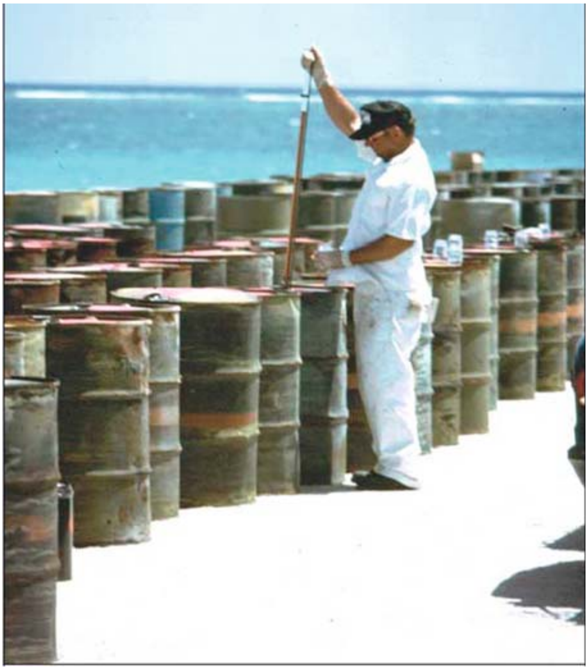

Fig. 5.3 Sampling drums of Agent Orange for dioxin content, 1973, Johnston Island. A random sample of 200 drums was assumed to represent a population of 25,220 drums (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

Fig. 5.4 Inspection of the Agent Orange Inventory at NCBC in 1975 (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

Table 5.8 Manufacturers of Agent Orange Identified by TCN and DSA Numbers, and the Number of 208-liter Drums for each Stock or Lot at the Naval Construction Battalion Center, 1973 (Department of the Air Force 1974; OEHL 1977)

Manufacturer	TCN[1]	DSA Contract No.	Number of Drums
Dow	8155-X052CXX	400-68-C-6163	6,949
Diamond Shamrock	8156-0001AA	400-68-C-5898	507
Hercules	8192-0001	400-68-C-6093	2,734
Monsanto	8183-X002	400-68-C-6607	2,138
Thompson Chemical	8155-X012	400-68-C-6250	468
Thompson-Hayward	8155-X032XX	400-68-C-6166	1,560
Monsanto	7163-X001XX	400-67-C-9087	724
Unknown	718-X011XX	Unknown	138
Unknown	8066-X031XX	Unknown	69
Total			*15,287*[2]

[1]Each of the TCN had prefix FY-9463, except Diamond Shamrock Co. (FY-9461), and Hercules, Inc (FY-9464).
[2]The total number of drums at NCBC fluctuated over time due to drums being received from Eglin AFB, Florida and Kelly AFB, Texas, and drums removed for disposal option studies.

that the drums on the left have a number painted in white on the lids (in this case number 10, representing the stock manufactured by Dow Chemical Company). There were seven major stocks identified by both their TCN (Transportation Control Number) and the DSA (Defense Supply Agency) Contract Number at NCBC when the samples were collected in June 1973. The Air Force Aerospace Research Laboratory, Wright-Patterson AFB, and Wright State University's Department of Chemistry performed the analysis for dioxin (2,3,7,8-TCDD), and for characterizing the herbicide at NCBC (Fee et al. 1975; Hughes et al. 1975; OEHL 1977). Table 5.8 provided a list of the manufacturers, the TCN Number, the DSA Contract Number, and the approximate quantities of 208-l drums in the Agent Orange Inventory at the Naval Construction Battalion Center in 1973.

5.6.2 Air Force Results of Johnston Island Analyses for Dioxin

When the 200 samples were collected in 1973, the Agent Orange Inventory on Johnston Island was estimated to be 26,689 208-l drums. This number was incorrect because in Project PACER IVY the actual number of drums was determined to be 25,220; in PACER HO 24,795 drums were emptied, and it was estimated that the remaining 425 drums had leaked or were spilled in the coral of the storage area. The arithmetic mean value for TCDD concentration was 1.909 mg/kg (ppm). Based on the estimated inventory of 26,689 drums, the total TCDD in the Orange stocks at Johnston Island was estimated to be 13.63 kg (Department of Air Force 1974).

The TCDD concentrations in the 200 samples were not normally distributed. Of the 200 samples, 153 or 76.5% contained TCDD concentrations of 1.0 mg/kg (1.0 ppm) or less. Of the 200 samples, 195 or 97.5% had TCDD concentrations of 10.0 mg/kg (10.0 ppm) or less. Five samples (2.5%) had TCDD concentrations larger than 10.0 mg/kg (10.0 ppm). Those five samples had values of 13, 17, 22, 33, and 47 mg/kg. The "outliers" were included in computing the arithmetic mean of 1.909 mg/kg (1.91 ppm) (Department of the Air Force 1974).

5.6.3 Results of the Naval Construction Battalion Center Analyses

Table 5.9 was a compilation of the results of the TCDD analyses of the seven major manufacturer's Herbicide Orange stock at the NCBC Gulfport. The number of drums (15,326) was obtained from the inventory at the time of the sampling in 1973.

The arithmetic mean concentration of TCDD in the NCBC inventory was calculated by summing the cumulative concentration of TCDD, and dividing by the sum of the number of kg of Agent Orange (7,265,980 mg divided by 4,100,226 Kg). By this method, the average concentration of TCDD in the Agent Orange Inventory at NCBC was 1.772 mg/kg or 1.77 ppm (Department of Air Force 1974). When the samples were collected in 1973, the total Air Force inventory of Agent Orange at NCBC and Johnston Island was estimated at 42,015 208-l drums or approximately 8.5 million liters. The weighted average concentration was 1.859 mg/kg or 1.86 ppm. The total amount of TCDD in the entire USAF inventory at NCBC and Johnston Island was estimated to be 20.1 kg (Department of Air Force 1974).

Based upon the above data, the Occupational and Environmental Health Laboratory (OEHL) estimated that 167 kg of TCDD may have been in the

Table 5.9 TCDD analyses of stock at the Naval Construction Battalion Center (Fee et al. 1975)

Number of drums	Kg Agent Orange	PPM TCDD	Mg of TCDD	Cumulative Mg TCDD
2,652	709,500	0.05	35,475	35,475
6,981	1,867,655	0.12	224,119	259,594
934	249,877	0.17	42,479	302,073
1,560	417,353	0.32	133,557	435,630
2,185	584,562	7.62	4,454,360	4,889,990
984	263,253	8.62	2,269,244	7,159,234
30	8,026	13.30	106,746	7,265,980
Total 15,326[1]	*4,100,226*		*7,265,980*	*7,265,980*

[1] Represented 98% of the total NCBC stock in 1973 at time of sampling.

2,4,5-T-containing tactical herbicides used in South Vietnam (Young et al. 1978). In 1974, the National Research Council had estimated the total amount of TCDD disseminated in Vietnam to be between 106 and 163 kg (NRC, 1974). The Columbia University group estimated 366 kg (Stellman et al. 2003). In July 2003, Dwernychuk of Hatfield Consultants, Ltd., stated: "The equivalent of about 600 kg of pure TCDD was sprayed and spilled in Vietnam during the war" (Hileman 2003).

5.7 A Re-analysis of TCDD in Agent Orange Stocks

5.7.1 A Re-evaluation of the NCBC and Johnston Island Agent Orange Inventories

In 1977, in preparation for Operation PACER HO, there were questions raised on the analyses of some of the stocks in the NCBC Inventory. The Project Director for Monitoring Programs, Major James Tremblay of the USAF Environmental Health Laboratory, requested clarification of data in Volume II of Technical Report ARL TR-75-0110 (Hughes et al. 1975). Dr. Michael Taylor, Research Associate Professor at Wright State University, wrote the following response in a 9 March 1977 letter:

> Dear Maj. Tremblay:
>
> In response to your inquiries made by telephone concerning the concentrations of TCDD in samples of Herbicide Orange reported in ARL-75-0110, we offer the following information in order to confirm and to supplement our telephone conversations of 8 March 1977.
>
> Regarding the raw data included in the technical report as Appendix F, we must underscore the fact that this was raw data and therefore was interpreted by the analyst before a final value for each determination was reported. As we discussed in our telephone conversation, the raw data in Appendix F had not been corrected for such factors as carry-over from the analysis of a sample or standard to the analysis of the succeeding sample. In addition, variations in various operating parameters bring about shifts in retention time of the TCDD peak and changes instrument response and other subtleties in the raw data, all of which must be taken into consideration by the analyst at the time of data reduction. These considerations make interpretation of the raw data a task that can be properly addressed only by analysts with first-hand knowledge of the analytical instrumentation and circumstances prevailing during the actual analysis.
>
> Concerning the TCDD concentration in the samples from ASN #s 5, 8, 10, and 14, we have tabulated the data on a barrel-by-barrel basis and the tabulated data are enclosed. It must be noted that the TCDD included in Volume II of ARL TR-75-0110 (page 5) are as is stated on Page 4 of the report "TCDD levels reported earlier by Dow Chemical"(Analytical Services Laboratory). Based on the eighty analyses that we have performed, we have determined the average concentration of TCDD in the Dow ASN 10 Herbicide Orange is 0.25 μg TCDD/g Herbicide Orange or 0.25 ppm. The average TCDD concentration in the Thompson ASN 5 Herbicide Orange, based on our analyses, is 0.13 μg/g or 0.13 ppm (Hughes et al. 1975).

Table 5.10 Revised estimates of TCDD concentration by manufacturer

ANS number	Manufacturer	TCN number	Number of samples analyzed	Estimated TCDD concentration (ppm)
5	Thompson	FY-9463-8155-X012	60	0.13 ppm
8	Hercules	FY-9464-8156-0001	57	≤0.02 ppm
10	Dow	FY-9463-8155-X052	80	0.25 ppm
14	Hercules	FY-9464-8192-001	52	≤0.02 ppm

Source: Information provided to Major James Tremblay in a 9 March 1977 letter from Dr. Michael Taylor clarifying data in Volume II of Technical Report ARL TR-75-0110

The attachment provided new data on the analyses of manufacturers of Agent Orange that differed from those in Table 5.9. The new data are presented in Table 5.10.

5.7.2 Statistical Methodology for Air Force Data

Historical records indicated that the Air Force had collected 525 samples from the Agent Orange inventories stored on Johnston Island in the Central Pacific Ocean and the Naval Construction Battalion Center (NCBC) in Gulfport, Mississippi, prior to incineration at sea. TCDD concentrations were determined for each sample. It was recognized that the samples were likely to have been most representative of the herbicide in use after 1967 because stocks shipped to Vietnam earlier were probably disseminated to support military operations.

Because the distributions were positively skewed (see Fig. 5.5), bootstrapping techniques were used to obtain a reliable estimate of the upper 95th percentile mean value of TCDD in the stockpiles, corresponding to an estimate of the upper 95% confidence interval of the mean concentration of TCDD in the stockpiles. Bootstrapping was a way of creating pseudo-replicate datasets by randomly re-sampling the original data for statistical analysis. A total of 5,000 pseudo-replicate datasets with 525 observations each were randomly generated from the 525 observations of the Johnson Island and NCBC combined dataset by re-sampling these data with replacement. Sample concentration values that were below the detection limit of the quantification technology were replaced with a value equal to ½ of the detection limit. This resulted in a total of 2,625,000 randomly selected total observations for the 5,000 pseudo-replicate datasets. The mean TCDD concentration for each of the 5,000, 525 observation datasets was determined. The 95th percentile mean TCDD concentration of the 5,000 datasets was calculated and used to estimate the quantity of TCDD dispensed in Vietnam.

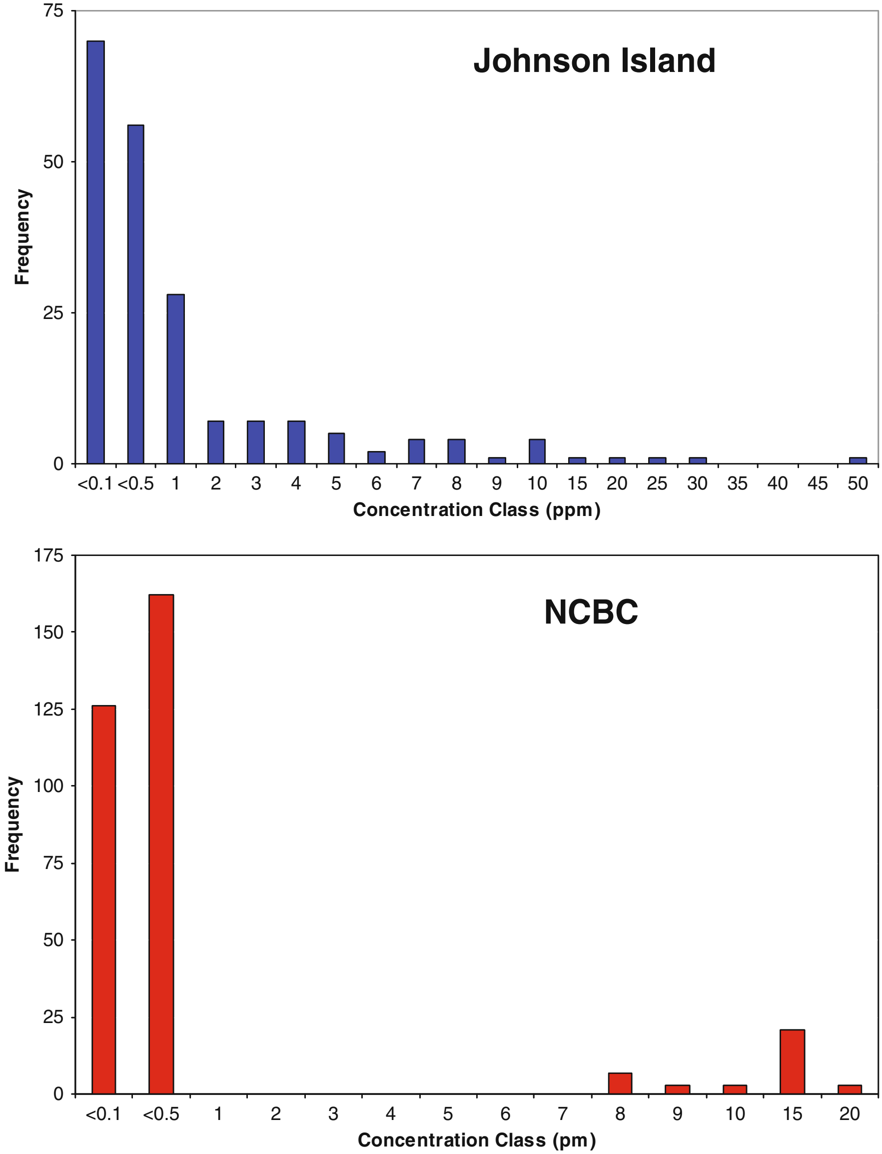

Fig. 5.5 Frequency distribution of observed TCDD concentrations in the Agent Orange inventory at Johnson Island and NCBC, Gulfport, Mississippi (OEHL 1977)

5.7.3 Results for NCBC and Johnston Island Agent Orange Inventories

The 95th percentile value for the arithmetic means of the Johnston Island inventory was 2.46 ppm TCDD, while the 95th percentile of the arithmetic means of the NCBC inventory was 1.75 ppm TCDD. The 95th percentile of the mean concentrations of the TCDD in the pooled datasets was calculated to be 1.88 ppm. This value can be used to infer the mean concentration of TCDD in the approximately 40,665 drums (8.48 million liters) of Agent Orange returned or not sent to Vietnam. The question remained, would the Agent Orange stocks purchased before FY 1967 have a similar mean level of TCDD? One solution to the question was to look at the data collected by the National Institute for Occupational Safety and Health (NIOSH) for their Dioxin Registry Study (Piacitelli et al. 2000).

5.8 TCDD Data from the NIOSH Studies of 2,4,5-T Production

In 1984, the Industrywide Study Branch of the National Institute for Occupational Safety and Health (NIOSH) in Cincinnati, Ohio began construction of a "Dioxin Registry", a compilation of demographic and work histories information of all US production workers who have synthesized products known to be contaminated with 2,3,7,8-TCDD and/or hexachlorodibenzo-*p*-dioxins (HxCDD). Fourteen production sites and approximately 7,000 workers were included in the Registry (Piacitelli et al. 2000). Six of these production sites produced Agent Orange including: Diamond Alkali Company/Diamond Shamrock Corporation, Newark, New Jersey (Marlow and Fingerhut 1986); Thompson-Hayward Company, Kansas City, Kansas (Marlow et al. 1990); Thompson Chemical Company, Saint Louis, Missouri (Marlow and Fingerhut 1991); Hercules Incorporated, Jacksonville, Arkansas (Marlow et al. 1991a); Dow Chemical Company, Midland, Michigan (Marlow et al. 1991b); and, Monsanto Chemical Company, Sauget, Illinois (Marlow et al. 1997). These six companies produced 236,040 drums of Agent Orange out of a total of 249,960, or 94% of all Orange produced.

5.8.1 Statistical Analysis of Dioxin Levels in Production Samples of 2,4,5-T Formulations

The data considered from the NIOSH documents in this analysis consisted of dioxin (2,3,7,8-TCDD) values determined for 2,4,5-T acid, 2,4,5-T butyl ester, 2,4,5-T isooctyl ester, and in a few cases the sodium salt of 2,4,5-trichlorophenol, a precursor compound. When considering dioxin concentrations it was assumed that 2,4,5-T acid, esters and precursor were equivalent in the sense that the dioxin measurement in these would be the same as the dioxin concentration in the final 2,4,5-T used in the production of Agent Orange (or Orange II). Since Agent Orange was one-half 2,4,5-T by weight, and there was no dioxin in the other component of Agent Orange, 2,4-D, it was assumed that dioxin concentrations in Agent Orange were ½ the concentration measured in 2,4,5-T or its precursors.

Finally for samples with dioxin levels less than the limit of detection (LOD) it was assumed that the dioxin concentration was ½ the LOD. This approach provided 557 dioxin values for the statistical analysis, Table 5.11.

For purposes of analysis each manufacturer/year combination was considered as a separate data set. There were several reasons for this. First, dioxin levels changed from both manufacturer-to-manufacturer, and year-to-year. Also, dioxin detection limits changed over time. Most importantly the object of this analysis was to get a good estimate of the total amount of dioxin present in the 2,4,5-T procured for use in Agent Orange in Vietnam, and manufacturers production volumes changed dramatically over time (Table 5.11). Thus the arithmetic mean level was taken for a given manufacturer/year combination which was the best estimate of dioxin level for those data and weight it by the total production for that year. If the average dioxin level was defined for a given manufacturer (i) and year (j) combination as $M_{i,j}$, a weighted arithmetic mean, W, level can be obtained as:

$$W = \left(\sum_i \sum_j P_{ij}\ M_{i,j}\right) / \left(\sum_i \sum_j P_{ij}\right) \tag{5.1}$$

Table 5.11 NIOSH data sets for TCDD from the Production of 2,4,5-T by five manufacturers

Company/year	Sample size	TCDD detects	Mean TCDD (ppm)	Liters produced
Diamond Alkali/Diamond Shamrock				
1966	11	11	8.27	208,198
1967	28	28	0.53	1,024,332
1968	11	11	2.03	1,373,272
1969	2	2	1.50	8,536
DOW Chemical Company				
1965	150	27	0.64	1,137,876
1966	4	0	0.18	774,628
1967	3	0	0.01	6,685,037
1968	14	0	0.20	7,688,171
Hercules Incorporated				
1965	12	0	0.25	1,249,716
1966	12	1	0.03	2,682,437
1967	12	0	0.03	3,020,531
1968	12	0	0.03	3,445,766
Monsanto Chemical Company				
1963	1	1	5.50	3,199
1964	1	1	6.00	225,629
1965	18	18	11.53	3,224,981
1966	27	27	5.27	2,073,175
1967	120	120	4.73	3,853,549
1968	32	32	2.61	7,688,171
1969	83	83	1.04	4,345,652
Thompson – Hayward				
1968	4	4	0.32	5,980,950
Total	557	366		56,693,806

Where Pij is the production for manufaturer i in year j. If one additional assumption was made, namely, that the probability of a given production unit of Agent Orange being actually used in Vietnam was the same for all production units, W would allow the estimate for the total dioxin (D) used in Vietnam as:

$$D = W\ U$$

Where U was the total amount of Agent Orange used in Vietnam, by weight.

The manufacturer/year combinations were quite variable in the amount of data available. Table 5.11 shows both total numbers of samples and total numbers of detected values for all manufacturer/year combinations. Total samples ranged from 1 to 150 and total detected values range from 0 to 120. A combined analysis for the overall mean could have been done by simply applying Eq. (1) to the data. However, a combined analysis of such diverse data to get an upper bound on the mean required a hybrid approach. The following conventions were adopted:

- For complete year/company samples (all detects) with 10 or more observations 5,000 bootstrap means were generated for each sample.
- For the Dow 1965 data where there were a total of 27 detects out of 150 samples, a tail-augmented bootstrap was used to generate 5,000 random means (Ginevan 2003). Here, for each mean, with replacement, 150 random numbers between 1 and 150 were generated. If the number was 124 or greater, the data value associated with that rank was selected; if it was less than 124 a random number was assigned from a uniform zero-one distribution. Note that this assumed that concentrations were uniformly distributed between the detection limit, which was 1, and zero, which was the same assumption inherent in assigning non-detects the value of ½ LOD.
- For all other samples, 5,000 random means were generated per sample assuming that the distribution was log-normal truncated at the 99th percentile (e.g. no random variables could be greater than about 2.33 standard deviations above the mean) with mean equal to the natural log of the mean estimator (LM; if all values were ND, this was ½ LOD) and logarithmic standard deviation equaled to 1. The later assumption was based on the large samples from Monsanto that suggested that logarithmic standard deviations were generally less than 1 for these sorts of data. To calculate a mean, N observations were generated, where N was the sample size for the company/year combination being considered, from a truncated log-normal distribution with mean LM and standard deviation 1. These logarithmic values (L) were then transformed to the original scale X, using the formula:

$$X = \exp(L)$$

A random mean was then generated as the mean of the N randomly generated X's.

At this point there were 5,000 randomly generated mean values for each company year combination. Each set of the resulting manufacturer-year means together with manufacturer-year production values were then used to calculate a random production weighted mean. The random production weighted means were sorted and the 95% upper bound was the 4750th largest value. The result was a 95% upper bound on the overall mean that reflected the uncertainties in the data.

The conventions adopted here reflected the fact that applying methods based on purely log-normal assumptions when estimating upper bounds on the arithmetic mean may result in substantial positive bias in the upper bound. That is, the upper bound is often much larger than any credible value (Ginevan and Splitstone 2002). Thus either a bootstrap procedure was employed or a log-normal distribution truncated at the 99th percentile (the logarithmic mean, which was taken here as ln(1/2 LOD), plus about 2.33. because it was assumed a logarithmic standard deviation of 1). Truncated distributions were produced by generating standard normal variates (mean = 0; standard deviation = 1), and randomly replacing all values greater than 2.33 with another standard normal variate until all values were less than 2.33 (Gentle 2003).

5.8.2 Results and Discussion of NIOSH Data Sets

The best estimate for the average dioxin concentration produced using Eq. (1) was 1.88 ppm, while the upper bound on this mean, produced using the procedures described above, was 2.14 ppm. That is, the 95% upper bound was only about 14% higher than the central estimate.

Note that the bootstrap analysis of the combined Johnson Island/NCBC data gave a best estimate of 1.58 ppm and a 95% upper bound of 1.88 ppm. It has been suggested that dioxin levels in the samples from Johnson Island/NCBC were biased low because they represented dioxin levels in late production runs that were lower than dioxin levels in early runs. While it was true that the Johnson Island/NCBC data did show slightly lower dioxin levels, the difference was not large. Thus, it can be said that these two large data sets give quite comparable answers in terms of both average levels and 95% upper bounds on average levels, which in turn suggests that estimates of average dioxin levels in Agent Orange of much greater than 2.2 ppm would not be very credible.

5.9 Conclusions as to the Amount of TCDD Disseminated in South Vietnam

The frequency distribution of the TCDD data for the Agent Orange samples from Johnston Island and NCBC was skewed toward the high concentrations of dioxin, and thus the statistical method employed was a tail-augmented bootstrap method to estimate the mean. This approach resulted in a mean of 1.58 ppm and a 95% upper bound of 1.88 ppm for the combined inventory of 40,665 drums of Orange. As noted, the 557 individual samples of 2,4,5-T from the NIOSH reports spanned the years 1963 through 1969. The mean TCDD concentration was 1.88 ppm, with an 95% upper bound of 2.14 ppm **IF** these samples of 2,4,5-T had been used in the production of Agent Orange. Thus, these two large data sets gave comparable estimates, suggesting that an estimate of the total amount of the contaminant TCDD in Agent Orange used in South Vietnam would be between 105 and 119 kg.

As noted previously, in addition to Agent Orange, other herbicides were used on a limited basis that also contained the herbicide 2,4,5-T and the contaminant TCDD. Reliable historical sampling data quantifying the TCDD concentrations in Agents Purple, Pink, and Green were unavailable. Agents Pink and Green contained 100% 2,4,5-T while Purple contained 50% 2,4,5-T making the concentration of TCDD in Pink and Green double the concentration in Agent Purple. Samples of 2,4,5-T from early production runs were also available from some of the chemical companies that produced Herbicides Green, Pink, and Purple. Statistical analyses of these samples resulted in an estimated (95% confidence level) mean concentration in Pink and Green of 12.2 mg/kg, and 6.1 mg/kg for Purple (Young et al. 2008). The total estimated contribution from these early tactical herbicides was 25 kg. "The total estimated amount of the contaminant 2,3,7,8-TCDD associated with the 2,4,5-T-containing tactical herbicides used in Vietnam therefore was between 130 kg and 144 kg".

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Chapter 6
The Testing of Aerial Spray Equipment, and Ecological Impacts of the Programs at Eglin Air Force Base, Florida

The training of the aircrews, the development of the interface between the aircraft and the spray equipment, and the test and evaluation of the entire aerial spray system was the responsibility of the Air Development Test Center (ADTC) at Eglin Air Force Base (AFB), Florida. For ten years (1961–1971), Eglin AFB provided the scientific and technical support for the RANCH HAND mission in Vietnam. It was of utmost importance in the development of the aerial spray systems that the equipment be tested under the most realistic conditions possible. An array of test grids (on Test Area C-52A) was developed where the aircraft and equipment could be monitored and evaluated in the field. Moreover, a decision was made that the equipment would be tested using the tactical herbicides that were deployed for use in Vietnam. The goal was not to test the effectiveness of the herbicides, but rather the effectiveness of the equipment in disseminating a concentration of a tactical herbicide determined to be at the "minimum biologically effective ground deposition level." This chapter is devoted to describing the test programs on Test Area C-52A, Eglin AFB, Florida, and the subsequent studies conducted on the soil persistence, environmental fate, and ecological impact of the tactical herbicides disseminated in the course of developing the aerial spray systems deployed in Vietnam. Very little information was known about the toxicity or environmental persistence of the dioxin contaminant, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD), in Agent Orange prior to the late 1969. Thus, the test programs at Eglin AFB involving 2,4,5-T herbicide were conducted in the belief that the herbicide was "essentially" non-toxic and of little ecological concern.

6.1 Introduction

From a technical perspective Operation RANCH HAND involved more than just the aerial spraying of herbicides in the Vietnam War. It involved the modification of aircraft that were not built for the mission of spraying tactical herbicides in a combat environment in Southeast Asia. It involved the

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development and testing of sophisticated aerial spray equipment, and most of all, it required a cadre of highly trained air and ground-support crews. A former Surgeon General of the United States Air Force stated:

> For nine years during the conflict in Vietnam, 1285 men served in an unusual unit performing an unusual task. "Combat Cropdusters" were employed to disrupt and burden the enemy. With no books to aid us, tactics and methods were well thought out, learned, and modified from day to day – year-to-year. Out of this experience grew a unit whose aviation skills, awards, comradery and esprit de corps were unequaled (Carlton, 2003).

Much has been written on the men who participated in Operation RANCH HAND (Buckingham 1982; Cecil 1986). As noted, these men participated in a unique aviation mission, i.e., dispensing tactical herbicides over Southeast Asian jungles while flying unarmed, obsolescent aircraft at tree-top level (Cecil 1986). The training for this mission began at Eglin AFB, Florida and specifically at Eglin's Auxiliary Field No. 9, Hurlburt Field (Cecil 1986). Frequently the training would involve actual spray missions at Eglin's Test Area C-52A, a fully instrumented test array for evaluation of spray equipment, to assist the Air Development Test Center (ADTC) and the Air Force Armament Laboratory (AFATL) in the evaluation of the aircraft and spray equipment that was subsequently used in Vietnam (Buckingham 1982). More than 300 h of flying time was accrued by RANCH HAND crews in conducting spray missions over the Eglin Test Range (Young 1974; Young et al. 1975). What was remarkable about this test program was that an active effort was underway throughout the Vietnam War to improve the aircraft and spray equipment used in Operation RANCH HAND, while the actual testing of the spray equipment involved the use of the same tactical herbicides used in Vietnam.

Thus, it was appropriate that in 1967 a contract was given to the University of Florida to construct "ecological records" for the Eglin AFB Reservation in the event that the aerial dissemination of herbicides might impact the ecology beyond the test grids on Test Area C-52A (Ward 1967, 1968, 1970). The studies by the University of Florida provided an excellent record of the soils and vegetation of the Eglin Reservation, and were instrumental in the subsequent studies of Test Area C-52A (Young 1974; Young et al. 1975, 1987; Bartleson et al. 1975; Thalken and Young 1983; Young 1983). Unfortunately much of this research was published as United States Air Force (USAF) technical reports, or in non-peer reviewed journals, and was not widely disseminated in the scientific community. In 2004, the major findings and conclusion from the 15-year study of Test Area C-52A were published in a peer reviewed article under the title "Long Overlooked Historical Information on Agent Orange and TCDD Following Massive Applications of 2,4,5-T –Containing Herbicides, Eglin Air Force Base, Florida" (Young and Newton 2004). This chapter will review much of the research conducted during the 1970s and early 1980s and published in military technical reports and other minor sources.

6.2 Background

The Eglin AFB Reservation in Northwest Florida served various military uses during the 1950s, 1960s and through 1970, including the development and testing of aerial spray equipment for disseminating the herbicides used before and during the Vietnam War (Acker et al. 1953; Ward et al. 1953; Department of Army 1970). It was necessary for this equipment to be tested under controlled conditions that were as near to those prevalent in South Vietnam as possible (Brown 1962). For this purpose, a testing installation was established in 1962 on the Eglin AFB Reservation. Direct aerial application was restricted to an area approximately 2.6 km^2 within Test Area C-52A (Brown and Whitman 1962; Young 1974). The Test Area covered an area of approximately 8 km^2 and was a grassy plain surrounded by a forest stand that was dominated by pine and oak species (Hunter and Agerton 1971; Bartleson et al. 1974). Figure 6.1 is a photograph of the Test Area C-52A, taken from an altitude of 3,200 m on 16 June 1972. Figure 6.2 is photograph of an UC-123B aircraft evaluating the M-1 Defoliant Spray System (Hourglass System) over Test Area C-52 in 1963.

The actual area for test operations was a cleared area occupied mainly by low growing grasses and herbs (Ward 1967). Much of the center of the range was established prior to 1960, but the first aerial sampling arrays (grids) were developed in late 1961 and early 1962. The first sampling grid was operational on 21 June 1962 (Brown and Whitman 1962). The test area was approximately

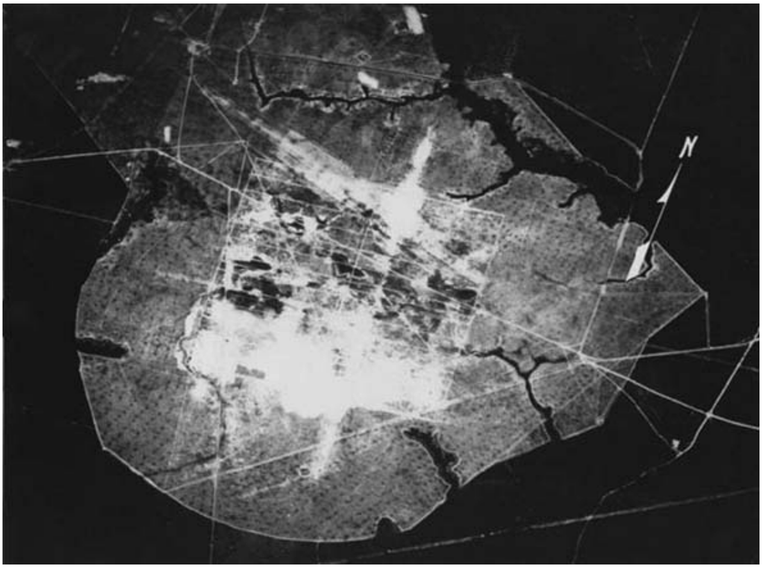

Fig. 6.1 Aerial view (from 3,200 m altitude) of the Spray Equipment Testing Grids on Test Area C-52A, Eglin AFB, Florida, 16 June 1972 (Photograph courtesy of the AFATL, Eglin AFB, Florida)

Fig. 6.2 C-123B RANCH HAND aircraft conducting a test and evaluation flight of the MC-1 Defoliant Spray System, Test Area C-52A, Eglin AFB, Florida, 1963 (Photograph courtesy of the AFATL, Eglin AFB, Florida)

28 m above sea level with a water table of 2–3 m below the surface of sampling arrays. Five small creeks whose flow rates were influenced by a 155-cm average rainfall drained the major portions of the test area. The soils of the test range were predominantly well drained acid sandy loam soils with less than 1% organic matter. The mean maximum annual temperature was 25°C, and the mean maximum relative humidity was 88%. Thus, the environmental parameters of the Eglin AFB Reservation, although not identical to those in Southeast Asia, were sufficiently similar so that the operational conditions of the aircraft, spray equipment, and behavior of the herbicides were as realistic as possible (Irish et al. 1969; Young 1974).

From March 1962 through January 1971, four test grids, each uniquely arrayed to match the needs of either fixed-wing, helicopter, or high performance jet aircraft, were established within the boundary of Test Area C-52A, encompassing the approximately 8-km^2 area (Young 1974). Test arrays were constructed and sampling systems developed to assess the dissemination and deposition characteristics of aerially delivered liquid and particulate materials from a variety of dissemination systems (Flynn 1964; Hazen and Maxwell 1967; Harrigan 1970a). As noted in Figs. 6.3 and 6.4, the original sampling grid (Grid 1) was located in the southern portion of Test Area C-52A and became operational in June 1962. It consisted of four intersecting straight lines in a circular pattern, each being at a 45-degree angle from those adjacent to it. This grid was discontinued in early 1964 after completion of the tests on the UC-123B/MC-1 Defoliant Spray System, the A-1H/FIDAL Defoliant Spray System, and the H-34 (helicopter)/HIDAL Defoliant Spray System (Lowry 1963; Boyer and Brown 1964). These spray systems were evaluated using Agent Purple (see Section 6.5). In 1964, it was recognized that more sophisticated test arrays were required to better evaluate the new spray systems being developed for use in Vietnam. To meet these requirements the Armament Development and Test Center constructed a "state-of-the-art" 2.6-km^2 fully instrumented test area immediately north of Grid 1 (Young 1974).

