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Review and Analysis: Environmental and Human Health Impacts of Herbicide Use Studies Conducted during the Vietnam War and Historical Lessons

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Abstract

During times of war, it is rare to find a government willing and able to require the military to fund and support environmental impact studies. In the 1960s, many United States scientists expressed concerns about the use of herbicides during the Vietnam War. This protest was led by Dr. Arthur Galston and eventually included scientists with the National Academy of Science. By 1970, the Department of Defense (DoD) was ordered to permit the scientists to visit South Vietnam during the war to document these impacts. In all 1500 scientist days were spent in South Vietnam. In addition, the US government and military funded research studies on the impact of herbicides on animals. The goal of military use of herbicides, as chemical weapons, was to defoliate jungle forests and destroy food crops as a strategy to win battles and the war. The primary objective of this research study is to describe how it is possible for a country to fund and carry out scientific studies during the conduct of a war rather than decades later. The environmental impact study findings often lack boots on the ground validation and can be inaccurate or misleading in some situations. The United States (US) and other countries, including Russia and Ukraine, need to learn the historical lessons from the US use of herbicides, containing dioxin TCDD and/or arsenic (As), as chemical weapons during the Vietnam War.

Keywords

Vietnam War, Herbicides, National Academy of Science, Russia-Ukraine War, Environmental Impact, Arthur Galston, Merry Band of Retirees,

Monsanto, BASF

1. Introduction

Early in 1965 many scientific organizations, led by Arthur W. Galston (then a professor at Yale University), warned the US government against the military herbicide program. Galston (**Figure 1**) strongly objected to the use of his early scientific discovery, using chemicals to speed up plant flowering, and 1943 U.S. Military contract research to extend his doctoral work (Ph D in Botany at University of Illinois) with trichlorophenol effects on crops [1]. That research was later used without Galston's knowledge in the development of the toxic herbicides for use in the Vietnam War [2] [3]. He thought, after discovery of the military use, it was a misuse of science and stated, "*Science is meant to improve the lot of mankind, not diminish it—and its use as a military weapon was ill-advised*", in a California Institute of Technology Archives Oral History Project [4]. Professor Galston was eventually recognized in 2004 by the University of Illinois Alumni Association for his scientific discovery and subsequent efforts to prevent its misuse by the US government and military. In all, 5000 scientists, including members of the Federation of American Scientists and American Association of the Advancement of Science, along with 17 Nobel Prize winners, petitioned the US military and the Nixon government administration to stop the use of chemical and biological weapons.

The primary objective of this research study is to describe how it is possible for a country to fund and carry out scientific studies during the conduct of a war rather than decades later. There is considerable risk to the scientists conducting these environmental and human health impact studies, especially when scientist's boots on the ground are required to validate the findings. But the benefits to the health of future generations can outweigh the potential cost. This historical assessment of the Vietnam War will address the failures and successes of environmental and human impact studies conducted during the war. The United States and other countries, including the leaders of Russia and Ukraine, need to learn the historical lessons from the use of herbicides in the United States, containing the compound 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) and/or arsenic (As), as chemical weapons during the Vietnam War.

2. Study Site Background

2.1. Mekong Delta Geomorphology and Geology

Olson and Chau [5] described the "*Mekong Delta Geography and Geology Early Quaternary and older alluvial deposits reveal the tectonic and sea level adjustments, fold and fault lines, subsidence and uplifts that characterize the evolving Mekong River* [6]. *The Mekong River is one of the world's most diverse and unique large rivers with a flood pulse that drives an extensive and productive*

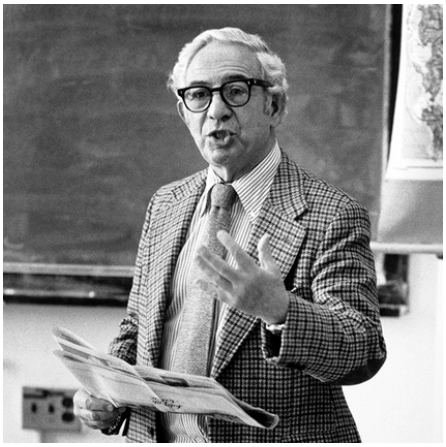

Figure 1. Arthur W. Galston picture taken during a lecture at Yale. Credit line: Yale Environment 360. Yale library. Beinecke Rare Books and Manuscripts library.

