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Agent Blue: A Secret Military and Environmental Chemical Weapon Used for Food Denial in South Vietnam during the Vietnam Civil War (1962-1965)

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Abstract

During the last 60 years, the southern Vietnam environment and Vietnamese living in the Mekong Delta have bio-accumulated arsenic from natural and anthropic (Vietnam Civil War (1962-1965)) sources via their drinking water (groundwater from tube wells) and food supply leading to an increasing risk of chronic poisoning over time. A synthesis and analysis of publications and records is presented to document the Republic of Vietnam (RV), the official name of the South Vietnam Government, and United States (US) militaries contribution to arsenic levels and toxic spikes in the Vietnam Mekong Delta groundwater. During the Vietnam Civil War, Agent Blue, in powder form, was shipped to Port Saigon, via the Saigon River, and transported to the Tan Son Nhut Air Force base during the Vietnam Civil War. After the official start of the American-Vietnam War (1965-1973) the tactical herbicides were re-routed to Bien Hoa Air Force base (1965 to 1971). Approximately 3.2 million liters of Agent Blue (468,008 kg As) was sprayed or dumped by the RV military with the assistance and support of the Central Intelligence (CIA), US Army and US Navy, during the 1962-1965 Khai Huang (Hamlet) Program. A portion of an additional 4.6 million liters of Agent Blue (664,392 kg of As) was sprayed between 1962 and 1965 by the US Air Force as part of Operation Ranch Hand and prior to the official start of the American-Vietnam War in August 1964. Operation Rand Hand began in 1962 and ended in 1971. The Institute of Medicine estimated a total of 7.8 million liters (1,132,400 kg As) of Agent Blue was applied to southern Vietnam landscape from 1962 to 1971. This total includes both the 1962 to 1965 RV Khai Huang program with the assistance of the CIA, US Army and US Navy, and the total Agent Blue

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applied by US Air Force Operation Ranch Hand from 1962 to 1971. The primary objective of this study was to document how Agent Blue, the arsenic-based herbicide, became a secret US military and environmental chemical weapon used by the RV and US militaries in southern Vietnam during the Vietnam Civil War years (1962-1965). This assessment found that the anthropic arsenic, including Agent Blue, added a toxic burden to the Mekong Delta soils, surface water, groundwater, drinking water, food supply, and human health. However, there are missing details regarding political decisions and a full accounting of the geographic locations sprayed and amount of Agent Blue used. Vietnam War Archives have paper correspondence and RV herbicide spray records that shed greater light on this period. These records are over 50 years old and need to be electronically scanned, stored, and made available for additional historical analyses.

Keywords

Arsenic, Cacodylic Acid, Agent Blue, Herbicides, Chemical Weapons, Fort Detrick, Department of Defense (DOD), President Kennedy, President Diem, CIA, US State Department, USDA, Khai Huang

1. Introduction

Interest in biological and chemical weapons, by the United States Chemical Warfare Service, began in 1941. That fall, U.S. Secretary of War Henry L. Stimson suggested the National Academy of Sciences (NAS) consider undertaking a study of U.S. biological and chemical warfare [1]. After the attack by the Japanese on Pearl Harbor on December 7, 1941, Dr. Ezra Kraus offered his services to the U.S. government and military. He was a founding member of a highly classified project on chemical and biological warfare under the National Academy of Sciences (NAS). At a top-secret meeting of the Biological and Chemical Weapons Committee of the War Bureau of Consultants (WBC) on Feb. 17, 1942 (just 9 weeks after Pearl Harbor), Dr. Kraus presented a paper on "Plant Growth Regulators Possible Uses" which included herbicides as military and environmental chemical weapons. The abrupt entry of the U.S. into WWII gave Dr. Kraus an audience of U.S. military and political leaders at the highest governmental level. In 1942, chemical and biological warfare scientists at Camp Detrick, Maryland, began investigating the possible uses of defoliant herbicides, based on Galston's scientific discovery, while working with 2, 3, 5-triiodobenzoic acid (TIBA) [1]. By the spring of 1943, a United States biological weapons program officially began in secret under orders from U.S. President Franklin Roosevelt. Safety "S" Division was first activated (1943) to serve as a "Biological Protection Branch", for the large stockpile of chemical and biological agents and weapons.

By 1946, production of U.S. chemical and biological warfare agents went from "factory-level to laboratory-level", with the establishment of the United States

Army Biological Warfare Laboratories at Camp Detrick. This military element formed the nucleus for a suite of research laboratories and pilot plant centers that operated during the first half of the Cold War. Camp Detrick was initially a Maryland National Guard property located in Frederick, Maryland. It became a United States Army Medical Command installation and was the center of the United States biological weapons program of Department of Defense (DOD) and OSS (renamed the Central Intelligence Agency (CIA) in 1947) even before it was officially named in 1952 [1]. It was designated a permanent installation for peacetime biological research and development shortly after World War II. The U.S. Department of Army's Chemical Corps Biological Laboratories initiated a major program in 1952 at Camp Detrick, Maryland to develop both the herbicide formulations and aerial spray equipment for potential deployment in Korean Conflict. The Agent Blue, precursor reagent, cacodylic acid, was formulated by military scientists at Fort Detrick in 1957. A closer examination of Agent Blue herbicide reveals its toxicity and effects when used as a chemical weapon of war.

The primary objectives of this research are to: 1) document how Agent Blue, the arsenic based herbicide used to destroy rice crops, became a secret US military and environmental chemical weapon that was used by the Republic of Vietnam and United States militaries in South Vietnam for food denial during the Vietnam Civil War (1962-1965), and 2) to determine the persistence and impact of anthropic arsenic, including Agent Blue, on the Mekong Delta soils, surface water, groundwater, drinking water, food supply, and human health.

2. Background and Locations

2.1. Arsenic

A natural element, arsenic, is present in the biosphere, hydrosphere, pedosphere and atmosphere. Arsenic is the 12th most abundant element in the human body, 53rd most abundant element in the earth's crust, and 14th most abundant in seawater. There are four oxidation states of arsenic: −3, 0, +3 and +5. Elemental arsenic is characteristic of the 0 oxidation state; gaseous arsine, in the form of AsH_3, is characteristic of the −3 oxidation state, arsenite is characteristic of the +3 oxidation state; and arsenate is characteristic of the +5 oxidation state [2]. The most readily available oxidation states for bioaccumulation are the +3 and +5 oxidation states.

Arsenic, crystalline oxides As_2O_3 and As_2O_5 are the hydroscopic and readily soluble in water to form acidic solutions. Arsenic a weak acid and the salts are called arsenates which are the most common arsenic contaminant in groundwater and affect the drinking water of the Vietnamese people living in the Mekong Delta.

Arsenic is water soluble but almost never found in its elemental form, rather, it forms compounds called arsenicals [3]. Arsenicals are detected in more than 200 different minerals [4]. Arsenicals are often associated with sulphurous minerals made up of sulphur, iron, gold, silver, copper, antimony, nickel and cobalt.

Arsenic has an atomic number of 33 and is a chemical element which occurs in many minerals. Arsenic and its compounds including trioxide are used in pesticides and insecticides. The herbicide use is declining due to the toxicity of arsenic and its compounds. Arsenic comprises about 1.5 ppm (0.00015%) of the Earth's crust and 53rd most abundant element. Typical background concentrations of arsenic are usually less than 3 ng/m^3 in the atmosphere, 100 mg/kg in the soils and 10 μg/L in freshwater.

2.2. Camp Detrick, Biological Weapons Laboratory

Camp Detrick a United States Army Medical Command installation located in Frederick, Maryland. Historically, Camp Detrick was the center of the United States biological and chemical weapons program. As Camp Detrick, it was designated a permanent installation for peacetime biological and chemical research and development shortly after World War II, however, its status was not confirmed until 1956 when it was renamed "Fort Detrick". The post had been called *Fort Detrick* as early as 1952, when expansion had begun.

Initial interest in biological weapons by the Chemical Warfare Service began in 1941. That fall, U.S. Secretary of War Henry L. Stimson requested that the National Academy of Sciences (NAS) undertake consideration of U.S. biological warfare [1]. The legacy of scientists' influence continued to be seen in military's development arsenal after the war. By 1946, production of U.S. chemical and biological warfare agents went from "factory-level to laboratory-level", with the establishment of the United States Army Biological Warfare Laboratories at Camp Detrick. They were a suite of research laboratories and pilot plant centers that operated during the first half of the Cold War.

In 1942, biological warfare scientists at Camp Detrick, Maryland, began investigating the possible uses of defoliant herbicides, based on Dr. Arthur W. Galston's scientific discoveries, while working with TIBA [1]. The U.S. Department of Army's Chemical Corps Biological Laboratories initiated a major program in 1952 at Camp Detrick, Maryland [1] to develop both the herbicide formulations and aerial spray equipment for potential deployment in the Korean Conflict. The Agent Blue precursor reagent, cacodylic acid, was invented at Fort Detrick in 1957.

2.3. Agent Blue, the Arsenic Based Herbicide, Manufacturing on the Menominee River

The Ansul Chemical Company at Marinette, Wisconsin manufactured the Agent Blue**,** an arsenic containing herbicide, used during the Vietnam War in the 1960s and 1970s. The Menominee River flows into Lake Michigan via Green Bay. The Agent Blue was shipped via Green Bay and the Great Lakes and the St. Lawrence Seaway to the Atlantic Ocean. The ocean going-ships then passed through the Panama Canal and the Pacific Ocean on the way to the South China Sea.