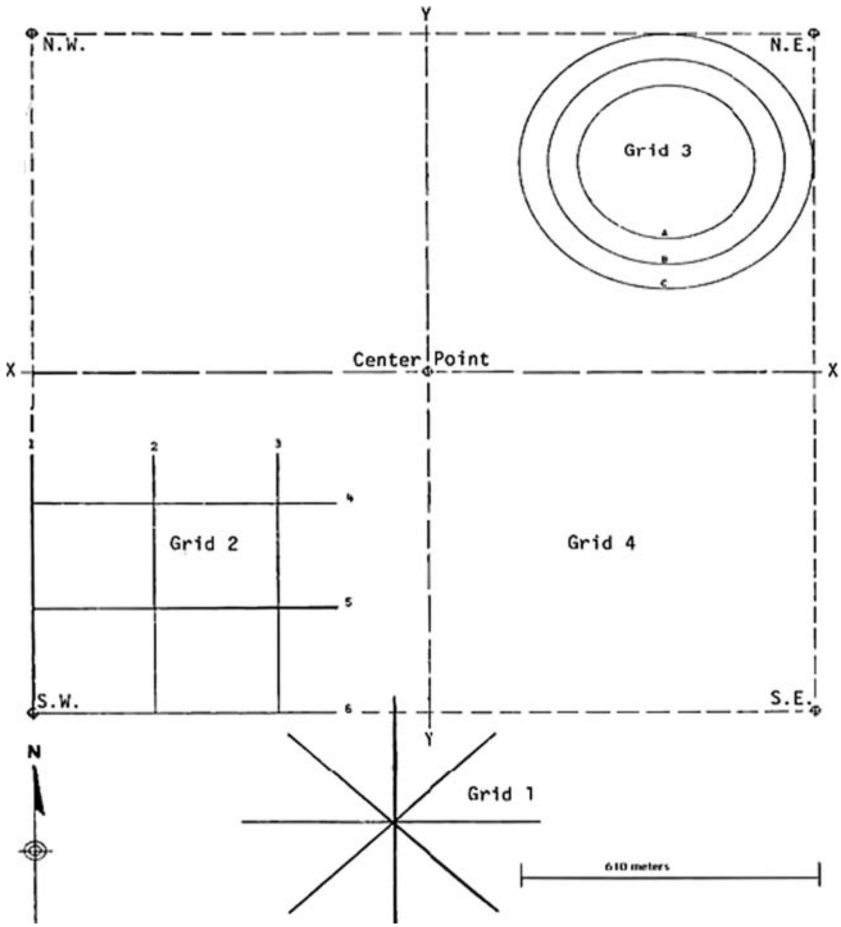

Fig. 6.3 Locations of test grids used during the development and testing of aerial spray equipment (1962-1971), Test Area C-52A, Eglin Air Force Base, Florida (Young 1974)

The construction of the fully instrumented test area included a 2.6-km^2 micrometeorological and aerosol/particulate sampling complex, and a control center for operation of the sampling instrumentation, grid support, and test data assessment. Micrometeorological conditions existing below 90 m over the test area were continuously described by an Automatic Meteorological Data Acquisition and Processing System (AMDAPS) which included wind, temperature, and dew point sensors on a 90-m tower at grid center (Figs. 6.5 and 6.6) and wind sensors on 3.7-m masts located at each of the four corners of the 2.6-km^2 grid and on the tower (Young 1974). A complex of defoliant grids, intersecting near the central AMDAPS tower and oriented to eight major compass headings, provided 16 discrete sampling grids, which could be selected for the most advantageous wind conditions prior to and during mission time.

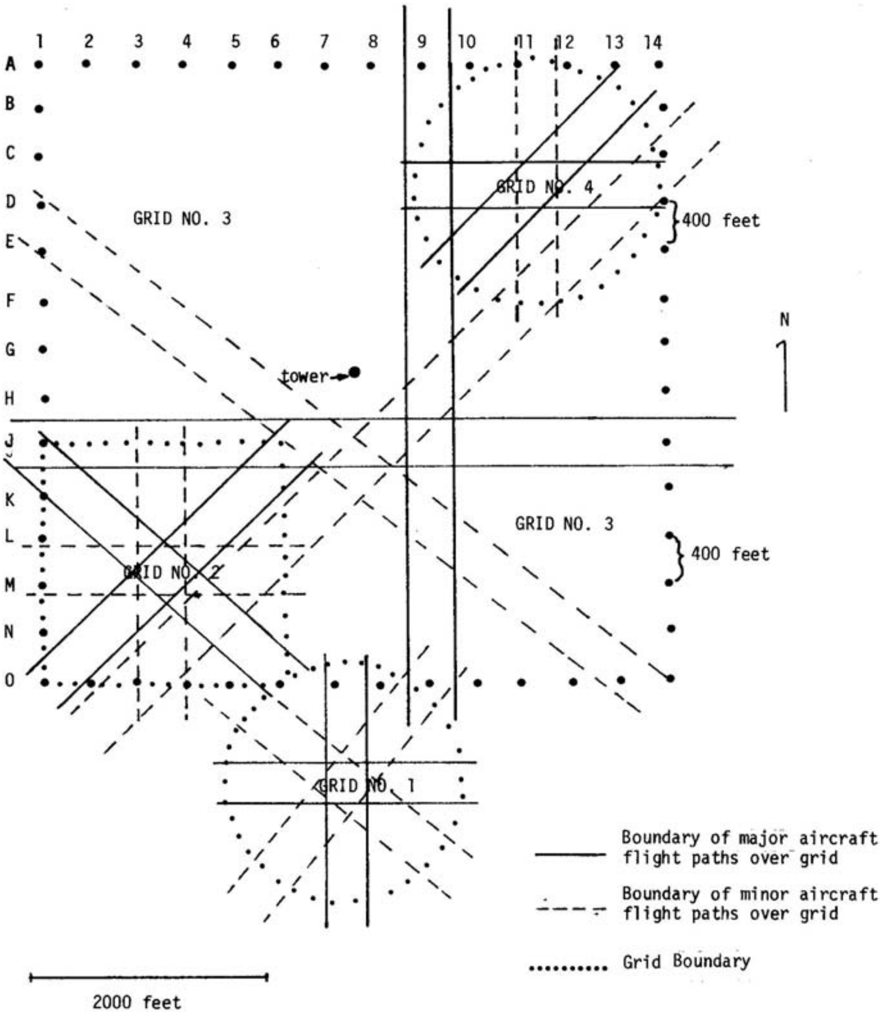

Fig. 6.4 Location of major flight paths over the test grids used for disseminating tactical herbicides over Test Area C-52 A, Eglin AFB, Florida (Young 1974)

Each of the 250 permanent sampling stations (Fig. 6.7), arranged on 122-m centers to form the 2.6-km^2 grid, employed glass plates and Kromekote cards for physical collection of test materials in droplet form (Fig. 6.8). Each permanent sampling station was also equipped with remotely operated automatic vacuum type samplers, which collected small particles and aerosols. Remotely controlled portable samplers were also available to gather data in specially designed grid configurations anywhere within the 8-km^{2}area. Fixed and portable illuminated flight line markers were available for missions during hours of darkness (Young 1974).

Fig. 6.5 The 90-m tower in the center of Test Area C-52A used for collecting dispersion and wind data in support of Spray Equipment Test and Evaluation Missions, Eglin AFB, Florida, 1969 (Photograph courtesy of A.L. Young)

Fig. 6.6 Sampling array for wind, temperature, and droplet dispersal data on the 90-m tower in the center of Test Area C-52, Eglin AFB, Florida, 1969 (Photograph courtesy of A.L. Young)

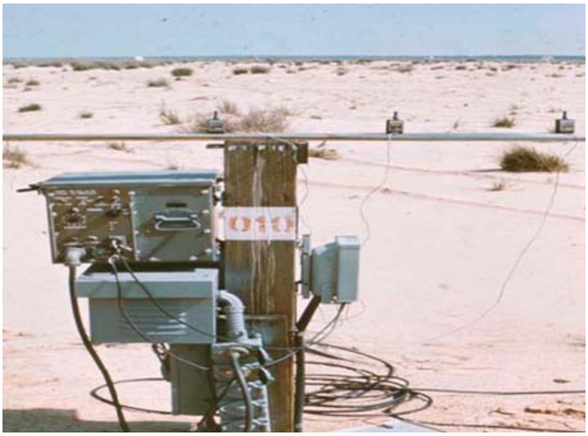

Fig. 6.7 The ground test arrays on Test Area C-52A, Eglin AFB, Florida, 1969. The array consisted of 250 battery-powered sampling units that were also configured to hold glass plates and Kromekote Cards (Photograph courtesy of A.L. Young)

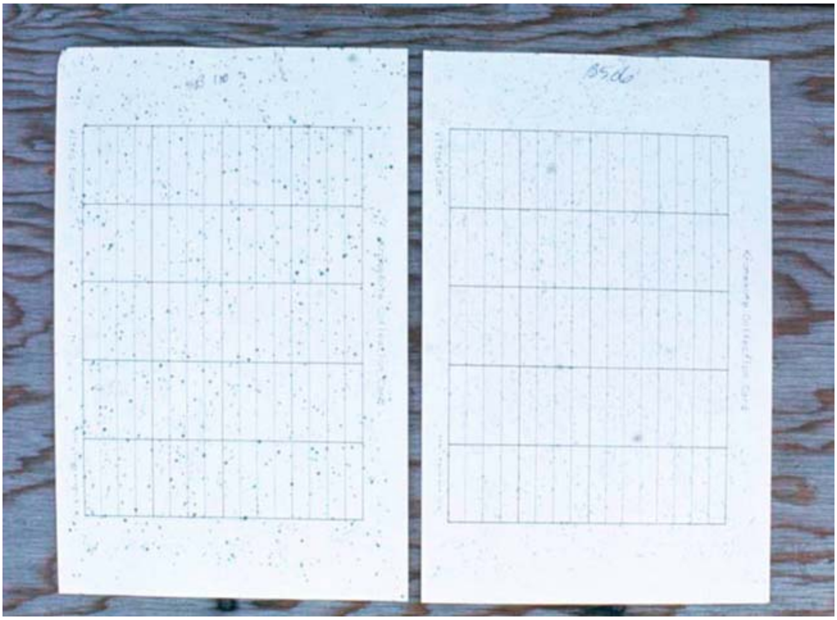

Fig. 6.8 Beginning in May 1968, 550 sampling arrays (two in-wind lines and four cross-wind lines) consisting of glass plates and Kromekote Cards (above) provided physical collection of test materials in droplet forms, Test Area C-52A, Eglin AFB, Florida (Photograph courtesy of A.L. Young)

As noted in Fig. 6.3, the second sampling grid (Grid 2) consisted of three parallel lines intersected at right angles by another set of three parallel lines. These lines were approximately 244 m apart, thus forming four equal quadrants. The southwest corner of the grid corresponded to the southwest corner of the 2.6 km^{2}grid. The parallel line grid was operational during the period May 1964–November 1965. The first evaluations of the A/A 45Y-1 Internal Defoliant Dispenser occurred on Grid 2 (Flynn 1964; Meyer 1966). The third sampling grid (Grid 3) consisted of three concentric circles, with respective diameters of 366, 488, and 610 m. This grid was located in the northeast quadrant of the 2.6-km^2 grid and was operational between October 1967 and April 1968. However, difficulty in interpreting data from this sampling array caused use of this grid to be discontinued (Hazen and Maxwell 1967).

The fourth sampling grid (Grid 4) consisted of the entire 2.6-km^2 grid, the center of which was marked by the 90-m tower. This was the last testing grid used on Test Area C-52A and its inward and crosswind sampling arrays extended into Grid 2 and Grid 3. The two inwind and four crosswind sampling arrays of Grid 4 became operational in May 1968 to support the development and testing of spray systems for the UC-123 K and high performance aircraft, i.e., sprays systems with the F-4 and F-105 jet aircraft (Harrigan 1970b, c). Each inwind array consisted of three parallel rows spaced 122 m apart, with 287 sampling stations per row. The aircraft flight path crossed the midpoints of the sampling lines. The crosswind sampling arrays consisted of three parallel rows 122 m apart, with 253 sampling stations per row.

6.3 Test and Evaluations Projects on Test Area C-52A

From 1962 through 1964, the USAF tested and modified the C-123B/MC-1 Hourglass Defoliant Dispenser (Brown and Whitman 1962; Lowry 1963; Boyer and Brown 1964). This system involved the dissemination of Agent Purple, and was the initial defoliation system deployed in the Republic of Vietnam (Brown 1962; Irish et al. 1969). Simultaneously beginning in late 1963 through 1964, a different test grid was used for the evaluation of both the HIDAL and AGRINAUTICS helicopter dissemination systems (Boyer and Brown 1964). From 1964 through 1966, modifications of the C-123/A/A45Y-1 Internal Defoliant Dispenser were evaluated for the dissemination of Agent Orange (Flynn 1964; Horan 1965; Meyer 1966). From late 1966 through 1968, testing and evaluation were conducted on the jet-modified aircraft (UC-123K) with the A/A45Y-1 Internal Defoliant Dispenser (Hazen 1967; Klein and Harrigan 1969). In 1969 through 1970, additional modifications were evaluated in the UC-123K system, and the first evaluation of both herbicide (Agent Blue) and insecticide (malathion) dissemination by high performance jet aircraft (F-105 and F-4) with the PAU spray system (Klein and Harrigan 1969; Harrigan 1970a, b, c Henricks 1971). Table 6.1 provided a comprehensive listing of the projects,

Table 6.1 Projects conducted on Test Area C-52-A, including type of aircraft and hours

Year	Project	Aircraft Project Title	Aircraft Type	Hours
1962	Agile	MC-1 Defoliant Spray System	C-123	25 (E)*
1963	Agile	MC-1 Defoliant Spray System	C-123	25 (E)
	Agile	FIDAL Defoliant Spray System	A-1H	15 (E)
	Agile	HIDAL Defoliant Spray System	H-34	20 (E)
	2525W3	Development Test of A/A45Y-1 Internal Defoliant System	C-123/C-130	50 (E)
1964	2525W3	Development Test of A/A45Y-1 Internal Defoliant System	C-123/C-130	25 (E)
	5957W1	Development Test of A/A45-Y2 Internal Defoliant System	C-123	25 (E)
1965	2525W5	Development Test of A/B23Y-1 Dispenser	A-1E	10 (E)
	2522W10	Development Test and Evaluation of A/B45Y-4 Dispenser	F-4	10 (E)
1966	2525W8	Feasibility Test of the Stull Defoliant	Civilian Aircraft	20 (E)
1967	5171W002	Calibration Test of A/A45Y-1 Spray System in UC-123B	UC-123	22

Table 6.1 (continued)

Year	Project	Aircraft Project Title	Aircraft Type	Hours
	5171W008	Engineering Evaluation of the TMU-28/B Liquid Agent Spray Tank	F-4/F-105	12
	3167W6	Support of the DTC Test 68-52 (Cliff Rose)	F-4	4
	0749 W	Support of TAC OT&E "Combat Lady"	F-4/F-105	12
1968	5172W003	Comparison Test for Defoliants	UC-123 K	56
	5186W001	Test of the TMU-66 Dispenser	F-4/F-105	6
1969	5171W004	Calibration Test of A/A45Y-1 Spray System in UC-123 K	UC-123 K	41
	5172W001	Test of the KMU-327 Wing Boom System with the A/A45Y-1 Spray System	UC-123 K	23
	1822W037	Engineering Evaluation of the PAU-7/A Spray Tank	F-4	6
1970	011KW01	Support of TAC Test 70A-016T, OT&E of PAU-7/A	F-4	12
	5186W004	Aerial Application of Insecticide with A/B45Y-1 Tank	F-4/F-105	15

equipment, and hours of flight time over the test grids in the course of evaluating the various aircraft-spray equipment systems.

6.4 Hardstand 7 Herbicide Loading and Storage Site

In support of the test and evaluation programs on Test Area C-52A, The Armament Development and Test Center established an herbicide storage and aircraft loading site at Hardstand 7, an asphalt and concrete aircraft parking area located west of the North-South Runway on the main Eglin Airdrome. Hardstand 7 was connected to the airdrome by an asphalt taxiway. This hardstand was the most extensively used loading site during the 1962 through 1970 test and evaluation programs (Harrison, Miller, and Crews 1979).

Hardstand 7 was approximately 20 m above sea level. The soil of the hardstand was sandy with good drainage properties. Directly behind the hardstand was a ravine that dropped off approximately 15 m to a small pond. Because of the packing caused by vehicular traffic and the water-repellent nature of the oil-based herbicide contamination, runoff of excess water caused erosion problems. Because of the concern for herbicide contamination in the runoff, a dike covered with asphalt was constructed on the rim of the ravine for soil stabilization. A storm drain was installed to control the accumulation of water from frequent rains. The pond behind Hardstand 7 drained into a small stream that subsequently flowed north until it entered a man-made reservoir named Beaver Pond. The drainage system eventually flowed into Tom's Bayou and Chocatawhatchee Bay, major water systems for the city of Fort Walton Beach, FL, and surrounding communities (Harrison et al. 1979). In years the after closure of Hardstand 7, studies of TCDD and arsenic (from Agent Blue) were conducted in and around the hardstand and in the drainage system associated with it (Bartleson et al. 1975; Cullers et al. 1976; Harrison et al. 1979; Harrison and Crews 1983).

The aircraft involved in the spray equipment test and evaluation flights parked at the hardstand in preparation for the mission. Figure 6.9 was a 1969 photograph of an UC-123 K aircraft being prepared for a mission on Test Area C-52 A (Harrigan 1970a). Several hundred 208-l drums of various types of herbicides were stored around Hardstand 7 for later transfer of their contents into tanks aboard the spray aircraft. In background of the photograph, drums of Orange and White were stacked upright in the storage area (Harrigan 1970a). The spray equipment was also frequently installed at the Hardstand. Figure 6.10 was an interior view of the UC-123 K aircraft with the A/A 45Y-1 Internal Modular System installed (Harrigan 1970a). Figure 6.11 was a photograph of the wing booms mounted on the UC-123 K with drums of Agent White in storage and the Eglin Airdrome in the background (Harrigan 1970a). Figure 6.12 was a photograph of ADTC personnel adding methylene blue dye to Agent White prior to a mission on Test Area C-52A. The methylene blue was used as a method to evaluate droplet size and deposition, using the Kromekote cards and glass plates on the test array on Test Area C-52A (Harrigan 1970a). Figure 6.13

Fig. 6.9 A UC-123 K RANCH HAND aircraft parked at Hardstand 7 in preparation for a spray equipment test and evaluation flight, Eglin AFB, Florida 1969 (Photograph courtesy of AFATL, Eglin AFB, Florida)

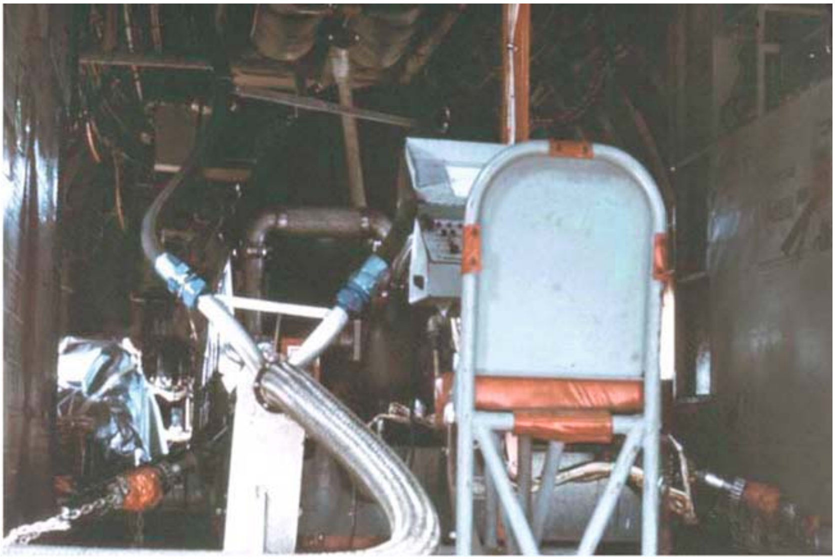

Fig. 6.10 An interior view of the A/A 45 Y-1 Internal Modular Spray System mounted in the UC-123 K aircraft, Hardstand 7, Eglin AFB, Florida 1969 (Photograph courtesy of AFATL, Eglin AFB, Florida)

Fig. 6.11 A wing defoliation spray boom mounted on the UC-123 K aircraft at Hardstand 7 in 1969; note drums of Agent White and the Eglin AFB Airdrome in the background (Photograph courtesy of AFATL, Eglin AFB, Florida)

Fig. 6.12 Air Development and Test Center (ADTC) personnel adding Methylene Blue Dye to Agent White prior to a mission on Test Area C-52A, Eglin AFB, Florida, 1969 (Photograph courtesy of AFATL, Eglin AFB, Florida)

Fig. 6.13 A photograph from a UC-123 K aircraft circling Test Area C-52A, Eglin AFB, Florida, prior to an aerial spray equipment evaluation mission, December 1969 (Photograph courtesy of AFATL, Eglin AFB, Florida)

was a December 1969 photograph taken from the UC-123 K aircraft that was circling Test Area C-52A prior to an aerial spray equipment evaluation mission (Harrigan 1970a).

As described above, Hardstand 7 was an asphalt aircraft staging area. It contained a 3-m deep concrete pit with a stairway leading to the pit's bottom opposite to the taxiway (Harrison et al. 1979). A dike was constructed between the hardstand and the ravine to its northwest before 1978 to control erosion and runoff from the hardstand into the hardstand pond (Harrison and Crews 1983). The area between the dike and hardstand was capped by asphalt (Harrison et al. 1979; Channell and Stoddart 1984). A storm drain was constructed to remove excess water to sediment ponds located more than 500 meters to the east of Hardstand 7 (Harrison et al. 1979; Channell and Stoddart 1984). In 1995, more drainage controls were incorporated to minimize soil erosion, and the hardstand was posted, fenced and guarded to limit access. In 1996, embankment stabilization measures were incorporated, and the drain pit and drum storage locations were excavated to remove the most highly contaminated soils. Finally, in 2001, the area around Hardstand 7 was capped (ATSDR 2003). This underscores the importance of quantifying the environmental persistence of TCDD in soil adjacent to Hardstand 7.

TCDD and other dioxin-like molecules are subject to a series of physical, chemical, and biological transformations that affect degradation in various media once released into the environment. For example, Isensee and Jones (1975) observed that polychlorinated dibenzo-dioxins and furans demonstrate a fast rate of disappearance in the water phase and a slow disappearance from solid phases, such as sediments and soils. This may be caused by the hydrophobic characteristics and the low water solubility of dioxin-like compounds, including TCDD (Exner 1986). Kapila et al. (1989) also found that TCDD was very persistent in soil. Surface photolysis and volatilization mechanisms degrade small amounts of TCDD. For soils with 1% organic carbon and with 30% water by volume, 99.9% of TCDD will be adsorbed on the soil at equilibrium. Kapila et al. (1989) concluded that TCDD will filtrate through the soil very slowly and that the mobility of TCDD in soil water will increase in the presence of co-solvents that can solubilize TCDD. Roger et al. (1994) found that TCDD was destroyed in soils in the presence of organic solvents or surfactant/water mixtures. However, Northcott and Jones (2001) found that when the soil was contaminated for long periods of time with polychlorinated aromatic hydrocarbons such as TCDD, they diffused and remained in remote and inaccessible soil regions thereby preventing the complete development of biotic mechanisms that would degrade the molecule. Photodegradation to less chlorinated chemicals and biodegradation through both aerobic and anaerobic microbial activities were identified as principal destruction mechanisms of TCDD in the environment (Young 2006). The environmental fate of TCDD is discussed in more detail in Section 6.10.

A field investigation of Hardstand 7 soils sought to characterize the extent of TCDD contamination in surface (0–8 cm) soil resulting from storage and handling of Agent Orange. Based on an earlier preliminary investigation conducted in 1978, the 1984 sampling was conducted with the assumption that TCDD contamination decreased as the distance from the center of the hardstand increased. A radial sampling protocol (Fig. 6.14) was adopted that increased the surface area represented by a sample as the distance from the hardstand increased (Crockett et al. 1987). Sampling points were placed at 19.8, 22.4, 26.5, and 33.5 m from the center of the hardstand. Each plot had six aliquot samples, which were combined into a composite sample to determine TCDD surface soil concentrations within the plot with a detection limit of 0.01 ppb. Quality assurance and quality control of the data was developed

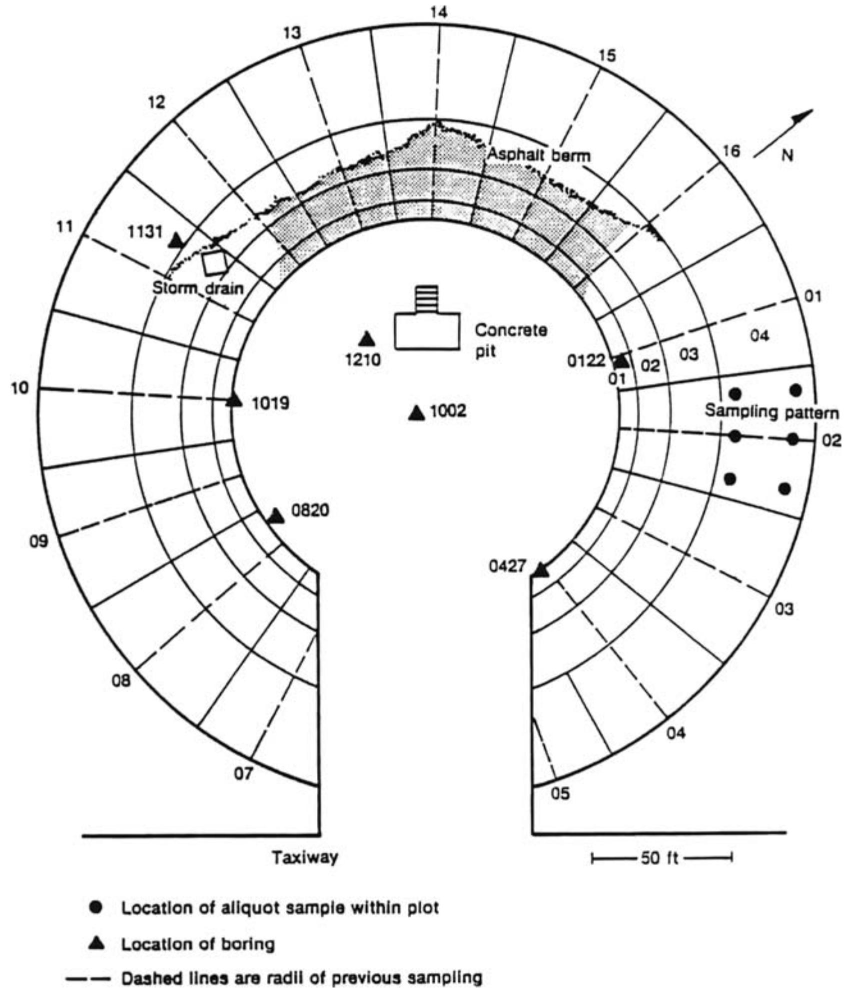

Fig. 6.14 Sampling radial design layout (Crockett et al. 1987)

using an in-house analysis of blank samples, matrix spikes, duplicate samples, and surrogate standards combined with an external analytical laboratory data review and validation (Crockett et al. 1987).

Vasquez et al. (2004) used the multimedia model CalTOX to provide insights into the potential persistence of TCDD in surface soils of the Hardstand 7 area for a 70-year time horizon beginning in 1984. CalTOX is a multimedia frugality model that has two main components: the transport/transformation model and the human exposure model (University of California at Davis 1993). Concentrations from the 1974 field sampling were used as the initial source term and the model was calibrated using the 1984 sampling data. The focus was on Hardstand 7 at Eglin AFB because that site was used extensively as a loading site for aircraft testing aerial spraying systems prior to deployment to Southeast Asia during the Vietnam War (Channell and Stoddart 1984). Drums of Agent Orange were stored at the Hardstand 7 for the purpose of testing spray equipment. As a result of purging spray systems and leaking drums, the surrounding soil of the Hardstand 7 became contaminated (Harrison et al. 1979; Channell and Stoddart 1984).

The fugacity approach described the escaping tendency of contaminants at low concentrations, especially nonionic organic chemicals, from one media to another. Under the condition of low concentrations such as Hardstand 7, fugacity was linearly related to concentration. CalTOX has seven compartments: air, ground-surface soil, plants, root-zone soil, vadose-zone, surface water, and sediments. There are three important processes within the model: sources, transport, and transformation. For each compartment and process, the model mathematically calculated how much of the contaminant was present in a compartment at time one, how much of the same contaminant remained in that compartment after time one, and how much was transported to other compartments or was transformed into other chemicals. Quantities within compartments were described by a set of linear, coupled, first-order differential equations (University of California at Davis 1993). CalTOX simulated decay and transformation processes, such as biodegradation and photolysis, as first-order, irreversible removals. Solid-phase flow and liquid-phase flow were two important mass flow compartments. CalTOX considered the transport in soil column as vertical directed. Within the atmosphere, chemicals moved vertically down to surface water and soil, or horizontally by means of wind. Transport from soil to surface water was considered to be horizontal (University of California at Davis 1993).

CalTOX assumed chemical equilibrium among phases within a single compartment but did not include equilibrium requirements between adjacent compartments. It also assumed greater vertical transport than horizontal transport in unsaturated soil layers (University of California at Davis 1994). CalTOX was particularly useful for landscapes with a large ratio of land to surface water area, and it was most reliable when dealing with nonionic organic chemicals. Because of the flat topographic features and erosion management structures

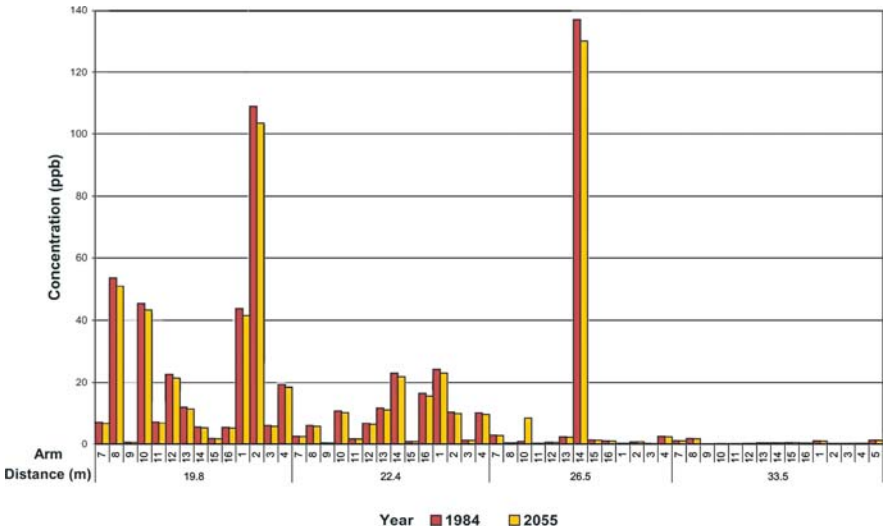

Fig. 6.15 TCDD surface soil concentrations: 1984 (observed) and 2055 (estimated using CalTOX) (Vasquez et al. 2004)

engineered into Hardstand 7, it was unlikely that large quantities of TCDD transported off site by erosion. The values used by CalTOX to determine the fate of TCDD were available (Vasquez et al. 2004).

Figure 6.15 illustrated the 1984 TCDD concentrations and the estimated TCDD concentration after a 70-year time interval. CalTOX predicted a decrease of 0.7 ppb in soil TCDD concentration between 1984 and 2055. These results indicated that TCDD was extremely persistent in soil with the initial TCDD concentrations only declining by approximately 5.03% over a 70-year period (Vasquez et al. 2004). The most highly contaminated soils around Hardstand 7 were excavated and the site capped in 2001 (ATSDR 2003).

The CalTOX simulation indicated that TCDD was highly persistent in the soil medium. The analysis suggested that natural attenuation between 1984 and 2055 would not significantly decrease TCDD soil concentrations (Vasquez et al. 2004). Instead, active risk management techniques such as those taken by Eglin AFB (access limitations, soil removal, capping, soil erosion controls) were prudent. In an environment without erosion controls, soil erosion may be an important factor in the transport of TCDD (Channell and Stoddart 1984). Modeling techniques that incorporate soil erosion may be required to provide better estimates of the fate and transport of TCDD contaminated soils in order to assess TCDD residues associated with the use of Agent Orange or other military herbicides during the Vietnam War.

6.5 Herbicides/Chemicals Sprayed in the Test and Evaluation Programs

As previously noted, the equipment tested on Test Area C-52A was tested under realistic yet controlled conditions. Most test projects involving military herbicides and insecticides actually included the pesticides themselves rather than simulants (Young 1974). Fuel oil was used both as a diluent with the tactical herbicide (i.e., with Agent Purple) and by itself in initial evaluations. An attempt was made to develop an "Orange Simulant" which consisted of glycerin, sodium thiosulfate and water (Klein and Harrigan 1969). However, it was generally found to be unsatisfactory and its use was limited. With the development of spray equipment for use by high performance aircraft, the Air Force Armament Laboratory (AFATL) developed "Stull Bifluid" which consisted of Herbicide Orange (85%) plus a chemical additive, which when mixed in the spray system pump during dissemination produced a gel defoliant (Hazen 1967). Table 6.2 gives the approximate volume of military herbicides, insecticide, and/or simulants applied to the test grids on Test Area C-52A, 1962–1970 (Young 1974; Young et al. 1975).

The data in Table 6.3 are expressed in kilograms of active ingredient for the herbicides disseminated on the grids of Test Area C-52A, 1962–1970. Despite excellent records as to number of missions and quantity of herbicide per mission, there was no way to determine the exact quantity of herbicide deposited at any point or on any one of the instrumented grids (Grids 2, 3, and 4). However, an estimate of the amount of herbicides disseminated can be calculated by grids, and by years the grids were used. These data are presented in Table 6.4

Table 6.2 Approximate total volume (liters) of tactical herbicides, insecticide, and/or simulants applied on Test Area C-52, Eglin AFB, FL, 1962–1970 (Young 1974)

Chemical	Liters disseminated
Orange	74,970
Purple	61,180
White	15,790
Blue	16,635
Stull BiFluid[1]	6,495
Fuel Oil	41,120
Orange Simulant[2]	5,525
Malathion Insecticide	815
Total	222,530

[1] Stull Bifluid consisted on Orange Herbicide (85%) plus a chemical additive, which when mixed in the spray system pump during agent dissemination produced a gel defoliant. Volume reported is for the chemical additive (Hazen 1967).

[2] Orange Simulant consisted of glycerin (68%), sodium thiosulfate (16.8%), and water (15.2%) (Klein and Harrigan 1969).

Table 6.3 Kilograms of active ingredient of the tactical herbicides disseminated on the test grids of Test Area C-52A, Eglin AFB, Florida, 1962–1970 (Young 1974*)

Herbicide	Kilograms active ingredient
2,4-D	76,000
2,4,5-T	75,000
Cacodylic Acid	3,800
Picloram	1,000
Total	155,800

*Data are corrected for the values of active ingredients in Agent Orange and Agent Purple.

Table 6.4 Approximate amount of herbicide (kilograms active ingredient) applied to the individual test grids on Test Area C-52A, Eglin AFB, Florida, 1962–1970 (Young 1974*)

		Kilograms herbicide			
Test grid[1]	Grid area[2] hectares	2,4-D	2,4,5-T	Picloram	Cacodylic Acid
Grid 1	37	**31,200** (1962–1964)[3]	**32,400** (1962–1964)		
Grid 2	37	**23,800** (1964–1966)	**24,700** (1964–1966)		
Grid 3	37 (1967)	**1,400** (1967)	**400** (1968)		
Grid 4	97	**19,600** (1968–1970)	**17,900** (1968–1970)	**700** (1969–1970)	**3,500** (1969–1970)

*These data are corrected for the values for active ingredients.
[1] The test grids are described in test and are shown in Fig. 6.3.
[2] In actuality, Grids 2 & 3 fall within the confines of the 260 hectares of Grid 4. However, the positioning of the test arrays on Grid 4 resulted in most of the herbicide being disseminated within a 97-ha area, with only slight infringement on the original sites of Grid 2 and 3.
[3] Years when the majority of the herbicide was applied.

6.6 TCDD in Agent Orange and Purple Disseminated on the Test Area

Only a few archived samples of Agents Orange or Purple were available from the Eglin AFB Spray Equipment Test and Evaluations Projects on Test Area C-52A. One sample of Purple was analyzed and found to contain 45 ppm (Young 1983). Recent investigations into the origin of the sample revealed that approximately 300 drums of Agent Purple were sent from Fort Detrick to Eglin AFB in the early years of the test program for use in the tests and evaluations of the UC-123B/MC-1 Defoliant Spray System and the helicopter spray systems that were to be deployed to Vietnam as soon as the systems were approved (Brown and Whitman 1962). Although the records are incomplete, apparently the herbicide was procured from a single manufacturer in 1953. The Purple formulation was approved for military procurement on 27 January 1953 (Department of the Army 1970). The herbicide was involved in field tests in 1953 in preparation for its potential use in the Korean Conflict (Acker et al. 1953; Ward et al. 1953). However, the spray systems and herbicide evaluated in the test programs were never used in Korea. At the close of the Korean Conflict, the remaining stocks were stored first on Guam in 1955 and later at Fort Detrick until the inventory was sent to Eglin for use in the test and evaluation projects. It is assumed that the concentration of 45 ppm TCDD was consistent throughout the production run.

Four archived samples of Agent Orange remained from the Eglin AFB program. The mean of these four samples (0.04, 0.04, 3.2 and 6.4 ppm) was 2.4 ppm (Young 1983). However, the analyses of TCDD of 525 Herbicide Orange samples from the Agent Orange Inventories at the Naval Construction Battalion Center, Gulfport, MS, and from Johnston Island, Central Pacific Ocean, had a weighted mean concentration of 1.88 ppm (Young et al. 2008). The estimated total amount of TCDD (in kilograms) contained in Agent Purple and Agent Orange and disseminated on the test grids on Test Area C-52A is presented in Table 6.5.

The total amount of TCDD (approximately 3.1 kg) applied to the test sites at Eglin AFB provided a unique opportunity for field studies of its persistence and environmental fate. Moreover, since the TCDD was aerially disseminated with the herbicide, it provided a "field laboratory" to what may have happened in Vietnam from aerial applications of the herbicide. However, in Vietnam a "typical" mission would have disseminated 14.8 kg 2,4,5-T/hectare versus 876 kg per hectare on Grid 1 at Eglin (Young and Newton 2004). Perhaps more importantly it is estimated that a hectare on Grid 1 would have received more than 1,300 times the amount of TCDD disseminated on a hectare in Vietnam (Young and Newton 2004). The impact of such large quantities of herbicide on the vegetation of the test grids can be seen in an aerial photograph of the Test Area in June 1970 (Fig. 6.16).