ecological system. About 40 *million years ago, the Mekong River precursor drained into the sea near where the Red River now flows through Hanoi, Vietnam. Over time, earthquakes and volcanic activity of the Himalayas altered the mountain drainage southward via steep gorges that appeared about* 13 *million years ago* [7] [8]. *Below this area was a wide inland sea during the Upper Mesozoic. It is likely that the Mekong River at that time flowed directly south and to the west of the Korat Upland, joining what has become the Chao Phraya River in Thailand* [8]. *There is evidence that subsidence in the Tonle Sap basin of Cambodia, perhaps during the last* 12,000 *years, drew the Mekong River eastward to its present course and flows to the South China Sea and away from its former Chao Phraya connection and the Tonle Sap basin. The modern-day Mekong River* [9] *carries a large supply of fluvial transported fine sediments and sands that originated in the Tibetan and Himalayan mountainous region to the Mekong Delta. These alluvial deposits have been mediated over time by glaciation, precipitation, and evapotranspiration* [6]. *The Mekong Delta begins near Phnom Penh, Cambodia* (**Figure 2**) *and extends east through Vietnam to the South China Sea. The Mekong Delta is the world's largest delta with* 35% *located in Cambodia and* 65% *in Vietnam. The* 4350 *km Mekong River flows south and then east into the South China Sea* [7]. *The Bassac River separates from the Mekong River near Phnom Penh and two rivers run parallel and east to the South China Sea. The Mekong River carries sediments and river water rich in arsenic* (*As*) *from the Tibet Highlands, the headwaters of the Mekong River. During the monsoon season, water flow in the Mekong.*"

"*River greatly increases resulting in flooding of the lower stretches of the Mekong River. During these flooding events, floodwaters cover much of the Mekong Delta and deposited sediment, creating natural levees that migrated over time. Based on the intensity and magnitude of major flows, the natural levees can be overtopped and create midstream silt and sand bars* [10]. *The Mekong Delta is a*

Figure 2. Borders of the Mekong Delta in Vietnam and Cambodia. Map created by Mic Greenberg. Re-published with copyright permission from Managing Editor of OJSS.

flat, broad floodplain with alluvial soils (*Entisols*) [11] *but has a 'flooded' mountain region west of the Bassac River and along the Cambodia-Vietnam border. Southern coastal dunes, along the South China Sea, are also high points above the marshlands and plains. This terrain is the result of folding by collision of Indian and Eurasian tectonic plates and tectonic uplift* [10]. *The Mekong River drainage system developed where the underlying geological structure is heterogeneous and active. The last glacial period ended abruptly* 13,000 *years ago when sea levels rose* 4.5 *m above present levels and the shoreline of the South China Sea reached modern day Phnom Penh, Cambodia* (**Figure 3**) [10]."

"*The Mekong Delta morphology was developed during the last* 6000 *to* 10,000 *years* [6]. *Eventually, the delta covered more than* 62,000 *km*^{2} *of the South China Sea and developed* 200 *km to the east overlying the continental shelf* [12]. *The Mekong Delta was built up through tidal and fluvial tidal processes and was generally sheltered from the South China Sea and the Gulf of Thailand wave action* [10]. *However, the delta deposits were exposed to marine currents and other wave action that re-distributed the sediment to the southeast creating the*

Figure 3. As the Mekong and Bassac Rivers flow south, through the Mekong Delta they water a diverse landscape, bringing freshwater to the lowlands around the flooded mountains and saltwater river regions in the wet season, and sediment loads that replenish the fertility of rice fields. Coastal dunes along the South China Sea are high points in the landscape. Farmers in the uplands of Vietnam grow coffee, rubber, fruit, and nut trees. Map by Mic Greenberg. Published with the copyright permission from Editor of Open Journal of Environmental Protection.

Ca Mau Peninsula, a more recent, 6000 *to* 10,000 *years old feature of the Mekong Delta. Due to the low flat topography and unconsolidated parent material of the Delta, the Mekong River has changed course many times. Riverbanks composed of unconsolidated sediments are unstable and highly erodible* [6]."