Most of the early (1962 to 1965) Agent Blue shipments (95 barrels [19,760 li-

ters] in powder form as organic arsenical cacodylic acid [ANSAR 138]) were sent to Tan Son Nhut Airforce base via the Saigon River and the Port of Saigon. After 1965 most of the Agent Blue 29,655 barrels (6,168,240 liters in liquid form as PHYTAR 560G) was transported to Bien Hoa Air Force base from the Port of Saigon which is on the Saigon River. The Agent Blue distribution to these Air Force bases was undertaken by trucks, boats and aircraft.

Almost all (99%) of the Agent Blue used during the Vietnam War from 1962 to 1971 was manufactured at Ansul Chemical plants (**Figure 1**) on the Menominee River in Michigan and Wisconsin [5]. The contaminated surface water and sediments near Ansul manufacturing plant flowed into the Menominee River. The groundwater and the river bottom sediments of the Menominee River are heavily contaminated with arsenic, which was released by Ansul Company from 1957 to 1977 resulting from the manufacture of Agent Blue.

2.4. Port of Saigon (Ho Chi Minh City)

Agent Blue was shipped to Port Saigon and transported in powdered form to the Tan Son Nhut Air Force base (1962 to 1965) and in liquid form to Bien Hoa Air Force base (1965 to 1971). Port of Ho Chi Minh City (port code: VNSGN), also known as Saigon Port (**Figure 2**), is the largest port in the southern Vietnam. Located on the west bank of Song Sai Gon, it is accessed via two channels of the Saigon and Soi-Rap Rivers [6]. The Saigon River is navigable by vessels up to LOA 220 m, draught 11.0 m, and deadweight 36,000 tn, while the Soi-Rap Rivers is limited to vessels with a maximum draught of 6.7 m. This port handles approximately 12,000,000 tn of cargo and 1,200,000 TEU annually [7].

Figure 1. Aerial view of the former Ansul company chemical plant on Menominee River in Marinette, Wisconsin (L) and Menominee, Michigan (R). The Menominee River flows into Green Bay. Published with copyright permission from Editor of Open Journal of Soil Science.

Figure 2. Port of Saigon. Ships being off loaded. Reprinted with the permission of the editor of the Open Journal of Soil Science.

2.5. Tan Son Nhut Airport (1962 to 1965)

In early 1962, Agent Blue was first delivered in powdered form (95 barrels (19,700 liters) of ANSAR 138) to Tan Son Nhut Air Force Base, near Saigon River and in southern Vietnam. There are records that show 42% [8] of all tactical herbicides used before 1965 was the arsenic-based Agent Blue herbicide (**Figure 3**). The RV government and military with the support of the US Army, US Navy and CIA did not document their food denial spraying missions and location and did not make this information available to the media and public [1]. The Mekong Delta region had a complex water network of wetlands, forest vegetated stream banks, small streams and natural river distributaries of the Mekong River as well as intricate human engineering canals, dykes, and ditches used to produce paddy rice [9].

Tan Son Nhut Airfield was built by the French in 1930s when the French Colonial government of Indochina constructed a small unpaved airport in the village of Tan Son Nhut near the city of Saigon which served as its commercial airport. Tan Son Nhut Air Base (1955-1975) was a Republic of Vietnam Air Force (RVNAF) base [7]. The United States military used it as a major base during the Vietnam War (1959-1975). The US Army, Navy and Marine units were stationed there. Following the fall of Saigon, it was taken over as a Vietnam Peoples'Air Force (VPAF) facility and is no longer in use [10]. It is a Vietnam War museum (**Figure 4** and **Figure 5**) with the lawn covered with aircraft and the museum was dedicated to Ho Chi Minh. The museum contained no information related to the Tan Son Nhut airport use by the US Air Force and then the RV Air Force from 1930 to 1975. The fate of the RV military spray records is unclear whether or not that they may have been transferred to the Vietnam War archive no. 2 in Ho Chi Minh City. Between 1968 and 1974, Tan Son Nhut Airport was one of the busiest military airbases in the world. The Tan Son Nhat International Airport is located a few kilometers away from the original site and is now a major Vietnamese civil airport for domestic flights.

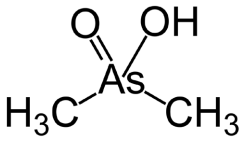

Figure 3. The chemical formula of Agent Blue. Reprinted with the permission of the editor of the Open Journal of Soil Science.

Figure 4. Tan Son Nhut Air Force base museum in Ho Chi Minh City. Reprinted with the permission of the editor of the Open Journal of Soil Science.

Figure 5. Tan Son Nhut Air Force base museum yard with a Vietnam War fight plane.

3. Findings

3.1. Agent Blue Use in South Vietnam

The first recorded use of Agent Blue by the US Air Force was in November of 1962 [3]. Approximately 3.2 million liters of Agent Blue (468,008 kg As) was sprayed or dumped by the RV military, with the support of the US military, during the 1962 to 1965 Khai Huang program [8]. In addition, 4.6 million liters (664,392 kg of As) were sprayed on South Vietnam from years 1962 to 1971 by the Operation Ranch Hand program (**Figure 6**). The Institute of Medicine [11] estimated a total of 7.8 million liters (1,132,400 kg As) of Agent Blue was applied to South Vietnam from 1962 to 1971. This total includes both the Agent Blue used in US Air Force Operation Ranch Hand (defoliation) and the Agent Blue used in the RV Khai Huang (food denial) program [8] with the assistance of the

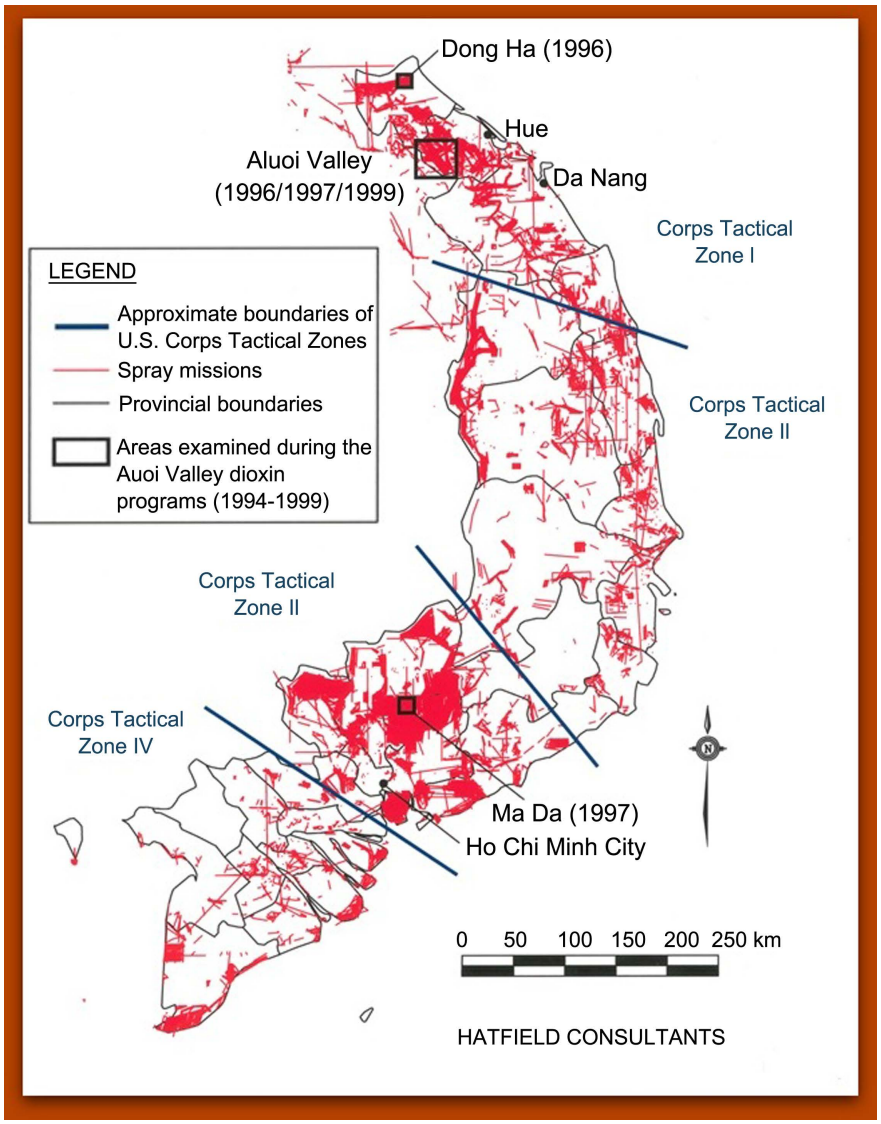

Figure 6. Operation Ranch Hand tactical herbicide spray mission in South Vietnam including the Mekong Delta. Photo Credit: Hatfield Consultants.

US Air Force, Army and Navy. New studies of US military flight logs suggest an even greater use of Agent Blue; however, the Agent Blue application total of 7.8 million liters (1,132,400 kg As) applied to South Vietnam, from 1962 to 1971, is the best available documented As total at this time [11]. The application rates of Agent Blue, especially on the military base perimeter fences, may have been much greater than recommended application rate especially if the base was attacked by the NVA and VC, such as Udorn Air Force base in Thailand. It was also possible for commercial herbicides to be purchased by both the RV and US military (Thailand) in addition to the tactical herbicides procured and distributed by DOD. The records for commercial purchases were not maintained by DOD but the records might exist in Vietnam War Archive number 2 in Ho Chi Minh City. There could also be records of the tactical herbicide transfers from US military to RV military. Some of the tactical herbicide shipments were marked commercial and not subjected to inspections by the International Control Commission (ICC) established under Geneva Accords of 1954. ICC had authority to monitor and inspect shipment of military equipment and chemical weapons entering South Vietnam but not "commercial herbicides" ordered by RV or US militaries which could bypass the ICC inspection process.