Table 6.5 The estimated total amount of TCDD (in kilograms) contained in Agent Purple and Agent Orange and disseminated on the test grids of Test Area C-52A, Eglin AFB, Florida, 1962–1970 (Young and Newton 2004)

Test grid	Years deployed	Amount of 2,4,5-T Kilograms	Source of tactical herbicideμg/g	TCDD
Grid 1	(1962–1964)	32,400	Purple 45 ppm*	2.9
Grid 2	(1962–1966)	24,700	Orange 2 ppm	0.1
Grid 4	(1968–1970)	17,900	Orange 2 ppm	0.1
Total				3.1

* The concentration of either Purple or Orange was essentially 50% 2,4,5-T; therefore, the concentration of TCDD in 2,4,5-T was twice the concentration of the TCDD in the formulation, i.e., 90 and 4 ppm, respectively.

Fig. 6.16 Looking south across Grid 4 in the foreground, an area that received Agent Orange in 1968–1970; in the background was Grid 1, a grid that received Agent Purple in 1962–1964. The aerial photograph was taken in June 1970, Eglin AFB, Florida (Photograph courtesy of AFATL, Eglin AFB, Florida)

6.7 The Military's Response to the Herbicides Sprayed on Test Area C-52A

The massive amounts of military herbicides disseminated on Test Area C-52A helped to foster recognition of the need for environmental pollution control and monitoring systems. At the same time it was realized that this area offered a unique opportunity for evaluating the ecological effects of military herbicides (ADTC 1969). On 21 April 1966, Air Force Regulation (AFR) 161-22, "Environmental Pollution Control", was released and stated that the Air Force Policy was to "eliminate or control environmental pollutants generated by or resulting from Air Force Operations". This regulation further stated:

> Alterations of the air, water, or soil by chemical, physical, or biological agents which adversely affect human health or comfort, animal and plant life, structures and equipment, to the extent of producing economic loss, impairing recreational opportunity, or marring natural beauty constitutes environmental pollution.

In order to comply with the spirit and intent of AFR 161-22, the Air Force Armament Laboratory (AFATL), on behalf of the Armament Development and Test Center (ADTC), at Eglin AFB initiated in 1966 the first studies on the ecology of Test Area C-52A through a contract with the University of Florida (Ward 1967; ADTC 1969). Simultaneously, ADTC directed the implementation of a herbicide-sensitive plant monitoring system, thus providing a basis for determining and monitoring downwind herbicide drift during all of the defoliant spray systems tests and evaluations. The monitoring system was requested by ADTC as a result of claims filed in the spring of 1964 by Walton and Holmes County farmers against the government for alleged crop damage due to spraying of herbicides on Test Area C-52A. Walton and Holmes Counties bordered the Eglin Reservation on the north and east. After an extensive investigation the claim was disallowed because of insufficient substantiated evidence (ADTC 1969).

In July 1966, the ADTC in preparation for a new series of tests and evaluations of defoliant spray systems requested the Director of the Base Medical Services to "evaluate the defoliants Orange, White, and Blue and indicate the hazards associated with each". The reply by the Director of the Base Medical Services stated:

1. Reference your letter dated 25 July 1966, subject "Herbicide Agent Evaluation";
2. Review of available information infers little hazard to man in the use of these agents if they are used in small quantities and with proper protective clothing. It is suggested that rubber gloves, protective apron, and face mask be used during the handling and loading operations of these herbicides. In the event of skin contamination it should be immediately washed with water and mild soap. If eyes are contaminated they should be washed with water and/or other first aid eye lotions;
3. Ground test personnel and observers should be stationed outside of the direct path of spray pattern. If a skin rash, reddening of the eyes, or other evidence of illness results from inadvertent exposure a physician should be consulted;
4. In is noted that all herbicides are generally moderately toxic to man and in some instances are cumulative in their action. For example, cacodylic acid toxicity is primarily attributed to its arsenic content that may be harmful even after long periods of leaching. Further the use of herbicides will alter the plant growth of the test site which will cause wild animals of all types to leave the area due to lack of food or cover. Rain water from a severely contaminated site will flow into the creeks and estuaries of the drainage basin destroying the plankton, algae, and other fish food which will, in turn, destroy the area outside the controlled test grid for productive sport fishing; and,
5. Since the primary objective of the test procedure is to determine the mechanical efficiency of an aircraft wing spray boom it is believed that the use of simulant herbicide sprays would accomplish the major part of the test objectives. It is suggested that actual herbicides be used only as a final test for the equipment (ADTC 1969).

In March 1967, the Director of the Base Medical Services was again solicited for information concerning hazards and toxicology associated with the military herbicides. In addition to answering the request for such information, the Director sent a letter (dated 27 March 1967) to the Directorate of Technical Support, ADTC, which stated:

1. Reference is made to:
   (a) A planning meeting on 23 March 1967 concerning the projected and continuing use of herbicides, insecticides, and other chemicals on the test grids of Range 52A in support of aircraft CW dispenser development.

(b) Letters dated 10 Aug 66 and 7 Mar 67, subjects, "Hazard Evaluation of Herbicides" and "Test of Chemical Anti-Crop Dispenser" in which you were informed that use of small quantities of these materials would probably cause little hazard to man but that some of the herbicides may be harmful, particularly to plants and wildlife even after long periods of leaching.

2. It is understood that such tests will be continuing on the Eglin range in the foreseeable future with increasing quantities of chemicals on the range. In this case it is important to keep informed whether concentrations of these potentially hazardous materials on the range foliage, wildlife, and in fish and oysters of the estuaries near the Range 52A drainage basin are reaching significant toxic levels from the human health and/or wildlife standpoint. Such data is essential and invaluable in determining safety of future test programs. Further, it will serve to defend the Air Proving Ground Center (now ADTC) position when challenged in court proceedings which claim damage to people, foods, crops, and/or natural resources on property adjoining the range.
3. It is strongly recommended that (you) initiate action which will result in data required for purposes of paragraph 2. It would seem that a rather long-term contract with some disinterested group to perform this analysis would be appropriate. Perhaps the US Public Health Service would be the logical group for such work since their opinion and experimental results are held in high esteem by the general public (ADTC 1969).

As a consequence of this letter, the Air Force Armament Laboratory was queried on 17 May 1967 as to a contract it had initiated with the University of Florida in 1966 concerned with an "Ecological Survey of the Eglin AFB Reservation". In a letter (dated 12 June 1967) from the Commander of the Armament Laboratory to the Directorate of Technical Support, ADTC, it was stated:

1. The Air Force Armament Laboratory is in agreement with the requirements for ecological surveillance as related to the Eglin ranges. The responsibilities for monitoring the effects of substances used on the reservation are clearly the responsibility of the Air Proving Ground Center (now ADTC). The responsibility for the development of substances used in tests and their effect on the plant, animal and marine life is the responsibility of the Air Force Armament Laboratory. Development includes investigation of effects on wide varieties of living organisms and the amounts of the various substances required to cause an effect. The Laboratory has been directed to accomplish this by HQ AFSC (Headquarters, Air Force Systems Command).
2. When a request is made to use a new substance on the Eglin range, all data pertaining to its characteristics, its effect on living organisms, and the amounts to cause an effect will be furnished to the Air Proving Ground by the Armament Laboratory. Responsibilities for damage will therefore be jointly shared by both organizations (ADTC 1969).

The basic concern of both ADTC and AFATL was the effective environmental pollution control and monitoring of Test Area C-52A. This concern included the effects on the ecology and water resources of the Test Area, and the agronomic crops associated with the areas adjacent to the Eglin Reservation. Recognizing the responsibility for conducting ecological and environmental studies on Test Area C-52A, the Commander of the Laboratory directed that the Laboratory would both broaden its contractual efforts underway with the University of Florida, and would develop an in-house capability to conduct such environmental and ecological research (Young 2004).

Throughout the remainder of 1967 and throughout 1968, the Laboratory began assembling a team of young scientists with backgrounds in environmental toxicology, plant pathology, microbiology, fisheries biology, weed control, animal science, and chemistry. By contacting the Air University, Wright-Patterson AFB, Ohio, the Laboratory was able to identify scientists who were military officers and who had just completed their PhDs and were available for immediate assignments. Most were graduates of Land-Grant Institutions and were familiar with herbicides (Young 2004).

In January 1969, Colonel John Hicks, Commander of the Air Force Armament Laboratory, addressed the group of 20 scientists and staff who had been selected and assembled to conduct major environmental studies on the ecology and water resources on and adjacent to Test Area C-52A. The charge given by the Commander was the following:

> The acceptance by the Department of Defense of a non-conventional weapon system, namely that of vegetation control, testifies to the success of the defoliation program in the Vietnam War. However, the use of an air-delivered vegetation-control chemical as a tactical weapon against both concealment vegetation and food crops has opened the program to public debate both at home and abroad. The major questions concern the ecological and environmental consequences of the repetitive uses of vegetation-control chemicals. Definitive answers as to chronic long-term toxicity, genetic impairment, and long-term ecological consequences of such chemical agents are not available to Vietnam any more than they are for the United States. We have available to us a test site that involves the repetitive aerial application of these vegetation-control chemicals, a site that may contribute to the elucidation of these questions (Personal Notes, A.L. Young, January 1969).

The remainder of this chapter describes these studies and their results.

6.8 Chemical and Bioassay Studies of Soil Cores from Test Area C-52A

From the rates that were applied during the years of testing spray equipment, it was obvious that Test Area C-52A offered a unique opportunity to study herbicidal persistence and leaching. The herbicides could be chemically present but because of soil binding, might not be biologically active. Moreover, many chemicals were applied to the test area, and a biological assessment might be the result of two or more chemicals interacting. Thus, both bioassay techniques and analytical analysis were employed (Arnold and Young 1975; Young 2004).

Persistence of herbicides is known to be related to how much herbicide was applied, when it was applied, and what environmental factors, especially rainfall, may have influenced both its degradation and or movement into the soil profile (Bovey 1980). Table 6.6 provided data on the rainfall and herbicide dissemination for the last 18 months that Test Area C-52A was operational, through June 1970. Rainfall data were collected through September 1970, at which time the meteorological instrumentation on the 90-m tower was shutdown. Estimated data on active ingredients per hectare was also provided in the

Table 6.6 The monthly recorded rainfall and the monthly amount of herbicide aerially disseminated on Grid 4 of Test Area C-52A, Eglin AFB, Florida, January 1969–July 1970 (Young 1974)

Month/year	Rainfall in centimeters[1]	Herbicide in liters
January 1969	1.58	3,270 Orange
February	9.22	1,120 Orange
March	20.09	1,711 Orange
April	11.45	2,214 Orange 1,692 White
May	15.90	5,670 White
June	5.00	2,158 White
July	37.90	2,672 Blue
August	26.42	5,254 Blue
September	12.57	none
October	0.25	none
November	4.09	4,429 Orange
December	7.70	5,167 Orange
Total for 1969	152.17	17,911 Orange 9,520 White 7,926 Blue
January 1970	2.92	none
February	26.72	none
March	20.78	none
April	0.53	none
May	10.80	1,000 White 5,397 Blue
June	9.55	100 liters of Malathion
July	37.90	Projects Completed
August	26.42	
September	12.57	Data Collection Terminated
Total for 1970	148.19	

Area of Grid 4 sprayed = 97 ha
Amount of 2,4-D = 11,660 kg[2] (120 kg 2,4-D/ha)
Amount of 2,4,5-T = 9,493 kg (98 kg 2,4,5-T/ha)
Amount of Cacodylic Acid = 4,930 kg (51 kg CA/ha)
Amount of Picloram = 684 kg (7.1 kg picloram/ha)

[1]Rainfall data collected from 90-m Tower in the center of Test Area C-52A
[2]Active ingredient

table. The average minimum temperature for the test area was recorded in January and was 4°C, and the average maximum temperature for the test area was recorded in August and was 31°C. The yearly mean temperature was 18°C (Young 1974). Table 6.7 provided data on a typical soil profile from Test Area C-52A. Figure 6.17 was a photograph of the first 30 cm of the soil profile. The soils of the range were predominantly well-drained, acid sands of the Lakeland

Table 6.7 A typical soil profile[1] (15-cm increments) for Test Area C-52A, Eglin AFB Reservation, Florida (Young 1974)

Depth, cm	% Sand	% Silt	% Clay	% O.M.[2]	CEC[3]
0–15	91.6	4.0	4.4	0.46	1.19
15–30	90.1	4.3	5.6	0.20	0.81
30–45	92.1	4.3	3.6	0.20	0.73
45–60	92.9	3.5	3.6	0.00	0.69
60–75	93.1	2.8	4.1	0.07	0.69
75–90	92.8	3.6	3.6	0.07	0.69

[1] As determined by the Soils Department, University of Florida, Gainesville, Florida
[2] Percent organic matter
[3] CEC (Cation Exchange Capacity) is the ability of a cation to be displaced or exchanged from the soil by another cation. The cation exchange capacity of a typical greenhouse potting soil is 11.43. A soil with a cation exchange capacity of 1 can "bind" or "fix" 10 ppm of a given cation(s)

Fig. 6.17 First 30 cm of a Lakeland Sand Soil Profile from Test Area C-52A, Eglin AFB, Florida, April 1970 (Young 1974)

Association with 0–5% slope. The Lakeland sand that covered most of the test grid area formed excessively drained thick deposits that extended to a depth of about 2 m. The sand was characteristically very dry, even with the 155 cm of annual rainfall (Young 1974; Young et al. 1975).

Bioassay studies on herbicidal persistence and soil leaching were initiated in April 1970 (Young 1974, 2004). By considering the flight paths, the water sources, and the terracing effects, it was possible to divide the test grid into 16 vegetation areas. The areas formed the basis for the random selection of 48 90-cm soil cores. Figure 6.18 was the statistically based soil herbicide residue-sampling scheme for the 2.6-km^2 test grid on Test Area C-52A. Figure 6.19 was a photograph of AFATL personnel using a soil auger to obtain the soil cores for bioassay in April 1970. Each of the cores were subdivided into 15-centimeter increments and bioassayed with soybean seeds (*Glycine max* (L.) Merr. Var. Clarke 63). Following two weeks in the greenhouse, the plants were washed,

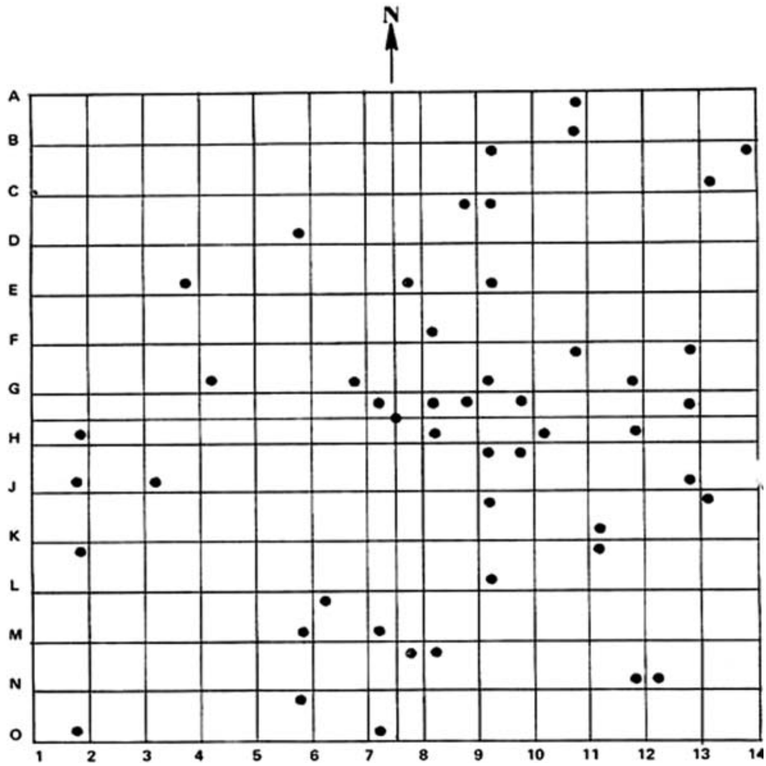

Fig. 6.18 Statistically-based soil herbicide residue sampling scheme, Test Area C-52A, Eglin AFB, Florida, February 1970 (Young 1974)

primary root length obtained, and compared with plants from a controlled field location and from prepared herbicide-standard soils (Young 1974).

In Fig. 6.18 A through O and 1 through 14 are the roads that intersected and connected the 196 permanent sampling stations. The roads also separated the 169 squares that measured 122 m on each side. Forty-eight cores were collected 15 m from randomly designated stations and in specified directions.

The results of the bioassays confirmed that there were evidences of herbicidal persistence and leaching: of 48 soil cores collected and bioassays from the test area, 27 cores were significantly different from control cores (95% probability level). Soil leaching was more prevalent along the dissemination flight paths than in other areas of the test grid. There were no statistical evidences of differences between wet and dry soils that received approximately the same amount of herbicide. By considering that all phytotoxic effects on the bioassay organism were from 2,4-D and /or 2,4,5-T (an assumption that was not valid), the approximate strengths of 2,4-D + 2,4,5-T in soils of high herbicide residue (top 15 cm of soil core) was 2.82 ppm (average of 8 soil cores) (Young 1974). Figure 6.20 was a photograph of the results of a soil core collected in April 1970 and bioassayed

Fig. 6.19 AFATL personnel using a hand soil-coring tool to collect 90-cm cores for herbicide residue study of Test Area C-52-A, Eglin AFB, April 1970 (Photograph courtesy of A.L. Young)

Fig. 6.20 Soybean bioassay of a 90-cm soil core from Site C-9 divided Into 15-cm increments (*left* to *right*) showing positive response to herbicide residues, April 1970, Test Area C-52A, Eglin AFB, Florida (Photograph courtesy of A.L. Young)

using soybeans. The bioassay confirmed the presence of phytotoxic compounds in each of the increments to a depth of 90 cm.

A follow-up bioassay experiment of six of the field locations showing greatest herbicide residue in the first experiment was conducted in December 1970 (Young 1974). This investigation showed that the varying levels of organic matter within a soil core influenced the amount of 2,4-D and 2,4,5-T residue available to the plants. It was necessary to conduct a series of standards (0.028–0.908 ppm 2,4-D and 2,4,5-T mixture (Orange Herbicide) for each 15-cm increment of soil core. Both soybean and cucumber (*Cucumis sativus* (L.) var. Long Green) were used as bioassay organisms. All bioassay (six treatment cores plus all standards from control cores) were conducted in a ISCO Environmental Chamber maintained at a diurnal temperature regime of 32–21°C, diurnal humidity of 65–85 %, and a 14-h day length. The results of this experiment indicated that herbicide residues, showing phytotoxic effects similar to 2,4-D and 2,4,5-T were in the concentration range of 0.01–0.33 ppm 2,4-D/2,4,5-T. Figure 6.21 was a photograph of the soybean bioassay of a soil core from site C-9 showing negligible levels of herbicide (phytotoxic) residue. This site was one of the sites that showed significant residue levels in April 1970, thus confirming the rapid disappearance of the herbicide (Young 1974).

The bioassays tests were analyzed by the Pesticide Degradation Laboratory, United States Department of Agriculture, Beltsville, Maryland for 2,4-D, 2,4,5-T and cacodylic acid. The soil cores were analyzed for picloram by the Analytical Services, Dow Chemical Company, Midland, Michigan. Typical results are shown in Table 6.8. The Pesticide Degradation Laboratory also examined the April 1970 cores for TCDD. No TCDD was detected at a detection limit of 1 part per billion (ppb) (Young 1974)

Fig. 6.21 Soybean bioassay of a 90-cm soil core from Site C-9 divided Into 15-cm increments showing negligible levels of herbicide residue, December 1970, Test Area C-52A, Eglin AFB, Florida (Young 1974)

Table 6.8 Results of chemical analysis for a typical soil core collected from the intersection of flight paths on Grid 4, Test Area C-52A, Eglin AFB, Florida, April 1970 (Young 1974)

Depth cm [1]	2,4-D ppb[2]	2,4,5-T ppb[2]	Picloram ppb[3]	Arsenic[4]ppm[2]	TCDD ppb
0–15	5.6	7.0	34	4.70	ND[5]
15–30	5.8	1.4	21	1.30	ND
30–45	7.6	2.8	6	0.90	ND
45–60	15.0	5.6	5	0.55	ND
60–75	5.0	2.8	<5	1.13	ND
75–90	13.2	6.8	<5	0.55	ND

[1]Mean of three samples.
[2]Analysis by the Pesticide Degradation Laboratory, USDA, Beltsville, Maryland
[3]Analysis by Dow Analytical Services, Midland, Michigan
[4] Cacodylic Acid is an organic arsenical. The analysis did not distinguish form of arsenic
[5] ND = Not Detected at a detection limit of 1 ppb.

As with the bioassays, there was significant leaching of the herbicide to the lower depths of the soil profile. The analysis of the December 1970 samples indicated that although the concentrations were significantly less, there were still detectable concentrations of the herbicides at the lower depths. In May 1974, a study was conducted with agronomic plants grown on plots near the intersection of Grid 1 and Grid 4, and from a control site that had no history of herbicide application (Agerton and Crews 1975). The experiment was designed to determine if seeds could germinate, develop into mature plants and produce fruit in an area that had received massive amounts of military herbicides during the period 1962–1970. Seven different agronomic crops, including tomato, cotton, peanuts, and beans were planted in a field plot that had been tilled to a depth of 30 cm. The crops were provided supplemental water and were fenced from the wildlife. All seven species germinated, produced significant vegetative growth and fruit (seed). There was no indication of herbicidal damage. No analyses were conducted on arsenic or TCDD content (Agerton and Crews 1975).

In summary, despite excellent records as to the number of missions and quantity of herbicide per mission, there was no way to determine the exact quantity of herbicide deposited at any point on the instrumented grids. Moreover, there was a problem of heterogeneity of the test grids themselves. Not only were there small geographic differences (soil types, contours, organic matter, and pH), and differences in vegetation density and locations of water, but most importantly, the herbicides had been sprayed on specific test arrays (i.e., along dictated flight paths) over a span of eight years. Bioassay and chemical analysis confirmed significant levels of herbicide residues in April 1970 as the test and evaluation programs in support of Operation RANCH HAND were completed. By December 1970, bioassay and chemical analysis confirmed that the herbicide residues were significantly less than in April 1970, and were found primarily in the lowest depths of the soil cores. Analytical studies for herbicide residues in the adjacent streams that drain from the test girds showed no indication that the residues were appearing in the aquatic systems at detectable levels.

6.9 Studies of the Vegetation of Test Area C-52A

The first ecological studies of Test Area C-52A were those concerned with vegetation. Testing of aerial spray equipment began in June 1962, and following heavy applications of Agent Purple in 1962 through early 1964, vegetation surrounding the test site showed changes suggestive of herbicidal damage. As noted earlier, concern about the extent of this damage led to the establishment of a contract in 1966 with the University of Florida, Gainesville, Florida. The purpose of the contract was to conduct a taxonomic study that would quantitatively measure changes in density of the vascular plants in the areas adjacent to the test grids (Ward 1967, 1968, 1970). Observations of tree growth rings in the reports by Ward prompted studies concerned with assessment of spray drift upon the forest trees adjacent to the test area (Hunter and Agerton 1971). A third study was concerned with the histological examination of a plant species growing in the flight lines on the test grid (Sturrock and Young 1970).

Two major vegetative succession studies were conducted on the 2.6-km^2 test grid (Grid 4) and on Grid 1 beginning in 1970 through 1974 (Hunter and Young, 1972; Young 1974). Plants collected during these studies were permanently mounted and added to the Eglin Reservation Herbarium. A photographic record of the vegetation coverage of Test Area C-52A including each of the individual grids was initiated in 1970 and some of the photographic records continued through January 2004 (Young and Newton 1974). Detailed information on methodologies and results including the listing of plant species are available in the technical reports. Subsequent studies of the vegetation were conducted in 1976 and 1983. The following synopsis is provided to give some magnitude of the amount of vegetative research that has been conducted on Test Area C-52A.

6.9.1 Synopsis of Vegetative Studies

In 1967, Ward studied the plants adjacent to the test area in order to determine the effects of the testing program on vegetation surrounding the test area (Ward 1967). Turkey Oak (*Quercus virginiana*), immediately adjacent to the test area, had been severely damaged by defoliant drift, but little or no damage was noticeable on longleaf pine (*Pinus palustris*) or sand pine (*Pinus clausa*). Ward observed the dominant vegetation in all directions from the test area, but was unable to find any damage other than that caused by the 1962–1964 period of equipment testing. In 1968, Ward collected and identified 54 species of plants occurring on the instrumented 2.6-km^2 test gird (Ward 1968). At that time the area was receiving repetitive applications of 2,4-D, 2,4,5-T, and picloram herbicides (Agents Orange and White). Nevertheless, Ward noted that the majority of the different plant species occurring on the test grid were broadleaf plants (dicotyledonous plants, herbicide sensitive). However, the bulk of the plant cover was composed of grasses and yucca (monocotyledonous, herbicide resistant). A final report by Ward in 1970 documented plant communities and plant species occurring on the Eglin Reservation (Ward 1970).

Based on Ward's 1967 observations, AFATL personnel measured the annual growth rings of selected trees (sand pine and longleaf pine) adjacent to the test area (Hunter and Agerton 1971). The annual diameter of 18 sand pines and two longleaf pines was measured to determine if tree growth was affected by defoliant drift from tests performed between 1962 and 1969. A comparison of the annual diameter growth during the years of defoliant testing with the diameter growth before testing showed no relationship between the amount of annual defoliant dissemination and the annual diameter growth. In a similar type of evaluation, a study was conducted on the crown tissue of yucca (*Yucca filamentosa*) found growing in the soil of the grid that contained detectable (ppm) levels of herbicide residue in 1969 (Sturrock and Young 1970). A gross comparison of control plants and those of the grid showed differences; however, a histological examination revealed no differences. Both samples followed the normal structural development described for yucca in the scientific literature.

Nine months after the last defoliant-equipment test mission (June 1971) on Test Area C-52A, AFATL personnel conducted the first detailed vegetative cover survey (Hunter and Young 1972). Since the 2.6-km^2 grid had 169 permanent air sampling stations, these stations and their interconnecting clay-covered access roads provided the boundaries for dividing the grid into 169 sections (each 122 m by 122 m). Within each section the percentage vegetative coverage was ranked as Class 0, 0–5%; Class I, 5–20%; Class II, 20–40%; Class III, 40–60 %; Class IV, 60–80%; and Class V, 80–100% covered. Sections were designated by the number of the permanent sampler in the northwest corner of the section, e.g., B-8 and J-4. Three of the 122-by-122-m sections within each coverage class were selected at random and a diagonal transect starting 6 m within the northwest corner of each section was walked to the southeastern boundary. All dicotyledonous (broadleaf) plants were collected along transects. Data were tabulated for the number of dicotyledonous plants occurring in each section. Then, one of the 122-by122-m sections from each class was randomly selected for further study and identification of plants. A control area 0.5 km northwest of the test area and the center of the area formerly occupied by Grid 1 were also surveyed (Young and Hunter 1972). This methodology was repeated in 1973, 1976, and 1983 (Young et al. 1975; Young and Hunter 1977; Young 1983). The data on vegetative cover for 1971, 1973 and 1983 are visually displayed in Figs. 6.22, 6.23, and 6.24, respectively. The data on number of

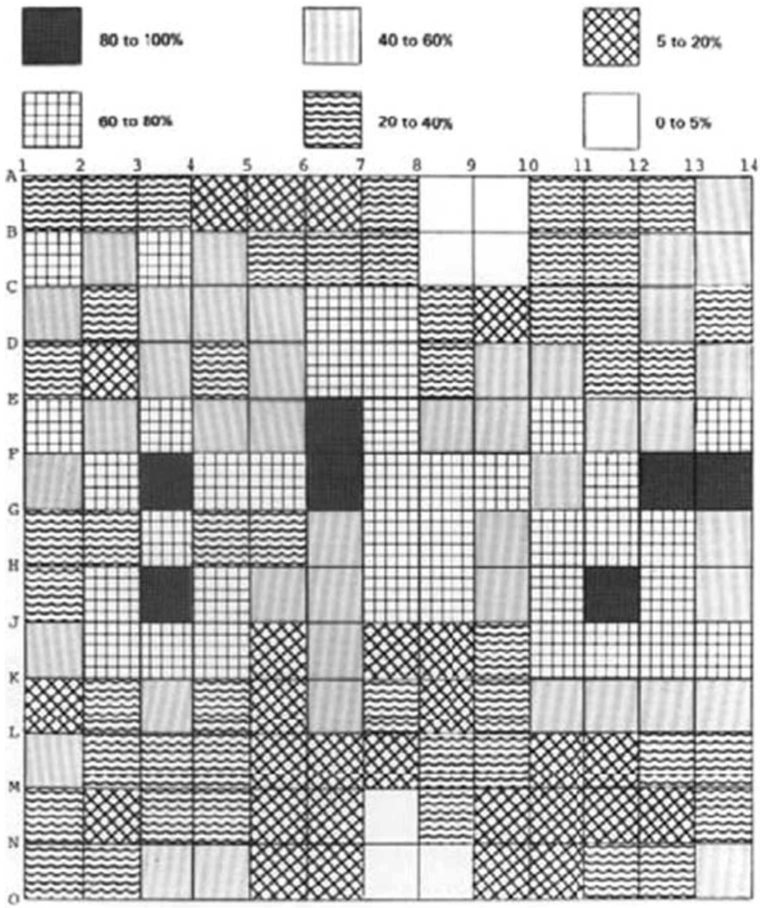

Fig. 6.22 Estimated vegetative cover 1971, Test Area C-52A, Eglin AFB, Florida (Young and Hunter 1972)

plant species recorded for 1971, 1973 and 1983 are diagrammatically presented in Fig. 6.25.

6.9.2 Discussion of the Sampling Procedure, Results, and Photographic Records

Whenever an ecological community is sampled, the data consist of lists of species present in each sample unit, and number of individuals of a given species in each sample unit. Normally, sample units are areas or quadrates of a specified size (Young 1974). Since the major grid on Test Area C-52A was the fully

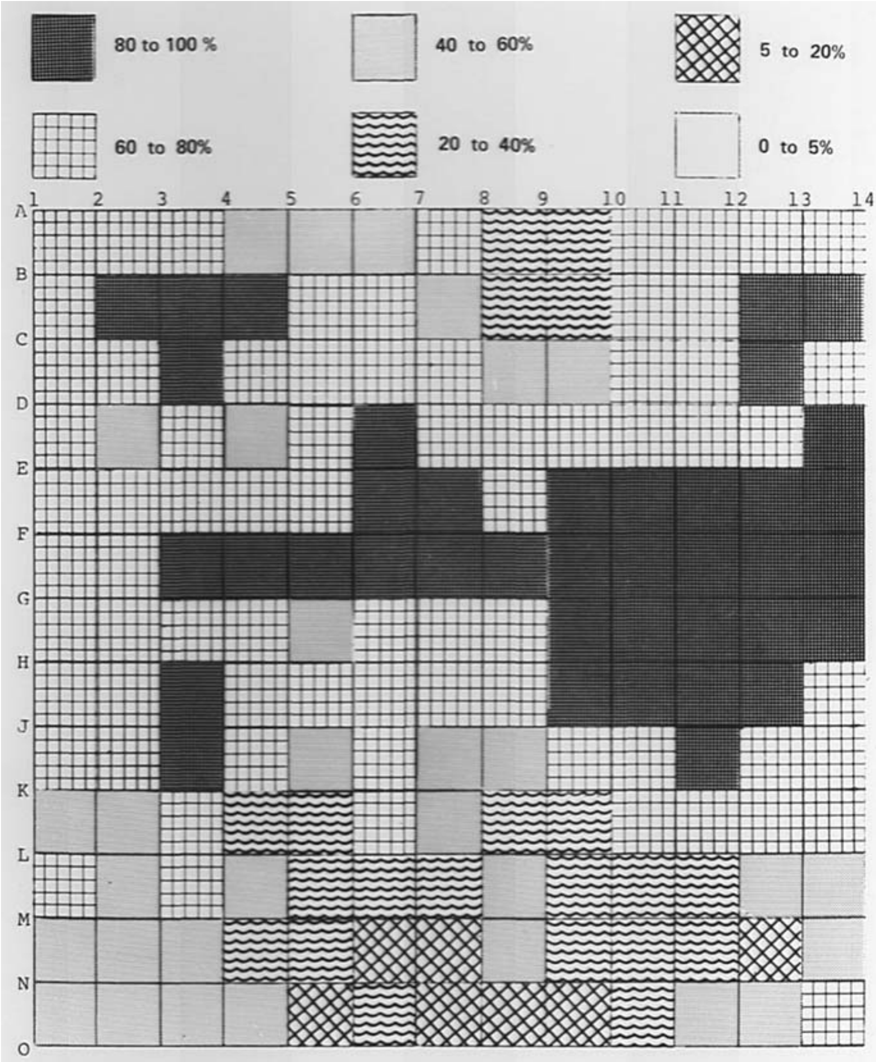

Fig. 6.23 Estimated vegetative cover 1973, Test Area C-52A, Eglin AFB, Florida (Young et al. 1975)

instrumented 2.6-km^2 gird (Grid 4), it was divided into 169 sections because of the instrumented sampling stations. Each of these sections was 122 × 122 m, and for all practical purposes seemed ideal as sampling units. However, when arbitrarily delimited quadrates are used, there is always a risk that the classification obtained may be markedly affected by history. The location of the flight paths used for dissemination tests, the location of water (ponds and drainage

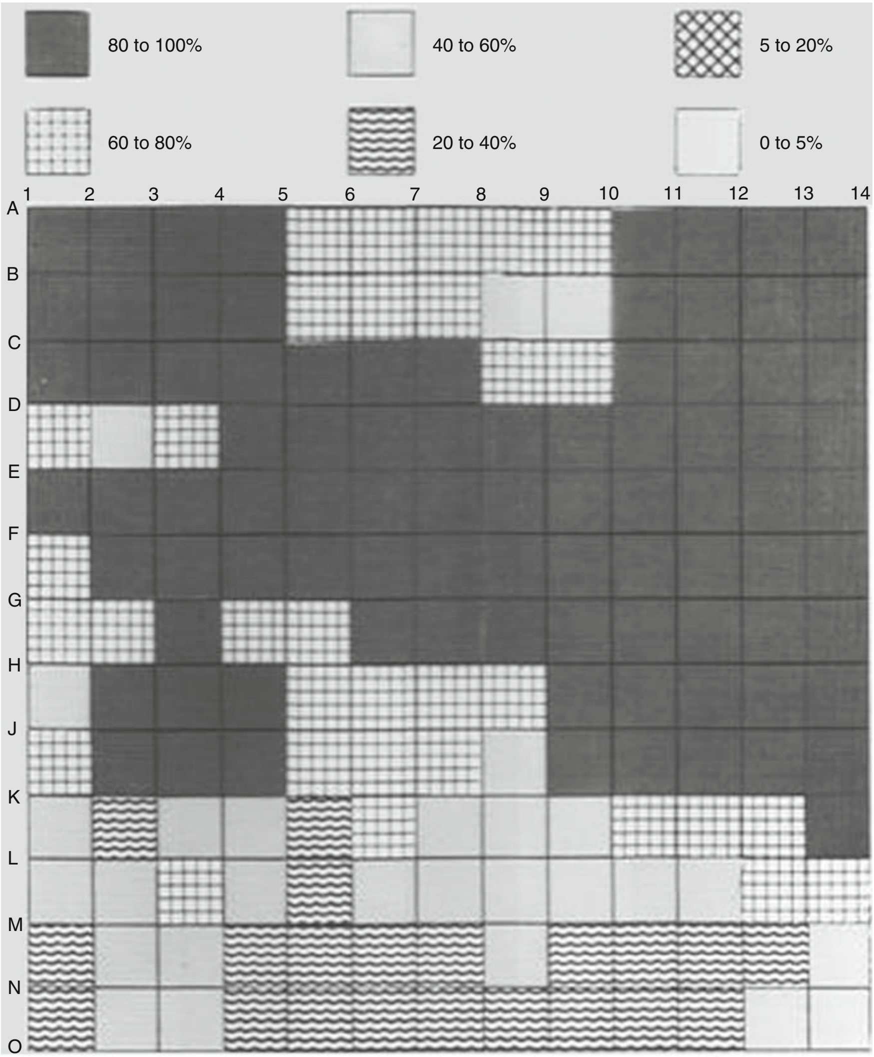

Fig. 6.24 Estimated vegetative cover in 1983, there was no 0–5% cover on the guid, Test Area C-52A, Eglin AFB, Florida (Young 1984a)

ditches), the change in soil type, and the impact of prior mechanical clearing all influenced the vegetative composition of the test grid and the vegetative succession process (Young 1974; Young et al. 1975).