2.2. Soils of the Mekong Delta

The soils of Vietnam were formed by alternating monsoon and dry seasons,

sedimentation during river flooding, and intrusions of the South China Sea [11] [13] [14]. The Mekong Delta soils include Inceptisols, Entisols, and Histosols (**Figure 4**) formed in the annual Mekong River and tributary fluvial deposits from the Xizang Highlands and carried by the river through the land masses of China, Laos, Thailand, Myanmar, Cambodia and Vietnam and into the South China Sea. When the South China Sea covered southeast Vietnam millions of years ago, "Old Alluvium" soils (Oxisols and Ultisols) formed about 10 m above the recent floodplain deposits (Entisols) of the Mekong Delta.

2.3. Delta Wetlands and Mangrove Forests

Olson and Chau [5] noted: "*Wetlands are distinct ecosystems where soils are seasonally or permanently water-saturated over extended periods from seasonal flooding and/or a highwater table* [15]. *The wetlands of the Mekong Delta range from shallow freshwater depressions and ponds, backwaters of streams and rivers to vast seasonally flooded plains with melaleuca forests, rice paddies* (**Figure 5**), *brackish salt marshes, mangrove swamps and tidal mudflats along the coasts, and many small offshore islands* [15]. *The wetland locations in the landscape include edges of streams, rivers, and low depressions or coastal seas where precipitation and groundwater accumulated and affect the animal and plants communities, which had to adapt to permanent shallow water conditions and fluctuating wet and dry periods.*"

"*The hydrology, topography, and climate of the Mekong Delta determine whether the wetland is salt or fresh water. Flooding and rain during the wet season flush saltwater rivers* (**Figure 6**), *canals, and temporally replace salty waterways with fresh water. The major wetland areas occur in the Plain of Reeds located in Vietnam, freshwater wetlands located in Cambodia, and lands in the central delta both between and on both sides of the Mekong and Bassac rivers. Seasonally deposited sediments were carried downstream by the Bassac and Mekong rivers are fertile, and when the flooding is moderate the soils* [16] *in this part of the delta are not acid or saline* [17]. *The central delta is densely populated with settlements primarily along the river levees where the land is higher and protected from most floods. The seasonally inundated wetlands on the backside of the natural levees and away from the rivers were drained in the late* 1970*s by canals* (**Figure 6**) *and the areas became the major rice growing areas.*"

"*The delta coastal dunes* (**Figure 3**) *were formed by currents, tides and waves of the South China Sea from alluvial sediments and sand of the Mekong River with its nine channels. As the delta sediment deposits extended into the South China Sea, the dunes became inland ridges above the coastal wetlands. Dat Mui Nature Reserve is a delta ecosystem. Most of the original mangrove forests were destroyed during the Vietnam War and later converted into shrimp ponds and other agricultural uses. Recently, the shrimp ponds have been phased out, and efforts are underway to revegetate coastal mudflats and inland mangrove forests* [5]."