These drainage systems crossed the entire Mekong Delta region (**Figure 7**). The drainage waterways were used as a navigation network and were accessible by non-motorized and motorized boats and floating platoons that were used by locals and militaries. To access and destroy the NVA and VC base camps in the Mekong Delta (**Figure 8**) and the rice food supply would have required the skills of water and land-based military forces including the US Army and Navy [3] [12]. Because there are currently no RV military, US Army and US Navy records of Agent Blue spraying in much of the Delta region (1962 to 1965), it is now impossible to distinguish natural from anthropogenic arsenic spikes in the Delta groundwater. However, Vietnam War Archive no. 2 in Ho Chi Minh City (**Figure 9**) may have paper copies of the RV herbicide (food denial) spray records and the Vietnam War historians and scholars need to read these documents and publish their findings. One could surmise that arsenic based Agent Blue herbicide (both commercial and tactical) was one of the vegetation management tools available to the RV military with the assistance of the CIA, US Army and US Navy. Agent Blue use throughout the delta increased both the arsenic levels and spikes in the Mekong Delta groundwater.

During the Vietnam Civil War (1962-1965), herbicides were sprayed by RV (food denial) and US military (mostly defoliation) forces at an order of magnitude greater than amounts used for domestic weed control [8]. The herbicides were stored and shipped in 208-liter barrels, and named after the colored band painted on each barrel [13]. The tactical herbicides were mostly sprayed by RV military, with the support of the US military, over the forests of South Vietnam to kill crops in order to deprive the NVA and VC troops of food, and to remove the vegetation cover used for concealment [14] (**Figure 10**), making ambushes more difficult [8]. RV and US Army soldiers used mortars and grenades in an

Figure 7. Mekong Delta drainage ways and canals. Reprinted with the permission of the editor of the Open Journal of Soil Science.

attempted to destroy rice paddies and rice stocks, but rice grains were very durable and not easily destroyed [3] [12]. Soon, the "rice-killing operations" became more sophisticated. Rubber or plastic bladders were dropped from helicopters directly into rice paddies, bursting on impact and releasing toxic herbicides including Agent Blue. Barrels of herbicides were also dropped into the water

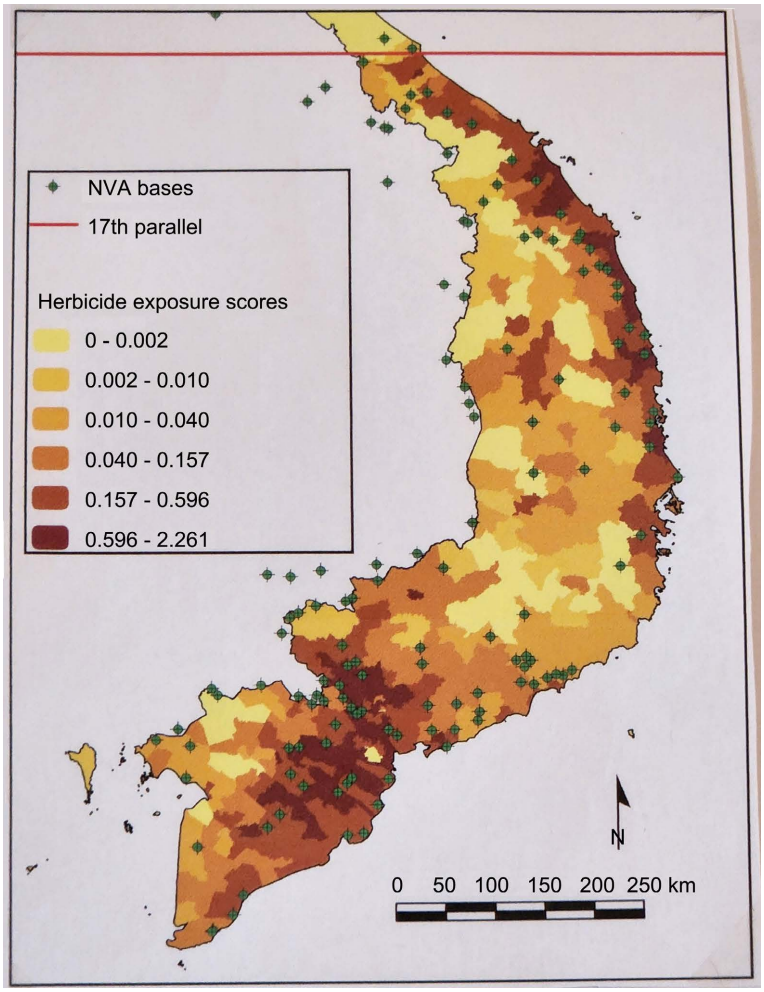

Figure 8. Distribution of herbicide exposure scores and location of North Vietnamese Army bases in Southern Vietnam. The modified figure shows the distribution of herbicide exposure scores and locations of NVA bases. Reprinted with the permission of the editor of the Open Journal of Soil Science.

Figure 9. The Republic of Vietnam and United States printed correspondence is kept at Vietnam War Archive number 2 in Ho Chi Minh City. Reprinted with the permission of the editor of the Open Journal of Soil Science.

Figure 10. Agent Orange and other color-coded herbicides were sprayed by low flying aircraft over the Vietnam jungle and rural landscapes and subject to small arms fire from the ground. Most these herbicides had short-half lives of hours, days and a few weeks; and vegetation regrowth required additional applications. Picture taken by US Army Flight Operations Specialist 4 John Crivello in 1969. Reprinted with permission from Editor of Open Journal of Soil Science.

irrigating rice paddies, polluting rivers and poisoning the soil and Vietnamese for many years [3] [12]. Agent Blue was used as a contact herbicide in South Vietnam for rapid defoliation, grassy plant control and rice destruction. Agent Blue was the agent of choice for the destruction of rice crops (food denial) by the RV military with the support of the US Army and US Navy [3] [12] [14].

More than 4.6 million liters of Agent Blue (also known as Phytar 560-G), were dispensed between 1962 and 1971 in the Ranch Hand herbicide program, according to US Air Force Operation Ranch Hand herbicide records [3] and 3.2 million liters of Agent Blue (also known as Ansul 138 was shipped as a powder) and then mixed with water. Agent Blue was sprayed, between 1962 and 1965, as part of Khai Huang program [8]. Agent Blue, also applied by the RV military with the assistance of the US Navy and US Army worked rapidly defoliating or desiccating a wide variety of plant species of grasses and grains. It works by uncoupling phosphorylation in plants. It was used in situations requiring rapid defoliation, causing browning or discoloration within one day, with maximum desiccation and leaf fall occurring within two to four weeks [12]. By starving rice plants of moisture, the enemy and millions of rice-growing villagers could be denied their most basic food source. This formed an essential part of the RV and US government and militaries "rice-killing operations". The term "Agent Blue" was first applied to cacodylic acid in powder form that was mixed with water before spraying. Cacodylic acid is a highly soluble organic arsenic compound that readily breaks down in soil [3]. It is considered to have very low toxicity for mammals.

The original commercial form of Agent Blue was so common and so profitable that it was among 10 toxic insecticides, fungicides and herbicides partially de-regulated by the US Environmental Protection Agency (USEPA) in February 2004, and specific limits on toxic residues in meat, milk, poultry and eggs were removed [3] [12]. However, in 2009, the USEPA issued a cancellation order to eliminate and phase-out the use of organic arsenical pesticides by 2013, with one exception—monosodium methanearsonate (MSMA), a broadleaf weed herbicide for use in defoliation of cotton. Small amounts of cacodylic acid (or disodium methanearsonate) were historically applied as herbicides on cotton fields, golf courses, backyards and other areas, but its use is now prohibited under the USEPA 2009 organic arsenical product cancellation. Other organic arsenicals (e.g. roxarsone, arsanilic acid and its derivatives) are used as feed additives for poultry and swine to increase the rate of weight gain, improve feed efficiencies, pigmentation, and to treat and prevent disease.

The highest exposure in herbicide manufacturing was usually found at the mixing, screening, drying, bagging, and drum-filling operations (**Figure 11**). During these operations, reported arsenic concentrations in air ranged from 0.5 - 45 mg/m^3. The World Health Organization (WHO) guideline for the safety

Figure 11. Repacking herbicide barrels and recovering buried barrels leaking into the ground. Reprinted with permission from Editor of the Open Journal of Soil Science.

limit of arsenic is 10 μg/L in drinking water [12]. In Vietnam, the legal arsenic concentration limit is five times higher than in the WHO guidelines. The problems were caused largely by the "tube wells", which draw water from depths of between approximately 10 and 40 m. The wells, designed to provide safe drinking water by avoiding polluted surface waters, inadvertently tapped into arsenic laden underground aquifers [3]. The use of Agent Blue during the Vietnam War and other industrial developments caused the levels of bio-available arsenicals to spike dangerously high [3]. The arsenic contamination levels varied from 1 - 3050 μg/L, with an average arsenic concentration of 159 μg/L in rural groundwater samples from private small-scale tube wells. In a highly affected rural area, the groundwater used directly as drinking water had an average concentration of 430 μg/L [3] [12]. Analysis of raw groundwater pumped from the lower aquifer for the Hanoi water supply yielded arsenic levels of 240 - 320 μg/L in three of eight water treatment plants and 37 - 82 μg/L in another five plants. Aeration and sand filtration applied in the treatment plants to remove iron lowered the As concentrations to 25 - 91 μg/L, but 50% remained above the Vietnamese standard of 50 μg/L.