The quantity of each species can be obtained by determining the ground cover occupied by a species. Ground cover may be defined as the area of ground

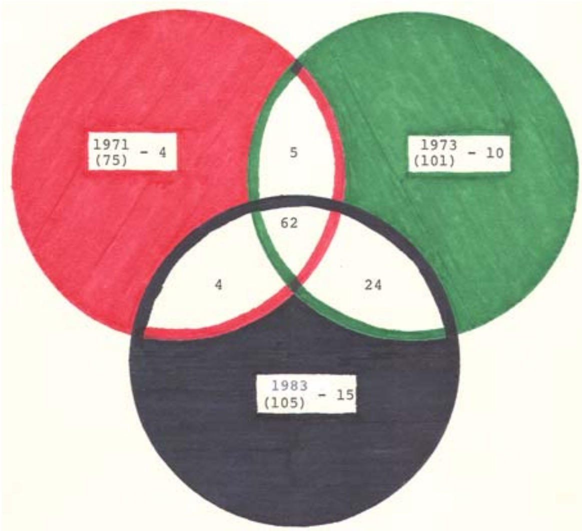

Fig. 6.25 A diagrammatic representation of the number of species on Test Area C-52A, Eglin AFB, Florida (1971, 1973, and 1983) (Young and Hunter 1972; Young et al. 1975; Young 1984a)

occupied by a perpendicular projection onto it of the foliage and stems of individuals of a particular species. Cover values are usually expressed as percentage figures and may either be estimated or measured (Young and Hunter 1972). As noted in Figs. 6.21, 6.22, and 6.23, the ground cover was estimated. However, it was measured by two different transect methods; the straight line and the square foot (90 × 90 cm frame) (Hunter and Young 1972). Three grass species dominated the ground cover found in all vegetative classes; namely, *Panicum virgatum*, switchgrass, *Panicum lanuginosum*, wooly panicum, and *Andropogon virginicus*, broomsedge. These species were abundant off the test site, herbicide resistant (except to cacodylic acid), and the availability of an abundance of seed were responsible for their invasion into bare areas of the test area. These species were also perennial species, and hence once established they were capable of persisting, spreading, and dominating as the new biomass (Young and Hunter 1977). After the termination of the equipment testing programs, and as the herbicide residues disappeared (via degradation and leaching), the first dicotyledonous species were weed species such as rough buttonweed, *Diodia teres*, and fragrant cudweed, *Gnaphalium obtusifolium* (Young 1974; Young et al. 1975). Eventually shrubs and trees began to appear (Young and Hunter 1977).

Because the climax vegetation on the Eglin Reservation was a forest stand dominated by pine and oak species, a survey of the trees appearing on the test area was conducted between June and August 1974 (Bartleson et al. 1974). Approximately 5,155 trees were counted on the 2.6-km^2 grid (Grid 4), representing an average of 20 trees per hectare, but 66% of the sampling plots on the test area contained no trees. The dominant species were live oak and turkey oak. Five other species of oaks, three species of pines, and common persimmon, *Diospyros virginiana*, were also found in the sample plots. The mean height for the trees was less than 1 m. Only 41 trees had a height over 2 m, the tallest being 3.5 m. Most of the trees were oaks found in small but dense clusters originating from the roots of previous trees. Trees starting from seeds, such as pines, persimmons, and single oaks, were sparse, but their presence indicated the area was recovering (Bartleson et al. 1974).

Photographic records from various locations on Test Area C-52A confirmed the rapidity of vegetative succession. Figures 6.26, 6.27, and 6.28 were photographs taken at sampling station 0-10 in June 1971, June 1976, and July 1983, respectively. Note the change in both dominant species and the appearance of pine and oaks trees. The site changed from Class I vegetative cover (5–20%) in 1971 to a Class II vegetative cover (20–40%) in 1976 and 1983. Figures 6.29, 6.30 and 6.31 are photographs taken near sampling station A-9 looking over Grid 4 in June 1970, June 1976, and January 2004, respectively. Note the 90-m tower in the photographs. In Figure 6.31 the vegetation has returned to climax stage after a period of more than 40 years. Such remarkable change over time can be seen in photographs taken of Grid 1, the grid that received massive amounts of Agent Purple in 1962–1964. Figures 6.32, 6.33, 6.34, 6.35, and 6.36 were photographs taken of Grid 1 in 1964, 1971, 1978, 1983, and 2004, respectively. The photographs taken in January 2004 confirmed that plant succession progressed over the 40 years to the climax vegetation for the Eglin site (Young and Newton 2004).

Fig. 6.26 Looking south at Sampling Station 0-10, June 1971, Test Area C-52A, Eglin AFB, Florida; the dominant vegetation is Switchgrass, *Panicum virgatum* (Photograph courtesy of A.L. Young)

Fig. 6.27 Looking south at Sampling Station 0-10, June 1976, Test Area C-52A, Eglin AFB, Florida. The dominant vegetation was switchgrass and broomsedge, *Andropogon virginicus*, with some dicotyledonous species appearing (Photograph courtesy of A.L. Young)

Fig. 6.28 Looking south at Sampling Station 0-10, July 1983, Test Area C-52A, Eglin AFB, Florida; the pine and oak trees have become established (Photograph courtesy of A.L. Young)

In May 1970, qualitative surveys were initiated to identify the animal, insect, and fish species that were associated with the spray-equipment testing grid on Test Area C-52A, and within the adjacent surrounding 30-km^2 area. The purposes of the survey were to determine the extent of faunal ecological

Fig. 6.29 Looking south from A-9 Grid 4, June 1970, Test Area C-52A, Eglin AFB, Florida (Photograph courtesy of A.L. Young)

Fig. 6.30 Looking South from A-9 on Grid 4, June 1976, Test Area C-52A, Eglin AFB, Florida (Photograph courtesy of A.L. Young)

alterations that may have occurred due to the repetitive applications of military herbicide (Pate et al. 1972).

6.9.3 Studies of the Mammals, Birds, Reptiles, and Amphibians

It was expected that repetitive applications of military herbicides would temporarily alter the faunal ecology of the area, primarily due to the changes in the vegetation. It had been suggested that animals would totally avoid the sprayed areas either due to lack of food, the offensive appearance or taste of the

Fig. 6.31 Looking South from Near A-9 on Grid 4, January 2004, Test Area C-52A, Eglin AFB, Florida (Photograph courtesy of AFATL, Eglin AFB, Florida)

Fig. 6.32 Photograph looking NE across Grid 1, June 1964, Test Area C-52A, Eglin AFB, Florida (Photograph courtesy of AFATL, Eglin AFB, Florida)

contaminated vegetation, or odors produced by the herbicides or their degradation products. More importantly, the report on the "Teratogenic Evaluation of 2,4,5-T" had just appeared from a research program sponsored by the National Institute of Health (Bionetics 1968; Courtney et al. 1970), and subsequent conclusion that the effects observed may have been do to the presence of TCDD. This report suggested to the AFATL scientists that animals exposed to 2,4,5-T on the test area might be receiving doses of the herbicide or TCDD that would affect their reproductive processes.

Over the next three years (May 1970–August 1973) animal surveys were conducted to determine species variation, distribution patterns, migration, and relative population sizes. Methods of study included early morning, midday, and night field trips for identification and collection of mammals, birds,

Fig. 6.33 Photograph looking NE across Grid 1, June 1971, Test Area C-52A, Eglin AFB, Florida (Photograph courtesy of J.H. Hunter)

Fig. 6.34 Looking NE across Grid 1, Test Area C-52A, Eglin AFB, Florida, July 1978 (Photograph courtesy of A.L. Young)

reptiles, and amphibians. Many of the species collected were brought into the laboratory where they were photographed and either preserved or mounted as part of the effort to establish a reference collection to facilitate identification for subsequent studies (Pate et al. 1972). A list of all species identified has been published (Young 1974; Young, Thalken, Ward 1975).

A total of 18 mammal species were observed off the test grid with 12 of these species also being found on the grid. All of the animals sighted on the grid used the area for foraging or as a source of drinking water except the beachmouse, *Peromyscus polionotus*, and the hispid cotton rat, *Signodon hispidus*, which were using the area as their habitat. The most important economic population in the area was the deer herd. Night field trips yielded average counts of 24–36 deer on

Fig. 6.35 Looking NE across Grid 1, Test Area C-52A, Eglin AFB, July 1983 (Photograph courtesy of A.L Young)

Fig. 6.36 Looking NE across Grid 1, Test Area C-52A, Eglin AFB, Florida, January 2004 (Photograph courtesy of AFATL, Eglin AFB, Florida)

the grid and within the immediate area. Close inspection of the aquatic areas on the grid (two small ponds) during early morning field trips revealed extensive activity the previous night. In addition to the deer herd a sizable herd of feral hogs earlier crossed with Russian Boars, also inhabited the area. The hogs frequented the marshy areas, drinking water and rooting for food (Pate et al. 1972).

During the spring of 1970, a red fox, *Vulpes fulva*, was frequently observed close to the grid and its den was found at the edge of the grid. Five kits were found in the den, and based upon gross observations, they appeared healthy and normal (Pate et al. 1972).

The most common rodent species on the grid was the beachmouse. Trapping studies during the summer of 1970 showed that this species was widely distributed throughout the grid except in areas with less that 5% vegetative cover or more than 60% vegetative cover. Because of its habitat on the test grid, the beachmouse was selected for additional studies of the potential impact of TCDD (Young 1974; Young et al. 1975).

At least 25 species of birds were observed in the area immediately adjacent to the grid or feeding within its boundaries. In 1970, seven species of water birds and waders were sighted repeatedly in the aquatic areas on or off the grid. Nine species of seed and insect gatherers were also observed feeding on or near the grid; the most common were the meadowlark, *Sturnella magna*, and the morning dove, *Zenaidura macroura*. Birds of prey and scavengers were well represented due to the high rodent population and good visibility afforded by an open area. Thus, it was significant that almost all birds sighted were medium to large species (Pate et al. 1972).

Eighteen species of reptiles were collected or observed, with 10 species recorded on the grid and 12 species from the surrounding area. Differences in faunal species composition on and off the grid due to vegetation differences were best illustrated with the reptiles. Those species that were adaptable and could occupy a variety of niches were found both on and off the grid in large numbers. The dominant species on the test grid was the six-lined racerunner, *Cnemidophorus sexlineatus*, and it was also one of the dominant species in the wooded area surrounding the grid. Those species whose habitat was characterized by definite vegetative type could not adapt to the open habitat of the grid. The southern fence lizard, *Sceloporus undulates undulates*, was one of these species. There were also species, which occurred in the forest areas but were more plentiful in the open areas of the grid, such as the eastern coachwhip, *Masticophis flagellum flagellum*. In 1973, the first softshelled turtle, *Ferox* sp., was seen on the grid (Pate et al. 1972; Young 1974).

Twelve species of amphibians were collected. The amphibian populations on the grid centered mainly around the aquatic areas with the exception of two toad species, which were also found in dry areas. There were breeding populations of amphibians throughout most of the year, especially with four species of frogs, *Rana, Hyla*, and *Acris* sp., and the two species of toads, *Bufo* sp. The slimy salamander, *Plethodon glutinosus glutinosus*, was one of the dominant species in the surrounding forest but did not occur because of its need for moist ground cover (Pate et al. 1972).

6.9.4 Aquatic Studies

One of the major parameters involved in the process of herbicide movement and/or persistence in soils is the adsorptive capacity of the soil. The adsorptive capacity, or the cation exchange capacity, is closely associated with the inorganic colloids (e.g., clay particles) and organic colloids (e.g., organic matter) of the soil. Soils with a low cation exchange capacity do not retain cationic herbicides (e.g., cacodylic acid, or sodium cacodylate), and thus, soil leaching of these herbicides would have been expected (Lehn et al. 1970). As previously noted, approximately 3,790 kg were sprayed on the test area during the period 1968–1970. Data from the analyses of soil cores confirmed the leaching of the cacodylic acid (as arsenic) through the soil profile (Hamme et al. 1970). Similar observations were noted for picloram (Young 1974).

A small pond existed on Grid 4 that was maintained by the presence of a spring and rainfall (Fig. 6.37). During the rainy season, April through September, water drained off of the test area to adjacent small streams (Fig. 6.38). Indeed, Test Area C-52A was drained by five streams: Mullet, Trout, Basin, Brassy, and Rucker Creeks (Fig. 6.39). The combined annual flow from these streams exceeded 6 billion liters of water. However, only Mullet, Trout, and Basin Creeks were closely associated with the test grid (Lehn et al. 1970).

Studies were conducted to determine (1) whether arsenic or picloram residues were entering the streams from the test grid, and (2) if so, whether these residues were having adverse effects on the fish populations in the streams or, in case of arsenic, were accumulating in oysters found at the mouth of streams adjoining Choctawhatchee Bay. Figure 6.40 was a photograph of AFATL personnel conducting species diversity studies of fish and aquatic insects in streams draining the test area (Lehn et al. 1970).

To assess the effects of possible arsenic residues, a diversity index study of fish populations of Mullet, Trout, and Basin Creeks was initiated 3 months prior to the aerial spraying of Blue in 1969 and continued for approximately 4 months after spraying. The aerial dissemination of Blue started in July of 1969 and the last mission with Blue was in May 1970. Of the three streams under investigation, Trout Creek seemed the most likely to arsenical residues from the grid area. The headwaters of the stream were at the bottom of steep-sided bayheads adjacent to the edge of the grid and directly in line with the lower extremities of the repeatedly used spray flight path (see Fig. 6.39). From its headwaters, the stream flows approximately 3 km directly south into

Fig. 6.37 A photograph of the pond on Test Area C-52A, Eglin AFB, Florida. The pond and associated fish species were sampled for species diversity and TCDD residues (Photograph courtesy of P.J. Lehn)

Fig. 6.38 Water frequently drained from the Test Area to small streams adjacent to Test Area C-52A. These streams were periodically studied for species diversity and herbicide and TCDD residues (Photograph courtesy of P.J. Lehn)

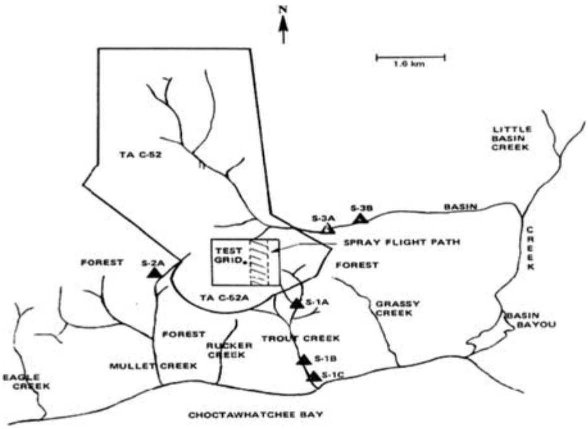

Fig. 6.39 Map of Test Area C-52A and adjoining area of the Eglin AFB Reservation showing streams in relation to the Test Grid (Grid 4) and the location of sampling stations used in the arsenic monitoring studies (Lehn et al. 1970; Hamme et al. 1970)

Choctawhatchee Bay. Three sampling stations were established on Trout Creek, two on Basin Creek, and one on Mullet Creek (Lehn et al. 1970; Hamme et al. 1970).

On each sampling date, observations were made in an effort to detect any gross changes in the population levels of selected benthic organisms. Fish were

Fig. 6.40 AFATL personnel conducting species diversity studies of fish and aquatic insects. This was an important method to evaluate off-site ecological impacts from the Test and Evaluation Programs conducted on Test Area C-52A, Eglin AFB, Florida (Photograph courtesy of P.J. Lehn)

collected with a variety of seines. For the first few months of the survey, the fish and benthic organisms were return to the stream after the total catch was made and counted. However, for the majority of the survey, the fish were preserved in 10% formalin and counted in the laboratory. Some of the fish were made available for arsenic analysis. In conjunction with the stream sampling, two ponds on the test grid were sampled using dip nets (Lehn et al. 1970; Hamme et al. 1970).

Water samples were routinely collected at all stations and in Choctawhatchee Bay after each rainfall following missions involving Agent Blue. If no missions were flown, water samples were collected monthly. The samples were sent to the Regional Environmental Health Laboratory, Kelly AFB, Texas where they were analyzed for arsenic. Detritus (bottom) samples were also taken and prepared for arsenic analysis (Lehn et al. 1970). Because oysters are filter feeder, “natural” arsenic content of their bodies has been correlated with that of their environment. Hence, oyster racks were established in Choctawhatchee Bay at the mouths of Basin, Trout, and Mullet Creeks, and oysters were periodically sampled from these racks and analyzed for arsenic (Hamme et al. 1970). Water samples were collected for picloram analysis from a small bayhead of Basin creek, an area nearest to the flight path for dissemination of Agent White (Young 1974).

Twenty-one species of fishes were collected, with three species occurring within the boundaries of Grid 4, and 20 species from the surrounding streams. The employment of a diversity index (i.e., a statistical comparison of the fish populations before and after the spray missions) showed a population change in one fish species at one of the six stations studied. This change, however, was probably due to an unidentified variable (e.g., variation in collecting techniques) rather than to arsenic residue (Lehn et al. 1970). The arsenic analyses for 588 water samples and 68 silt/detritus samples were negligible (less than 1 ppm and not significantly different from control streams). A comparison of arsenic contents of 73 oyster samples taken from the oyster racks established in Choctawhatchee Bay showed no significant differences from control samples taken elsewhere in the bay at the 95% probability level (1.32 ppm versus 1.45 ppm) (Hamme et al. 1970).

The results of water samples collected from the streams and analyzed for picloram showed that picloram concentrations as high as 11 ppb were present is samples from Basin Creek Bayhead near Sampling Station A-11. Picloram residues were detected at this site until December 1971 (Young 1974). The last mission involving Agent White was in May 1970. Additional studies of the aquatic ecosystem associated with the test area were also conducted in 1975 and again in 1976 (Young et al.1975; Crews 1976).

6.9.5 Insect Studies

A 1973 sweep net survey of the arthropods of Grid 4 on Test Area C-52A resulted in the collection of 5,966 specimens belonging to 71 insect families and two arachnid orders (Young 1974). Figure 6.41 was a photograph of an entomologist conducting the sweep net survey of the grid. The total number of specimens represented the collections of five paired sweeps over a 1.6-km section of the test grid. A similar study performed in 1971 had produced 1,796 specimens, representing 70 insect families and one arachnid order, from five paired sweeps of the same area using the same basic sampling techniques (Valder 1972). A much greater number of small to minute insects were taken in the 1973 study. Vegetative coverage of the test area had significantly increased since the 1971 study. Comparison of the results of the two studies also show significant increases in the number of arthropod specimens and varieties per sampled grid transect, but there was little overall change in calculated community density (Young et al. 1975). These results were not

Fig. 6.41 Insect studies of the Test Area were conducted in 1971 and 1973, Test Area C-52A, Eglin AFB, Florida. Both the number of specimens and insect families increased over time (Photograph courtesy of A.L. Young)

Table 6.9 Results of Ecological Survey, 1969–1978 of Test Area C-52, Eglin AFB Reservation, Florida (Young et al. 1975, 1979)

Number of species observed or collected	Organisms
123	Plants
77	Birds
71	Insect families
21	Fish
18	Reptiles
18	Mammals
12	Amphibians
2	Mollusks

unexpected, and the population was predicted to increase as the test area stabilized and developed further plant cover, thus allowing a succession of animal and insect populations to invade the recovering habitat.

6.9.6 *Summary of Ecological Surveys*

Perhaps the most startling observation about Test Area C-52A was the abundance of biological organisms. From the first studies initiated in 1969 to the final observations in 1978, the composition of species was diverse and the distribution extensive. Table 6.9 is the summary list of the 342 species of organisms observed and identified on or associated with the test grids of Test Area C-52A.

The sheer number of species testified to the extensiveness of the ecological studies that have been conducted on this unique test area. In the years after 1973, many of the studies focused on collecting species that may have been exposed to and had retained detectable levels of the contaminant TCDD.

6.10 Persistence of TCDD in the Soils of Test Area C-52A

In the spring of 1971, soil cores were selected that previously had high levels of herbicide residues in them as indicated by the bioassay studies. These cores were collected from Grid 4, an area that had been sprayed with Agent Orange from 1968 to 1970. The samples were analyzed by the United States Department of Agriculture's Pesticide Degradation Laboratory, Beltsville, Maryland, and found to be negative at a detection limit of 0.001 ppm TCDD. No additional samples were collected until 1973 (Young 1974). That year, new data from studies conducted in Vietnam by other researchers (Baughman and Meselson 1973) suggested that TCDD might persist in sites sprayed with Agent Orange. A critical review of the history of the test grids, combined with data suggesting that the 2,4,5-T herbicide from Agent Purple may have been heavily

Fig. 6.42 Two AFATL scientists collecting 15-centimeter soil samples to a depth of 90 centimeters from Grid 1 for analysis of TCDD in June 1973, Test Area C-52A, Eglin AFB, Florida (Photograph courtesy of A.L. Young)

contaminated with TCDD, indicated that the site to search would be Grid1. Simultaneously, the analytical detection for TCDD was approaching the level of parts-per-trillion (ppt). The subsequent analysis of Grid 1 soils in 1973 confirmed the presence of TCDD (Young 1974). Figure 6.42 is a photograph taken in June 1973 of two AFATL scientists collecting soil samples from Grid 1 for TCDD analysis. Note that no precaution was taken to prevent skin contamination. The spatula was rinsed in acetone between collection of samples, and the samples once collected were transferred to glass bottles. A subsequent fat biopsy for TCDD from one of these individuals was conducted in 1978 (Young 2002).

A variety of sampling and residue monitoring studies for TCDD have been conducted on the test area (Young 1974; Young et al. 1975, 1979, 1987; Bartleson et al. 1975; Young 1983; Harrison and Crews 1983; Young and Cockerham 1985). Because of the long-term nature of these studies, it has been necessary for more than one laboratory to provide analytical services. The TCDD analyses reported were obtained through Air Force contracts for analytical services from five different laboratories.

The analytical results of a 1974 sample from Grid 1 revealed that most of the TCDD was in the top 15 cm of the soil profile (Table 6.10). This was also confirmed in 1984 with soil samples collected and analyzed from approximately the same location, and these data are also presented in Table 6.10. The methodology for the collection of these composited soil samples was illustrated in Fig. 6.43. A soil block of 1.0 × 0.5 m was carefully excavated and, for example, ten 10 ×10 × 2.5-cm soil increments or 10 × 10 × 5.0-cm soil increments were carefully removed from the block. Each increment representing the same depth was mixed with its other increments and a sub sample was submitted for TCDD analysis.

From June 1974 through April 1978 soil samples were collected in an attempt to define the magnitude of TCDD contamination remaining on the three grids that received 2,4,5-T herbicide (Young et al. 1979). These data are shown in Table 6.11. The aerial distribution of herbicides on a test grid was neither

Table 6.10 Concentration of TCDD in soil profiles from the center of Grid 1, Test Area C-52A, Eglin AFB, Florida (Young et al. 1987)

	TCDD[1]	
Soil depth (cm)	1974	1984
0–2.5	150	460
2.5–5.0	160	815
5.0–10.0	700	2,375
10.0–15.0	44	1,100
15.0–30.0	ND[2]	35
30.0–45.0	ND	ND

[1] Grid 1, an area of 37 ha, received approximately 32,425 kg 2,4,5-T containing approximately 2.918 kg TCDD
[2] None detected; minimum detection limit <10 ppt in 1974, and <3 ppt in 1984

Fig. 6.43 The methodology for collecting soil cores for TCDD analysis in 1974 and 1978, Test Area C-52A, Eglin AFB, Florida (Photograph courtesy of A.L. Young)

Table 6.11 Concentration of TCDD, parts-per-trillion, in top 15 cm of soil on the three test grids receiving 2,4,5-T herbicide, Test Area C-52A, Eglin AFB, Florida (Young 1983)

Grid number	Number of samples[2]	Range	Median	Mean
1	22	<10 – 1,500	110	325
2	6	<10 – 470	30	115
4	26	<10 – 150	20	30

[1] Samples collected during the period June 1974 through April 1978

uniform nor random, but rather along discrete sampling arrays arranged to measure particle size and disposition. Moreover, since the flights also occurred either in-wind or crosswind, and the testing of the aerial dissemination equipment for Grid 1 extended from June 1962 through July 1964, tremendous variations in residue levels would have occurred (note the range of soil TCDD

Table 6.12 Results, parts-per-trillion, from a study on the disappearance of TCDD from top 10 cm of soil of Grid 1 sampled in 1974 and 1978, Test Area C-52A, Eglin AFB, Florida (Young et al. 1987)

Plot number[1]	August 1974	January 1978
1	1,500	420
2	610	300
3	1,200	580
4	270	100
5	440	400
Mean	805 ± 525^2	360 ± 175^2

[1] Five 10-cm soil samples sub sampled from each 1-m2 plot and composited for a single analysis
[2] Means between the two dates were not significantly different

levels for Grid 1 in both Tables 6.10 and 6.11). To overcome these variations, and to assess whether "disappearance" of TCDD was occurring, composite samples from 1-m^2 plots were sample to a depth of 10 cm on Grid 1 in August 1974 and again in January 1978. These data are shown in Table 6.12.

The data from the composite samples collected in August 1974 and again in January 1978 suggested a downward trend in the concentration of TCDD (Young 1983). However, the magnitude of decrease between the samples was inconsistent. These data suggested that factors other than actual disappearance of TCDD was involved. Indeed, samples collected and analyzed in 1974 were analyzed by a different laboratory than samples collected and analyzed in 1978. Moreover, studies of the TCDD concentrations in soils at Hardstand 7 confirmed that TCDD was very persistent once it was bound within the soil profile (Vasquez et al. 2004). The key to the disappearance of TCDD on the test grids of Test Area C-52A must have been factors that were present at the time the contaminated herbicide was disseminated (Young 1983).

6.11 Routes of TCDD Disappearance on Test Girds Receiving 2,4,5-T Herbicide

Data from a review of operational records from evaluations of the particle/droplet distribution of herbicide from the spray equipment tested on Test Area C-52A indicated that approximately 87% of the herbicide droplets fell within the instrumented area (Flynn 1964; Harrigan 1970a). Therefore, if 87% of the TCDD in the herbicide applied to Grid 1 impacted the 37-ha test grid, then approximately 2.54 kg TCDD needed to be accounted for on Grid 1 (see Table 6.4; $2.918 \times 0.87 = 2.54$ kg). If a mean value of 325 ppt (Table 6.10) was used as the level of TCDD in 1978 for the top 15 cm of soil, and the density of the Lakeland Sand was 1.4 grams per cubic cm, then 25.25 grams of TCDD remained in 1978, or approximately 1% of the TCDD remained 14 years after application of the Herbicide Purple (Young and Newton 2004).

Numerous routes have been proposed for the disappearance of TCDD from soil (Young et al. 1975; Crosby and Wong 1977). The methods most likely responsible for TCDD disappearance from the test grids include photodegradation, wind and water movement of contaminated particles, volatilization, microbial degradation, and biomass removal (Young 1983).

When Agent Orange containing known amounts of TCDD and exposed to natural sunlight on leaves, soil, or grass, most of the TCDD was lost in a single day, due principally to photochemical dechlorination (Crosby and Wong 1977). Furthermore, it was found that three requirements were needed for significant TCDD breakdown in the environment; namely, dissolution in a light-transmitting film, the presence of an organic hydrogen donor such as a solvent or pesticide, and ultraviolet light. All three conditions were normally met during the practical application of 2,4,5-T herbicide (Crosby and Wong 1977).

During the major years of testing spray equipment, an Automated Meteorological Data Acquisition and Processing System (AMDAPS, see Section 6.1) was continuously monitoring micrometeorological conditions existing below 9 m over the test area (Grid 4) (Young 1974). This system automatically measured, processed, and stored data from meteorological sensors on a series of towers on the test grid. Thus a mechanism for monitoring temperature, wind, rainfall, dew point, and periods of sunlight was available in scheduling test operations. Missions were generally scheduled and conducted when environmental conditions were optimal (Young 1974). This suggested that conditions favorable for dissemination of Agents Orange and Purple were probably the same conditions favorable for the photodegradation of TCDD. Thus it was most likely photodegradation that occurred immediately after herbicide dissemination that was responsible for the majority of TCDD disappearance. More than 70 personnel were directly involved in the day-to-day operations of the test site, during the years of its operation, 1962–1970. The failure of test operations personnel to observe or record animal deaths or to have experienced readily detected health problems, e.g., chloracne, suggested that significant TCDD accumulation on the test girds did not occur (Thalken and Young 1983). However, the limitation of anecdotal information has been recognized.

Examination of the soil horizons in excavated profiles of Grid 1 clearly showed discrete layers within the top 15 cm that differed from the parent soil (see Fig. 6.43). In reviewing climatic data from the test area, it was possible to plot the surface wind quadrates (Young et al. 1975). It was found that the direction and speed of the prevailing winds resulted in soil moving not only back and forth across Grid 1, but because of slight differences in topography between Grids 1 and 2, contaminated soil from Grid 2 could have been deposited in low areas of Grid 1. Thus the variation in TCDD concentration with depth as noted in Table 6.10. It is also likely that water moved contaminated particles into low-lying areas of Grid 1 (Young 1974). TCDD movement through water erosion into the aquatic systems adjacent to Grid 1 has been documented (Young et al. 1975). The magnitude of this loss could not be measured but it was likely low because monitoring studies consistently detected amounts ranging from non-detected levels (less than 10 ppt) to 35 ppt in eroded soil.

Biomass removal of TCDD has been documented on the test grids (Young 1983). Two major biologic systems functioned in the removal of TCDD from the test grid soils. The first system involved the plant uptake of TCDD, and the second system involved the accumulation of TCDD in animal tissues and pelts. Both of these methods have been described and the magnitude of their role in removing TCDD from the soil has been estimated to be very low (Young 1983).

As of 1987, less than one percent of the TCDD remained in the ecosystem of the test site with the bulk of the 1% retained in the soil of Grid 1 (Young et al. 1987). Nevertheless, it appeared that mechanisms were operative for the removal of TCDD from soil. The "crude" data available on the processes of water and wind transport of contaminated particles, and on biomass removal suggested that far less than one percent of the TCDD annually disappeared through these mechanisms. Studies conducted adjacent to Grid 4 in 1984 on soils from experimental plots treated with Agent Orange by subsurface placement confirmed the volatility of TCDD in soil, but it was described as a process that occurred very slowly (Freeman and Schroy 1989).

6.12 Animal Studies of TCDD Uptake

As previously noted, studies of the animals of Test Area C-52A began in 1969. However, detailed investigations of key species, e.g., the beachmouse, *Peromyscus polionotus*, and the six-lined racerunner, *Cnemidophorus sexlineatus*, did not begin until 1973 (Young 1974). Key species have been repeatedly studied in subsequent years (1974, 1975, and 1978). The birds were studied in 1974 and 1975. Insect studies were conducted in 1970, 1971, and 1973, while aquatic communities were initially examined in 1970, and then more thoroughly in 1973 and 1974. Lists of species, description of habitats, and after 1973 TCDD residue analysis, were conducted throughout the years of study. Results of many of these surveys have been published (Young et al. 1975, 1979, 1987; Bartleson et al. 1975; Young 1983). More than 300 biological samples were analyzed for TCDD. TCDD residues have been found in a wide spectrum of animals collected from the test area. Approximately one-third, or 32, of the different animals species examined for TCDD residue have been positive. Tables 6.13, 6.14, 6.15, 6.16, and 6.17 provide data on those mammals, birds, insects, reptiles and amphibians, and fish, respectively, found to have had detectable levels of TCDD.

Why were the above species contaminated with TCDD while other species found on the same test area were not? Examination of the species by ecological niche suggested that the commonality was a close relationship to the contaminated soil (Young et al. 1987). For example, the beachmouse and the hispid cotton rat dig burrows. The cotton rat dug burrows near the water and in areas of high vegetation density. The beachmouse preferred areas of low vegetation

Table 6.13 TCDD residues, parts-per-trillion, in mammals collected from Test Area C-52A, Eglin AFB, Florida (Young et al. 1987)

Species	Tissue	Concentration (ppt TCDD)	Detection limit (ppt)
Deer	Fat	ND[1]	4
	Liver	ND	5
	Kidney	ND	4
Opossum	Fat	ND	10
	Liver	ND	10
Rabbit	Liver	ND	8
	Pelt	ND	2
Cotton Rat	Liver	10 –210	
Beachmouse	Liver	300–2,900	
	Pelt	130–300	

[1]ND = Not Detected

Table 6.14 TCDD residues, parts-per-trillion, in avian species collected from Test Area C-52A, Eglin AFB, Florida (Young et al. 1979, 1987)

			TCDD Residue (ppt)	
Species	Tissue	Number of samples[1]	Range	Mean
Southern Meadowlark	Liver	3	100–1,020	440
	Stomach	1		10
Mourning dove	Liver	2		50
	Stomach	1		10
Savannah Sparrow	Liver	1		69
	Stomach	1		84

[1]Composites from at least six birds.

Table 6.15 TCDD residue, parts-per-trillion, in insects collected from Test Area C-52A, Eglin AFB, Florida (Young et al. 1987)

Family	TCDD residue (ppt)
Grasshoppers	ND (3)[1]
Crickets	18–26
Composite of soil and plant-borne insects	40
Burrow spiders	115
Insect grubs (Coleoptera)	238

[1](3) = Detection limit

Table 6.16 TCDD residue, parts-per-trillion, in reptiles and amphibians collected From Test Area C-52A, Eglin AFB, Florida (Young et al. 1987)

Species	Tissue	TCDD residue (ppt)	Detection limit
Six-lined Racerunner trunk	Viscera	360	50
370–430 40			
Snake	Whole Body	420	20
Southern toad	Whole Body	1,360	90
Western Coachwhip Snake	Muscle	ND[1]	14
	Fat	148	64
	Skin	20	20
Pin snake (immature)	Whole Body	ND	70

[1]ND = Not Detected

Table 6.17 TCDD residue, parts-per-trillion, in aquatic species collected from the drainage system of Test Area C-52A, Eglin AFB, Florida (Young et al. 1987)

Species	Tissue	TCDD residue (ppt)
Mosquito fish	Whole body	12
Sailfin shiner	Whole body	12
Spotted sunfish	Skin	4
(Grid 4 Pond)	Gonads	18
	Muscle	4
	Gut	85

density, e.g., the centers of the old flight paths. The deer, opossum, and rabbit did not burrow, but rather rested/nested upon the vegetation. The crickets, ground spiders, and soil-borne insects were significantly contaminated, but the grasshoppers were not. The Southern Toad was found in abandoned rodent burrows. The Spotted Sunfish was a bottom feeder and its visceral mass was comprised largely of silt and detritus (Young et al. 1975).

In general, the mean level of TCDD found in the soil was closely related to the levels of TCDD in the organisms. Table 6.11 reported mean values of 325, 115, and 30 ppt TCDD for the top 15 cm of soil on Grids 1, 2, and 4, respectively. Most of the racerunners (360 ppt), snakes (148–420 ppt), Southern Toad (1,360 ppt), and soil-borne insects and grubs (40–238 ppt) were captured on Grid 1. The cotton rat (10–210 ppt) was captured on Grids 2 and 4 (115 and 30 ppt, respectively). The exception to this observation was the beachmouse, Southern Toad, and the Southern Meadowlark. Observational studies of the beachmouse and Southern Meadowlark revealed a similar habit – they were both fastidious groomers/preeners (Young et al. 1987).

The Southern Meadowlark kicked up top soil and "dusted" its feathers. Preening resulted in the ingestion of the contaminated soil. However, it should be noted that the Meadowlark also ingested soil-borne insects. These insects probably had a significant amount of TCDD on them due to the adherence of contaminated soil particles. Thus, the role of the insects in contaminating birds was not clear. The Southern Toad ingested primarily soil-borne insects, and here too, the role of contaminated soil particles on the insect versus ingested TCDD with the insect was not clear.

It can be concluded from the Test Area studies that accumulation of TCDD occurred in numerous animal species. The magnitude of the concentration of TCDD detected in an animal was apparently dependent upon the level of TCDD residue found in the soil environment where it inhabited (Young et al. 1987). Only two species have been adequately studied to address body-burden levels of TCDD. The six-lined racerunner was the second most commonly observed animal (reptile) on the test area. It was especially common on Grids 1 and 2, where the vegetation density was light. Figure 6.44 was a photograph of the six-lined racerunner, *Cnemidophorus sexlineatus*. Samples of the six-lined racerunner were collected and analyzed over three consecutive years, 1973,

Fig. 6.44 The Six-lined Racerunner, *Cnemidophorus sexlineatus*, was the most abundant reptile and the second most abundant animal observed on Test Area C-52-A, Eglin AFB, Florida (Young et al. 1975)

1974, and 1975. The TCDD levels in the samples collected were consistent for all three years; i.e., 360, 370, and 430 ppt TCDD. The levels in the visceral mass and the trunk were essentially the same, suggesting that the levels of TCDD in the two portions of the body were at equilibrium. If the median (not mean) soil levels for TCDD were used (because of distribution – the racerunner had an extensive range within its habitat) then, a concentration factor of approximately four existed (110 ppt in soil as compared to 400 ppt as body burden) (Young et al. 1987).