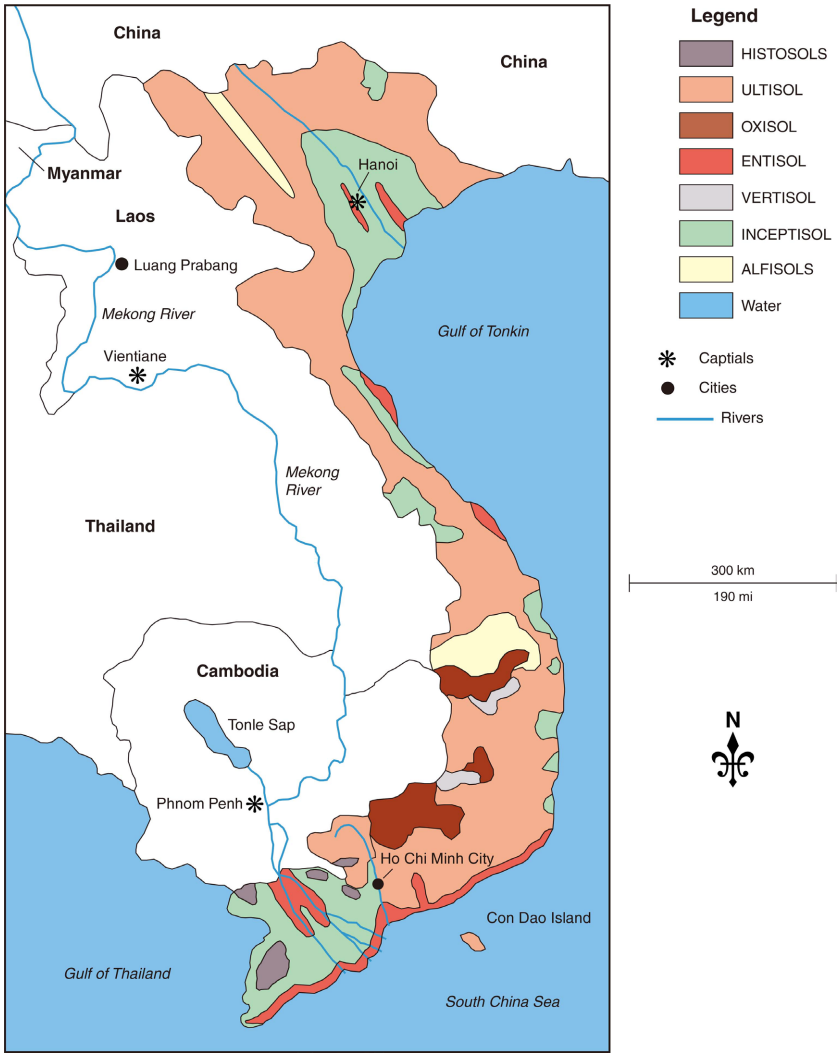

Figure 4. A soil map of Vietnam. Adapted from FAO/UNESCO Preliminary Definitions, Legend and Correlation Table for the Soil Map of the World. World Soil Resources Report No. 12; Rome: 1964. Adapted from Moormann. F. R. The Soils of the Republic of Vietnam. Saigon: Ministry of Agriculture, 1961. Map created by Mic Greenberg. Re-published with copyright permission from Managing Editor of OJSS.

Figure 5. Rice paddies in the Mekong Delta. A view from Sam's mountain located near the Cambodia and Vietnam border.

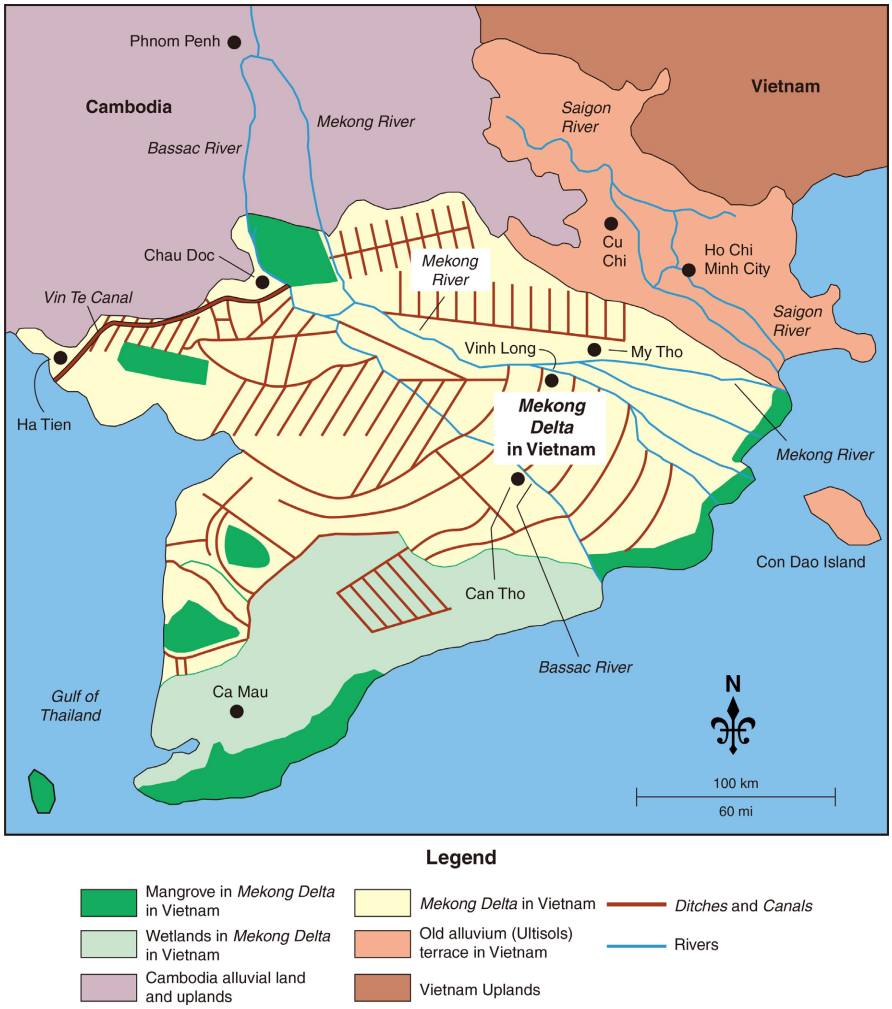

Figure 6. Mekong River and waterways and drainage ditches. Re-published with copyright permission from Managing Editor of OJSS. Map created by Mic Greenberg.