The herbicides were stored and shipped in 208-liter barrels, and named after the colored band painted on each barrel. They were mostly sprayed over the forests and rice paddies of South Vietnam to kill the mature rice crop in order to deprive the NVA and VC troops of food, and to remove the vegetative cover used for concealment, making ambushes more difficult [8]. Agent Blue was used as a contact herbicide in South Vietnam for rapid defoliation, grassy plant control and rice destruction. Blue (and later called Agent Blue) was the agent of choice used by the RV and U.S. militaries for the destruction of rice crops (food denial program).

Agent Blue affects plants by causing them to dry out (**Figure 12**). Because rice is highly dependent on water to live, using Agent Blue on these paddies can destroy an entire field and leave it unsuitable for further planting. This is why Agent Blue was also used where food was not a factor, but foliage was. The Communist insurgents (NVA and VC) had an advantage while fighting in South Vietnam given they were used to the abundance of plant life on the battlefield. The U.S. found themselves at a disadvantage and based on the precedent set by the British in Malaya [15] decided that the best retaliation would be to take away the enemy's advantage by removing their cover. Along roads, canals, railroads, and other transportation networks, Ranch Hand cleared several hundred meters using the herbicides to make ambushes more difficult for the enemy. In Laos, herbicide removed the jungle canopy from roads and trails used for infiltrating men and supplies, making them more vulnerable to attack from the air.

Although the acute and chronic effects of organic arsenicals are not as severe as inorganic arsenicals (carcinogen), organic arsenicals have a significant impact on human health. Additional studies may uncover more currently unproven or unknown health effects. The present public health concern to human exposure

Figure 12. Rice residue in dried out fields similar to the rice paddies sprayed with Agent Blue in the 1960s and 1970s. Reprinted with permission from Editor of the Open Journal of Soil Science. Reprinted with the permission of the editor of the Open Journal of Soil Science.

to arsenic was linked to the consumption of arsenic-rich drinking water. This is a result of the alluvial sediments on the floodplains being rich in arsenic [3] [12]. Current epidemiological and experimental studies have attempted to elucidate the specific mechanism of arsenic carcinogenicity. This has led to the question of whether it is an epigenetic carcinogen. Due to the complexity of the mechanism of toxicity at the molecular level, and because of genetic polymorphism in the human population, both options continue to remain plausible [3]. However, recent studies show that the trivalent organic arsenicals that are metabolic products of inorganic arsenic could possibly be more toxic than the parent compound [3] [12]. The mechanism of arsenic includes inhibition and oxidative stress, as well as immune, endocrine, and epigenetic effects.

Analytical determination of arsenic poisoning may be made by examining arsenic levels in human urine, hair and toenails. Kapaj and Pederson [16] found communities and individuals relying, on groundwater sources for drinking water, need to measure arsenic levels to ensure their water supplies are safe. Communities with arsenic levels greater than 5 μg/L in drinking water should consider a program to document arsenic levels.

Since arsenic poisoning of humans can occur by gradual accumulation of small doses until lethal levels are reached, the use of Agent Blue (during the Vietnam War) and other organic arsenicals pose a long-term danger [16]. Neurological symptoms are usually more frequent than gastrointestinal effects over prolonged exposure to organic arsenicals. Cacodylic acid may cause paresthesia

and/or weakness in the hands and feet [12]. Repeated skin contact may cause hyper pigmentation and keratosis. Malnourished people are more susceptible to arsenic-related skin lesions [16].

3.2. Agent Blue Use in the Mekong Delta by RV Military and US Air Force's Operation Ranch Hand

In the fall of 1961, RV President Diem's government suffered from a formidable political breakdown. The NVA and VC, with the support of local guerrillas, controlled the Mekong Delta Region. The number of guerrilla attacks triple in the month of September of 1961 [17]. Morale at the Saigon headquarters was shattered by seizure of Phuoc Thanh, a provincial capital only 90 km away. The NVA and VC only controlled the capital for a few hours, however the public beheading of the province chief affected RV moral. The NVA and VC soldiers left town before RV troops arrived. The deteriorating situation, lead to another high round of decision making in Washington, DC on Vietnam.

A paper entitled "Concept of Intervention in Vietnam" was discussed at a meeting of the US State Department and DOD secretaries [17]. Deputy Under Secretary of State Johnson outlined the "concept" for introducing United States forces into South Vietnam, and perhaps Laos, under the Southeast Asia Treaty or United Nations umbrella. The military objective would be to secure South Vietnam's borders and prevent the infiltration of men and supplies from North Vietnam. Such a mission would require only 22,800 men. A supplemental note suggested that a "clean up" of the NVA and VC threat would require about 40,000 US troops and as many as 128,000 might be needed if North Vietnam and China intervened. Defoliation operations were one of several proposed supplemental actions and suggested defoliation operations could be carried out immediately while decisions on committing combat troops were being made.

The original October 10, 1961 Johnson paper proposed that the US aircraft being used to conduct a "*major defoliant spray program in South Vietnam*". However, the US aircraft would carry South Vietnamese markings and pilots would wear civilian clothes. The next day, another supplemental note, rephrased the defoliation proposal differently. "*Carry out defoliant spray operations, using hired commercial planes* (presumably CIA)". These operations would initially be experimental, designed to prove out and further develop the capability to use defoliant sprays to clear off jungle access routes [17]. On October 11, 1961, National Security Council meeting with President Kennedy dealt with the Johnson paper. The President deferred a decision on the major question of sending large numbers of American troops to South Vietnam as well as on the defoliation option [17]. The defoliation option development had started previously on September 23, 1961. A joint State-Defense message stated the emergency actions were needed to support the Diem government and suggested that defoliation be included in an operational program and be delivered without delay.

The combat Development and Test Center developed a massive operational program at the same time. The plan had four goals [17]:

"*Stripping the Cambodian-Laotian-North Vietnam border of foliage to remove protective cover from the NVA and VC reinforcements* [17];

Defoliating a portion of the Mekong Delta area known as 'Zone D' (Ca Mau) in which Viet Cong have numerous bases [3] (**Figure 6** and **Figure 8**);

Destroying abandoned manioc groves which Viet Cong use as food source [3]; *and*

Destroying mangrove swamps within which the Viet Cong used as a food source [3]".

While the Deputy Under Secretary Johnson plan was not immediately implemented, over time all four goals were addressed including Laos, Cambodia and North Vietnam borders. The crop destruction component of the plan and modified versions gave the Joint Chiefs of Staff a cause for concern. The Joint Chiefs of Staff opinion that conducting aerial defoliant operations against abandoned manioc (tapioca) groves or other food growing areas was sensitive. Therefore, care must be taken to ensure that the United States did not become the target of charges of employing chemical or biological warfare. International repercussions against the United States could be most serious. In that connection, it is recommended that the operations be covered concurrently with a publicity campaign as outlined by Task Force Vietnam in Saigon [17].

President Kennedy was concerned regarding the marking to be used on US defoliation aircraft and the nationality of the crews who would fly the missions. The Deputy Under Secretary Johnson noted again that the food denial operation could be carried out by South Vietnamese Air force and crews. In addition, he mentioned the possibility of placing South Vietnamese marking on the aircraft (presumably, Air Force C-123s and having them flown by "cover" air crews (presumably CIA). Secretary Johnson did not believe such measure would be effective in hiding the US role and recommended against it, however, eventually this approach was used in South Vietnam, Laos and Cambodia for both food denial and defoliation.

DOD Deputy Under Secretary Gilpatric presented President Kennedy two possible alternative decisions [17]:

"*To avoid the use of the material wholly on grounds of net adverse local reaction, and particularly of worldwide disapproval. On these, we have no clear judgment, since it depends on factors that can best be assessed by the Department of State.*"

"*To go ahead with a selective and carefully controlled program starting with the clearance of key routes, proceeding thereafter to food denial only if the most careful basis of resettlement and alternative food supply has been created, and holding Zone D (Ca Mau) and the border areas until there is a realistic possibility of immediate military exploitation.*"

The clearance of key routes, proceeding thereafter to food denial only if the most careful basis of resettlement and alternative food supply has been created, and hold Zone D (Ca Mau) and the border areas until the US military has a realistic possibility of immediate exploitation.

The DOD preferred the 2nd option. Secretary of State, Dean Rusk, told President Kennedy "*That use of defoliants does not violate and is an accepted tactic of war*" [17]. He cited the British crop-spraying operations in Malaya as precedent. Rust expressed the view that: "*successful plant-killing operations in Vietnam, carefully coordinated with an incidental to larger operation, can be substantial assistance in the control and defeat the NVA and VC*". On November 30, 1961, President Kennedy accepted the joint recommendation for limited initial defoliation program restricted to transportation routes (presumably the Ho Chi Min Trail in Cambodia and Laos).

At the time of President Kennedy's decision was one of many that required his immediate attention including Laos. In support of the pro-Western factions the United States almost sent troops to Laos in 1961. Many of the important decisions regarding South Vietnam were made, in part, in response to the more serious situation in Laos.

In South Vietnam, Cambodia and Laos, the US government and military opted to use tactical herbicides instead of the introduction of ground troops. At a meeting of the Joint Chiefs of Staff on Nov. 27, 1961, Secretary McNamara told the Chiefs that South Vietnamese would conduct crop destruction missions (food denial) using their own helicopters and that the US Air Force aircraft and crews would fly defoliation mission to remove jungle cover.