6.13 Long-term Field Studies of the Beachmouse, *Peromyscus polionotus*

Detailed investigations of the beachmouse, *Peromyscus polionotus*, did not begin until 1973, approximately three years after the last mission of Herbicide Orange on the test area. Figure 6.45 was a photograph of the beachmouse. Its

Fig. 6.45 The Beachmouse, *Peromyscus poliontus*, was the most frequently observed mammal species on Test Area C-52A, Eglin AFB, Florida (Photograph courtesy of P.J. Lehn)

Fig. 6.46 Typical habitat of the Beachmouse was sparsely covered sandy soil with tufts of *Pancium* grass and low growing herbaceous plant species. Areas denuded by herbicide were ideal sites for the Beachmouse. This Photograph was taken in June 1973 on Grid 1, Eglin AFB, Florida (Photograph courtesy of A.L. Young)

large ears and sandy color distinguished it from the common field mouse. The beachmouse thrived in open sandy area; the typical habitat found along the Florida Gulf Coast. Studies of population density confirmed that the beachmouse was the most commonly observed species on the test grids (Young et al. 1975). Indeed, as shown in Fig. 6.46, the beachmouse thrived in areas denuded by the herbicide on Test Area C-52A.

In the laboratory, teratogenesis from exposure to TCDD has been documented only in the mouse (Bionetics 1968). For other species, fetotoxicity occurred rather than teratogenesis. Thus, it was reasoned that a study of the beachmouse at the Eglin test area would provide an understanding of the impact of TCDD in a "real world" environment. Certainly significant concentrations of TCDD had been present in the soils of Grid 1 for at least 11 years (1962–1973). Animal populations were diverse on Grid 1, and many species were shown to be heavily (by normal field standards) contaminated with TCDD (1–2 parts-per billion). Thus, extensive studies of the beachmouse were conducted in 1973, 1974, 1975, and 1978 (Thalken and Young 1983).

Initially "Have-a-Heart" traps were used to capture the beachmouse. But this method did not allow for capturing beachmouse "families", nor did it permit correlating the contaminated soil, associated with the burrow and nest, with the TCDD levels in the animals (Young et al. 1975). Figure 6.47 was a photograph of an active beachmouse burrow. Note the mound soil, i.e., the soil removed during the digging of the burrow by the animal. The best method to capture the beachmouse, the "family", the nest contents, and obtain samples of "mound" soil and soil profile for comparing environmental concentrations of TCDD to biological concentrations was to "dig" the burrow (Young et al. 1975). Figure 6.48 was a photograph that illustrated this method of digging the burrow. Thus, TCDD analyses have been conducted on components of the beachmouse and its habitat. The analytical capability permitted an analysis of a single liver sample. The significance of this capability is shown in Table 6.18. Note that mature animals, pups, and fetuses were analyzed for TCDD. The female beachmouse typically was nursing four pups while

Fig. 6.47 A photograph of an "active" Beachmouse burrow and the mound soil taken on Grid 1 in July 1974, Test Area C-52A, Eglin AFB, Florida (Photograph courtesy of A.L. Young)

Fig. 6.48 The best method of capturing the Beachmouse (the male, female, and pups) was to use a shovel and dig up the "active" burrow; Grid 1, Test Area C-52A, Eglin AFB, Florida, July 1974 (Photograph courtesy of A.L. Young)

simultaneously carrying four fetuses (Thalken and Young 1983). Figure 6.49 was a photograph of fetuses removed from a pregnant beachmouse capture on Grid 1.

It was clear from these studies that the liver was the site of TCDD accumulation in the beachmouse. The magnitude of those levels apparently depended upon the levels of TCDD in the soil (Thalken and Young 1983). The mound soil was that soil removed during the course of digging the burrow by the animal. It was, however, a mix of contaminated soils that had a wide range of concentrations from non-detectable below 15 cm to levels of almost 500 ppt in the top 15 cm of soil (see Table 6.18). Thus, the analysis of the mound soil was treated as a representative level of soil contamination (Thalken and Young 1983). If the concentration of TCDD in the mound soil represented mean exposure, then the concentration factors for animals from site 0–4 was between 6 and 7 (500 ppt

Table 6.18 TCDD residue, parts-per-trillion, in soil and the Beachmouse from selected sites on Grid 1, Test Area C-52A, Eglin AFB, Florida (Thalken and Young 1983; Young 1984b)

Component		Grid 1 locations Site 0-4		Site 0-7
Soil		0–5 cm = 150		0–5 cm = 510
		5–10 cm = 155		5–10 cm = 520
		10–15 cm = 70		10–15 cm = 440
		[1]Mound Soil = 75		Mound Soil = 285
Beachmice				
Burrow 1	Female	Liver = 500	Female	Liver = 1,900
		Pelt = 110		Pelt = 160
	Pups	Liver = 500	Fetuses	Whole Body = 15
		Pelt = 150		
	Fetuses	Whole Body = 40	Male	Liver = 2,600
				Pelt = 150
Burrow 2	Female	Liver = 490		
		Pelt = 140		
	Composite Males	Liver = 1,400		
		Pelt = 160		

[1]Soil removed by the mouse from the burrow

divided by 75 ppt = 6.67) for females and 18–19 for males. The concentration factors for site 0–7 were between 6 and 7 for females and approximately 9 for males. It was assumed in these studies that body burden levels of TCDD were actually liver levels of TCDD. The Beachmice obtained from the field were not found to contain significant levels of body fat, which is consistent with other studies of wild mouse populations (Thalken and Young 1983).

But how was the beachmouse contaminated? The beachmouse burrowed in contaminated soil, and during the evenings it left and entered the burrow frequently. Each time it went into or out of the burrow, it passed through the soil "zone of contamination"; generally a 15-cm zone of contaminated particles.

Fig. 6.49 Beachmouse fetuses examined following necropsy of the pregnant female. Mice from both a control site and Test Area C-52A were critically examined; no abnormalities were observed (Photograph courtesy of the Armed Forces Institute of Pathology, Washington DC)

Once in the nest, the animal groomed the contaminated particles from the pelt, thus providing a biological environment where the digestive system stripped the TCDD from the particle and accumulated it in the liver (Young et al. 1975; Cockerham and Young 1982; Cockerham and Young 1983). Studies were conducted on 23 beachmice brought into the laboratory where the fur on the central thoracic and abdominal regions, side, back and tail on each test animal was dusted with alumina gel containing 2.5 parts-per-billion (ppb) TCDD. Control animals were dusted in the same body areas but with alumina get alone. The dusting procedure was repeated every third day for a total of 10 applications during a 28-day period. The beachmice were observed grooming themselves frequently. At the end of study, the test animals averaged 125 ppt in their livers, while the control animals had undetected levels of TCDD (Young et al. 1975; Cockerham and Young 1982). Obviously, in the field, the beachmouse could have also ingested TCDD from its food sources. As previously noted, soil-borne insects and grubs were contaminated with TCDD (Young et al. 1987).

Sections of liver tissue from both the laboratory-exposed and field-exposed levels of TCDD noted above were also used for an ultrastructural study and compared to control animals. No significant differences were noted in either the laboratory comparison or field comparison, i.e., no significant histopathological lesions were observed (Cockerham and Young 1982). When field animals were compared with laboratory animals, significant differences were noted in certain organ weights and cellular structural components. These differences were attributed to dissimilarities in field and laboratory environments (Cockerham and Young 1983).

How long did it take beachmice to accumulate the levels of TCDD in their livers as noted in Table 6.18? In 1974, beachmice were obtained from a control site on the Eglin Reservation, and raised in an animal colony in the laboratory. In October 1975, hundreds of mature animals were "tagged" and transported to Grid 1 and released. Three months later (December 1975), a small number of these animals were recaptured. The analyses of livers and pelts of the tagged animals, plus captured indigenous (native) animals from the same site, are shown in Table 6.19. The data suggested that body burden levels were obtained at this site within 3 months. Note also that the body burdens were between 5 and 8 for tagged and natives, respectively. However, the tagged animals were pooled

Table 6.19 A TCDD exposure study of the beachmouse released and recaptured on Grid 1, Test Area C-52A, Eglin AFB, Florida (Thalken and Young 1983)

Mean soil concentration of the 0-15-cm "contaminated zone" = 326 ppt TCDD	Results[1]	
Beachmice released 16 September 1975	Tagged beachmice	Livers = 1,700 ppt (Male/Female) Pelts = 200 ppt
Beachmice recaptured 22 December 1975	Native beachmice	Livers = 2,600 ppt (Male) Pelts = 190 ppt

[1]Pooled Samples.

and the analysis represented both sexes, while the native beachmice samples were pooled and represented only males (Young et al. 1975; Thalken and Young 1983).

Did the levels of TCDD residue impact the health and reproduction of the beachmouse? The approach to answer this question was to collect beachmice from the test grid and a control site and compare them for as many parameters as possible (Young et al. 1975). In those females that were pregnant, the fetuses were also critically examined. All animals were prepared for examination using a cervical dislocation procedure to accomplish humane euthanasia. The euthanized animals were photographed, weighed, measured, and systematically examined for defects such as cleft plate, cleft lip, polydactyly, and microphthalmia. All internal organs were examined for gross lesions and individually weighed. Representative sections of each tissue were placed in neutral 10% buffered formalin and processed for microscopy study by the Veterinary Pathology Division, Armed Forces Institute of Pathology, Washington DC. Remaining liver tissues from mice captured in the test and control areas were placed in glass vials, frozen, and retained for TCDD analysis (Young et al. 1975; Thalken and Young 1983).

Histopathological examinations were performed on 255 adult, immature, or fetal beachmice from the test area and a control area. Examinations were performed on the heart, lungs, trachea, salivary glands, thymus, liver, kidneys, stomach, pancreas, adrenals, large and small intestine, spleen, genital organs, bone, bone marrow, skin and brain. Initially, the tissues were examined on a blind study basis. All microscopic changes were recorded including those interpreted as minor or insignificant. The tissues were then re-examined on a control versus test basis, which demonstrated that the test and control mice could not be distinguished histopathologically (Young et al. 1975; Thalken and Young 1983). Figure 6.50 was an example of the histopathological study conducted

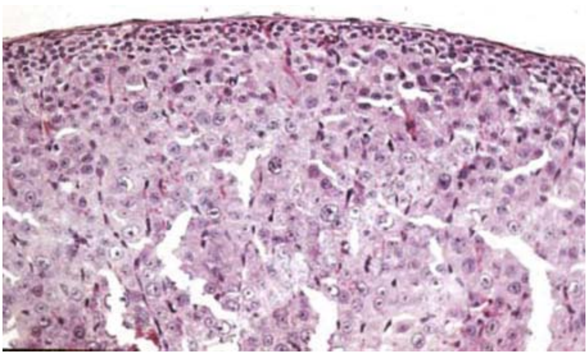

Fig. 6.50 Photomicrography of the liver of a Beachmouse showing damage from hepatitis. The Beachmouse was collected on Test Area C-52A, Eglin AFB, Florida, in July 1974. The histopathology was conducted by the Armed Forces Institute of Pathology, Washington DC (Photograph courtesy of the Armed Forces Institute of Pathology)

Table 6.20 Mean body weights and liver weights of pregnant female and mature male Beachmice, *Peromyscus polionotus*, from control and TCDD-exposed field sites, Test Area C-52A, Eglin AFB, Florida (Thalken and Young 1983)

		Females			Males		
Site	Year	Number of animals	Body wight (g)	Liver (mg)	Number of animals	Body weight (g)	Liver (mg)
Control	1973	3	16.29 ± 2.66	955 ± 308	4	11.88 ± 1.03	708 ± 114
	1974	3	11.98 ± 0.85	640 ± 220	11	12.02 ± 1.21	611 ± 111
	1975	1	15.84	955	3	13.25 ± 0.24	837 ± 103
	1978	2	13.94 ± 3.48	868 ± 140	2	11.91 ± 0.32	667 ± 5
Test grids	1973	6	15.45 ± 2.00	1253 ± 175	18	11.84 ± 1.12	819 ± 223
	1974	6	15.75 ± 1.33	1035 ± 98	14	11.49 ± 0.93	664 ± 150
	1975	4	16.05 ± 1.74	1138 ± 58	7	11.67 ± 0.83	774 ± 112
	1978	6	15.67 ± 2.20	1115 ± 171	7	12.25 ± 1.35	756 ± 130

by the Armed Forces Institute of Pathology. It was a photomicrograph of a liver tissue removed from a beachmouse collected on Grid 1. The tissue confirmed damage due to hepatitis, a condition common to both test grid and control beachmice.

Table 6.20 provides body and liver weights for the pregnant female beachmice and the mature male beachmice, respectively. These were the two largest segments of the population that was captured. A two-factor (treatment and year) disproportional analysis of covariance of organ weights revealed that liver weights for pregnant females were significantly heavier ($P < 0.01$) between the control and test area beachmice, and these differences were consistent over the years of observation. The lack of adverse effects from TCDD seen in beachmice from Grid 1 may have indicated the presence of some mechanism for physiological adaptation. Indeed, the increase in liver weight may have reflected an increase in enzymatic activity associated with low-level exposure to TCDD. An ultrastructural study of liver tissue from test and control site females found no morphologic differences (Thalken and Young 1983; Cockerham and Young 1983).

The mean number of fetuses per observed pregnancy was 3.1 and 3.4 for the test area and control area, respectively. A single female beachmouse is capable of producing litters every 26 days. At this frequency, the animals collected in 1978 may have been at least 50 generations removed from the population studied in 1973 (Thalken and Young 1983; Young and Newton 2004).

6.14 Actions to Control the Movement of TCDD from Hardstand 7 and Test Area C-52A

In March 1981, the USAF Occupational and Environmental Health Laboratory (OEHL), Brooks AFB, Texas provided recommendations to the Commander of the Air Development and Test Center, Eglin AFB in reference to a request as to public or military personnel having open access to Test Area C-52A (Ord 1981). The Recommendations by OEHL included:

- The northern one-half of Test Area C-52A can be used in an unrestricted fashion for mission support activities;
- The southern one-half of Test Area C-52A can be used to support mission activities with the only restriction being that of limiting off-road vehicular traffic; and
- All efforts should be extended to prevent erosion-causing activities on Grid 1.

In April 1984, the Engineering & Services Laboratory, Tyndall AFB, Florida recommended that for "*Grid 1, usage should be restricted to essential mission activities. Reasonable and prudent efforts should be undertaken to prevent erosion-causing activities*" (Channell and Stoddart 1984). In 2003 a public health assessment concluded that the dioxin levels on Test Area C-52A and potential exposures were below levels that have been demonstrated to cause illness or measurable adverse health effects (ATSDR 2003).

A series of actions were taken to control the movement of contaminated soil from Hardstand 7. In 1978 a dike was constructed to control erosion into a small pond directly down slope from the Hardstand (Harrison, Miller, and Crews 1979). In an April 1984 report it was concluded that soil contamination levels in and immediately adjacent to Hardstand 7 were well in excess of EPA action levels (Channell and Stoddart 1984). Accordingly, the area between the dike and the Hardstand was capped by asphalt, and a storm drain was constructed to remove excess water to sediment ponds located 500 m east of the Hardstand. In 1995, more drainage controls were incorporated to minimize soil erosion, and the Hardstand was posted and fenced to limit access. In 1996, embankment stabilization measures were incorporated, and the drain pit and drum storage areas were excavated to remove the most highly contaminated soils. Finally, in 2001, the area around Hardstand 7 was capped with concrete and remediation activities were concluded (ATSDR 2003).

6.15 Conclusions

The training of RANCH HAND aircrews, the development of the interface between the aircraft and the spray equipment, and the test and evaluation of the entire spray system was the responsibility of the Air Development Test Center (ADTC), Eglin Air Force Base (AFB), Florida. For ten years, 1961–1971, Eglin AFB provided the scientific and technical support for the RANCH HAND mission in Vietnam. It was of utmost importance in the development of the aerial spray systems that the equipment be tested under the most realistic conditions possible. The geological and meteorological conditions of the Eglin Air Force Base Reservation provided the appropriate test and evaluation environment that was as realistic as possible to the conditions of Vietnam.

From 1962 through 1970, more than 20 major test and evaluation projects were conducted on Test Area C-52A. These projects primarily involved the actual use of the herbicide or insecticide, rather then the use of a stimulant. In the course of conducting the tests and evaluations, more than 222,530 l of military herbicides (Agents Purple, Orange, White, and Blue), insecticides (malathion), or simulants (Stull BiFluid, Fuel Oil, Orange Simulant) were disseminated at the test grids. Approximately 156,000 kg of active ingredient herbicides were disseminated on the test grids of Test Area C-52A. The 75,000 kg of 2,4,5-T herbicide was estimated to have contained 3.1 kg of the toxic contaminant 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). The 37-hectare test grid (Grid 1) that was in use in 1962–1964, received appropriately 32,000 kilograms of 2,4,5-T and 2.9 kg of TCDD. The 2,4,5-T was contained in Agent Purple. Vegetative studies of Test Area C-52A began in 1967, but it was not until 1969 that ADTC tasked Eglin's Air Force Armament Laboratory (AFATL) with the responsibility for conducting monitoring and ecological studies of the Test Area and the surrounding area. Between 1970 and 1987, more than 30 technical reports were prepared on the ecological studies conducted on Test Area C-52A and the associated Eglin Reservation.

Analytical studies of soil cores in 1973 confirmed the presence/persistence of TCDD in the soils of the test grids. Subsequent studies and comparisons of data on the amount of TCDD thought to have disseminated on the test area with the remaining residues suggested that less than 1% remained. The micrometeorological conditions favorable for the dissemination of Agent Orange and Purple were probably the same condition favorable for the photodegradation of TCDD. Although TCDD disappearance could have occurred by volatilization, and by soil movement by wind and water, it was most likely the photodegradation that occurred immediately after herbicide dissemination that was responsible for the majority of TCDD disappearance.

From the first studies initiated in 1969 to the final observations in 1978, the composition of species was diverse and the distribution extensive. More than 340 species of organisms were observed and identified on or associated with the test girds of Test Area C-52A. Studies of TCDD in the ecosystem of Test Area C-52A confirmed that significant levels of TCDD contaminated much of the biota of this unique test site. More than 300 biological samples were analyzed for TCDD. Approximately one-third, or 32, of the different species examined for TCDD residue were positive.

The six-lined racerunner, *Cnemidophorus sexlineatus*, and the beachmouse, *Peromyscus polionotus*, were the only two species adequately studied to address body-burden levels of TCDD. Comparisons of body burden levels of TCDD versus the surrounding soil where the species were located suggested that the racerunner had a concentration factor of 4 (110 ppt in soil as compared to 400 ppt as a body burden). The Beachmouse females had a concentration factor of between 6 and 7 (285 ppt in the mound soil compared to 1,900 ppt in the liver), while the male had a factor of 9 (285 ppt in the mound soil compared to 2,600 ppt in the liver).

Histopathological examinations were performed on 255 adult, immature, or fetal beachmice from the test area and a control area. All microscopic changes were recorded including those interpreted as minor or insignificant. The tissues were then re-examined on a control versus test basis, which demonstrated that the test and control mice could not be distinguished histopathologically. A two-factor (treatment and year) disproportional analysis of covariance of organ weights revealed that liver weights for pregnant females were significantly heavier ($P < 0.01$) between the control and test area beachmice, and these differences were consistent over the years of observation. This increase in liver weight may have reflected an increase in enzymatic activity associated with low-level exposure to TCDD. An ultrastructural study of liver tissue from test and control females found no morphologic differences.

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Chapter 7
Monitoring Studies of Former Agent Orange Storage Sites in Mississippi and Johnston Island

In 1962, the responsibility for the management of tactical herbicides was assigned to the United States Air Force Logistics Command (AFLC), and specifically to the Middletown Air Materiel Area (MAAMA), Olmsted Air Force Base (AFB), Pennsylvania (SAAMA 1968). In August 1966, the management for tactical herbicides was transferred to the San Antonio Air Materiel Area (SAAMA), Kelly AFB, Texas (Craig 1975). Management responsibilities included the procurement and shipment of all the tactical herbicides sent to Vietnam. Although the United States Army Chemical Corps, and specifically the Plant Science Laboratories at Fort Detrick, was responsible for the selection, evaluation, and purchase description of the herbicides, the Product Engineering Branch, Directorate of Aerospace Fuels, San Antonio Air Logistic Command at Kelly AFB was the organization that contracted for the tactical herbicides Orange, White and Blue through the Directorate of Procurement and Production, Defense General Supply Center, Defense Supply Agency, Richmond, Virginia (Craig 1975; Irish et al. 1969).

Beginning in 1967 and through 1968, more tactical herbicide was delivered to the Port of Mobile than was being shipped to South Vietnam. As a result, the tactical herbicide inventory became so large that additional temporary storage was required (SAAMA 1968; Young 2006b). In June 1968, SAAMA negotiated with the Naval Construction Battalion Center (NCBC), Gulfport, Mississippi for NCBC to receive and store additional drums of tactical herbicide (Young 2006b). By December 1968, 66,700 drums had been moved to NCBC. Over the next eight months (in 1969), drums were again shipped to Vietnam out of both the Outport at Gulfport and from the Port of Mobile. Most of the later shipments were Herbicide White and Herbicide Blue (Craig 1975; Miller et al. 1980). Long-term storage at NCBC was initiated in late fall 1969. The inventory was comprised primarily of Agent Orange (approximately 13,855 208-l drums) and a relatively small quantity of Orange II (approximately 1,545 208-l drums). The inventory at NCBC was removed from the storage site between 24 May 1977 and 10 June 1977 in Operation PACER HO, and destroyed by at-sea incineration (Young et al. 1978; Tremblay 1983).

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The inventory on Johnston Island was placed there in April 1972 at the completion of Operation PACER IVY, the removal from South Vietnam of all remaining stocks of Agent Orange. The inventory consisted of 5.2 million liters (25,220 208-l drums) of herbicides. The bulk of the inventory was Agent Orange, but very small amounts of Purple and Pink were likely present in the inventory (Darrow 1967; Young et al. 1978). The inventory at Johnston Island was removed from the storage site between 27 July 1977 and 23 August 1977 and destroyed by at-sea incineration (Tremblay 1983). This chapter describes the Site Monitoring and Reclamation Programs that were initiated at NCBC and Johnston Island following the final destruction of Agent Orange.

7.1 Requirements for Site Reclamation of NCBC and Johnston Island

As the Air Force prepared for the destruction of Agent Orange by at-sea incineration in 1977 (Operation PACER HO, see Chapter 4), they were required to obtain both a research permit and a final permit for the destruction of the herbicide (EPA 1975; EPA 1977; Tremblay 1983). The Air Force Programming Plan, and the Environmental Protection Agency (EPA) permits for the disposal of the herbicide committed the Air Force to a follow-on storage site reclamation and environmental monitoring program.

Annex 8 of the *Programming Plan for the Disposal of Orange Herbicide* provided instructions for “Storage Site Treatment and Monitoring” (AFLC 1977). The Plan stated:

- Storage site clean-up can be minimal in undisturbed areas because biodegradation of herbicide will occur in the soil.
- At Johnston Island (JI), the coral soil of the island readily absorbs Orange Herbicide. This absorptive capacity of the compacted coral within the storage site has confined spilled herbicide to the upper 12–18 in. of soil and within the immediate area of the spill. Clean-up of the storage site can be accomplished by covering the area with clean coral and compacting to control any possibility of herbicide runoff or re-suspension during in situ biodegradation.
- At the Naval Construction Battalion Center (NCBC), the soil at the storage site has been treated with cement and compacted. This treatment has created a 12–18-in. layer of cement/soil that is relatively impervious to water and herbicide; however, the layer is about three inches below the ground surface. The upper 3-in. layer is similar to the normal soil of the area that appears to be a sandy clay. This site should be covered with a material such as oyster shells at the completion of the de-drumming and transfer operation.
- Additional clean-up procedures at both NCBC and JI may be necessary if a facility is to be constructed on either storage site. The exact nature of the construction will determine the extent of additional clean-up procedures required.

- Prior to commencement of any construction, soil samples will be collected and analyzed for Orange Herbicide constituents. If herbicide is detected, it may be necessary to remove the soil and dispose of it in an approved sanitary landfill.
- Soil samples from the storage sites at both NCBC and JI will be collected and analyzed for Orange Herbicide after the completion of transfer operation. These analyses will aid in the establishment of a schedule for future monitoring. The site monitoring program will be concluded upon mutual agreement of all agencies.

Per the instructions from Annex 8, Storage Site Treatment and Monitoring, at the completion of the transfer operations at NCBC, oyster shells were used to cover the area where spills of herbicide had occurred. Figure 7.1 was a photograph taken in June 1977 at NCBC showing the placing of oyster shells on sites where herbicide had been spilled. Figure 7.2 was a photograph of the storage site at Johnston Island, Central Pacific Ocean, taken in late September 1977 showing the storage site after treatment and compaction with new coral the previous month (August 1977).

Note in Fig. 7.2 how the herbicide spills soaked through the former storage area despite a treatment and compaction with new crushed coral the previous month (August 1977). In July 1977 and in August 1977, following the completion of the PACER HO de-drumming and subsequent site clean-up operations at NCBC and Johnston Island, respectively, the United States Air Force Occupational and Environmental Health Laboratory (OEHL) initiated an

Fig. 7.1 A photograph taken in June 1977 at the Naval Construction Battalion Center's former Herbicide Orange Storage Site at the conclusion of Operation PACER HO showing the use of oyster shells (background) to cover spills of the Orange Herbicide (Photograph courtesy of A. L. Young)

Fig. 7.2 A photograph of the former Herbicide Orange Storage Site at Johnston Island, late September 1977 at the conclusion of Operation PACER HO (Photograph courtesy of A.L. Young)

extensive environmental monitoring program of the two sites where Herbicide Orange had been stored (Doane 1979). The major objectives of the Storage Sites Monitoring Program were to:

1. Determine the magnitude of Herbicide Orange contamination in the storage sites;
2. Determine the soil persistence of 2,4-D and 2,4,5-T, their phenolic degradation products, and TCDD (2,3,7,8-tetrachlorodibenzo-*p*-dioxin) in soils of the storage sites;
3. Monitor for potential movement of residues from the storage sites into adjacent water, sediments, and biological organisms; and,
4. Recommend managerial techniques for minimizing any impact of the herbicides or TCDD residues on the ecology and human populations adjacent to or near the storage sites, with the ultimate goal of returning the sites to full beneficial unrestricted use (Young, Thalken, Cairney 1979).

7.2 Historical Background on the Naval Construction Battalion Center

As previously noted, although temporary storage was available, long-term storage of herbicide at the NCBC did not occur until late 1969 (Craig 1975). The Naval Construction Battalion Center is located in Gulfport, Mississippi, with the outside herbicide storage site located near the center of the NCBC and about three kilometers from the docks and with convenient access to the railroads. The storage site was fenced and isolated from public traffic. The NCBC

Fig. 7.3 A photograph of the storage of Herbicide Orange on dunnage and in rows at the Naval Construction Battalion Center, July 1975 (Photograph courtesy of AFLC, Kelly AFB, Texas)

provided surveillance personnel as well as a controlled access. The site was planned and set up for long-term storage. The soil in the outdoor storage areas of NCBC had been treated in the 1940s with cement and compacted. This treatment created a 25–30 cm "hardpan" of stabilized soil approximately 8–15 cm below the present surface (Craig 1975). As noted in Fig. 7.3, to provide good drainage, 5 × 15-cm dunnage (creosoted lumber) was laid on the hard surface, and drums were stacked in double rows, three high, and in pyramidal fashion. The number of drums in each single row, bottom to top, was usually 55, 54, and 53. To allow inspection of the bungs, there was a 45-cm (approximately 18 in.) walking space between each double row.

7.2.1 The Issue of Defective and Damaged Drums

In February 1968, a study was conducted to determine the frequency of damaged and defective drums received and/or stored at the Port of Embarkation (POE, in this case the Mobile Port) (SAAMA 1968). At that time there were 125 drums at the Port that had been rejected for shipment by the Port Authority. The drums had been rejected for the following reasons: 37 drums had leaked at the seam as a result of dents incurred through improper rail car loading and bracing; 84 drums had leaked at seams or bungs because of defects in the drum (see Fig. 7.4); and, 4 drums had been punctured by stevedores during handling. To lessen drum damage during shipment, the companies were provided instructions (UFC Rule 27, Sec 3) requiring proper loading and load bracing of railroad boxcars (SAAMA 1968; Craig 1975).

Fig. 7.4 A photograph of a leaking drum in June 1975 within the NCBC Herbicide Orange Inventory (Photograph courtesy of AFLC, Kelly AFB, Texas)

Initially, liability for damaged drums was accepted by the stevedore company for drums puncture during handling, by rail carriers for drums damaged during transit, and by herbicide suppliers for seam leakers attributed to defective drums. Subsequently, SAAMA authorized re-drumming of all defective leaking drums, and the costs incurred for re-drumming operations were charged to the railroads because they were held responsible for accepting the material for shipment. The railroads in turn identified and photographed the "leakers" by rail car number and gave copies and invoices to the herbicide producer. The producer, in turn, took the defective drum problem and invoice to the drum supplier (SAAMA 1968). This eventually improved quality control at the drum manufacturer's plant, so that the rate of defective drums dropped to less than 1 drum out of 1,000 new manufactured drums (Craig 1975).

Within the storage at NCBC, the responsibility for re-drumming operations was the Air Force Logistics Command (SAAMA 1968). As noted in Figs. 7.3 and 7.4, external corrosion due to salty sea air, expansion-contraction caused by temperature changes, and handling of the drums continually reduced the structural integrity of the steel drums. Hence, a full-time crew was contracted to maintain oversight of the NCBC Herbicide Orange inventory. In May 1971, during an inspection of the inventory, it was noted that deterioration of some of the drums had required NCBC personnel to re-drum the product. As drums were removed from the stacks, indications of additional leaking drums became apparent. Previously, leaking had been attributed to breakdown of the bung seals used in the drum closures or an occasional seam leak. Now there were indications of leaks starting in the drum surfaces. During 1972, military personnel moved, inspected, and re-drummed as required, the entire inventory of approximately 15,400 drums. Thereafter, an intensive drum surveillance program was initiated in which all drums were routinely inspected and moved or re-drummed as required. From 1972 through mid-1977, 500 ($\sim$3%) of the inventory was re-drummed at NCBC (Miller et al. 1980). The drum surveillance program was continued until May 1977, when Operation PACER HO began (Young et al. 1979).

7.2.2 Results of the USAF Academy Monitoring Program, 1974–1976

The observations in 1971 and 1972 that drums were deteriorating prompted the Air Force Logistic Command, Wright-Patterson AFB, Ohio, to task the USAF Environmental Health Laboratory, Kelly AFB, Texas, and the Department of Chemistry and Biological Sciences, United States Air Force Academy, Colorado, to undertake a cursory chemical and biological monitoring program of the storage site. This was the first major monitoring program at NCBC (Young et al. 1979). The USAF Environmental Health Laboratory subsequently became the USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas.

In July 1974 and June 1975, members of the Air Force Academy's Department of Chemistry and Biological Sciences conducted extensive surveys and ecological assessments of the herbicide storage area and collected soil, water, and biological samples. There was considerable evidence of herbicide contamination within the storage area itself (i.e., visual evidence of leaks and spills on the soil); however, there was no evidence that any of the material had been carried from the storage area by the surface drainage system. In 1972, in preparation for the USAF disposal of Herbicide Orange, personnel from the USAF Environmental Health Laboratory, Kelly AFB had identified 16 distinct "lots" of herbicide from seven companies that had produced the herbicide, or were remaining inventories brought from Kelly AFB, or Eglin AFB, Florida (Miller et al. 1980). For example, the drums identified as having been purchased from The Dow Chemical Company were labeled as ASN "10", where the ASN was the abbreviation for "Analysis Sequence Number" (OEHL 1977). Figure 7.5 was a photograph taken of the soil contamination due to a "pinhole" size leak in a drum of Orange Herbicide. Dow Chemical Company had produced almost 7,000 drums of product in the inventory (Department of the Air Force 1974).

Soil samples were collected on the banks of the drainage system, and silt samples were collected at various points in the drainage ditches. Figure 7.6 was

Fig. 7.5 A photograph taken at NCBC on June 1975 showing the soil contamination initiated by a "pinhole" size leak in a drum of Agent Orange identified by an Analysis Sequence Number 10 (ASN 10), as a product produced by The Dow Chemical Company, and found to have a TCDD mean concentration of 0.25 ppm (Photograph courtesy of AFLC, Kelly AFB, Texas)

Fig. 7.6 A June 1975 photograph of part of the drainage system on the NCBC Herbicide Orange Storage Site. Herbicide residues were not found in the silt in the ditches or on the banks of the ditches (Photograph courtesy of A.L. Young)

a photograph of one of the drainage ditches adjacent to the drum storage area. One soil sample was taken between the ditch and the drum shown in the photograph. It was negative for herbicide residues at a detection limit of 1 ppm, as were all of the sediment samples collected in the drainage ditches (Young et al. 1979). Water samples from the drainage ditches had no detectable levels of herbicide at a detection limit of 50 parts per billion (ppb). One of the water samples did, however, contain hydrocarbon residues apparently from washing operations in the area. A soil sample taken between rows of drums was positive for TCDD at 0.015 ppb (15 parts per trillion, ppt) (OEHL 1977).

The biological samples collected in 1974 (frogs, tadpoles, minnow) were not analyzed for TCDD because there was no evidence that the aquatic drainage system was contaminated at that time. Upon gross examination no abnormalities were seen in any of these aquatic specimens. A complete survey of the flora surrounding the storage area was also completed during July 1974. Plant damage of an herbicidal-nature (twisting and bending of leaves and stems) was noted on two plant species as far as 80 m west (downwind) of the drum storage site (Young et al. 1979).

In January 1976, USAF Academy personnel again conducted an aquatic and soil survey of the herbicide storage site. During this survey, soil, sediment, and biological samples were collected from throughout the storage area and the surface drainage system (Young 1984). These samples were frozen and archived as baseline samples should the need arise to evaluate similar types of samples during or after Operation PACER HO. Selected samples from this collection were later analyzed in 1977 (OEHL 1977).

7.2.3 Environmental Health Laboratory Monitoring Program, 1974–1976

During the period of August 1974 through October 1976, personnel from the USAF Environmental Health Laboratory, Kelly AFB, Texas, made 11 trips to the Naval Construction Battalion Center to monitor pilot plant operations, perform drum rinse studies, and to conduct environmental monitoring including the collection of water samples from the herbicide storage area drainage ditches (Doane 1979; Young et al. 1979). Prior to the initiation of Operation PACER HO, the USAF conducted, or contracted for many studies of various methods to either reprocess the herbicide, remove the TCDD, or to find an alternative method of destroying it (Department of Air Force 1977; Young 2006b). Some of these tests were conducted at NCBC and adjacent to the storage area (Young 2006a). For example, Agent Chemical Inc. developed a reprocessing system for removing the TCDD from the herbicide by filtering it through activated charcoal canisters. A pilot facility for reprocessing was constructed in 1975, and operated adjacent to the drum storage area (Hightower, 1976). Hence, the opportunity of polluting with herbicide the drainage system adjacent to the storage area was very high.

Due to the increased activities occurring around and in the storage area, water samples collected by the Environmental Health Laboratory began to be positive. Indeed, by the fall of 1975, water sample locations from the drainage ditches had average mean values of 0.15–409 ppb for 2,4-D, and 0.3–519 ppb for 2,4,5-T (OEHL 1977). Sediment samples collected from the drainage area contained 2,4-D in a range of mean values of 40–240 ppb; the 2,4,5-T ranged from 40 to 420 ppb. All of the sediment samples were negative for TCDD; however, the analytical laboratory used for the study could not establish a level of detection for TCDD because of interferences (OEHL 1977). In the summer of 1976, of 26 water samples analyzed for herbicide, 13 samples contained more than 10 ppb herbicide. However, no herbicide was detected in water samples collected at the discharge point leading off of the installation. Of the sediment samples analyzed, only two exceeded 100 ppb herbicide. No TCDD was detected in the sediment samples, at a detection level of 0.01 ppb (OEHL 1977). Soil sample data in October 1976 were not sufficient to make an interpretation as to the degree of severity of the herbicide contamination in the soil of the storage site (Young et al. 1979).

The Environmental Health Laboratory made the following conclusions and recommendations in October 1976:

1. The levels of Herbicide Orange (2,4-D and 2,4,5-T) in the ambient air were not high enough to create concern about on-base or off-base exposure. This was also borne out by the biomonitoring that had been performed during the Agent Chemical, Inc. operation at NCBC. If the TCDD analytical results were viewed as upper limits, as suggested by the analytical laboratory (Wright State University), then there was no need for concern;
2. There was no indication of any off-base discharge of herbicide residue or TCDD in the water or sediment samples;
3. Quarterly environment monitoring surveys should be continued; and,
4. There was a need for a comprehensive sampling program of the soil in the Herbicide Orange Storage Site to permit a better evaluation of the degree and extent of contamination by both herbicides and TCDD (Young et al. 1979).