3. Methodology

The methodology used by the National Academy of Sciences (NAS) was developed during the American-Vietnam War. NAS [18] described the origin of the study and methodology as follows:

"*The study had its origin in the widespread public concern that the extensive use of herbicides in the Vietnam War may have had serious adverse effects, perhaps irreversible, on the environment and people, major economic losses because of damage to forest and crops, and reproductive failures, congenital malformations, and genetic damages in humans.*"

"*In response to this public concern, Congress in late* 1970 *directed the Department of Defense* (*DoD*) *to contract with the National Academy of Sciences, for a study of the ecological and physiological effects of the widespread military use of herbicides in South Vietnam* (*SVN*). *A* 17*-member committee, with additional professional staff and* 30 *consultants, carried out the study, which included field, laboratory, and library research. Some* 1500 *man-days were spent in SVN during*

the study, the results of which are discussed in a report."

"*Additional details are available in the public records of the Committee. The committee conducted the work on the following*:

1) *Inventory of the sprayed areas by herbicide type, date, and frequency of spray applications as related to vegetation types and to population density.*

2) *Effect on vegetation, with emphasis on the inland and mangrove forest – the two vegetation types subjected to the most extensive herbicide spraying and with consideration of effects of crop production.*

3) *Persistence of herbicides in the soil, and their effects on soil fertility, i.e., on the content of essential nutrients available to plants.*

4) *Effects on animals* (*limited to studies on animal populations in estuaries, and on the populations of disease vectors, both in the mangrove*).

5) *Effects on people* (*medical, socioeconomic, psychological*)."

"*The extent to which these problems could be effectively dealt with was highly variable. The Committee could construct on a tentative initial program; this had to be modified repeatedly in the course of the work. The principal limitation on the Committee's work was the security conditions in SVN, which render long-term field studies virtually impossible. Moreover, the Committee started its work in SVN in September* 1971, *while all major herbicide operations were terminated early in that year; the Committee had somewhat over one year for gathering most of its materials. Hence, on the one hand, relatively short-term effects were difficult to study; on the other hand, except where detailed historical information such as aerial photographs were available, research was limited to short periods of time, whereas some of the effects, for example on succession of vegetation in forests, are long-term ones. Statistics and inventories on SVN population, forestry, and agricultural were not available or did not contain sufficient detail to allow quantitative assessment of many herbicide effects, particularly at the national level. Despite these limitations, US scientists carried out field studies on the number of problems* (*effects on estuarine life and on ecological-epidemiological effects of defoliation, and on the perception of herbicides and their effects by humans*), *and the available documents, including extensive aerial photography, were examined and evaluated* [18]."

4. Findings

4.1. Manufacture of 2,4,5-T With Unknown Amounts of Dioxin (TCDD)

On March 8, 1949, the Monsanto Chemical Plant manager in Nitro, West Virginia (**Figure 7**) heard the noise of high-pressure gases rushing through a vent on an oven. The factory whistle, intended to alert the workers, was drowned out by the sound of chemical vapors spewing up into the air of the chemical manufacturing plant [19]. Since no one was injured, the "explosion" was relatively "unremarkable" [20] [21]. Safety devices worked, and the accident was not considered newsworthy (*in other words, there was no need to tell the media or public*). With the

Figure 7. The North American locations of the eight Agent Orange chemical manufacturing plants, the primary Agent Blue chemical manufacturing site and the two Ports on the Gulf of Mexico where tactical herbicides were loaded on ocean-going ships. Map created by Cruz Dragosavac. Re-published with copyright permission from Managing Editor of Open Journal of Soil Science.