On December 3, 1961 US Ambassador Nolting in Saigon continued to recommend Ranch Hand aircraft carry civilian marking and their crews wear civilian clothes. The anticipated political problems with International Control Commission (ICC) established under Geneva Accords of 1954. ICC had authority to inspect shipment of military equipment entering South Vietnam. A shipment of 7.5 mt of cacodylic acid (Agent Blue in dry powder form) and 75,000 liters of Agent Pink and Agent Green herbicides for use in crop destruction had already arrived unannounced in Saigon by military aircraft and had bypassed ICC inspection. Ambassador Nolting was concerned that when a future shipment of herbicides (chemicals) by commercial ship co-signed to MAAG could not be fit under existing ICC credits or justification of title. He suggested it be a civilian cargo consigned to US Operations Mission (USOM) in South Vietnam which would exempt them from ICC inspection. Civilian aircraft and crews were to maintain consistency with "civilian" chemicals [17]. It also appears logical that the US Air Force's Operation Ranch Hand would probably not keep civilian records of the RV chemical (food denial missions) use and application. This could account, in part, for the lack of Operation Ranch Hand spray missions (**Figure 10**) in the Mekong Delta since the RV military, with the assistance of the US Army and US Navy, sprayed the food crops in the Mekong Delta using their own helicopters and spray equipment. They could also purchase commercial herbicides, similar to Agent Blue, to bypass ICC inspections.

Future arrivals of US personnel and equipment would not be announced by the South Vietnamese government to the ICC. Also, the US would not admit that Geneva Accords were being violated. On December 4, 1961 the Secretary of

Defense met with Joint Chiefs of Staff and set December 25 as target date for beginning defoliation operations. Delays encountered in shipping chemicals to South Vietnam resulted in the final target being missed. Seventy-six thousand liters of Agent Pink and Agent Green herbicides and three hundred and eight thousand pounds of cacodylic acid (in powder form) were already in Saigon. The herbicides were sent for use in RV crop destruction operations but could not be used since the 1961 rice crop had already matured in the target area. However, RV military used Agent Blue on the rice crops starting in 1962. This suggests that the RV had access to Agent Blue powder before the official spray start date of December 25, 1961 and may have used it.

Ranch Hand sprayed herbicides along 46 km of canals on Ca Mau peninsula. Eight sorties dispersed 28,000 liters of chemicals including Agent Blue, mixed with water, were flown in region IV Corps. Between June 6 and 9, 1963, a target on the Ca Mau peninsula received a handful of spray sorties in January of 1964 (**Figure 10**). In February, Ranch Hand returned to the peninsula and sprayed a wide canal located on southern tip of South Vietnam along the Gulf of Thailand. The Navy ships protected the aircraft. Ranch Hand targets during March and April 1964 were also on Ca Mau peninsula.

On July 6, 1963 US Marine Major General V. H. Krulak, after a visit to South Vietnam, observed that Vietnamese forces already possessed the necessary chemicals, sprayers and helicopters and thus had the capability to conduct defoliation and crop destroying herbicide missions on their own, without the consent of the United States (and had been for almost 2 years). Only by a "gentlemen's agreement" did the Vietnamese recognize an American veto over the use of herbicides and associated equipment. The Olenchuk report noted that 533 ha of crops had been destroyed manually by RV military in III Corps (north of the Mekong Delta) during May, June, and July of 1963 [17].

A mission flown by Ranch Hand along the Bay Hap River in the Mekong Delta on April 22, 1964 resulted in allegations of crop damage near the model strategic hamlet of Cha La. Preliminary discussions between RV and US officials to arrange for aerial defoliation of rivers and canals controlled by NVA and VC in An Xuyen Province had taken place on December 1963 [17]. These officials rated a 38 km segment along Bay Hap River as the first priority for spraying because the VC continually ambushed or harassed convoys traveling to the outposts of Cha La and Thuan Hung. At a March 4, 1964 meeting, Vietnamese officials certified the authorized limits of target around Cha La by their signatures and official seals on a special 1:4000 scale aerial photograph. Ranch Hand flew against the complex of targets on April 22, 1964.

In May, Jim G. Lucas, a Scripps-Howard staff reporter submitted an article that was published as an editorial in Washington Post on May 26, 1964.

"*The miscalculation that caused the destruction by defoliants of food crops in the friendly South Vietnam village* (*Mekong Delta*) *has again called into question the wisdom of using such herbicide agents at all in this kind of war. The sort*

of unselective and non-discriminatory warfare simply is not suited to the pursuit of guerrilla infiltrators. We are burning the barn to get at the rats."

"*The employment of the devices of chemical warfare even in enemy country where the inevitable hardships fall upon the enemy's civilian population is open to all sorts of ethical doubts. Their employment is a civilian war, where the consequences are visited upon a civilian population we are trying to defend is folly compounded*".

"*Their consequences of employment by error and miscalculation are simply terrible. But we can avoid the rest of errors, in the employment of these* (*chemical*) *weapons but not using them at all in an environment which they are totally unsuited*" [17].

The reaction from the Pentagon was immediate. The same day the Joint Chiefs sent a message to Admiral Felt and General Harkins along with an outline of the Lucas story. Two days later Saigon's initial reply confirmed the Lucas story was "*basically true but not* (*the*) *whole truth*". A follow-up report on June 3rd, suggested Ranch Hand aircraft had not sprayed Cha La and there was no plant damage at Cha La. However, there was some browning of about fifty coconut, palm, banana, and betel nut trees that may have been caused by herbicide drift. On June 9, 1964 a RV official visited Cha La and paid indemnification without an investigation (US official recommendation) to 57 residents of the village and surrounding area for their claimed loss of 5569 coconut and areca nut trees. These trees were both inside and outside the authorized spray target.

Before late 1964, America was reluctant to allow South Vietnamese (RV) to conduct chemical crop destruction operations and even more reluctant to participate. Secretary McNamara at a March 10, 1964 meeting reconfirmed the decision to keep the United States out of direct involvement in the RV chemical crop destruction (food denial) program.

General Maxwell Taylor, soon to be Ambassador to South Vietnam, supported the McNamara decision. However, after he became Ambassador he changed his mind. RV military refused to use their helicopters to spray two potentially lucrative targets, VC food productive areas in Phuoc Long Province and Zone D. Ambassador Taylor then order Ranch Hand to destroy these food crops using the Farm Gate concept. That meant Ranch Hand aircraft would carry temporary South Vietnam marking for these missions and crews would be "ostensibly under the control of South Vietnamese aircraft commander" [17].

One October 3, 1964 Ranch Hand began its first crop destruction project called "Big Patch". The Ranch Hand spray planes flew 19 sorties between October 3 and 13 against fields near War Zone D [17]. During November and December, the C-123s flew 15 crop destruction sorties in Phuoc Long Province as part of operation "Hot Spot". Ground fire was heavy on both projects. The spray planes took 40 hits from small arms fire from the ground. In spite of the resistance, 3050 hectares of food crops alleged to have been destined for VC consumption were sprayed. MACV rated Ranch Hand operations against the food crops as highly successful [17].

3.3. North Vietnamese Army and Viet Cong Bases in the Mekong Delta

Tactical herbicides, including Agent Blue and Agent Orange were sprayed around suspected NVA and VC areas (**Figure 8**) in southern Vietnam [3] to improve visibility and destroy the enemy food supply [17]. The intensity of spraying was greatest in the proximity to NVA's bases that were identified by the U.S. Intelligence during the Vietnam War [3] (**Figure 8**). Between 1962 and 1971, the U.S. Air Force sprayed 50 million liters of tactical herbicides [8] across the Republic of Vietnam (RV). In addition, the U.S. Navy and U.S. Army sprayed both Agent Blue and Agent Orange on the rice paddies and mangrove forests of the RV. However, these spray missions were either not recorded, were classified or the records were not maintained. These spray missions of the U.S. Navy and Army also contributed to the dioxin TCDD and arsenic levels in the Mekong Delta.

It is estimated that up to 366 kg of pure dioxin TCDD and 1,100,000 kg of pure arsenic were sprayed in the operations areas as many as 4.8 million Vietnamese civilians were subsequently exposed [18] [19] [20]. The tolerable daily dioxin TCDD intake is defined by WHO to be between 1 and 4 pg (picograms) per kg of body weight (one pg equals 10^{-15} kg). Numerous biological and epidemiological studies have shown robust medical linkages between herbicides exposure to dioxin TCDD or arsenic and a range of health problems. Among the most comprehensive Veterans and Agent Orange research and reports was one conducted by the National Academies of Science, Engineering and Medical. This report was updated annually and led to the Agent Orange Act of 1991 [21].

The first tactical (rainbow) herbicide delivered to Tan Son Nhut Air Base, RV, in early 1962, was Agent Blue. The herbicide was in powder form (ANSAR 138) then mixed with water for spraying. This process often resulted in spills of Agent Blue and its main ingredient cacodylic acid, both of which have short half-lives. Unfortunately, the compounds were degraded to water-soluble arsenic and released into the surface water, soil and the groundwater.