7.3 Historical Background on Johnston Island

Johnston Atoll has had a varied history. It is one of the most isolated atolls in the entire Pacific Ocean. Originally it consisted of two small, insignificant islands, a partial coral reef to the west and northwest and a rather large, shallow lagoon to the east and south (Amerson 1973). It became a large Department of Defense complex that was recently turned over to the Department of Interior (USAF 2004). Because of the unique bird species and populations the island was originally under the jurisdiction of the Department of Agriculture, but in 1940 this responsibility was transferred to the Department of the Interior

(Amerson 1973). In February 1941, the airspace above and the water within the 5-km boundary were designated as the Johnston Island Naval Airspace Reservation and the Johnston Island Naval Defense Sea Area, respectively. Construction to enlarge the island began in 1942. Channell approaches and a seaplane landing area were dredged, and living quarters, runways, parking aprons, storage sheds and gun emplacements were constructed (Department of the Air Force 1974, Appendix H).

On 1 July 1948, the Secretary of the Navy transferred operational control of Johnston Atoll to the Department of the Air Force. During the years of the Vietnam War, Johnston Atoll supported the flow of air traffic en route to and returning from Southeast Asia. In April 1972, the Herbicide Orange that had been collected, and re-drummed as needed, in Operation PACER IVY in South Vietnam was placed in storage on the southwest peninsula of Johnston Island. In 1973, the acreage for Johnston and Sand Island were increased to 262 ha. The surface of the islands was compacted coral that supported a flora consisting of a few grasses, herbs, and dwarf shrubs that were sparsely distributed. The bird population was dominant on the islands and was composed of 17 different species of oceanic birds or transient shorebirds (Amerson 1973; Department of the Air Force 1974).

7.3.1 Results of Early Monitoring Programs on Johnston Island

Because of the deteriorating condition of the drums, the Johnston Island inventory required continual maintenance. From 1972 through mid-1977, approximately 10,000 drums of Herbicide Orange required re-drumming on Johnston Island. Re-drumming operations averaged about 29 drums per week with a peak of 97 drums in a one-week period (Miller et al. 1980). Many of the drums were no longer recognizable with the orange "band" around the center of the drums. Leaks and spills occurred frequently, but the prevailing attitude was that the herbicide was slowly absorbed into the calcium matrix and that the leaching into the coral was generally confined to the top 15 cm of soil (Department of the Air Force 1977).

Personnel from the Department of Chemistry and Biological Sciences, United States Air Force Academy visited Johnston Island on 30–31 July 1974. A thorough survey of the herbicide storage area was conducted and samples of contaminated coral were taken. No evidence was found to indicate contamination of the adjoining ocean shoreline. Certain species of saltwater algae, e.g., the blue-green alga *Lyngbya majecula*, are likely sensitive indicators of herbicide presence, were found close to the shoreline in the vicinity of the storage area (Amerson 1973). Observations were made of the sparse flora in and around the storage area. Some evidence of herbicide vapors were detected as slight deformation (twisting) in the broadleaf species *Erigeron*, especially in an area approximately 70 m downwind of the storage site (Young and Arnold 1974).

Two areas where drum ruptures had occurred were identified within the storage site, and core samples of the coral were obtained. Contractor personnel indicated that the ruptures had occurred within the past 2–5 months. In obtaining the core samples, it was noted that penetration of the herbicide appeared to be minimal due to the extremely hard-packed condition of the coral. This was also apparent when the Academy team visited the de-drum facility and noted that as late as eight hours after a spill, penetration of the herbicide had not occurred to any appreciable extent (Young and Arnold 1974). Data from the two core samples were provided in Table 7.1.

The samples collected in 1974 were only analyzed for the herbicide components. The methodology could distinguish the esters forms, i.e., n-butyl, iso-butyl, or iso-octyl esters. The samples were analyzed for herbicide components by a method developed by Arnold (Arnold and Young 1976). Figure 7.7 was a gas chromatogram of an extract of prepared soil sample containing the n-butyl esters and acids of 2,4-D and 2,4,5-T herbicides. In the case of samples from Johnston Island, to quantify the acids it was necessary to convert them from the sodium salt to the methyl esters.

7.3.2 Potential Water Contamination of Johnston Island

The data from the analysis of the Johnston Island samples confirmed that the herbicides were essentially bound within the first 15 cm of coral. The mechanism of disappearance of the herbicide was not known. Presumably, the loss was attributed to evapo-transpiration, weathering, and to microbial degradation

Table 7.1 Data (ppm) from the analysis of two coral samples collected in the Herbicide Orange Storage Site, Johnston Island July 1974 (Young and Arnold 1974)[1]

Depth	2,4-D		2,4,5-T		Total
(cm)	Acid	Ester	Acid	Ester	(ppm)
1. Sample U–2 (two months following herbicide spill)					
0–5	11,600	7,600	14,000	10,000	43,200
5–10	1,000	1,400	950	2,100	5,650
10–15	240	220	160	310	930[2]
15–20	150	<100	160	<100	< 510[2]
20–25	200	<100	310	<100	< 710[2]
25–30	360	120	400	180	1,060[2]
2. Sample N-2 (five months following herbicide spill)					
0–5	3,300	2,100	2,600	2,600	10,600
5–10	100	<100	250	100	< 550[2]
10–15	560	400	300	650	1,910[2]

[1] Analytical method (Arnold and Young 1976).
[2] Probable contamination from upper depths during sample collection.

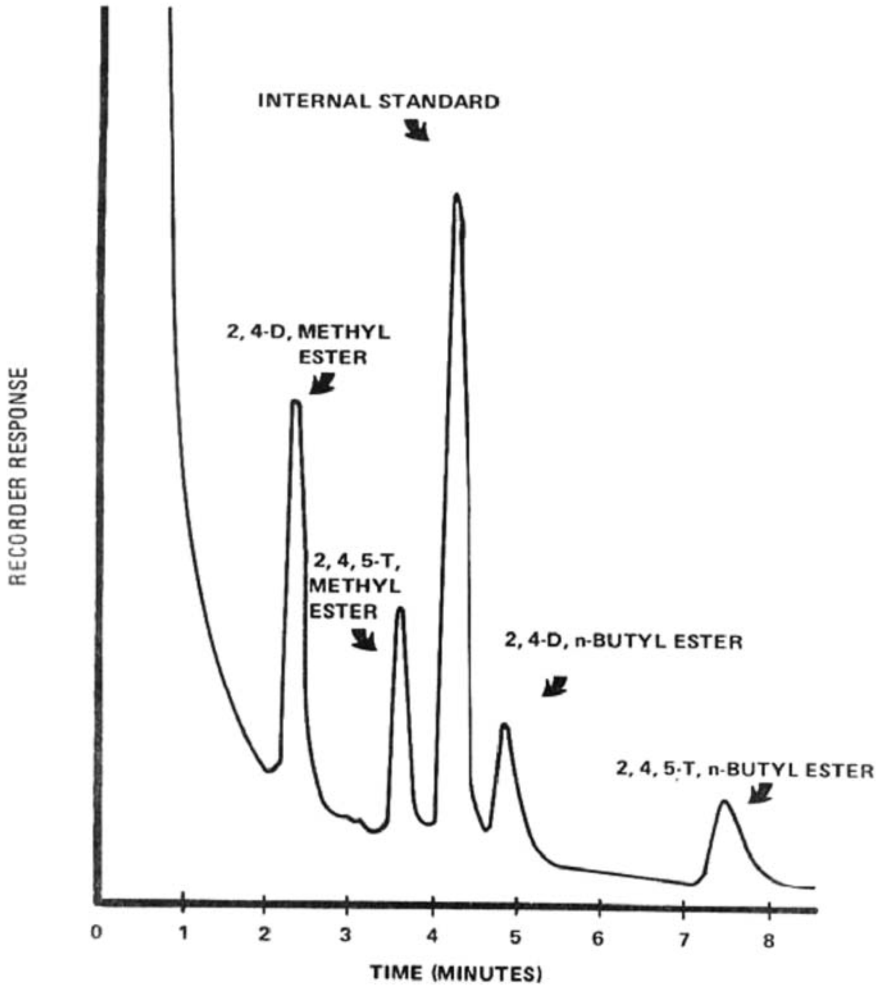

Fig. 7.7 Gas chromatogram of the extract of a prepared soil sample containing the esters and acids of 2,4-D and 2,4,5-T. The acids were converted to methyl esters for detection and measurement (Arnold and Young 1976)

(Thomas et al. 1978). However, at the close of the PACER HO Operations, a memorandum was sent from Dr. Lee Taft, Battelle Columbus, to the Manager of Johnston Island. It was dated 29 August 1977, and the subject was "Contamination of Soil at the Herbicide Orange Storage Area". The memorandum stated:

> The amount of herbicide spilled onto the soil (coral) as a result of de-drumming operations appears to be little except the area where leakers were stored during the operation. Of major concern, however, is the large quantity of herbicide that was spilled during the six or so years of storage. It appears that this quantity may be as

> high as 20,000 to 30,000 gallons (76,000–114,000 liters). Soil samples have been taken of the 0–6-inch depth (0–15 centimeters) from scattered locations in the storage area. Also, one area where heavy spillage has occurred has been sampled down to a depth of 24 inches (60 centimeters). Because of the apparent sandy nature of the profile and the close proximity to the water table, I feel that there is considerable danger of movement into the ground water. In my opinion the profile needs to be fully characterized to a depth of at least 6 feet (1.8 meters) in at least three locations. **If a likelihood of movement can be substantiated then consideration should be given to removal of the contaminated portion of the profile** (Thomas et al. 1978).

Contrary to the tone of the memorandum, the salt water around Johnston Island and the freshwater system had been monitored for the presence of 2,4-D and 2,4,5-T since 1973 by the USAF Environmental Health Laboratory. The maximum concentrations observed in the offshore area near the herbicide storage site were in the order of 3μg 2,4-D/liter and 0.6 μg of 2,4,5-T/liter, and those samples taken near the saltwater intake were 2.3 and 0.7 μg/l, respectively. Two other offshore sites exhibited maximum concentrations below 0.5 μg/l. Samples taken in the desalination plant never showed measurable concentrations, although one sample from the storage reservoir had a concentration of 1.6 μg/l of 2,4,5-T. The National Interim Primary Drinking Water Standard was 100 μg 2,4-D or 2,4,5-T per liter (Thomas et al. 1978).

7.4 Design of the Protocol for Monitoring the Herbicide Storage Sites

Before undertaking the long-term commitment to monitoring of the Herbicide Orange Storage Sites at the Naval Construction Battalion Center and Johnston Island, it was essential that a protocol be developed that would provide scientifically valid data to answer questions as to the environmental fate of high levels of herbicide residues and the associated TCDD existing within the sites (Young et al. 1983). Four problem areas were apparent in the design of a study:

1. Over 25 individual chemical components in Herbicide Orange had been identified by mass spectrometry (Hughes et al. 1975). Should or could a monitoring program include all of these components? The low percentage in content of most of these compounds, combined with their known low toxicity and/or rapid biodegradability (e.g., butanol, toluene, and xylene), suggested that only the principal herbicides (acid and esters of 2,4-D and 2,4,5-T), their major breakdown products (di- and trichlorophenol), and TCDD should be followed.
2. What criteria should be used to determine the number and location of sampling sites on areas of approximately 5 ha? Spills due to handling of the drums during de-drum operations (during and prior to Operation PACER HO) or to leakage (prior to Operation PACER HO), could have

occurred almost anywhere on the storage areas over the 8-year period for NCBC and 5-year period for Johnston Island. Certainly, the persistence and fate of individual herbicides, phenols, or the dioxin might be determined more readily if a technique could be used to differentiate old spills from new spills.

3. What factors associated with the actual storage sites at NCBC or Johnston Island would have enhanced or inhibited the penetration of herbicides, their breakdown products, or the TCDD into the soil profile?
4. In an "ideal" monitoring program, some method would be required to determine a minimum level of residue that could be considered both biologically and ecologically acceptable, i.e., a *de minimis* level, i.e., beyond regulatory control.

The depth of routine soil sampling was of major concern in designing the monitoring program. In 1976, field studies in Kansas, Florida, and Utah, had shown that neither the herbicide components of Orange nor the TCDD had appreciably moved four years after the plots had received concentrations of 4,480 kg herbicide/hectare by a simulated subsurface injection at a depth of 15 cm (Young et al. 1976; Freeman and Schroy 1989). Whether the herbicide would penetrate more rapidly and to a greater depth after it was spilled (and pooled) on the surface was not known. The 1974 preliminary data on Johnston Island suggested that although the compacted coral had a depth of 4.5 m, it was the top 8 cm of coral that contained at least 90 percent of the residue 5 months following a spill (Young and Arnold 1974). At NCBC the "hardpan" was 8–25 cm below the surface, and the upper 8 cm consisted of a sandy loam soil. In locations where spills had occurred, a 5-cm layer of oyster shells covered the spill (Young et al. 1979).

All of the above factors influenced the decision to select only one depth for primary sampling; that was to be the top 8 cm of soil or coral. In the case of NCBC, the oyster shells were to be removed from the sample. A single sample was to consist of an 8 × 8 × 8-cm cube that was to be removed from the sampling site by the use of a ceramic spatula that was to be rinsed with acetone between uses to prevent carry-over of residue and microorganisms. The approximate 200-g samples were to be placed in new 400-ml dark glass jars with an aluminum cover between the glass and the cap (Young et al. 1979, 1983).

7.4.1 Preliminary Evaluation of the Protocol at NCBC

In July 1977, a preliminary sampling study was initiated at the NCBC. This consisted of assessing the heterogeneity of the soils on the storage site and the heterogeneity of the areas where spills had occurred. Twelve sites were selected for sampling; six were in areas of obvious spills and six in areas that showed no indication of a spill. A numbered metal stake was placed where the sample was

Fig. 7.8 A photograph of a sampling site for herbicide residue from the former Herbicide Orange Storage Site at NCBC in July 1977. Note that the oyster shells were removed before the soil sample was obtained. The sample was collected 15 cm from a numbered metal stake (Photograph courtesy of A.L. Young)

obtained. In the case of a sample from a spill, the sample was taken from the area that appeared to be the center of the spill. Not only were the spills discernible by sight but also by smell (Young et al. 1979). Figure 7.8 was a photograph of a sample site on the NCBC taken in July 1977, while Figure 7.9 was a photograph of a sample site on Johnston Island in August 1977. The results of these first samples taken after Operation PACER HO were shown in Table 7.2.

Fig. 7.9 A photograph of Sampling Site Number 12 on Johnston Island, 25 August 1977. Note that the coral was so compacted that a hammer and chisel were required to collect the sample; a numbered metal stake was placed in the approximate center of the spill for identification for future sampling (Photograph courtesy of A.L. Young)

Table 7.2 Concentration (ppm) of total herbicides, total phenols, and TCDD in 12 samples collected in July 1977 or August 1977 from the former Herbicide Orange Storage Sites at the Naval Construction Battalion Center or Johnston Island, respectively

Location	Number of sites	Total herbicide[1] (ppm)	Total phenols[2] (ppm)	TCDD (ppm)
Spill sites				
Johnston Island	8	58,000±42,000	135±120	0.073±0.07
NCBC, Gulfport	6	78,000±42,000	152± 90	0.240±0.27
No-spill sites				
Johnston Island	4	26±15	3±2	NA[3]
NCBC, Gulfport	6	14.2±12.4	<1	NA

Source: Young et al. (1983).
[1] Total herbicides referred to concentration of acids and esters of 2,4-D & 2,4,5-T.
[2] Total phenols refers to concentration of dichlorophenol and trichlorphenol.
[3] NA = Not analyzed. The analyses of the samples were conducted by the Flammability Research Center, The University of Utah at Salt Lake City, Utah.

7.4.2 Implementation of the Formal Protocol

The sites selected within the two storage areas for monitoring were determined by whether a spill had occurred or not occurred at the specific location, i.e., whether a herbicide "stain" was discernible as heavy, light, or absent. Two scientists with Dow Chemical Company had noted that the olfactory senses could detect a butyl ester formulation of 2,4,5-T at levels of 0.4 ppb (Winston and Ritty 1971). This became the basis for determining whether a spill was recent or not, i.e., whether an herbicide odor was detectable as strong, mild or absent. Thus, within each storage area, numerous locations were found that had a heavy stain and strong odor (labeled H/H, presumably representing a recent spill); a light stain and mild odor (labeled L/L, presumably representing an older spill); and no stain and no odor (labeled O/O, presumably representing an uncontaminated area). Fourteen replications of each treatment were then randomly selected to represent the storage area (thus a total of 42 permanently marked sampling locations at both NCBC and Johnston Island) (Young et al. 1983). Twelve of these locations had been tentatively located and marked on 28 July 1977 for NCBC and 25 August 1977 for Johnston Island. The remaining 30 sites were located and marked with numbered metal stakes in January 1978.

At both locations maps were constructed of the storage site with the sampling points identified. Forty-two samples were taken in January 1978 and again in November 1978. In collecting the samples, an 8-cm square was marked 15 cm from the site marker pin (see Fig. 7.10). At each sampling date soil/coral was taken from a different "point-of-the-compass" with reference to the marker pin to ensure a "fresh" and undisturbed profile. An 8 × 8 × 8-cm cube of soil was removed with a ceramic spatula and placed into a clean dark 400-ml glass jar.

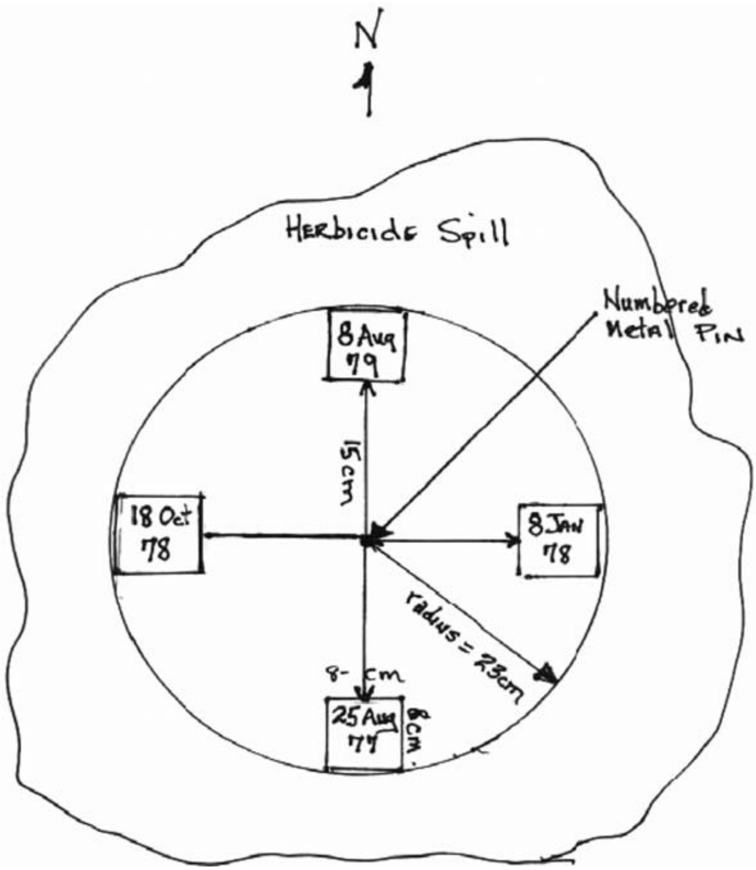

Fig. 7.10 A schematic for collecting soil samples for Johnston Island and NCBC (Source: Young et al. 1979)

7.4.3 Chemical Analyses of Samples

All of the soil samples were appropriately labeled and transported to the laboratory where each was uniformly mixed and sub-sampled. The sub-sample used for chemical analyses was immediately frozen. The remaining sample was used for microbial studies. All soil samples collected from NCBC and Johnston Island in July/August 1977, January 1978, November 1978, and August 1979 were submitted for chemical analyses to the Flammability Research Center, University of Utah, Salt Lake City Utah. Each soil sample was analyzed for the esters and acids of 2,4-D and 2,4,5-T. In addition, each sample was analyzed for di- and trichlorophenols, and selected samples analyzed for TCDD (Young et al. 1983; Young 1984). Analytical checks on selected samples were conducted at Brooks AFB Texas (Arnold and Young 1976).

7.4.4 *Microbial Analyses of Samples*

Sub-samples of all soils were sent to the Air Force Academy's Department of Chemistry and Biological Sciences for microbial analyses. All samples were analyzed for total populations of actinomycetes, fungi, and bacteria. In addition, key species presumably responding to the presence of herbicides were identified. The method employed in the microbial analyses had been previously described (Young 1974; Young et al. 1975, 1983). It was hoped that quantitative and qualitative studies of the microorganisms from each of the treatment classes used in association with residue data would permit an establishment of no effect level.

7.5 Results and Discussion of Herbicide and Microbial Data

A summary of the analytical results for the 42 sites sampled in January and November 1978 from the herbicide storage site at the Naval Construction Battalion Center was provided in Table 7.3. A statistically significant decrease

Table 7.3 Mean concentrations (ppm) of total herbicides, phenols, and TCDD in soils collected in January and November 1978 from selected locations on the former Herbicide Orange Storage Site at the Naval Construction Battalion Center

Location	Number of sites samples[1]	Total herbicides (ppm)[2]	Total phenols (ppm)[3]	TCDD (ppm)
"No" Spills (O/O)[4]				
January 1978	14	32 α	3.5 α[5]	ND (4)[6]
November 1978	14	3 β	0.4 β	NA
"Old" Spills (L/L)				
January 1978	14	1,202 α	86 α	0.0364 (3)
November 1978	14	492 β	23 β	0.0438 (3)
"New" Spills (H/H)				
January 1978	14	51,285 α	437 α	0.2064 (10) α
November 1978	14	30,005 β	253 β	0.1444 (11) α

Source: Young et al. (1983) and Young (2006a)

[1] Each sample consisted of a cube of soil/coral (8 × 8 × 8-cm) removed adjacent to a designated marker pin

[2] Total herbicides refers to the total concentration of acids and esters of 2,4-D & 2,4,5-T.

[3] Total phenols refers to the total concentration of dichlorophenol and trichlorohphenol.

[4] The codings O/O, L/L, and H/H are described in the text

[5] Means within columns within subtitles followed by the same letters are not significantly different at the 0.05 probability level. For the statistically analyses, the Wilcoxon Paired-Sample Test was used. A test for a one-tailed hypothesis with paired samples was used in the procedure for nonparametric data since it could not be assumed that the levels of residue detected were from a normal distribution, and it was expected that the level of residue would decrease with time.

[6] ND = not detected; NA = not analyzed; ( ) the number within the parentheses refers to the number of positive TCDD samples use in calculations of the means. The detection limit was generally 0.0002 ppm TCDD. In L/L sites, the other 11 samples were either ND or NA; in H/H sites the remaining samples were ND.

in the levels of total herbicides and total phenols was found to occur between the two dates. There was also a downward trend in TCDD levels, but it was not statistically different. This trend in decreasing levels of TCDD (as well as in herbicides and phenols) was even more pronounced when the July 1977 data for spill sites (Table 7.2) were compared to the 1978 data. Unfortunately, because of differences in site delineation between 1977 and 1978, data for spills versus no spills between the two years could not be "paired" and statistically analyzed. Similar levels of herbicides, phenols, and TCDD have been found in selected soils of the herbicide storage site on Johnston Island. Table 7.4 compared the trends in these compounds over four sampling dates (September 1977, January and October 1978, and August 1979) from four sites heavily contaminated with herbicide (new spill sites in 1977). Although herbicide levels significantly

Table 7.4 Concentration (ppm) of total herbicides, total phenols, and TCDD in coral samples from four selected spill sites for four dates from the former Herbicide Orange Storage Site on Johnston Island

Sample dates and sites	Total herbicides[1] (ppm)	Total phenols[2] (ppm)	TCDD (ppm)
25 August 1977			
5	38,000	93	0.0330
9	52,270	205	0.0417
10	135,250	460	0.1960
12	76,080	172	0.1780
Mean	75,400	233	0.1122
08 January 1978			
5	38,980	123	0.0340
9	70,090	181	0.0220
10	141,300	477	0.2300
12	57,000	110	0.0800
Mean	76,840	223	0.0915
18 October 1978			
5	31,440	34	0.0191
9	60,530	111	0.0286
10	159,700	456	0.2350
12	42,840	47	0.1110
Mean	73,630	162	0.0984
08 August 1979			
5	3,560	ND	0.0410
9	44,230	149	0.0530
10	48,660	136	0.1300
12	18,430	54	0.0810
Mean	28,720	113 (3)[3]	0.0763

Source: Young et al. (1983)
[1] Total herbicides referred to concentrations of acids and esters of 2,4-D and 2,4,5-T
[2] Total phenols referred to concentrations of dichlorophenol and trichlorophenol
[3] Referred to number of samples included in obtaining the mean; ND = not detected

decreased over the periods of sampling, trends for disappearance of TCDD were not as well defined.

The data for the four sites (and four dates) illustrated the inherent weakness of the sampling protocol. When a spill occurred on a site, the concentration of chemicals varied significantly within the spill perimeter. Although the marker pin for permanently locating the site was placed as near the center of the spill as possible, that did not necessarily define the zone of greatest soil contamination. Soil samples collected over time were collected at different "points-of-the-compass" around the marker pin and within a 23-cm radius. Although the spill site was not homogeneous, it was assumed that the random variance within the sampling zone would be minimal by selecting 14 replications. Data for samples collected at the same site and among other spill sites were generally of similar magnitude (Young et al. 1983). Note in the previous table, Table 7.3 that there was a consistent relationship between the disappearance of TCDD and the disappearance of the herbicide in "old" spills versus "new" spills (Young 2006a). A similar trend was noted in Table 7.4 over the four dates. Indeed, the protocol had merit. The question remained, "Were there sufficient samples to conclude that the TCDD was disappearing?"

Table 7.5 was a summary of the data collected on TCDD from the L/L and H/H sites for the four dates. The data illustrated the absence of definitive data on TCDD disappearance from the coral of Johnston Island. The very wide fluctuations in TCDD levels between sites and between samples within a site over the four sampling dates were noted by showing standard deviations (Young 2006a).

Penetration of the herbicides and the TCDD occurred within the soil profile of either of the former Herbicide Orange Storage Areas. The data from the analysis of a soil core collected more than 2 years after an herbicide spill at NCBC are shown in Table 7.6. The hardpan, a stabilized zone within the soil, effectively prevented penetration of the herbicides or TCDD (Young et al. 1979).

Table 7.5 Concentrations (ppm) of TCDD in selected coral samples from the former Herbicide Storage Orange Site on Johnston Island

Date	Number of Samples	Mean Concentration of TCDD[1]
25 August 1977	8	0.073 ± 0.073
8 January 1978	27	0.029 ± 0.048
18 October 1978	27	0.037 ± 0.058
8 August 1979	27	0.041 ± 0.049

Source: Young et al. (1983).

[1]When locations previously sampled and found to be positive for TCDD were re-sampled at subsequent dates, and were found to be non-detected at or below a specified detection limit (usually < 0.002 ppm), means were calculated with the detection limit provided as a value.

Table 7.6 Penetration of herbicides (ppm), phenols (ppm), and TCDD (ppm) in a soil profile collected in June 1979 from a Site (Number 17, H/H) where an herbicide spill occurred in June 1977 during Operation PACER HO in the former Herbicide Orange Storage Site on the Naval Construction Battalion Center

Description of site	Soil depth (cm)	Total herbicide[1]	Total phenols[2]	TCDD(ppm)
Surface layer	0–8	61,560	365	0.3250
Above hardpan	8–16	34,690	95	0.3400
Within hardpan	16–24	1,620	48	0.0210
Within hardpan	24–32	322	11	ND[3]

Source: Young et al. (1983).
[1] Total herbicides referred to concentrations of acids and esters of 2,4-D & 2,4,5-T.
[2] Total phenols referred too total concentration of dichlorophenol and trichlorophenol.
[3] Not detected. The detection limit was 0.000480 (480 ppt) for this sample.

Table 7.7 presented the data from the analysis of selected cores from Johnston Island. Although the data indicated that penetration of the herbicides and TCDD had occurred throughout the profiles sampled, the bulk of the chemical remained near the surface.

Data from the microbial analyses of soil samples collected from the former herbicide storage site at the Naval Construction Battalion Center in July 1977, and in January and November 1978, are shown in Tables 7.8 and 7.9. Although the biological activity was high in the three treatment areas (O/O, L/L, and H/H), trends in populations were discernable. The July 1977 data in Table 7.8 indicated the impact that activities associated with Operation PACER HO may have had on the storage area. During Operation PACER HO, not only did personnel and vehicular traffic disturb the entire site, but also crushed oyster shells were placed in selected sites where spills of herbicide and fuel oil had occurred. The bacteria were especially affected; note that the July 1977 levels in either no spill or new spill sites were much lower than the other two dates. However, these data may have also reflected an effect of PACER HO, a lag-

Table 7.7 Penetration of herbicides, phenols, and TCDD in soil profiles collected August 1979 from sites Number 10 (H/H) and Number 37 (H/H), where herbicide spills had occurred during PACER HO in July 1977, former Herbicide Orange Storage Site, Johnston Island

Site number	Soil depth (cm)	Total herbicides[1] (ppm)	Total phenol[2] (ppm)	TCDD (ppm)
Site 10 (H/H)	0–8	48,850	135	0.1190
	8–16	20,600	45	0.0440
	16–24	22,600	55	0.0490
Site 37 (H/H)	0–8	22,700	80	0.1160
	8–16	825	10	0.0110
	16–24	600	10	0.0080

Source: Young et al. (1983)
[1] Total herbicides referred to the concentration of acid and esters of 2,4-D & 2,4,5-T.
[2] Total phenols referred to the concentration of dichlorophenol and trichlorophenol.

Table 7.8 Microbial population levels (number of organisms per gram of soil) in soils collected in July 1977, January 1978, and November 1978 from selected sites on the former Herbicide Orange Storage Site, Naval Construction Battalion Center

Location/sampling date	Number of sites	Bacteria, $\times 10^7$	Fungi, $\times 10^5$
"No" spills (0/0)[1]			
July 1977	6	29.7	29.6 (5)[2]
January 1978	14	45.6	7.8
November 1978	14	40.2	6.2
"Old" spills (L/L)			
January 1978	14	41.8	10.2 (8)
November 1978	14	36.3	4.2 (8)
"New" spills (H/H)			
July 1977	6	15.4	28.6 (5)
January 1978	14	49.4	7.7 (7)
November 1978	14	34.6	6.1 (7)
Control site[3]			
January 1977	1	38.0	3.0
November 1978	1	35.0	3.2

Source: Young et al. (1979, 1983).
[1] The coding O/O, L/L, and H/H are described in the text.
[2] The number within parenthesis referred to number of samples where colonies could be counted. Fungi in soils contaminated with herbicides frequently showed no growth after 7 days, or growth was random.
[3] Control samples were taken in an open grassy area 1.5 km from Herbicide Orange Storage Site.

phase effect in the adaptation of the bacteria to the herbicide, or seasonal variations. The highest levels of bacteria were found in highly herbicide-contaminated sites in January 1978. Of the several bacteria genera isolated and identified, *Psuedomonas* spp. predominated in samples with the highest levels of herbicides. Levels of fungi decreased both with time and herbicide concentration. Only 50% of the H/H sites in January or November 1978 had detectable levels of fungi, and then, as noted in Table 7.9, they were not always of genera found in O/O or control sites. Proliferation of certain organisms might have indicated their ability to metabolize or co-metabolize herbicide or herbicide degradation products, or it might have indicated elimination or inhibition of natural competitors. Specific metabolic activity studies using the predominant organisms would have been necessary to determine their exact role, if any, in biodegradation (Young et al. 1979, 1983).

Data from the microbial analyses of coral samples collected from the herbicide storage site at Johnston Island, and from two adjacent islands that served as control sites are shown in Table 7.10. Figure 7.11 was a photograph of a member of the Department of Chemistry and Biological Science, Air Force Academy, collecting coral samples from a new spill site (H/H) for chemical and microbial studies in January 1978. Microbial quantitative data for Johnston

Table 7.9 Predominant fungal genera found in soils collected from selected sites in July 1977 and 1978 on and off of the former Herbicide Orange Storage Site at the Naval Construction Battalion Center

		On-site		
Predominant genera	Off-site control	O/O	L/L	H/H[1]
Aspergillus spp.	**X**	X		
Penicillium spp.	X	X	X	X
Cunninghamella spp.	X	X		
Zygorhynnchus sp.	X	X		
Alternaria sp.	X	X		
Mycelial molds		X	X	
Candida spp.	X	X		
Rhodotorula sp.	X	X	X	
Geotrichum sp.		X	X	
Trichoderma spp.	X	X	X	
Mucor spp.	X		X	X
Rhizopus sp.	X	X		
Absidia sp.	X	X		

Source: Young et al. (1979) and Young (2006a).
[1] Coding O/O, no spill; L/L, old spill; H/H, new spill; see additional comments in text.

Island were not presented in the tables, but in general they were similar to population levels reported in Table 7.8 for NCBC. The most striking observation from Table 7.10 was that organisms found proliferating in the coral with high concentrations of herbicides and TCDD were not found in other sites. This suggested that these fungal organisms were using the herbicides and the phenols

Table 7.10 Predominant fungal genera found in compacted coral collected from selected sites in 1977 and 1878 on and off the herbicide storage site on Johnston Island, and the two islands adjacent to Johnston Island

			Johnston Island		
Predominant genera	Sand Island	North Island	O/O	L/L	H/H[1]
Penicillum spp.	**X**	**X**	**X**		
Cunninghamella spp.	**X**				
Phizoctonia sp.	**X**				
Ulocladium sp.	**X**				
Cvulariopia sp.		**X**			
Ovulariopis sp.		**X**			
Fusarium sp.		**X**	**X**	**X**	
Mycelia molds		**X**			
Nocardia sp.					**X**
Schizosaccharomyces sp.					**X**
Candida spp.					**X**
Rhodotorula sp.					**X**
Geotrichum sp.					**X**

Source: Young et al. (1983).
[1] Coding O/O, no spill; L/L, old spill; H/H, new spill; see additional comments in text.

Fig. 7.11 A photograph of a member of the Air Force Academy's Department of Chemistry and Biological Sciences collecting coral from a "New Spill" site (H/H) of Herbicide Orange for chemical and microbial analyses, January 1978 Johnston Island (Photograph courtesy of A.L. Young)

as potential carbon sources, perhaps playing a key role in the disappearance of the herbicides (Young 2006a).

7.6 Aquatic System Monitoring for TCDD at NCBC, 1977–1979

The toxicity associated with 2,3,7,8-TCDD and its occurrence as a contaminant of 2,4,5-T herbicide (and hence, Agent Orange) dictated that it had to be the focus of any residue monitoring study. The location of the Naval Construction Battalion Center in relationship to the communities of Gulfport, Mississippi, meant that any water leaving NCBC would likely pass through a populated area. During site visits to NCBC, it was common to observe people fishing in the streams, ponds, and a lake that were associated with the drainage from NCBC (Young et al. 1979). Previous ecological studies at Eglin AFB, Florida (Young 1974, 1983; Young et al. 1975) confirmed that aquatic drainage systems were contaminated by water erosion of soil particles containing TCDD. The NCBC herbicide storage site was drained by a series of small ditches (Fig. 7.12) that connected in to a single ditch immediately adjacent to the storage site (Fig. 7.13). This larger ditch was fed by other small ditches as it transversed the property of NCBC and drained into a canal located immediately outside the NCBC property, about 4,000 meters from the herbicide storage site (Young et al. 1979).

In an effort to obtain baseline data on TCDD in this aquatic system, archived biological samples that had been collected in January 1976 were

Fig. 7.12 A 1977 photograph of the small ditches that drained the former Herbicide Orange Storage Site at the Naval Construction Battalion Center (Photograph courtesy of A.L.Young)

Fig. 7.13 A photograph of the convergence of small ditches into a larger ditch that transversed the Naval Construction Battalion Center property, and drained into a canal off-base and into the community of Gulfport, Mississippi. This larger ditch was monitored for herbicide and TCDD residues during Operation PACER HO, May–June 1977 (Photograph courtesy of USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas)

analyzed in November 1978 and found positive for TCDD residues. Thereafter, additional environmental samples were collected in the drainage system in January, February, and June 1979 at distances of 1,000, 2,000, 3,000, and 4,000 m from the immediate herbicide storage site. Figure 7.14 was a photograph of a sediment sample being collected in the large drainage ditch 2,000 meters from the herbicide storage site in June 1979. The analytical results of these environmental samples were received in September and November 1979. A summary of the TCDD residue data for the aquatic system draining from the herbicide storage site is shown in Table 7.11.