passage of time, it became a most "unremarkable" episode in environmental and occupational health history. Perhaps the most important single event in the United States related to the effects of "dioxin" on chemical plant workers and their community, which was buried in a Monsanto company report. It was not until after the 1953 BASF plant explosion in Europe that the chemical company manufacturer's medical doctors, the U.S. Government (USDA, VA, CIA, and DOD) knew that trichlorophenol was contaminated with dioxin. The BASF chemical company, with the assistance of Dow Chemical, discovered the TCDD negative health effects, including causing chloracne and cancer, on workers after the European explosion in 1953 [22]. Elmore [20] [21] suggested: "*If the Monsanto chemical plant at Nitro* (*West Virginia*) *had been shut down and its dioxin TCDD problems exposed to the public in the early* 1950*s* (*instead of being covered up by Monsanto and their medical doctor reports hidden from the workers, media and public*), *the toxic hazard of* 2,4,5-*T, with unknown amounts of TCDD, might never have been exported and sprayed during the Vietnam War. There, halfway around the world, hundreds of thousands of American soldiers and millions of Vietnamese soldiers and citizens would later be exposed to TCDD and come to know about dioxin's dangers.*"

By the early 1950s, the U.S. Government, DoD, VA, CIA, USDA, medical doctors, and chemical companies, (including Monsanto, BASF, and Dow) were aware of the environmental and health consequences of the contaminant TCDD [2] [22] [23] [24]. It took until 1985 for the herbicide 2,4,5-T with unknown amounts of

TCDD to be banned for worldwide agricultural use [25]. During those 30 years, tens of millions of people were impacted from TCDD exposure, and their offspring are still being affected 60 years later.

By 1953, the chemical companies, including BASF, had also discovered the TCDD health effects on workers after an explosion [22] but were slow to inform the US government and military of the extent and magnitude of the TCDD contaminant in Agent Orange and commercial versions of 2,4,5-T. During the Vietnam War, to increase production, the 2,4,5-T combustion temperature was raised 5˚C (9˚F) [26] [27]. This permitted 2,4,5-T to be produced faster and cheaper but also resulted in a significant increase (up to 30 times) in the contaminant, TCDD, levels. Dioxin TCDD by-product was also in other Rainbow herbicides, Agent Purple, Agent Pink, Agent Green due to inclusion of 2,4,5-T as a component, with associated risks to the environment and human health [18] [27]. This delay in notifying the US government and military about the increase level of TCDD during the manufacturing process, may have increased the 11 chemical companies' manufacturing 2,4,5-T past, current, and future legal exposure [26].

By the late 1960s, the US government and military became fully aware of the environmental and health consequences of the TCDD [21] [28] [29]. In 1970, President Nixon (**Figure 8**), acting in his role as Commander-in-Chief, ordered the US military to stop spraying Agent Orange in Southeast Asia. The next year, he ordered all Rainbow herbicide spraying, including Agent Blue, to be stopped and be removed from Vietnam. Agent Orange barrels were collected at Bien Hoa Airbase (**Figure 9**) (about 32 km northeast of Saigon/Ho Chi Minh City) from all the military airbases in Vietnam and shipped to Atoll Johnston Island in the Pacific Ocean (**Figure 10**). Many of the barrels were leaking and had to be resealed prior to shipment. This exposed the barrel handlers (**Figure 11**) and transporters to TCDD. Agent Orange with high levels of TCDD either leached into the ground or was carried by runoff water into the waterways, streams, rivers, ponds, and lakes [26]. During the dry season, dioxin TCDD-contaminated dust from the perimeter road and border fence (**Figure 12**) where it had been applied or spilled was blown into the adjacent landscapes.

Fifty years after the US military stopped spraying Agent Orange, there is still a fish and shrimp ban on a lake outside the Bien Hoa Airbase hotspot, the most contaminated location in Vietnam. The TCDD attached to the sediment, which then settled at the bottom off the lake. Bottom-feeding fish and mollusks then fed off the floor of the lake, and the dioxin TCDD was ingested and concentrated in their tissue. When contaminated fish and shrimp are eaten from such water bodies, TCDD can still get into the current food supply and increases human health risks. Research by the US Department of Defense later led to the discovery that the contaminant TCDD in Agent Orange caused birth defects in laboratory rats [28].

Arthur W. Galston's 1943 University of Illinois (Botany) PhD thesis (**Figure 13**) and research focused on the use of the chemical TIBA (2,3,5-Triodobenzic acid) to increase flowering and grain yield of soybeans (Glycine max [L.] Merr.)