Records [17] (**Figure 9**) indicate that 42% of the herbicide used in southern Vietnam prior to 1965 was the herbicide Agent Blue. Agent Blue was used to destroy the rice crop, with the active ingredient cacodylic acid containing arsenic. However, there are limited publically available US Air Force records and no Navy, CIA and Army records of the Agent Blue defoliation (**Figure 11**) spray missions or crop (food denial) areas sprayed in the Mekong Delta prior to 1965 and few records after that date. The stated US and RV government and military goal, prior to 1965, was to eliminate the food supply of the enemy (NVA) by destroying the South Vietnamese rice crop just prior to harvest (**Figure 12**). Most of the rice crop was grown in the Mekong Delta and not the Central Highlands. So why would the U.S. Air Force spray records (Operation Ranch Hand) primarily reflect (**Figure 6**) the Agent Blue spraying in the Central Highland? Apparently, the Agent Blue sprayed by the RV military on food crops (food denial)

in Mekong Delta with the assistance of the U.S. Army, CIA and U.S. Navy was not included as part of the U.S. Air Forces Operation Ranch Hand defoliation mission. Air Force kept and maintained their own spray mission records. The goal of the US Air Force's Ranch Hand spraying program was to defoliate the jungle, including the stream banks on the canals, waterways and rivers to prevent ambush and to expose the NVA and VC and their base camps (**Figure 8**). There were at least 26 NVA and VC base camps in the Mekong Delta. Most were located in mangrove forest surrounded by rice paddies and adjacent to a waterway. Agent Purple was used to defoliate the forest and Agent Blue was used to destroy rice crops (1962-1965). It took almost two weeks for leaf drop to occur, after a forest was sprayed with Agent Purple and/or Agent Blue. These two tactical herbicides were sometimes combined (Agent Orange was not available for use until 1965) to speed up the defoliation process. The RV food denial program (Khai Huang) including Agent Blue spraying and subsequent burning of the rice residue (to eliminate the seeds) by the RV and US militaries significantly reduced the capacity of the Vietnamese living in the Mekong Delta to feed themselves or NVA and VC soldiers.

Some of the rural Vietnamese in South Vietnam supported the NVA and VC soldiers while others did not. However, the NVA and VC soldiers had weapons and could take the rice if not freely provided by local farmers. As the result, during the early 1960s many of the rural Vietnamese in South Vietnam were without a stable food supply. Nearly 2 million Vietnamese living in both the Mekong Delta and Central Highlands were forced to re-locate into slums of Saigon or hamlets as part of a RV Strategic Hamlet (Khai Huang) project (easier to defend the rural population if concentrated in urban areas or hamlets). All of the southern Vietnam rural providences lost population during the Vietnam War (1955-1975). This is because of population shifts (hamlet strategy) and civilians being killed during the war.

The US Army, Blue Water Navy and Brown Water Navy continued to spray the Mekong Delta stream banks (**Figure 10**), rice paddies and mangrove forests after the U.S. government officially entered the Vietnam War in August of 1964. Once again, Mekong Delta Agent Blue spray records were either not kept, were classified, or not maintained. In 1965, Agent Blue (arsenic), along with Agent Orange (with 2, 4, 5-T with unknown amounts of dioxin TCDD) replaced Agent Purple, were also used in combination by U.S. Air Force as part of Operation Ranch Hand, to defoliate the mangrove forests used by the NVA and VC base camps in the Mekong Delta (**Figure 8**). This deforestation exposed the stream banks and shoreline to soil erosion and destroyed the livelihoods of the local woodcutters.

The total amount of Agent Blue shipped to Vietnam was more than the Operation Ranch Hand C-123s (**Figure 13**) and helicopters sprayed, according to the official Operation Ranch Hand records for the Vietnam War (from 1962 to 1971). In South Vietnam, Agent Blue was used as a contact herbicide for grassy

Figure 13. C-123s Fairchild Provider aircraft that was used during the Vietnam War to spray tactical herbicides. Reprinted with the permission of the editor of the Open Journal of Soil Science. Reprinted with the permission of the editor of the Open Journal of Soil Science.

plant control and rice destruction. More than six million liters of Agent Blue (known as Phytar 560-G), manufactured at the Ansul Chemical Plant on the Menominee River (**Figure 1**) in Wisconsin and Michigan, were sprayed as part of the DOD and USDA herbicide program called Operation Ranch Hand (1962 to 1971). These Air Force spray records indicate that over 664,392 kg of Arsenic (As) was sprayed on South Vietnam, Laos and Cambodia. This does not seem to include the Agent Blue (468,000 kg of As) in powder form that was mixed with water and sprayed on and adjacent to NVA and VC base camps and adjacent lands in the Mekong Delta (**Figure 8**) and/or the Central Highlands. Agent Blue was sprayed by the RV military, with the support of U.S. Army, Brown Water Navy, Blue Water Navy and CIA, primarily between 1962 and 1965. The RV military food denial program was extended from the start of the American Vietnam War in 1965 to the end of the Vietnam War in 1975. Commercial herbicides similar to Agent Blue were shipped to the RV military to bypass the ICC inspections. Why no US Navy and Army spray records? The U.S. Navy and Army did not seem to keep spray records and if they did, they were not maintained or were classified. Most of the U.S. Air Force Operation Ranch Hand spray was applied in South Vietnam (**Figure 6**) as part of the defoliation program in remote areas of the jungle to defoliate and expose enemy positions.

The purpose of the RV military food denial program conducted with the U.S. Army, CIA and U.S. Navy support was to eliminate the local food supply (primarily rice) in South Vietnam so the rural Vietnamese could not feed themselves

or the NVA and VC soldiers. Agent Blue was applied by Ranch Hand on the perimeters of NVA and VC base camps (Figure 6 and Figure 8) and more selectively in more populated areas of the Central Highlands and the Mekong Delta. The RV spray equipment used on fields included hand and backpack sprayers and sprayers on helicopters and vehicles. The US Navy and Army assisted using back pack and hand held sprayers on Brown Water Navy boats and from military vehicles (Army) (Figure 14) and from military land based helicopters (Figure 15) and some on Blue Water Navy ships. While it was easy to explain

Figure 14. Tactical herbicides sprayed from a M113 Armored Tracked Personnel Carrier, Reprinted with the permission of the editor of the Open Journal of Soil Science.

Figure 15. Tactical herbicides being sprayed by a helicopter on mangrove forests. Reprinted with the permission of the editor of the Open Journal of Soil Science.

the US Operation Ranch Hand defoliation objective to the press and the public, it was not so easy to explain why the U.S. government and military were eliminating the local food supply and starving of the rural Vietnamese living in South Vietnam. Since the RV military ran the food denial (Khai Huang) program, they had to explain it by calling it the hamlet strategy to protect the South Vietnamese from the NVA and VC. The elimination of the local food supply was primarily done by the Republic of Vietnam (RV) to force the rural Vietnamese to move to hamlets, which would be easier for the RV military to defend them since located in loyal areas.

However, the U.S. military's attempts to assist the RV military in destroying the local Vietnamese food supply was not considered by US media and public to be a noble mission. Perhaps that elimination of the local food supply (RV food denial program) was part of the reason. The Army, CIA and Navy when assisting the RV military did not keep spray records, or classified them or if recorded were not maintained and shared with the media or public. Most of the U.S. media focus during the Vietnam Civil War (1962 to 1965) was on US Air Force's Rand Hand program of defoliation of the jungle to expose the enemy.

To the credit of the U.S. Air Force, they did keep excellent spray mission records, as part of Operation Ranch Hand; however, the total tactical herbicides applied the records did not seem to include Agent Blue and commercial formulations applied by the RV military with or without the assistance of U.S. Blue Water and Brown Navy, CIA and U.S. Army. Lacking these spray mission records it is hard, after 50 years, to locate areas where Agent Blue was applied to destroy the rice crop, especially in the Mekong Delta. Therefore, it is difficult (nearly impossible) to overlay the arsenic spikes in the Mekong Delta groundwater with the spray and application mission records of the RV military, US Navy, CIA and US Army (**Figure 6**). It is not clear why the Air Force could keep spray mission records and maintain them and the Army, Navy and CIA could not.

Agent Blue was sprayed primarily on the mangroves, rice paddies, and the surrounding forest of the Central Highlands and Mekong Delta in southern Vietnam. Agent Blue was also used in Laos and Cambodia, along the Ho Chi Minh trail, to kill food crops including upland rice in an attempt to deprive the North Vietnamese communist and insurgent troops of a food source [12] [17]. The Agent Blue was applied at the average rate of 2.831 kg As/ha to the rice paddy and forest areas. Many areas were sprayed only once while other areas received four or more applications. The forest and mangrove areas were usually sprayed at a different rate than the rice paddies. Unable to control the insurgent's access to their food supplies or eliminate their grassroots village support, the RV military with US military (Army and Navy) support response was simple: "If you cannot control it, kill it" [12] [17].

Arsenic has no half-life and is water-soluble. Once it leaches into the groundwater it can be pumped back to the surface by hundreds of thousands of tube

wells (Figure 16), constructed after 1975 to supply fresh water needs of rice paddies, shrimp ponds and to meet household and drinking water needs of the Vietnamese living on the Mekong Delta or the Central Highlands. Most of the anthropic arsenic remains in the southern Vietnam environment to this day. The primary loss of anthropic arsenic from the southern Vietnam landscape would have occurred when Agent Blue spray drifted into or was sprayed directly on rivers and on adjacent stream banks. Surface runoff waters, with water-soluble cacodylic acid and arsenic components into the Mekong Delta Rivers, flowed into the South China Sea or the Gulf of Thailand (Figure 7 and Figure 17). However, most of the Agent Blue was utilized to destroy rice crops and arsenic, with no half-life, has remained in the rice paddy root zone soils and/or leached into the groundwater only to be returned to the soil surface by tube wells, for urban and agricultural use.

Figure 16. Tube wells in the Mekong Delta. Reprinted with the permission of the editor of the Open Journal of Soil Science.