Fig. 7.14 A photograph of a sediment sample being collected in the large drainage ditch 2,000 m from the former Herbicide Orange Storage Site, June 1979, on the Naval Construction Battalion Center (Photograph courtesy of A.L. Young)

Aquatic monitoring studies detected TCDD residue levels in ppb and ppt levels. Thus, the average mean level of TCDD in storage site soils (H/H) in July 1977 was 237 ppb, 206 ppb in January 1978, and, 144 ppb in November 1978 (from Table 7.3). The sediment and biological samples were at least two orders of magnitude below levels in the soil in the storage sites. This was consistent with the results of the sediment, and biological samples found in the aquatic

Table 7.11 The 1979 Summary of results (parts-per-billion, ppb) for TCDD residue studies in water, sediments, and biological organisms associated with the drainage from the former Herbicide Orange Storage Site on the Naval Construction Battalion Center

Distance from Storage Site (meters)	Water (ppb)	Maximum concentration Sediments (ppb)	Biologicals (ppb)
Immediate area	ND[1]	3.60	0.14–3.50[2]
1,000 m	NA[3]	2.70	0.20–2.20
2,000 m	NA	0.01	0.045[4]
3,000 m	NA	0.02	0.020[5]
4,000 m	NA	ND	ND[6]

Source: Young et al. (1979).
[1] ND = not detected. The detection limit varied with the sample. The University of Utah analyzed sediment and water samples, whereas the biological samples were analyzed by the University of Nebraska.
[2] First sample set collected in January 1976 and analyzed and reported in January 1979. The second set of samples was collected in January 1979 and the results reported September 1979.
[3] NA = not analyzed.
[4] This value was a mean value for a single crayfish that was analyzed twice. The mean detection limit was 0.01 ppb.
[5] This value was a mean value for a single crayfish that was analyzed twice. The mean detection limit was 0.008 ppb.
[6] A composite sample of mosquito fish that was analyzed three times. The sample was considered negative at a detection limit of 0.007 ppb.

system of Test Area C-52A, Eglin AFB, Florida (Young et al. 1975). As noted in Table 7.11, a mix of organisms was collected in the immediate area of the storage site. The mix included snails, fish, tadpoles, crayfish, and aquatic insects. The TCDD levels ranged from 0.14 to 7.2 ppb.

7.7 Management Recommendations for the NCBC Herbicide Storage Site

The aquatic monitoring studies clearly showed that TCDD was moving from the herbicide storage site in to the drainage system of the Naval Construction Battalion Center. The November 1979 Technical Report (Young et al. 1979) provided the following recommendations for the management of the storage site:

1. At this time, the approximate 5-hectare herbicide storage site should be left undisturbed, permitting the continuation of "natural" degradation of the herbicides and TCDD;
2. Access to the storage site should be restricted so vehicular traffic would not "track" contaminated particles to other parts of the installation;
3. Stabilize and elevate the drainage ditch banks with concrete or similar material so that an initial catchment occurs on the storage site. The ditches should be allowed to have plant growth in them to slow the movement of water and silt. In several places along the drainage system, dams should be constructed to slow water movement creating small siltation ponds in the ditch system;
4. Allow native vegetation to invade the storage area and establish a plant community to restrict both wind and water erosion; and,
5. Develop a research protocol to determine possible methods for returning the area to full beneficial use. The protocol might include techniques to decontaminate TCDD-laden soil, increase TCDD degradation rates, and to characterize the distribution and effects of TCDD in the aquatic environment.

Upon receiving the report and recommendations, the Commander of the Naval Construction Battalion Center implemented the recommendations. Figure 7.15 is a 1980 photograph showing the stabilization of the ditch banks and the re-vegetation of the site. Figure 7.16 was a 1980 photograph showing the construction of a dam in the draining system to slow the water and allow the silt to settle out. Similar dams were constructed throughout the entire drainage system, but especially near the area where the drainage water left the installation and flowed into the canal adjacent to NCBC.

On 24 March 1980, a document entitled "Research Requirements for Reclamation of Herbicide Orange Storage Sites" was submitted through channels to the Secretary of Air Force requesting funding for continuation of monitoring and the planning for the reclamation of the storage sites (Young and Thalken

Fig. 7.15 A 1980 photograph showing the stabilization of the ditch banks and the re-vegetation of the former Herbicide Orange Storage Site on the NCBC (Photograph courtesy of A.L. Young)

Fig. 7.16 A 1980 photograph showing a rock-constructed dam in the draining system leading away from the former Herbicide Orange Storage Site on the NCBC (Photograph courtesy of A.L. Young)

1980). Inherent within the Requirements Document was the recommendation that the Air Force Engineering and Services Center (AFESC), Tyndall AFB, Florida be given the responsibility. The Office of the Secretary concurred and the "Storage Site Treatment and Monitoring Program" was transferred from the USAF Occupational and Health Laboratory, Brooks AFB, Texas, to the Engineering and Services Laboratory at Tyndall AFB, Florida (Channell and Stoddart 1984).

7.8 Implementation of the AFESC Herbicide Orange Monitoring Program

In June 1980, the AFESC/Engineering and Services Laboratory was designated as lead laboratory for monitoring and reclamation research for the NCBC and Johnston Island herbicide storage sites (Channell and Stoddart 1984). Because the Engineering and Services Laboratory had a dedicated research mission, rather than routine analyses, the site-monitoring program was consolidated within the Dioxin Research Program. Under that program it was directed that: (1) a sampling and analysis program be initiated; (2) a small program to look at methods to destroy in situ dioxin (TCDD) be started, but no full-scale effort take place unless further directed by the Office of the Secretary of the Air Force; and (3) progress on assessing long-term breakdown and movement of dioxin be addressed yearly at the AFESC Technical Review (Channell and Stoddart 1984).

The Engineering and Services Laboratory (ESL) adopted the protocol for sampling used by the USAF Occupational and Environmental Health Laboratory with one exception. The ESL protocol used a single sampling plot, 30-cm^2 by 8 cm deep. The square plot was located 15 cm from the numbered marker pin placed in the center of the spill in July 1977 or January 1978 for NCBC, or August 1977 and January 1978 for Johnston Island. The same sampling site was re-sampled on all subsequent sampling dates. The soil was removed, sieved to remove rocks and debris, homogenized, sampled, remixed, and returned to the plot (Fig. 7.17 for NCBC and Fig. 7.18 for Johnston Island). It was noted that the main disadvantage of this sampling protocol was the fresh exposure of

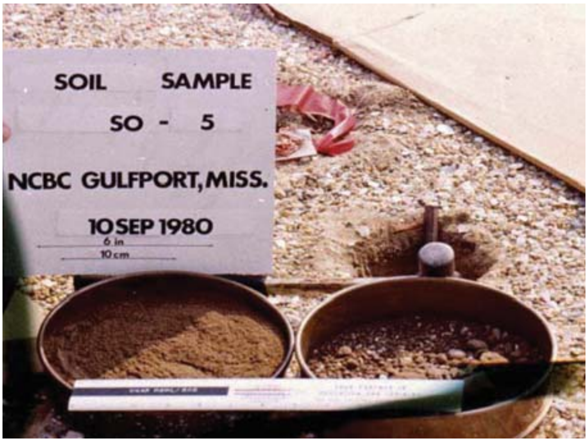

Fig. 7.17 A photograph taken 10 September 1980 by personnel from the Engineering Services Laboratory showing the sampling protocol for collecting soil samples on the former Herbicide Orange Storage Site, NCBC (Photograph courtesy of Air Force Engineering and Services Laboratory, Tyndall AFB, Florida)

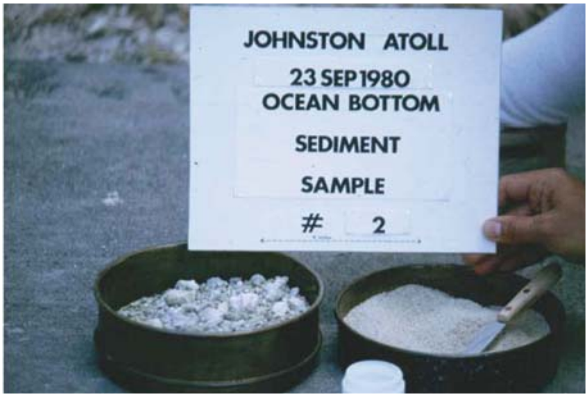

Fig. 7.18 A photograph taken 23 September 1980 by personnel from the Engineering Services Laboratory showing the sampling protocol for collecting samples from and adjacent to the former Herbicide Orange Storage Site on Johnston Island (Photograph courtesy of Air Force Engineering and Services Laboratory, Tyndall AFB, Florida)

contaminated soil or coral to sunlight, resulting in a potential bias caused by accelerated photodecomposition of the TCDD compared to that of undisturbed soil or coral (Channell and Stoddart 1984).

The ESL personnel sampled NCBC and Johnston Island in September 1980, November 1981, and April 1982. They re-sampled the aquatic drainage system at NCBC in 1980 and 1982. Table 7.12 provided a comparison of data on four selected sites for the January 1978 and April 1982 sample dates for NCBC. Table 7.13 provided comparison data on two spill sites (Number 5 and 12, both H/H sites) from August 1977 to April 1982.

Although the sampling method in April 1982 was slightly different from the January 1978 sampling, the data confirmed that the herbicides had

Table 7.12 Concentrations of phenoxy herbicides (ppm) and TCDD residues (ppb) from four sites sampled in 1978 and 1982 from the former Herbicide Orange Storage Site at NCBC

Site	Date	Total herbicides (ppm)	TCDD concentration (ppb)
1	January 1978	69,500	320
	April 1982	96	166 ± 36 (9)[1]
5	January 1978	29,100	<2
	April 1982	1,970	1.8 ± 1.1 (5)
17	January 1978	57,900	510
	April 1982	3,566	238 ± 98 (9)
41	January 1978	34,100	230
	April 1982	680	148 ± 59 (9)

Source: Young et al. (1979) and Channell and Stoddart (1984).
[1] The number of times the sample was analyzed is in parenthesis.

Table 7.13 Concentration of phenoxy herbicides (ppm) and TCDD residues (ppb) four sites Sampled in 1978 and 1982 From the Herbicide Storage Site on Johnston Island

Site	Date	Total herbicides (ppm)	TCDD concentration (ppb)
5	January 1978	37,900	34
	April 1982	5	22 ± 16 (7)[1]
10	January 1978	129,000	230
	April 1982	1,620	119 ± 60 (9)
12	January 1978	57,100	81
	April 1982	255	50 ± 23 (9)
41	January 1978	80,500	85
	April 1982	1,490	77 ± 22 (9)

Source: Young et al. (1979) and Channell and Stoddart (1984).
[1]The number of times the sample was analyzed is in parenthesis.

essentially disappeared from the storage areas. There was evidence at both locations that some of the herbicide had penetrated into the soil profile. At NCBC, herbicide and TCDD residues were found to a depth of 20 cm, while at Johnston Island, herbicide and TCDD residues were found to a depth of 30 cm (Channell and Stoddart 1984; Young et al. 1979). Although sediment and biological samples were collected in 1982 from the drainage system at NCBC, there was no indication that movement of TCDD had increased from the 1979 sampling.

7.9 Site Characterization Study of NCBC in Preparation for Reclamation

In April 1984, the Air Force Engineering and Services Center, Tyndall AFB, Florida, contracted with EG&G Idaho, Inc., Idaho Falls, Idaho to thoroughly characterize the storage site at the Naval Construction Battalion Center, and determine if an excavation and cleanup project would be required. In accordance with EPA interim standards, a cleanup criterion of 1 ppb was recommended (Crockett et al. 1987).

The approximate 5-ha storage site was divided into 1,300 plots, where each plot was a 6- by 6-meter square. Each plot was sub-sampled to a depth of 8 cm, the samples composited for that plot. To determine the depth of penetration of the TCDD into the cement-stabilized soil, 35 locations were sampled to a depth of 60 cm, and at 15 locations, samples were collected to a depth of 1.5 m. Over 1,700 soil samples were collected. The samples were analyzed for both herbicides (2,4-D and 2,4,5-T) and for TCDD (Crockett et al. 1987).

The analytical data indicated that TCDD contamination was highly variable and random. TCDD concentrations in the top 8 cm ranged from less than a detection limit of 0.01–646 ppb. The arithmetic mean for all surface plots inside the storage area was 10.7 ppb. Based on the results of subsurface sampling, it appeared that, except for three samples, TCDD concentrations above 1 ppb were limited to 60 cm in depth with a maximum of 310 ppb in the 0–8-cm interval, 93 ppb in the 8–16-cm, and 12 ppb in the 16–24-cm interval. The maximum concentration in the soil/cement layer was 1,000 ppb (1 ppm). The 15 subsurface samples were also analyzed for herbicides. The concentration of herbicides ranged from a detection limit of 5–20,800 ppm for 2,4-D and 27,700 ppm for 2,4,5-T, where the highest concentrations were found in the soil/cement layer (Crockett et al. 1987).

The volume of material requiring excavation for a TCDD cleanup effort was calculated at the 65 and 95 percent confidence levels for a conservative excavation depth of 60 cm. The 95 percent confidence value for a clean up criteria of 1 ppb was 20,630 cubic meters of soil. If excavation in 15-cm intervals was performed followed by sampling the bottom of the hole, it was estimated that this would reduce the volume to approximately 5,160 cubic meters of soil (Crockett et al. 1987).

7.10 Final Reclamation Actions at the Naval Construction Battalion Center

In September 1986, the Air Force Engineering and Services Center contracted with EG&G Idaho, Inc, Idaho Falls, Idaho, to proceed with a full-scale demonstration of a rotary kiln incinerator to process soil contaminated with TCDD in the herbicide storage site at the Naval Construction Battalion Center (AFESC 1988; Cook and Haley 1990).

The demonstration project consisted of three phases. The first phase, the verification test burn, demonstrated the effectiveness of the 900 metric tons/day incinerator to process soil contaminated with phenoxy herbicides and TCDD (Stoddart and Short 1989).

The second phase demonstrated the ability of the incinerator to meet the requirements of the Resource Conservation and Recovery Act (RCRA), which specified that the incinerator must meet or exceed a Destruction and Removal Efficiency of 99.9999%. Five verification test burns were conducted and evaluated after which EPA, Region IV, issued a permit in accordance with the RCRA of 1976, as amended (Stoddart and Short 1989).

The third phase determined the cost and reliability of using the incinerator on a long-term basis. During this phase, 1,006 6- by-6-meter plots were excavated from a depth of 8 cm to as much as 130 cm. As the soil was excavated, it was placed in one of three soil storage tents located near the incinerator. A material handler, using a front-end loader, transferred the soil from the storage tents to the weigh hopper/shredder unit where it was weighed, shredded, and dropped into the feed hopper where the auger fed the soil into the rotary kiln incinerator. The soil in the rotary kiln was subjected to a minimum temperature of 790° C for 20–40 min to volatize the organics. At the outlet of the kiln, the burned solids (ash) fell into a water quench tank while the gases and sub-micron particulate flowed upward through a second combustion chamber. After analysis, the treated soil was placed back in the field. None of the treated soil required reprocessing (Cook and Haley 1990).

The third phase demonstrated that the project could be successfully completed. From May 1987 through February 1989, the entire herbicide storage site at NCBC was reclaimed for unrestricted use. The cost of the entire Project from September 1986 through February 1989 was $9,473,315 (Cook and Haley 1990). The site was accepted as clean by the Department of Defense in 1989, however a "delisting" of the site was not granted from EPA and the State of Mississippi (Cook and Haley 1990).

In 1991, the Department of The Navy expressed concern that the ash from the incineration project could not be "delisted" by EPA and State of Mississippi under the Resource Conservation and Recovery Act (RCRA) (Hilderbrand 1991). Accordingly, the Commanding Officer of the NCBC directed that the Air Force Directorate of Engineering and Services, Bolling AFB, Washington DC should propose a solution to the problems created by the ash. Subsequently the Air Force Directorate of Engineering approved a project on soil/sediment "treatability" (Tetra Tech 2001). Researchers with Tetra Tech NUS, Inc., proposed that it would be necessary to treat nearly 62,000 cubic meters of soil and sediment from the 12-ha storage site and surrounding area, and 8 km of drainage ditches with a cement-based solidification/stabilization matrix. The approximately 62,000 cubic meters of soil, ash, and sediment was mixed with 4.7% cement and layered over the former storage area (Tetra Tech 2001). Additionally, the walls of the drainage ditches associated with the former storage area were all subjected to cement stabilization. Testing confirmed that performance standards were met, and dioxin-leaching results were "non-detected. Final approval from EPA and State of Mississippi is pending.

The 2005 "Public Health Assessment" by the Agency for Toxic Substances and Disease Registry (ATSDR) of NCBC concluded that the average dioxin levels detected in off-site surface soils and sediments were well below ASTDR's established action level for dioxin in soil (ATSDR 2005). The swampy area north of Canal # 3 (the area receiving drainage from NCBC), referred to as the off-base area of concern, was the most contaminated off-site location, but did **NOT** contain dioxins in soils or sediments "at levels that have been demonstrated to cause illness or measurable adverse health effects" (ATSDR 2005).

On February 3, 2006 the US Environmental Protection Agency released the analytical results from sediment samples taken at NCBC as part of ongoing hurricane cleanup efforts as a result of the site having been potentially impacted by Hurricane Katrina (EPA 2006). Results were consistent with background data.

7.11 The Reclamation of the Johnston Island Herbicide Storage Site

In 1985, the Air Force Engineering and Services Center (AFESC) negotiated a contract with International Technology Corporation (IT Corporation), Knoxville, Tennessee, to demonstrate a new technology for the potential reclamation of Johnston Island. The technology was a thermal desorption/ultraviolet photolysis process (TD/UV). The process employed three primary operations – thermal desorption to volatilize the contaminants, condensation and absorption of the contaminants in a solvent, and photochemical decomposition of the contaminants (Helsel et al, 1987). Bench-scale experiments established the relationship between desorption conditions (time and temperature) and treatment efficiency. Laboratory tests using a batch photochemical reactor defined the kinetics of 2,3,7,8-TCDD disappearance (Helsel et al. 1987).

Based on the information developed from the laboratory test program, a pilot-scale TD/UV system was designed and assembled (Helsel et al. 1987). Three skids were used to mount the desorber, scrubber, and photolysis systems; the largest skid was 1.5 m by 4.3 m. A conventional pilot-scale, rotary, indirect-fired calciner was used as the desorber. The calciner consisted of a 3.3 m long by 16-cm internal diameter rotating tube through which the soil was transferred, and a gas-fired furnace which surrounded the middle 2.0 m of the tube length. The initial and final tube sections were used for feeding and cooling. The flow rate and residence time of soils traveling through the desorber were controlled by varying the tube inclination and the rotational speed. Temperature of the soil was measured at different locations by a thermowell probe extending inside the tube. Soil was fed to the desorber from a small hopper using a variable speed screw conveyor (Helsel et al. 1987).

In July 1986, the pilot-scale TD/UV system was assembled at Johnston Island and three desorption tests and one photolysis test was conducted to compare the effects of different soil characteristics and investigate higher processing rates. The coral-like soil used for the tests contained levels of TCDD from Herbicide Orange in the range of 50 ppb (Crockett et al. 1986). As much as 95 kg/h of soil was successfully decontaminated to less than 1 ppb 2,3,7,8-TCDD using desorption temperatures of 550°C. Treated coral from all three desorption tests had non-detectable residual tetra-hexa CDD (chlorodibenzodioxins) and CDF (chlorodibenzofurans) cogeners, 2,4-D, 2,4,5-T, and corresponding chlorophenols. Analysis of carbon removed from the desorber-scrubber system vent showed no detectable concentrations of CDD or CDF. Gas samples taken downstream of the carbon adsorber, showed non-detectable concentrations of CDD, CDF, 2,4-D, 2,4,5-T, and chlorophenols. Some additional technical information was needed for a complete evaluation of the process and to provide the basis for design of a full-scale system for on-site remedial action (Helsel et al. 1987).

In 2001, AFESC briefed the Commander of the Pacific Air Force (PACAF), and a contract was negotiated with CH2M Hill to begin the reclamation of Johnston Island in 2003 using the Thermal Desorption – Ultraviolet Photolysis Process (USAF EIS 2004; CH2M 2004).

Following the signed contract between AFESC and CH2M Hill, efforts were initiated for all buildings, roads, runways, docks and piers to be demolished and the former Herbicide Orange Storage Site, Johnston Island sampled to a depth of 24 cm. In February 2002, composite soil samples were collected from the former Storage area and the data were presented in Table 7.14

In June 2003, the entire 2.5-ha area of the former Storage Site was divided into 12 × 15-m "cells". All vegetation was removed. Each cell was excavated to a depth of 20 or 30 cm, as determined from the analysis of previous soil cores. The berm constructed near the shoreline in 1972 was also removed and the resulting soil processed. As noted the technology selected for the destruction of the remaining TCDD in the coral soil of Johnston Island was an on-site thermal desorption system (TDS) employing low temperature thermal desorption technology (Helsel et al. 1987). The TDS included eight separate Matrix Constituent units. In each unit, the soil was placed into 30 cm deep trays. The soil was heated using JP-5 fired infrared heater tubes which were located directly below the trays. Heat transfer involved radiant (from the burner tube), convective (combustion gases passing through the soil) and conductive (soil particle to soil particle contact) heating (Helsel et al. 1987; USAF EIS 2004; CH2M 2004). The contaminated soils were heated to 510°C causing partitioning of water and contaminants from the soil into the gas phase. The purge gas was condensed and treated through a waste water treatment plant. Off gases were treated through a thermal oxidizer. The soil was returned to the site. The TDS activities were completed in March 2004. A re-vegetation program was undertaken to develop habitat for sea birds (Fig. 7.19) (CH2M 2004).

In January 2004, the Department of the Air Force issued an Environmental Impact Statement (USAF EIS 2004) proposing to terminate the Air Force Mission on Johnston Atoll Airfield. The draft statement stressed the successful treatment of the remaining hazardous wastes prior to the turn over of the atoll to the United States Fish and Wildlife Service. With the final action complete on Johnston Island to remove the TCDD from the coral, the closure of the

Table 7.14 The 2002 results of testing composite soil samples from the former Herbicide Orange Storage Site, Johnston Island

Depth of sampling	TCDD concentration (ppb)
0–8 cm	0.043 ppb (8)[1]
8–16 cm	1.894 ppb (5)
16–24 cm	0.867 ppb (5)

Source: USAF EIS (2004) and CH2M (2004).

[1] Number of samples analyzed (mean concentration).

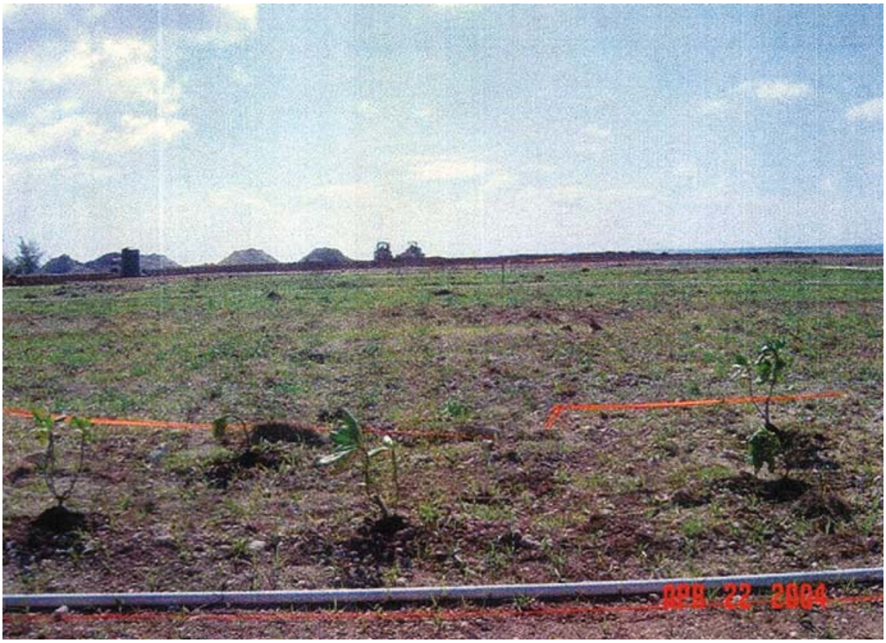

Fig. 7.19 A photograph of Johnston Island in April 22, 2004 following the final remediation actions and re-vegetation. Piles of coral and asphalt in the background were from the removal of the airstrip on Johnston Island (Photograph courtesy of Air Force Engineering and Services Laboratory, Tyndall AFB, Florida)

Herbicide Orange Site Monitoring Program was concluded. It was a program that extended for 30 years (1974–2004).

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Chapter 8
Agent Orange and Dioxin Remediation and the Return to Vietnam

Almost every aspect of the War in Vietnam has been controversial. It was a war that generated bitter emotions, and for the men and women who served in that War, regardless of where they were from, the memories of their experiences have lingered. Thus, the idea of returning to Vietnam by the US Government had by necessity required that many issues from that War be resolved before re-establishing diplomatic relations. Much has happened in the past 14 years. President Richard M. Nixon ordered the embargo of the "Republic of Vietnam" on April 30, 1975. President William Clinton dropped the embargo on February 3, 1994. In January 1995, the United States and Vietnam signed agreements on those claims related to the War, absolving both nations of damages incurred. On July 15, 1995, President Clinton announced normalization between the US and Vietnam and stated: "The time has come to move forward and bind up the wounds from War." On August 5, 1995, the US Embassy was opened in Hanoi, and on April 10, 1997 Douglas "Pete" Peterson, a former POW, became the first Ambassador to the Socialist Republic of Vietnam. Thus, the normalization and building of relationships between the United States and Vietnam has all essentially occurred in just over a decade. But when did Agent Orange become an issue between the two nations?

8.1 The National Academy of Sciences Study, 1971–1974

In 1970, funds were appropriated by the Congress for Public Law 91-44, an Act that directed that the Secretary of Defense: "*shall undertake to enter into appropriate arrangements with the National Academy of Sciences to conduct a comprehensive study and investigation to determine (A) the ecological and physiological dangers inherent in the use of herbicides, and (B) the ecological and physiological effects of the defoliation program carried out by the Department of Defense in South Vietnam*" (NRC 1974). On February 15, 1974, the Chairman of the National Academy of Sciences Committee tasked with the study, Dr. Anton Lang, transmitted the report "The Effects of Herbicides in South

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Vietnam" to The President of the Senate, The Speaker of the House of Representatives, and The Secretary of Defense (NRC 1974). Dr. Lang was careful to place limits on how the study was conducted:

> As we entered upon the task, some of its inherent difficulties were self-evident: Appraisal of the effects of herbicide usage necessarily had to be undertaken well after the fact. Since the war in Vietnam was certainly not conducted as a controlled experiment, valid conclusions might well be constrained by the complexity of actual circumstances, by lack of adequate records or qualified observers on the scene at the time of the spraying program. Patently, separation of the effects of herbicides from all other aspects of the war would be difficult at best. Most importantly, military activity was and still is continuing in most areas that had previously been sprayed with herbicides; accordingly, safe access to large areas of the country was denied to our field teams, thereby in no small measure frustrating their efforts to secure critical data (NRC 1974).

In the February 15, 1974 transmittal letter, the following four findings were elaborated:

1. "The Committee was unable to gather any definitive indication of direct damage by herbicides to human health. However, to a greater extent then in other areas, there were consistent, albeit large 'secondhand' reports from Montagnards, of acute and occasionally fatal respiratory distress, particularly in children. The inability of the Committee to visit the Montagnards in their own locales so as to verify these tales is greatly regretted. Although these reports did no come from medically qualified observers, the Committee considers it to be important that this matter be pursued at the earliest opportunity."
2. "Attempts to assess the social, economic, and psychological effects of the program of herbicide spraying on the peoples of South Vietnam were less than satisfying. Certainly the spraying program on that population now appears relatively trivial as compared with other aspects of the upheaval in that country. About 200–300 pounds *(91–136 kg)* of TCDD was a contaminant in the 50 million pounds *(22.6 million kg)* of 2,4,5-T dispensed over South Vietnam. That no serious sequelae have since been definitely discerned is fortunate indeed. However, the continued presence of possible significant concentrations of this material in fish and in inland rivers, taken as recently as 1973, is considered to be a matter that warrants further attention. On balance the untoward effects of the herbicide program on the health of the South Vietnamese people appear to have been smaller than one might have feared."
3. "The effects of herbicides on vegetation were largely confined to those resulting from direct contact during spraying. It was found that the various herbicides disappear from the soil at a rate sufficiently rapid as to preclude any significant effect on the next crop of food plants, or on the next growing season of trees, shrubs, etc. All evidence indicates that standing food crops, of all sorts, were highly vulnerable to the spray program. It was not possible, however, to assess the nutritional consequences of that program on the affected local populations."

4. "A major effort of the Committee was devoted to appraisal of the effects of the herbicide spraying program on the forests of South Vietnam. The mangrove forests were found to have been extremely vulnerable.... The large bulk of the herbicides spraying were addressed to the large inland forests of South Vietnam, a total of 6.5% of the total land area of South Vietnam.... Thus, whereas one cannot rationally assign some dollar value to the herbicide-caused economic loss to Vietnam, either in the past or the near future, there will be serious penalties to the long term unless a commensurate effort is undertaken to prevent them. And, as in the case of the mangrove, there is the burden of conscience to restore these forests to their natural or improved conditions (NRC 1974)."

The 1,000-page report issued by the Committee on "Effects of Herbicides in South Vietnam" was comprehensive, but *un*sensational (NRC 1974). Birth defects had not shown detectable correlations with the period of defoliation applications. The half-life of 2,4,5-T was short, (five days), and that of 2,4-D was two days. Scientists serving on the Committee were able to grow several phenoxy-sensitive and locally important vegetables within six weeks of application at rates applied operationally (Blackman et al. 1974; Byast and Hance 1975; Newton and Young 2004). Rice crops generally benefited from the use of 2,4,5-T because it killed weeds and did not injure the rice (Blackman et al. 1974). Forests appeared to be damaged more by fire and bombs rather than anything else; the fire was certainly facilitated by defoliation that led to a deposit of dry fuel during the dry season, but fire was the agent that killed most of the thin-barked upland tree species. Most species recovered if not burned, and desirable regeneration was occurring in forests that were heavily damaged by being sprayed three times (Bethel and Turnbull 1974). Mangroves were regenerating even where repeatedly sprayed (Ross 1974).

8.2 The Period of Limited Access to Vietnam and Studies on Agent Orange, 1976–1995

Since the National Research Council published its 1974 report and associated parts, there has been a continual interest in conducting studies in Vietnam. However, it was not until the fighting had ceased that in-country studies could be conducted. In 1976, Westing published a book on the "Ecological Consequences of the Second Indochina War" (Westing 1976). In commenting on the use of anti-plant chemicals, he noted that, although not an innovation of the Second Indochina War, its use had become inseparably associated with it. However, he acknowledged the broader impact of War on vegetation:

> Vegetation on the battlefield is subject to severe abuse. This became particularly so as a result of the several indiscriminate methods of wide-area attack which were developed in Indochina. Indeed, the chemical anti-plant agents and Rome ploughs employed so extensively by the United States during the Second Indochina War were designed

> specifically to accomplish massive vegetational destruction. The same can be said for concussions bombs used, though on a far lesser scale, and might have been said for the forest fires attempted, had it been possible to develop satisfactory techniques (Westing 1976).

In 1984, Westing edited a proceeding of an International Symposium on "Herbicides in War: The Long-term Ecological and Human Consequences", held in January 1983 in Ho Chi Minh City, Vietnam (Westing 1984). In a commentary on the Symposium, it was noted that there were more than 160 scientists from 21 countries and delegates from 3 United Nations agencies (Carlson 1983). Some 72 papers were presented on ecological and health aspects of the long-term effects of military herbicides used in the Vietnam War. The commentary concluded with a statement that the Vietnamese wanted to talk science, not politics. They wanted reprints and books, and they wanted to be invited to American and European laboratories and symposia to learn about new techniques and scientific advancements.

As noted above, the international community took great interest in the issues of dioxin and human health in Vietnam. Much of this was due to what had occurred in the Seveso, Italy accident of 1976 (Reggiani 1983). Frequently, international scientists and science writers would visit Hanoi and report on the Agent Orange and dioxin "pending crisis" in Vietnam. In 1978, Dr. Alastair Hay, University of Leeds, England visited Vietnam and subsequently reported:

> Resolving the "dioxin problem" is not one of Vietnam's top priorities; there are too many other areas, medical and agricultural, requiring urgent, immediate attention. What the long-term effects will be is impossible to say: the evidence is just not available. With contamination on this scale, Vietnam is in a unique situation, not to be envied. It is to be hoped that, when she asks for assistance from the scientific world, it will be promptly forthcoming (Hay 1978).

Hay subsequently published a book on his investigations into Seveso, Vietnam and Love Canal titled: "The Chemical Scythe: Lessons of 2,4,5-T and Dioxin" (Hay 1982). It was not until the mid-1980s that Vietnamese Scientists began inviting and working with scientists from the international community. For scientists from Western countries, arranging visits, traveling throughout Vietnam, and collecting specimens for dioxin and furan analyses were at times daunting tasks (Schecter et al. 1986).

Agent Orange and its associated dioxin contaminant have been topics of interest at each of the past 26 international conferences on "Chlorinated Dioxins and Related Compounds" (Young 2002). The Second International Symposium (DIOXIN 1981) was held in Alexandria, Virginia. Eight papers were presented at the first organized session of this topic. The focuses of the early presentations were primarily on the environmental fate of Agent Orange and TCDD and the potential routes of human exposure (Tucker et al. 1983). DIOXIN 1986 was held in Fukuoka, Japan, and it was at this Symposium that the first papers on TCDD residues in tissues of veterans and Vietnamese were presented. It was also at this Symposium that the first studies of Vietnamese populations were discussed. Eight presentations were presented by Vietnamese scientists and collaborating colleagues in the special session on "Observations in Man" (Masuda 1986). Since 1986, there have been an increasing number of manuscripts published both as extended abstracts in the DIOXIN Symposium Series, and as full papers, initially in *Chemosphere* (a non-peer reviewed journal), on the presence of TCDD in river sediment, food, and human tissue (Schecter et al. 1986; Schecter et al. 1989a, b; Yang 2001). Many of these studies associated the dioxin contaminant with health effects in Vietnamese civilians (Lang 1986; Phiet et al. 1989; Phuong et al. 1990; Dai et al. 1990). The majority of papers listed both Western and Vietnamese scientists as collaborators in the sampling and analysis.

The surprise for Western scientists doing studies in Vietnam was that the tremendous research programs sponsored by the United States government and under the auspices of the Agent Orange Working Group in the United States (Chapters 1 and 5) did not support concerns of Vietnam veterans about Agent Orange and its associated dioxin (Hanson 1987). Indeed in November 1987 the outcome of most government-sponsored research revealed the following results:

> Over the past couple of months, a number of events have converged to bring Agent Orange back into public attention. The issue – whether Vietnam veterans have been made ill by exposure to the herbicide used as a defoliant during the Vietnam War – still evokes considerable emotion almost a decade after it was first raised. It is these emotions, and the politics, that so confuse the issue.... The level of research is such that by the time the RANCH HAND Study (The Air Force Health Study) is completed in 2002, TCDD will be the most heavily studied man-made compound in humans. At this time, though, it appears that the low levels found in people of industrial societies, that is, 4 to 10 ppt, are not causing any health problems. Vietnam veterans may face mounting evidence as time goes on that Agent Orange is not the source of their health problems (Hanson 1987).

Just prior to the normalization between the United States and the Socialist Republic of Vietnam, the Institute of Medicine released its first report on "Veterans and Agent Orange: Health Effects of Herbicides Used in Vietnam (IOM 1994)". In its report, the IOM examined all of the available studies that had been conducted in Vietnam and on Vietnamese. The IOM Committee felt that in-depth studies of Vietnamese populations exposed to herbicides might be possible and potentially useful (IOM 1994). However, the IOM cautioned:

> Accurate disease ascertainment and exposure reconstruction may pose difficult problems. The actual exposure of this group to herbicides would be extremely difficult to determine accurately because (1) serious problems with recall bias are likely; (2) given the war conditions, documents about location during the war in Vietnam are unlikely to be completely available or reliable; (3) the Vietnamese in question may have relocated in the intervening decades, and (4) current serum TCDD measures may not be practical or relevant. Before significant resources are committed to studies of the Vietnamese population, the Committee recommends that feasibility studies of both exposure reconstruction and disease monitoring be conducted (IOM 1994).