Figure 8. President Nixon portrait. Photo credit: Jack E. Kighlinger (White House photograph). In Public Domain. Re-published with copyright permission from Managing Editor of Open Journal of Soil Science.

Figure 9. Picture of active Bien Hoa Air Force Base taken in the 1960s during the Vietnam War. Credit line: Photograph courtesy of Vietnam War Commemoration (https://vietnam50th.com/). Re-published with copyright permission from Managing Editor of Open Journal of Soil Science.

Figure 10. Tactical herbicides being stored on Johnston Island beach in Pacific Ocean to be incinerated in 1977. Re-published with copyright permission from Managing Editor of Open Journal of Soil Science.

Figure 11. Agent Orange being re-barreled on Johnston Island Photo Credit: ResearchGate.

Figure 12. US military bases used herbicides to defoliate the base perimeter as a security measure to protect against surprise attacks. Picture was taken by US Army Flight Operations Specialist 4 John Crivello in 1969. Re-published with copyright permission from Managing Editor of Open Journal of Soil Science.

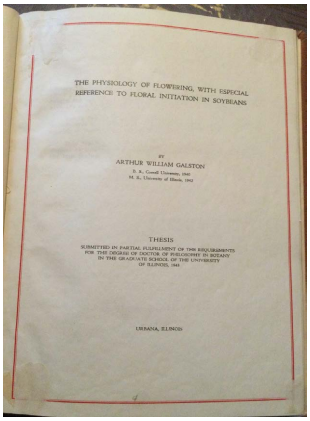

Figure 13. Arthur W. Galston's 1943 thesis contained the scientific discovery that led to Agent Orange formulation by military scientists at Camp Detrick. Agent Orange adversely affected the lives of millions of US Vietnam Era veterans, who were exposed to dioxin TCDD and/or arsenic and their children but had at least ten times more of an effect on the Vietnamese people and their offspring. The picture is of the title page of the Galston thesis. Credit line: University of Illinois Library. Cover picture taken by Pam Olson. Re-published with copyright permission from Managing Editor of Open Journal of Soil Science.

[23]. Galston also noted that in higher concentrations, it would cause soybeans to lose leaves and kill the plants. Galston's discovery of TIBA was an inadvertent precursor which enabled military labs to create the Agent Orange herbicide [23]. In 1943, Dr. Galston moved to the California Institute of Technology to work with Nobel Prize winner Dr. George Beadle on World War II defense-related (synthetic rubber) research. While working on that contract the US Military asked Galston to also extend his original Doctoral research on the effect of 2,4,5-Trichlorophenoxyacetic acid and 2,4-Dichlorophenoxyacetic acid (2,4,5-T and 2,4-D, respectively). Galston was drafted into the Navy in 1944 as an enlisted man and served as a natural resources officer while stationed in Okinawa, Japan, until 1946 receiving an honorable discharge after World War II was over [1].

4.2. National Academy of Sciences and Agent Blue

During August and September of 1970, Dr. Matthew S. Meselson (**Figure 14**), a Harvard geneticist and molecular biologist, led a scientific team in the Republic of Vietnam to conduct a pilot study of the ecological and health effects of the military use of herbicides, on behalf of the American Association for the Advancement of Science (AAAS). Upon returning to Cambridge, he and his students developed an advanced mass-spectrometric method for the analysis of the toxic herbicide contaminant TCDD and applied it to environmental and biomedical samples from Vietnam and the United States. While in Republic of Vietnam, Dr. Matthew Meselson [12] tested Vietnamese for arsenic (As) (a major component of Agent Blue) and found "*little evidence of any* 1970 *health effects* (*A personal communication during virtual Zoom session at the April* 2021 *Vietnam War conference* (**Figure 15**) *hosted by the Vietnam War Archive in Lubbock*, *Texas*). *Cacodylic acid* (*an organic compound containing As*) *is broken down in soil by microflora*, *mostly to inorganic arsenate bound as insoluble compounds*, *which also exist naturally in the soil. Acute and chronic toxicity studies in a variety of animals indicate a low to medium toxicity rating. No teratological studies nor toxicity studies in man seem to have been reported*".