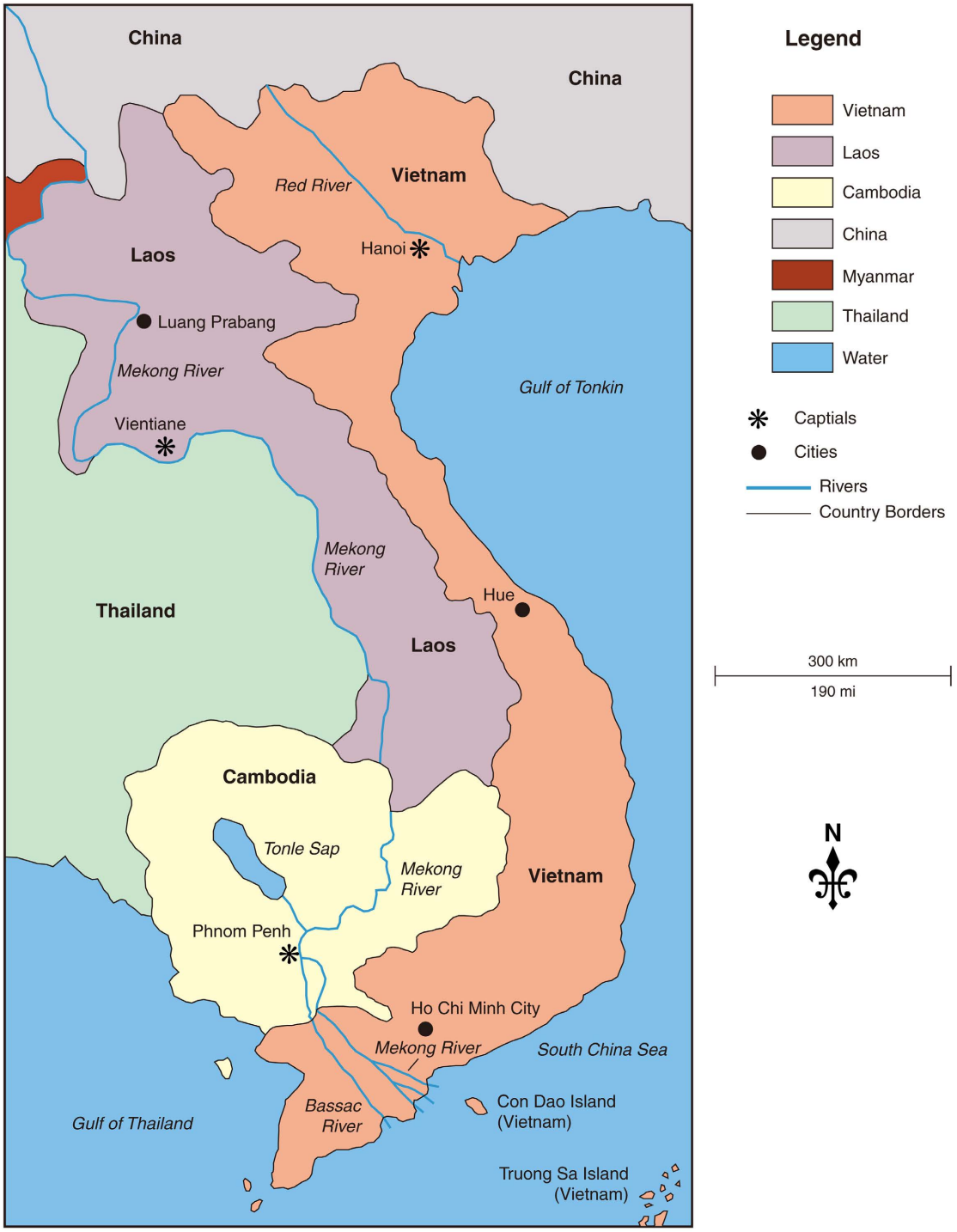

Figure 17. South East Asia countries including Vietnam. The Mekong and Bassac Rivers flow south into the Mekong Delta. Reprinted with the permission of the editor of the Open Journal of Soil Science. Map by Mic Greenberg. Reprinted with the permission of the editor of the Open Journal of Soil Science.

3.4. Agent Blue, the Arsenic Based Herbicide Used to Destroy the Rice Crop

During the Vietnam War, Agent Blue [(CH_3) As OOH] was sprayed for the primary purpose of destroying rice and other food crops (Figure 12). As part of the

RV and U.S. government and military strategy to destroy the food supply of both the communist insurgents and the southern Vietnamese living in rural areas as part of the Diem government's "Strategic Hamlet" program [12]. Agent Blue, a mixture of two As compounds, cacodylic acid and sodium cacodylate, was the most effective of all the tactical (Rainbow) herbicides in killing rice. Arsenic has been a known poison since the middle Ages. During the Vietnam War, the U.S. government, DOD and USDA ignored warnings of thousands of scientists of its hazards and sprayed Agent Blue on rice paddies, mangroves, bamboo groves (**Figure 18**) and U.S. military base perimeter fences. This resulted in exposure, of Vietnamese civilians, NVA and VC infiltrators and the U.S. military personnel who were stationed (boots on the ground) in in the Mekong Delta, to As.

Spraying and dumping of Agent Blue by the U.S. Navy and Army to desiccate rice plants before maturity added massive quantities of water-soluble As to the soil root zone and the surface water and ground waters of rice paddies. Southeast Asia is a region where natural occurring As in soils and sediments tends to be higher because of the occurrence of As containing geologic formations in the region [8]. Spraying significantly added to the As load in Mekong Delta environment. In addition, the U.S. used an estimated 7.8 million liters of Agent Blue herbicide (1,132,400 kg of As), as part of Operation Ranch Hand, as a chemical (herbicide) weapon for "crop destruction and defoliation". For the last 50 years, this As has been ingested by the Vietnamese living in the Mekong Delta via the food and drinking water.

Figure 18. Bamboo growing in Mekong Delta. Reprinted with the permission of the editor of the Open Journal of Soil Science.

Water-soluble As leached into the soil root zone and into the groundwater from the frequent application of Agent Blue by the U.S. Army and Navy (in addition to the Air Forces Operation Ranch Hand) and/or was transported by the surface runoff water directly into the waterways and rivers (Figure 7). After the Vietnam War was over, vast amounts of natural and residual manufactured arsenic laced groundwater was pumped from private wells (Figure 16) to the surface to irrigate the rice paddies, fill shrimp ponds (Figure 19) and to meet the drinking water needs of the 20 million people living in the Mekong Delta. The water-soluble As continues to cause health effects in both animals and humans. In addition, during the 1962 to 1971 period, animals and humans absorbed As primarily through skin contact with Agent Blue in their environment.

3.5. Vietnam War Archive No. 2—Ho Chi Minh City

Official RV government records are all stored at the Vietnam War archive number 2 in Ho Chi Minh City (Figure 9). The Archive no. 2 staff have indexed (Table of Contents) and stored these documents in loose binders. Unfortunately, the documents are not yet scanned into electronic files. That needs to be done since the paper copies are 50 to 60 years old and the information needs to be preserved.

These records include personal and government correspondence between the RV President Diem and US President Kennedy administrations. After reading other publications by historians and other Vietnam Era veterans and connecting dots over the years, it is now apparent that US President Kennedy's administration and US military were hesitant to introduce chemical weapons into the Vietnam War. There was a lot of concern on the part of the Kennedy administration (1960 and 1961) that they could be prosecuted in World Court, after war's end, for war crimes related to use of chemical weapons. Since the British first used herbicides in the Malaysia conflict in the 1950s, the US government and military justified their use of tactical herbicides, including Agent Blue. They were not the first country to use herbicides in a war or conflict.

Figure 19. Shrimp farm in Mekong Delta of Vietnam that was developed after 1975. Reprinted with the permission of the editor of the Open Journal of Soil Science.

In addition, President Diem administration's requested Agent Blue herbicide shipments and US military assistance in spraying the South Vietnam rice crop to help implement the RV hamlet strategy. The US government was initially reluctant to destroy the food supply of our RV partners' people. The RV military using their own helicopters and spray equipment sprayed Agent Blue on the crops as part of their food denial program. In war, the goal is often to eliminate the food supply for the enemy and their people not the food supply of your people/allies. The reason the RV military sprayed the South Vietnamese food crops was to get the rural Vietnamese to move into the slums of Saigon or into hamlets so the government could better protect them from the NVA and VC. Most of RV President Diem's supporters were in the urban areas. Many rural Vietnamese actually favored "Unification of Vietnam" and supported the NVA and VC and not the Republic of Vietnam's government lead by President Diem. This suggests the RV hamlet strategy (food denial) was really an attempt to control the rural southern Vietnamese by eliminating their food supply and forcing them to move into either the slums of Saigon or into hamlets which could be more easily protected by the RV military. Once in the hamlets or slums, the rural southern Vietnamese could be "protected" from the "enemy (NVA and VC)". But in reality, many locals were NVA and VC guerrilla supporters and favored re-unification efforts. They provided food in support of the NVA and VC unification effort. The RV government needed to "control" the rural South Vietnamese people. This background knowledge helps to explain why the RV government wanted to obtain Agent Blue and other tactical and commercial herbicides from the US and requested US military assistance in spraying Agent Blue on South Vietnam rice crops when NVA and VC ground fire was intense. Historical documents suggest that the President Kennedy administration struggled with RV request for tactical herbicides and assistance, but after extensive deliberations got President Kennedy to signed off on the use of military and environmental chemical weapons for defoliation missions. The US government and military decision to supply Agent Blue and commercial formulations to South Vietnam military was justified, since it was done at the request of the request of the RV government and military and in support of their hamlet strategy (Khai Huang program).