8.3 Normalization Between the United and the Socialist Republic of Vietnam, 1995-Present

With the announcement of normalization between the United States and the Socialist Republic of Vietnam in July 1995, access to opportunities to conduct more extensive Agent Orange and TCDD studies in Vietnam occurred. However, the new studies were conducted with a different thrust, namely to establish exposure and causation that would provide evidence for legal proceeding. The precedents for these actions were obvious. First the settlement (for $180 million) in the United States of the class action involving 2.4 million Vietnam veterans, their wives, and offspring brought against seven chemical manufacturers for injuries allegedly suffered as a result of exposure to Agent Orange in Vietnam (Maskin 1988). The second precedent was the passage and implementation of the Agent Orange Act of 1991 that established presumptive compensation to Vietnam veterans having certain diseases "associated" with exposure to the tactical herbicides and TCDD (IOM 1994).

From a scientific perspective, the approach for Vietnamese scientists and their Western colleagues for establishing causation was to find populations in Southern Vietnam with significant levels of dioxin in their bodies, and attempt to relate these levels with the spraying of Agent Orange and with detrimental health outcomes. Searching for the persistence of residues of dioxins and furans in human tissue is a valid bio-monitoring approach (Young 2004b; Sexton et al. 2004). These data were then to be compared to dioxin levels in Northern Vietnam citizens (where defoliants were not sprayed) and to determine the frequency of detrimental health outcomes in the North. Crucial to this approach was to first establish the levels of dioxins, furans, and related compounds in parts of Vietnam as compared to other countries, both developed and not developed. The first such comparisons were published in 1994 and 1998, and presented data from the US, Germany, the former Soviet Union, Thailand, Cambodia, China, South Africa, and Guam (Schecter et al. 1994; Schecter 1998). Comparisons of dioxin levels between populations in the South versus the North of Vietnam were also published in 1994 through 1998 (Verger et al. 1994; Schecter et al. 1995; Schecter 1998). The relationships between dioxin levels, Agent Orange, and implications for health studies were the focus of research and concerns published in 2000 to 2002 (Longnecker et al. 2000; Schecter et al. 2001; Dwernychuk et al. 2002; Palmer 2004; and Stone 2007). Although these researchers were successful in identifying varying levels of dioxins and furans between Southern and Northern Vietnam, and that certain populations in Southern Vietnam appeared to be contaminated at levels significantly above populations in most developed countries, they were unable to show that the levels of dioxins were responsible for health problems. These studies did not overcome the concerns expressed by the IOM in 1994 (i.e., recall bias, impacts of decades of war, population re-locations, and relevant serum dioxin measurements).

Over the years of study, the method of assessing potential sources of dioxins and furans became more sophisticated, and pattern recognition techniques to look at the 17 major dioxins and furans were used (Schecter et al. 2002; Dwernychuk et al. 2002; Schecter et al. 2003, 2006; Mai 2004; Hofmann and Wendelborn 2007; Hatfield Consultants 2007). These studies showed that although the absolute concentrations of 2,3,7,8-TCDD were greater in the Southern and Central regions, the identity of the polychlorinated dibenzo-*p*-dioxins (PCDD) and the polychlorinated dibenzofurans (PCDF) profiles suggested a common source for all parts of the country, including Northern Vietnam. Such a common source could not have been Agent Orange since defoliation operations did not occur in North Vietnam. It is most likely due to rapid industrialization, and the indiscriminate burning at low temperatures of municipal wastes and perhaps forest fires (Minh et al. 2004; Hofmann and Wendelborn 2007).

A key value of the later research was in identifying potential "hot spots" where soil TCDD concentrations were higher because they were obtained from sites on former Allied Airbases where loading, storage, and/or re-drumming operations occurred with Agent Orange during Operation RANCH HAND and Operation PACER IVY (Schecter et al. 2003; Dwernychuk et al. 2006; Hatfield Consultants 2007). These sites are potential sources of contaminated soil and its subsequent movement into aquatic ecosystems. These data were similar to data collected at former Agent Orange Storage Sites in the United States (Young 2006; see Chapter 7).

8.4 The Agent Orange Dioxin Remediation Workshops, 2005–2007

8.4.1 Background on the Workshops

The legacy of Agent Orange remains an issue between the United States and Vietnam from the "Vietnam-American War", as it is referred to in Vietnam. Generally the term "Agent Orange" has been used by the Vietnamese, general public, and news media to describe a group of "Tactical Herbicides" used in combat operations by the US Military and other Allied Forces in the Vietnam War for the suppression and control of vegetation.

In February 2000, United States Secretary of Defense and Department of State personnel visited Vietnam in preparation for a visit later in that year by President Clinton (Young 2002). One of the topics discussed during that visit was Agent Orange, and a tour was conducted of two former air bases (Da Nang Air Field, and Bien Hoa Air Base) where RANCH HAND aircraft were stationed and Agent Orange stored during the War (Young and Andrews 2005). Following their return to the United States, the National Institute for Environmental Health Sciences (NIEHS) was authorized to begin the planning of an appropriate research program that would be done in collaboration with the Vietnamese and United States scientists with funds being provided by the United States. Indeed, recommendations were provided to the White House, and President Clinton discussed these recommendations while on his visit to Vietnam prior to leaving the Presidency (Young 2002).

In March 2002, a joint meeting co-sponsored by NIEHS and the Vietnamese Ministry of Science, Technology and the Environment was held in Hanoi (NIEHS 2002). The conference was organized under the auspices of a Joint US-Vietnam Cooperative Research Program on the Health and Environmental Effects of Agent Orange and its associated dioxin. Experts from throughout the world were invited to provide a broad assessment of the data available on the health and environmental effects of Agent Orange and dioxin and the need for future funding. In a Memorandum of Understanding that was signed by both governments, US Ambassador to the Vietnam Raymond Burghardt stated:

> This agreement and the scientific conference that preceded it mark a new step forward in our relations with Vietnam. It is too soon to predict what the eventual benefits will be, but it is certain that Americans and Vietnamese working together in pursuit of a common interest can achieve a great deal (NIEHS 2002).

Indeed, scientists from the Vietnamese Ministry (Institute) of Science, Technology and the Environment, the Vietnamese Ministry of Health, the US NIEHS, the US Environmental Protection Agency, and the US Centers for Disease Control and Prevention established a research agenda that addressed two major areas of research: direct research on human health outcomes from exposure to dioxin, and environmental and ecological effects of dioxin and Agent Orange. A process for obtaining funding and guiding the research was also proposed, but as the Director of the NIEHS Division of Extramural Research and Training, Dr. Anne Sassaman remarked at the Conference:

> This framework for collaboration is an important step forward. The real difficulties lie ahead; agreeing to the research is the easy part. The more difficult task will be to develop research studies that are definitive and address the underlying causes of disease in Vietnam (NIEHS 2002).

Although funding did become available, Dr. Sassaman's remarks were to be most apropos, since Vietnamese scientists and the Vietnamese government could not reach agreement as to what studies they would recommend and jointly support. As noted, the plan envisioned the preparation and implementation of a broad-based research program that would be conducted in collaboration with Vietnamese and US scientists. In June 2005, during the visit of Vietnamese Prime Minister Phan Van Khai's state visit to the US and following government-to-government discussions, the US Government agreed to sponsor a "Workshop for Stabilizing and Cleaning-up Dioxin Contaminated Sites." This was the only project to be accepted and implemented by both parties since the March 2002 Conference in Hanoi (Young and Andrews 2005).

8.4.2 The 1st Agent Orange and Dioxin Remediation Workshop, August 2005

The "1st Agent Orange and Dioxin Remediation Workshop" was held in Hanoi, Vietnam in August 2005 (Young and Andrews 2005). Forty-seven Vietnamese

Military Officers, 4 Vietnamese Civilians, and 5 US participants attended the three-day Workshop. All of the Vietnamese participants were from Vietnam's Ministry of National Defence, including the Military Medical University, the Vietnam Institute for Science, Technology and Environment, and the Office of the National Committee 33, the Government's current office in directing the dioxin study and decontamination activities. Ambassador Michael Marine and the Defense Attaché from the US Embassy in Hanoi, and 3 members of the US Technical Team (Mr. William Van Houtem, US DOD; Dr. Alvin Young, The University of Oklahoma; and, Professional Engineer William Andrews, Battelle Memorial Institute) represented the United States.

Introductory comments by Ambassador Marine and Lieutenant General Do Trung Duong, Deputy Chief of General Staff, People's Army of Vietnam, and Head of the Vietnam Delegation (see Fig. 8.1) emphasized the importance of working together in a constructive manner to define the problems of potential dioxin contamination and to look for ideas on how to proceed with the scientific work to be done. Both men recognized that it might take a combination of technologies and scientific approaches if the former sites are currently

Fig. 8.1 Introductory comments being given by US Ambassador to Vietnam Michael Marine and Lieutenant General Do Trung Duong, Deputy Chief of General Staff, People's Army of Vietnam, and Head of the Vietnam Delegation to the 1st Agent Orange and Dioxin Remediation Workshop, Hanoi, Vietnam, 16–18 August 2005 (Photograph courtesy of Vietnam's Ministry of National Defence)

contaminated with 2,3,7,8-TCDD. Ambassador Marine emphasized that the United States Department of Defense would not have an active role in cleaning-up contaminated sites in Vietnam. General Duong concurred that it was the responsibility of Vietnam's Military to cleanup any contaminated sites. Both men also concurred that the focus of the Workshop was on remediation and not on health issues, although the US views of the health issues were of interest.

With this understanding, the objectives of the 1st Workshop were to: (1) share the scientific and engineering studies conducted in the United States at former Herbicide Orange storage and/or loading sites; (2) open a dialogue with Vietnamese scientists and engineers on how to evaluate the present status of former herbicide storage/loading sites; and, (3) provide guidelines on how to determine the most appropriate use of soil stabilization actions or applications of available remediation technologies. The key issues of site characterization, development of sampling and monitoring protocols, and the application of remediation technologies were demonstrated from the lessons learned over 35 years of research and engineering studies in the United States at former sites where Herbicide Orange had been used in the development of spray equipment for use in the Vietnam War (Test Area C-52A, Eglin AFB, Florida), and/or where it had been stored and disposed of after the War (Hardstand 7, Eglin AFB; Naval Construction Battalion Center, Gulfport, Mississippi; and, Johnston Island, Central Pacific Ocean) (Young and Newton 2004; Young 2004a; Young et al. 2004; Vasquez et al. 2004; Young 2006).

A major issue for the Vietnamese Military was the need for information on the former sites where Operation RANCH HAND activities had occurred and where it was likely that residues of TCDD could still be found. The US Technical Team presented information on the logistics of the tactical herbicides including the identification of the military bases where they had been stored, re-drummed, and where flightline operations had occurred during Operation RANCH HAND. Information was also provided on the concept of isomers and congeners in the identification of dioxin sources. Lastly, the technologies employed for the remediation of contaminated sites were highlighted and discussions where held on whether these technologies might be applicable for use in Vietnam (Young and Andrews 2005).

At the conclusion of the Workshop, formal "Minutes of Meeting" were prepared and signed by Mr. Van Houten for the United States, and Major General (Dr.) Nguyen Ngoc Duong, Director of the Institute for Science, Technology and Environment, Ministry of National Defence, and the individual designated as the Principal Point of Contact on all issues related to site investigations, analytical studies, remediation technologies, and final site reclamation in Vietnam. All parties agreed that a 2nd Workshop should occur that would provide a better understanding of where potential "hot spots" might be located. A photograph of the Workshop participants was taken (Fig. 8.2).

Fig. 8.2 Photograph of the Vietnamese and American Participants at the Agent Orange and Dioxin Remediation Workshop, 18 August 2005, Hanoi, Vietnam (Photograph courtesy of Vietnam's Ministry of National Defence)

8.4.3 The 2nd Agent Orange and Dioxin Remediation Workshop, June 2007

The "2nd Agent Orange and Dioxin Remediation Workshop" was held in Hanoi, Vietnam 18–19 June 2007. Approximately 40 Vietnamese Military Officers and Civilians and 6 US Participants attended the Workshop. Most of Vietnamese Participants were from Vietnam's Ministry of National Defence (MOD), primarily from the Agency for Science, Technology and Environment. Major General Nguyen Ngoc Duong, Director, Agency for Science, Technology, and Environment provided introductory comments for the Vietnamese Delegation. Mr. Jonathan M. Aloisi, Deputy Chief of Mission, Embassy of the United States provided introductory comments for the US Delegation. Mr Aloisi introduced Mr. William J. Van Houten, US DOD, Washington, DC, and Dr. Alvin L. Young, Visiting Professor, University of Oklahoma (Young et al. 2008).

At the beginning of the Workshop, Mr. Van Houten presented to Major General Duong from the Vietnam's Ministry of National Defence (MOD) a special Report prepared by the United States Department of Defense on "The History and Maps of the Former Tactical Herbicide Storage and Loading Sites in Vietnam" (Young and Andrews 2006). The Report provided: (1) Detailed information on the quantities of tactical herbicides used or spilled in Southern Vietnam; (2) Detailed information on the types and quantities of dioxins in Herbicide Orange; (3) Maps of the Air Bases used in Operation RANCH HAND and Operation PACER IVY detailing the sites where loading, storage and re-drumming operations had occurred; and (4) An update on remediation and environmental studies. At the request of DOD, the MOD provided: (1) Detailed results from analytical studies conducted in and around Da Nang Air Field; (2) Results of studies on the detoxification of dioxin in soil by an active landfill bioreactor; and, (3) Research data on adsorption efficiency of activated carbon for PCDDs/PCDFs from aqueous solutions. After each presentation, thorough discussions occurred (Young et al. 2008). Summary details of the Report as presented to the Vietnam's MOD are described below. Data on isomeric composition of Agent Orange were provided in Chapter 5, Table 5.4; data on the estimated quantities of tactical herbicides used in Vietnam were provided in Chapter 1, Table 1.1, and Chapter 5, Table 5.7.

8.4.4 History and Maps of the Former Tactical Herbicide Storage and Loading Sites in Vietnam

8.4.4.1 Tactical Herbicide Mapping Project

The purpose of the Vietnam Tactical Herbicide Mapping Project was to gather information on where the United States Air Force (USAF), the Army of the Republic of Vietnam (ARVN), the Army Chemical Corps, or Allied units temporarily stored and maintained inventories of tactical herbicides used in Operation RANCH HAND. Records indicated that the USAF sprayed 95% of the tactical herbicides in Operation RANCH HAND. The remaining 5% was primarily sprayed from helicopters belonging to US Army Chemical Corps (3–4%) and Combat Engineers belonging to Australian, Korean, or ARVN units (Stellman et al. 2003; Young et al. 2004).

In the "Development Phase" of Operation RANCH HAND (January 1962–March 1965), all tactical herbicides were shipped from the United States to the Port of Saigon (Ho Chi Minh City). The drums were off-loaded and placed on flatbed trucks for transport to the RANCH HAND units at Tan Son Nhut Airport. In the "Operational Phase" of Operation RANCH HAND (March 1965–January 1971), 65% of the tactical herbicides were shipped to the Port of Saigon for transport to Bien Hoa Air Base, and 35% of the tactical herbicides were shipped to the Port of Da Nang for transport to the air base. When drums arrived in South Vietnam, the ownership was transferred to ARVN at the 20th Ordnance Storage Depot, Saigon, or at the ARVN 511th Ordnance Storage Depot, Da Nang. Drums of tactical herbicides were distributed from these locations to RANCH HAND operating locations, US Army Chemical Corps operating locations, or to Allied Forces as requested and approved (Young et al. 1978; Cecil 1986; Young et al. 2004; Young and Andrews 2006).

Historical records provided information on six major air bases that were used by either the RANCH HAND aircraft (UC-123s) for tactical herbicide operations or for insecticide operations (Operation FLYSWATTER); the latter being under the direction of the US Military Assistance Command, Vietnam's (MACV) Surgeon General's Office (Cecil and Young 2008). One additional air base (Tuy Hoa) was identified as part of Operation PACER IVY, the re-drumming and return of the remaining stocks of Herbicide Orange to Johnston Island, Central Pacific Ocean (Department of Air Force 1974). The Air Force bases in Southern Vietnam that were used by the United States and Allied Forces for military operations involving tactical herbicides and insecticides are identified in Table 8.1.

8.4.4.2 Distribution of Tactical Herbicides

The preparation of maps of the former US and Allied air bases, where tactical herbicides may have been spilled during storage or loading operations, required information on when and how much of the tactical herbicides were destined for a particular air base. Procurement data on the three major "tactical herbicides" were obtained from historical records of the Defense Supply Agency and the Air Force Logistics Command. These records provided the yearly quantities of tactical herbicides by manufacturer and port destination (in Vietnam). Dates were available when the various tactical herbicides were first shipped and deployed in Southern Vietnam. In addition, the US Army Chemical Corps maintained a record of all defoliation and crop destruction missions conducted by the Chemical Corps and by Operation RANCH HAND.

Table 8.1 Air force bases in southern Vietnam used by US and allied forces for tactical operations

	Military operation[1]			
Vietnam air base	RANCH HAND	Pacer IVY	FLYSWATTER	Years[2]
Tan Son Nhut	X			1962–1966
Bien Hoa	X	X	X	1966–1972
Da Nang	X	X	X	1964–1972
Phu Cat	X			1968–1970
Nha Trang	X			1968–1969
Phan Rang			X	1970–1972
Tuy Hoa		X		1971–1972

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

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

These records were computerized and became known as the HERBICIDE REPORTING SYSTEM or HERBS Tape. The HERBS tracked all missions from August 1965 through the close of the program in February 1971 (Cecil 1986). Combining data from all sources, an estimate was made of how much tactical herbicide was shipped and dispersed from RANCH HAND operating locations. These data were provided in Table 8.2**.**

The PACER IVY re-drumming operation was done by former ARVN troops and overseen by USAF Base Bioenvironmental Engineers at Bien Hoa, Tuy Hoa, and Da Nang. Spills occurred at all three locations during this operation. Approximately 11,000 drums of Herbicide Orange were shipped from Bien Hoa to the Port of Saigon in March 1972; approximately 6,000 drums were shipped from Tuy Hoa to the Port at Cam Rhan Bay; and approximately 8,220 drums were shipped from Da Nang Air Base to the Port of Da Nang. The ship *M/T TransPacific* transported the drums from all three Ports to Johnston Island in the Central Pacific Ocean, arriving in mid-April 1972 (Department of the Air Force 1974; Young and Andrews 2006)

8.4.4.3 Construction of Air Field Maps

The Mapping Project provided "best estimates" on the quantities of tactical herbicides distributed to former Allied air bases in Southern Vietnam. The Project also identified approximate locations on those air bases where tactical herbicides were stored or where they were loaded on the aircraft used by RANCH HAND, US Army Chemical Corps, or ARVN and used in support of tactical operations. In addition, sites were described where re-drumming of Agent Orange occurred in 1971–1972 in support of Operation PACER IVY.

Table 8.2 Quantities of tactical herbicides (number of 55 gal/208 L drums) at Former US and allied air bases in Southern Vietnam

	Transient[1]			Temporary[2]
Location	Orange	White	Blue	Orange
Tan Son Nhut	57,300	17,000	4,330	(14,155 drums Purple, Pink, Green)[3]
Bien Hoa	98,000	45,000	16,000	(11,000)[4]
Da Nang	52,700	29,000	5,000	(8,220) [4]
Phu Cat	17,000	9,000	2,900	
Nha Trang	9,000	4,800	1,100	
Tuy Hoa				(6,000) [4]
Totals	~234,000	~104,800	~29,330	(25,220)[4]

[1]Transient refers to stocks sent to the base and deployed in combat operations.
[2]Temporary refers to Agent Orange stocks stored and re-drummed in Operation PACER IVY.
[3]Early "Tactical Herbicides" used from January 1962 to March 1965; includes new procurement information not included in the Mapping Report.
[4]Removed from Vietnam to Johnston Island in Operation PACER IVY.

Recent satellite images (from QuickBird or Ikonos satellites) were overlaid with the following air fields or sites where herbicides were temporarily stored in support of tactical operations: Tan Son Nhut Airport, and Bien Hoa, Da Nang, Phu Cat, and Nha Trang Air Fields. Routine maintenance and transportation activities in support of Operation PACER IVY also occurred at Bien Hoa, Da Nang, and Tuy Hoa Air Fields. The locations marked on the satellite images represented more area than likely used in the military operations. Thus, increasing the probability that the actual area of use was "within" the marked area (Young and Andrews 2006).

At the Workshop, the presentation of the seven large Satellite Image Maps by Mr. Van Houten included a "table walk around" activity where Professor Young explained the information on the 1 × 1.25 m colored maps (Fig. 8.3). Each of the satellite images had a resolution of 1 m, and was pan-sharpened, multi-spectral, and geo-referenced to geographic coordinates (Young and Andrews 2006). A joint DOD–MOD discussion of each map revealed that MOD had mis-identified many objects on the maps that were not related to tactical herbicide operations. The Satellite Image Map for Bien Hoa Air Base is shown in Fig. 8.4.

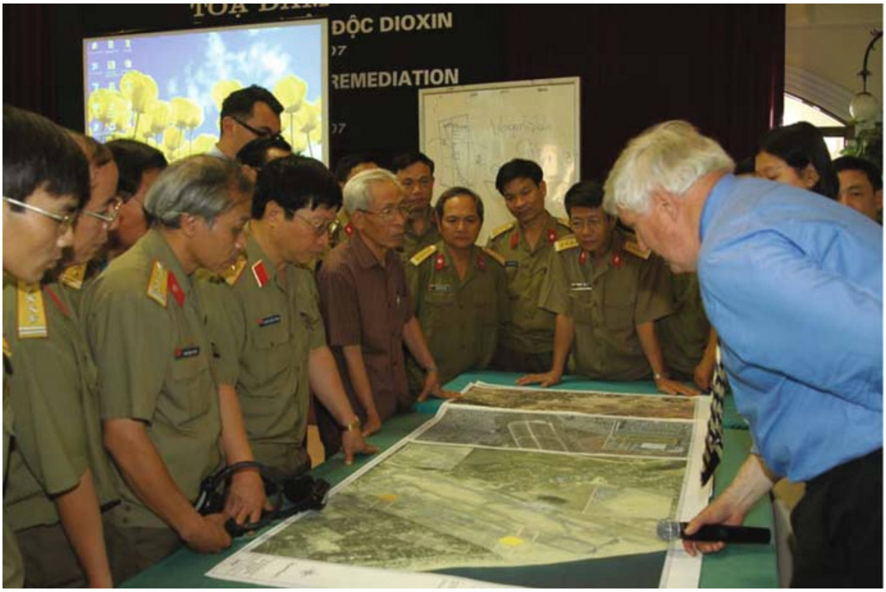

Fig. 8.3 Photograph of Professor Young discussing with Vietnam's Ministry of National Defence the Satellite Image Maps showing the location of former Tactical Herbicide Storage and Loading Sites in Southern Vietnam (Photograph courtesy of Vietnam's Ministry of National Defence)

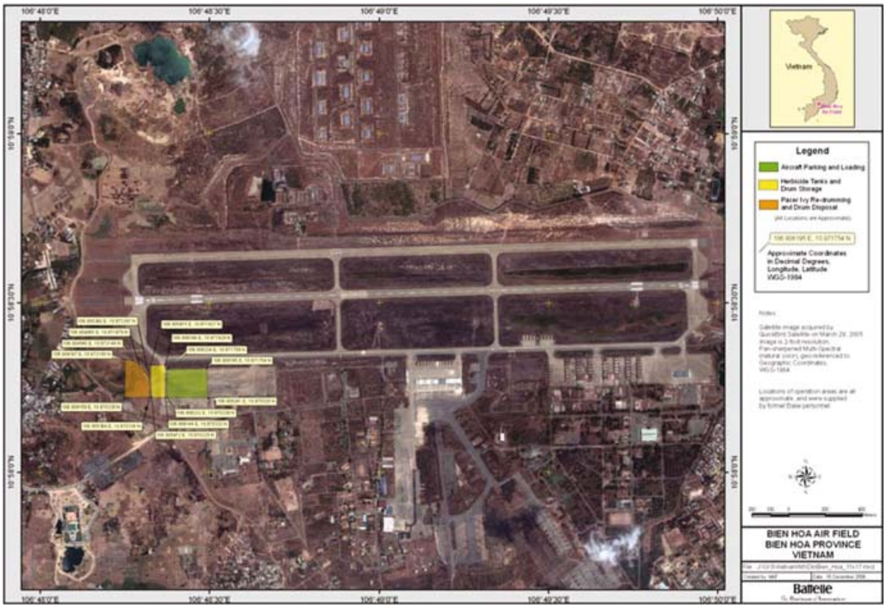

Fig. 8.4 A Satellite Image Map of Bien Hoa Air Base showing the location of the December 1966–February 1970 RANCH HAND Operations (Green and Yellow) the site of PACER IVY Operations April 1970–March 1972 (*Brown*). (Photograph courtesy of Battelle Memorial Institute)

8.4.4.4 The Issue of Hot Spots

Tactical herbicides sent to Vietnam were either used as intended for vegetation control, unintentionally spilled during handling, or removed from Vietnam for disposition when use of the material was ended (Operation PACER IVY). The science of the environmental fate of TCDD supported the expectation that the TCDD aerially applied with Agent Orange would have photodegraded on the surface of the vegetation (or as vapor in the air) within a few hours of application (Crosby and Wong 1977). However, once the TCDD moved with the herbicide beneath the soil surface (colloidal movement), as in the case of spills, the TCDD could persist for decades (Vasquez et al. 2004).

In the Report "*The History and Maps of the Former Tactical Herbicide Storage and Loading Sites in Vietnam*," the DOD suggested that the sites of greatest interest for potential hot spots were at the locations where Operation PACER IVY had occurred. As previously noted, on 15 April 1970, the US DOD suspended all uses of Agent Orange in Vietnam. The remaining Orange Herbicide stocks were placed in temporary storage at Da Nang and Bien Hoa Air Bases (now Air Fields). In addition, the US Army Chemical Corps also stored small quantities of tactical herbicides at Special Forces Camps, e.g., in the Aluoi Valley (Dwernychuk et al. 2002). Small quantities were also located at the Air Bases at Phu Cat and Nha Trang. On 15 September 1971, the 7th Air Force directed that all stocks be consolidated at Bien Hoa, Tuy Hoa, and Da Nang Air Bases. Under the PACER IVY project, all remaining Agent Orange stocks in III and IV Corps were consolidated at Bien Hoa Air Base, those in II Corps were consolidated at Tuy Hoa Air Base, and those in I Corps were consolidated at Da Nang Air Base (Young and Andrews 2006). In March 1972, all the remaining stocks of Agent Orange in Vietnam were returned to the United States (to Johnston Island, Central Pacific Ocean).

Of the estimated 130–144 kg of TCDD that were calculated to have been present in the tactical herbicides used in Vietnam, it was likely that at least 96–98% of the TCDD was aerially sprayed over the jungles and mangrove swamps of Vietnam (Young et al. 2008). A recent re-analysis and update of the HERBS Tape indicated that approximately 344,000 drums of tactical herbicides were sprayed, compared with approximately 356,545 drums deployed in Vietnam (~ 96%) (see Chapter 3). Thus, only about 2–4% of the dioxin from Agent Orange (estimated at 105–119 kg) would have remained in hot spots, which was estimated at about 2.1–4.8 kg. This is a very different picture than previously visualized in Vietnam (Hatfield Consultants 2007). Similar handling losses occurred with the 25,220 drums of Herbicide Orange that were removed from Vietnam in 1972 and sent to Johnston Island. During five years of storage, more than 10,000 leaking drums were re-drummed before Operation PACER HO (the disposition of Herbicide Orange by at-sea incineration) in 1977 (Tremblay 1983). PACER HO destroyed 24,795 drums indicating that about 2% of the herbicide had spilled in the storage area from 1972 to 1977 (Tremblay 1983).

A point of confusion is the fate of the TCDD contained in the 96–98% of tactical herbicides sprayed over the jungles and mangrove swamps of Vietnam. The 15-year ecological research program conducted at Eglin Air Force Base in Northwest Florida, 1969–1984 (Young and Newton 2004), and the dioxin research reported on the Ma Da Forest in 2007 (Hofmann and Wendelborn 2007), provided results indicating that a substantial preponderance of 2,3,7,8-TCDD was degraded by sunlight immediately after application of the 2,4,5-T-containing tactical herbicides. Thus validating the importance of focusing attention on any remaining hot spots in Southern Vietnam.

The issue of hot spots has been extensively covered in recent studies conducted in Vietnam (Hatfield Consultants 2007). Limited analytical data collected during the past two years from Da Nang Air Field and Bien Hoa Air Field were presented by MOD at the Workshop. Soil and sediment samples from the Da Nang Air Field perimeter areas averaged ~ 40 pg/g or 40 ppt. Six samples (0.7–365 ng/g, ppb, mean 95 ppb) were collected beneath the tarmac where RANCH HAND loading operations had occurred. Five samples from an area identified by MOD as a former storage area ranged from 0.1 to 100 ppb, mean of ~45 ppb. Nine samples of sediments from a lake on the Da Nang Air Field averaged ~2.3 ppb. The MOD has proposed a clean-up standard of 1 ppb. However, as noted by MOD during the Workshop, this standard is a US Environmental Protection Agency standard and may or may not be applicable to the situation at Da Nang Air Field. MOD also reported human samples collected in the Da Nang Community by Hatfield Consultants, West Vancouver, British Columbia, Canada (Hatfield Consultants 2007). The samples contained numerous dioxins, furans, and PCBs suggesting potential multiple sources of contamination probably including Agent Orange. The levels of 2,3,7,8-TCDD in soil and sediment samples on the Da Nang Air Field were generally consistent with TCDD residues reported for both former Herbicide Orange Storage Sites on Johnston Island and at Gulfport, Mississippi (Young 2006).

8.4.4.5 Follow-On Activities

At the conclusion of the presentations, and with the signing of formal "Minutes of Meeting", both the DOD and the MOD agreed to continue sharing information (both published and unpublished), remediation experiences, and best scientific practices for the purpose of promoting and understanding the legacy of Agent Orange and its associated dioxin. Both the United States and Vietnam recommended that the next activities should include:

- Joint program involving sampling, surveys and analyses of potentially contaminated sites at the other Air Fields identified for MOD at the Workshop.
- Joint program to develop scientifically credible remediation programs "based on risk," as required (Young et al. 2008).

On May 15, 2008 the Deputy Assistant Secretary for East Asian and Pacific Affairs addressed the US House of Representatives Foreign Affairs Committee:

> We will continue to pursue constructive ways to work with the Government of Vietnam and other donors to address concerns related to Agent Orange and dioxin. Our efforts will continue to focus on supporting Vietnamese efforts to ensure a safe environment and assisting Vietnamese living with disabilities, regardless of their cause. In particular, we with seek to work with Vietnamese Scientists and health experts to address Vietnam's concern over human exposure to dioxin and other toxins in the environment; and support Vietnam's promotion of good prenatal care to minimize disabilities (Marciel 2008).

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Postlude
Can There be a Satisfactory End to the Agent Orange Controversy?

The Resolution in Vietnam

Since the early 1970s, scientists from throughout the world have been conducting studies on the toxicology, human risk and environmental fate of dioxin (TCDD). A significant portion of this research has focused on the perception of harm that may have occurred as a result of the use of Agent Orange in Vietnam. This extensive research has centered primarily on studies in animals and more recently on studies in human. Both have certainly contributed to defining the issues. However, public discussion and scientific research have proceeded largely on the assumption, rather than a determination, of widespread substantial exposure to tactical herbicides and the associated dioxin to Vietnamese civilians (Young 2004, 2008). The historical military records from the Vietnam-American War did not support the supposition of direct spraying of Allied tactical herbicides on Vietnamese civilians. Detailed policies and procedures minimized any circumstances in which spraying of Allied combat troops and non-combatant civilians with tactical herbicides in Vietnam would have resulted in human exposure. Reports by Vietnam War veterans and Vietnamese civilians of repeated sightings of RANCH HAND aircraft spraying Allied Bases and associated Vietnamese Communities are confused with the mission of Operation FLYSWATTER, the spraying of insecticide for the control of malaria-carrying mosquitoes (Young et al. 2004a; Cecil and Young 2008).

The establishment of "TCDD Hot Spots" in Southern Vietnam due to Agent Orange led the United States Department of Defense and Vietnam's Ministry of National Defence to jointly sponsor two "Agent Orange and Dioxin Remediation Workshops". By agreement between the two governments, the Workshops were focused on issues related to remediation activities and on the historical use of the of former Tactical Herbicide Storage and Loading Sites in Southern Vietnam that might constitute a source of TCDD contamination to adjacent communities (Young and Andrews 2005, Young et al. 2008).

At the June 2007 Workshop, the United States committed to working with Vietnam in a joint program involving sampling, surveys, and analyses of potentially contaminated sites at the seven Air Fields identified for the Ministry of National Defence. However, it is in the best interest of both Nations that a scientifically credible remediation program be based on a risk assessment process that involves reconciling the available data with the satellite image maps, and preparing a comprehensive plan to conduct additional site investigations needed to improve the technical understanding of the sources, extent, and the potential hazards of all contaminants. This plan would involve significant commitments to visit and assess each of the Air Fields, and then jointly prepare a comprehensive risk management program covering all installations. The implementation of such a plan would bring closure to the Agent Orange and Dioxin Remediation Program. To assist the Vietnamese Government, the US initiated a five-year $2 million project between the US Environmental Protection Agency (EPA) and the Vietnamese Academy of Science and Technology and Ministry of National Defence to build capacity for laboratory analysis of dioxin and related chemicals and site evaluation at the Da Nang Airport (Marciel 2008). Moreover, the Department of State and EPA have provided $400,000 for technical assistance for mitigation planning for the Da Nang Airport (Marciel 2008). Additional costs incurred for this would likely proceed with the current initiatives of mobilizing international donor funds and non-governmental support (Palmer 2004). However,

As to the broader issue of "victims of Agent Orange":

> I do not accept the term "victims of Agent Orange". The United States humanitarian assistance to the disabled in Vietnam is not based on evaluation of causes of disability.
> Statement of Ambassador Michael W. Marine, 9 August 2007, Hanoi, Vietnam

Absent evidence of widespread exposure to TCDD either from tactical herbicides or from soil or other sources in Vietnam, published reports suggesting that Agent Orange has caused widespread disease in veterans and their families and the Vietnamese people should be viewed with skepticism (Young et al. 2004a; Young et al. 2004b; Young et al. 2004c). Scientifically valid evaluations of causal relationships fail to establish a connection. Without evidence of widespread exposure to dioxin from tactical herbicides or contamination linked to the use of the tactical herbicides, there is little reason to expect causation will be established; see the recently published article in Science and Nature magazines (Stone 2007; Editorial 2008). Indeed, many effects attributed to the tactical herbicides and TCDD are readily explained by alternative factors. For example, neural tube defects (e.g., *spina bifida* and anencephaly) in Vietnamese children are frequently attributed to Agent Orange. However, other risk factors, primarily related to nutritional deficiencies of folic acid, are much more likely to be the underlying causative factors of such defects (Young et al. 2004b). A wider view of potential causative factors other than that of TCDD will re-focus scientific and medical resources toward the real causes of health problems in Vietnam. To these ends, the United States has expended in Vietnam more than $43 million in humanitarian assistance (Marciel 2008).

The Resolution for Vietnam Veterans

The extensive medical and scientific (including environmental fate) studies of Agent Orange and its associated dioxin over the last 35 years have provided ample evidence that most Vietnam veterans were not substantially exposed. They also show that even veterans with measurable serum 2,3,7,8-TCDD have not suffered ill effects as a result. The historical records from the Vietnam War have also supported the conclusion that spraying of troops with Agent Orange was minimal (Young 2004; Young et al. 2004a). Nevertheless, there remains a perception of harm to the Vietnam veteran. The emotional impact of this perception on the veteran and his family has been severe; see the recently published articles in Science and Nature magazines (Stone 2007; Editorial 2008). How can we counter this perception? The actions by the United States government via the Agent Orange Act of 1991 (Public Law 102-4) provides presumptive compensation in the absence of exposure and causation, an expression by the political system intended to acknowledge the sacrifices of the Vietnam veteran. Yet, it creates an unfair condition for veterans who develop diseases and illnesses not associated or suspected of being associated to Agent Orange or other tactical herbicides. Recently, the Institute of Medicine established a "Committee on Evaluation of the Presumptive Disability Decision-Making Process for Veterans" (IOM 2008). The report noted:

> The more recent IOM Agent Orange reports have emphasized findings of observational studies on association and interpretation that might have been enhanced by placing the findings within a biological framework strengthened by greater attention to other lines of evidence. In the Agent Orange case studies, the category "limited/suggestive" for classifying evidence for association has been used for a broad range of evidence from indicating the mere possibility of an association to showing that an association is possibly causal....Both prostate cancer and type 2 diabetes illustrate situations in which the contribution of military exposure should be assessed against a background of disease risk that has other strong determinants: age in the case of prostate cancer and family history, and obesity in the case of type 2 diabetes (IOM 2008).

Vietnam and Agent Orange are now public policy issues. There are strong public policies favoring our veterans and rightly so. It has become apparent that science alone has not eliminated this perception of harm. The courts may resolve the massive litigation that has characterized this controversy, but the acrimony that has resulted from the Vietnam War and the use of tactical herbicides appears likely to be with us for many more years.

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