These Vietnam War Archive no. 2 documents could prove whether or not the US government sent Agent Blue and a similar commercial version to South Vietnam (Tan Son Nhut AFB between 1962 and 1965) for RV spraying of rice crops (food denial program) in that Mekong. Apparently, the Blue powder was mixed with water and then sprayed by the RV military, with and without US military assistance, on the rice crops in the Mekong Delta to eliminate the food supply. In addition, RV and US militaries sometimes sprayed a crop area and then burnt the rice crop residue. The smoke adversely affected nearby villages and there should be reports in the Vietnam War Archive no. 2 files documenting these incidents. It appears that the US DOD has never had access to these Viet-

nam War Archive no. 2 files. These documents need to be protected since the US Army, CIA and US Navy spray records, in support of the RV military, do not exist. The RV spray records can be used to show that Agent Blue was sprayed by the RV military as part of the food denial program in the Mekong Delta, with the assistance of the US military. This could support the Olson and Cihacek previous calculation that more than 1 million kg of pure arsenic [3] [12] was applied to South Vietnam between 1962 and 1971. Much of the initial RV Agent Blue spraying was done using their own helicopters and hand held and backpack sprayers. The Agent Blue powder (1962-1965) was mixed with water before application then sprayed in a liquid form.

The Vietnamese archives staffs were provided the Merry Band of Retirees, which includes nine US Army and Vietnam Era veterans, and four Agricultural College Professors, published documents, a total of 20, which are now being archived (**Figure 9**). Vietnam War Archive no. 2 in Ho Chi Minh City and Vietnam War Archive no. 1 in Hanoi have agreed to accept the 12 to 14 team refereed journal articles (**Figure 9**), four Vietnam Veteran News radio podcasts of Mack Payne on Agent Blue, and four Ken Olson ppt lectures on both Agent Orange and Agent Blue. The Olson exhibit contains more than 500 Open Journal of Soil Science journal pages on Agent Orange and Agent Blue, 64 minutes of radio podcasts on Agent Blue and four ppt talks on both Agent Blue and Agent Orange which will be available for future Vietnam War researchers and scholars. While the Olson slide talks and Payne radio podcasts are very important, our Merry Band of Retirees refereed journal articles are the primary source of the most important information of value to future Vietnamese War scholars and historians. The radio podcasts and power point talks are designed to inform and educate the current Vietnamese government, media, scholars including students and the public.

4. Summary

In 1962, the Tan Son Nhut Air Force base on the northern edge of Saigon received the first shipments of Agent Blue, the arsenic based herbicide used to destroy rice crops. The Tan Son Nhut Air Force base has been covered by urbanization and the only building still standing is the Tan Son Nhut Air Force base museum with a horticultural garden and lawn with many aircraft on display on apparently arsenic rich soil. These soils need to be tested for As.

The Vietnam War Archive no. 2 in Ho Chi Minh City houses both the correspondence between the RV and US government related to the Khai Huang program as well as the RV Agent Blue spraying flight records in the Mekong Delta. Paper copies of the RV correspondence, between President Diem's administration and the President Kennedy administration, are shelved in loose binders at the Vietnam War Archive no. 2. Since the binders only have a Table of Contents, it will take considerable time and effort to find the key documents. Our team attempted, unsuccessfully, for more than two years to obtain the US

military Agent Blue spray mission records for the Mekong Delta. Therefore, it is important that the RV Agent Blue spray records for the Mekong Delta be preserved. The limited US Air Force Operation Ranch Hand flight records suggest that the Agent Blue spraying in the Mekong Delta was minimal. However, the William A. Buckingham book "Operation Ranch Hand: The Air Force and Herbicides in Southeast Asia 1961 to 1971" [17] documents many cases where the RV military, with or without assistance from US Army, CIA and US Navy, sprayed Agent Blue and/or similar commercial herbicides containing cacodylic acid and arsenic on Mekong Delta food crops as part of the food denial program. Buckingham also documents many Operation Ranch Hand (US Air Force) defoliation missions in the Mekong Delta. There is strong evidence that the RV and US military goals were to eliminate the NVA and VC food supply to implement the RV hamlet strategy and to defoliate the transportation corridors including the waterway and canals. Most of the South Vietnam rice was produced in the Mekong Delta, not the Central Highlands. The US Army, CIA and US Navy Agent Blue spray records were either not kept or not maintained. However, Vietnam Archive no. 2 may have the Agent Blue spray records of the RV military's food denial program that was used to implement the RV hamlet strategy.

The United States Department of Defense (DOD) and United States Department of Agriculture (USDA) Operation Ranch Hand records for the tactical herbicide spraying in South Vietnam during the American Vietnam War, with the exception of the Mekong Delta, are very detailed, rather complete and available. The same is not true for the spraying by RV military during the Khai Huang program, which was supported by the US Army, US Navy and CIA in the Mekong Delta. Agent Blue was sprayed by the RV military for three years during the Vietnam Civil War (1962 to 1965) and before the official start of the American-Vietnam War. The Vietnam War Archive no. 2 in Ho Chi Minh City may have the RV Mekong Delta spray records. No US Army, US Navy and CIA spray records exist, from the period, 1962 to 1965, during the Vietnam Civil War. Vietnam War veterans, historians and scholars have reported the spraying of 3.2 million liters (468,008 kg As) Agent Blue on the rice paddies and mangrove forests of South Vietnam by the RV military, with and without the support of the US Army, US Navy and CIA on the rice paddies and mangrove forests in the Mekong Delta and Central Highlands. The RV military may have maintained spray records, including location and amount records, like the U.S. Air Force (Operation Ranch Hand) did and these records should be in Vietnam War archive no. 2 in Ho Chi Minh City. The Institute of Medicine estimated that 3.2 million liters (468,000 kg of pure As) were sprayed during RV Khai Huang program (primarily between 1962 to 1965). This was in addition to the U.S. Air Force's Operation Ranch Hand spraying of the tactical herbicide Agent Blue primarily by C-123 aircraft for defoliation of the jungle and transportation corridors (1962 to 1971). The Operation Ranch Hand missions were recorded and maintained (sprayed over 4,712,000 liters or 664,392 kg As. The RV military, US

Army, US Navy and CIA spray records were classified.

Agent Blue and cacodylic acid had short half-lives and are degraded to water soluble arsenic, which was released into the surface water and/or leached into groundwater. Once the water-soluble arsenic leached into the Mekong Delta groundwater, arsenic rich water was pumped back to the surface by tens of thousands of tube wells for urban and agricultural use. The environmental impacts of Agent Blue, on the Menominee River, at manufacturing sites in the United States, were studied to identify possible arsenic remediation and mitigation strategies. The lessons learned at the Agent Blue manufacturing Ansul Chemical plant sites in Wisconsin and Michigan, United States should be applied in the Mekong Delta to help mitigate and remediate arsenic rich surface water, soil, sediment and groundwater found in the Mekong Delta.

The fact that U.S. military was assisting the RV military in eliminating the food supply of the South Vietnamese was left to the RV government to explain. The official reason for the RV military hamlet strategy to make it easier for their soldiers to defend the civilians from enemy attacks.

5. Conclusion

Agent Blue, the arsenic based herbicide, was a secret US military and environmental chemical weapon that was used by the RV and US militaries in South Vietnam for food denial during the Vietnam Civil War (1962-1965) and continued to be used until President Nixon order cessation of defoliations in 1971. The addition of 1,132,400 kg As during the Vietnam Civil war and the subsequent American Vietnam War would have increased the arsenic levels and spikes in Mekong Delta groundwater. Similarly, arsenic levels in the soil (root zone) and drinking water were increased. In many places in the Mekong Delta there are arsenic spikes, both anthropic and natural, which exceed the WHO standard of 10 μg/l, for the food supply, including raised arsenic levels in rice, shrimp and fish. During the Vietnam Civil War the bio-accumulation of arsenic in the environment adversely affected human health of the Vietnamese, those directly exposed to Agent Blue (cacodylic acid and arsenic), and their off-spring.

6. Vietnam War Archive Record Recommendations

1) The Vietnam War Archive no. 2 in Ho Chi Minh City needs to electronically scan and store the 1960 to 1963 correspondence between US President Kennedy's administration and RV President Diem's administration (removed from office in 1963 after a political uprising) related to the shipment and use of tactical herbicides in southern Vietnam. This will make the documents available to current and future Vietnam War historians and scholars.

2) The Vietnam War Archive no. 2 in Ho Chi Minh City needs to electronically scan and store the RV Agent Blue spray records for the Mekong Delta including the date of application, the amount of Agent Blue used, and the geographic application locations. This will make them available to current and fu-

ture Vietnam War historians and scholars.

3) The soils at the former Tan Son Nhut Air Force base, which is now a museum, plantation and lawn needs to be sampled and tested for arsenic.

4) The Vietnam War archive no. 1 in Hanoi and Vietnam War Archive no. 2 in Ho Chi Minh City should consider preserving the 12 to 14 Merry Band of Retirees refereed journal articles on tactical herbicides, four radio podcasts of Mack Payne on Agent Blue, and four Ken Olson Agent Blue and Agent Orange lectures. These documents focus on both Agent Orange dioxin TCDD contaminated soil and sediments and Agent Blue, the arsenic base herbicide used to destroy the rice crops, and make the information available for future Vietnam War researchers and scholars.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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