The National Academy of Sciences (NAS) and their fieldwork and research in southern Vietnam, its scope was limited to the on-going American-Vietnam War and its findings are now dated. This NAS study (1971-1972) (**Figure 16**) was conducted, after DoD ordered the stopping of Agent Orange spraying in 1970 and all tactical herbicide spraying in 1971. President Nixon signed the Paris Peace Accords on January 27, 1973, ending the direct U.S. involvement in the Vietnam War. Furthermore, the scientific study was conducted from aerial observations due to the unstable political environment on the ground. This gave little chance for boots-on-the-ground scientists to gather first-hand soil, water and vegetation samples and observe herbicide use effects on the landscape or the Vietnamese people close-up. Subsequent research and re-assessments of the fate of Agent Blue, cacodylic acid, and arsenic including both water soluble and inorganic arsenate and arsenite make it clear that NAS conclusions were inadequate. It is now time for new assessments and a fresh look at past data and current conditions [12] [30].

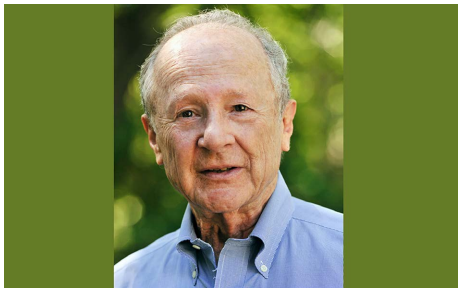

Figure 14. A picture of Matthew S. Meselson, a Harvard geneticist and molecular biologist, emeritus professor, who led a boot on the ground AAAS study in 1970 (during the American Vietnam War). Harvard University Library. Photo Credit: Janet Montgomery, 31 Aug. 2010.

Figure 15. Texas Tech Library is the home to the U.S. Vietnam War Archive which is in Lubbock, Texas. Photograph courtesy of Ken Olson. Picture taken in April 2018 during the Annual Vietnam War Conference in Lubbock, Texas. Re-published with copyright permission from Managing Editor of Open Journal of Soil Science.

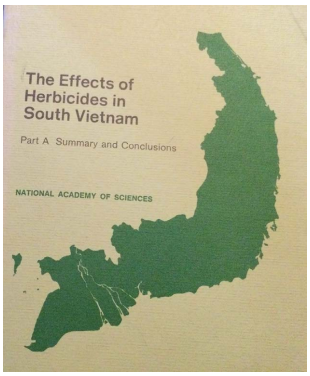

Figure 16. Picture of the 1974 National Academy of Sciences report. The NAS study was conducted during the Vietnam War years of 1971 and 1972. Photo credit: Cover picture taken by Pam Olson. Re-published with copyright permission from Managing Editor of Open Journal of Soil Science.

Arsenic is a heavy metal and thought to be a carcinogen. Arsenic-rich feed had been used to make chickens more marketable (plumper, redder and prevent certain chicken diseases) [31]. There has been recent research [32] studying the effects of feeding chickens' organic arsenic (non-toxic) supplements and their ability to convert them into inorganic arsenic (toxic Group-A carcinogen). Because of these findings, chicken producers started eliminating the use of organic arsenic rich feed from 1999 to 2004. The use of organic rich arsenic feed was banned in the United States in 2013 by Food and Drug Administration (FDA).

4.3. NAS Damage Assessment of Tactical Herbicide Spraying

Olson and Cihacek [12] found *An Act of Congress*, *Public Law*-441, *and Fiscal Year* 1971 *Military Procurement Authorization Act Section* 506-9*c authorized a NAS study. The Secretary of Defense was required to make arrangements with the NAS to conduct a comprehensive study* (*Sep*. 1971 *to Sep*. 1972) *and investigate physiological and ecological dangers in inherent use of the defoliation program by Department of Defense in South Vietnam* [12] [29] (**Figure 16**). *NAS scientists spent* 1500 *scientist days working in Vietnam during the Vietnam War and found it impossible to determine whether As found in the rice paddy soils* (**Figure 17**) *was from the herbicide spraying of Agent Blue, from other sources, or was present naturally in the soil prior to the spraying.*

The NAS overflight was conducted on January 27, 1972, *of the Song-Re Valley, Quang-Ngai Province. This over flight of an area, which was sprayed with Agent Blue on August* 9, 1970, *found that rice fields and vegetable plots appeared normal from the low flying aircraft. NAS* [27] *analyses of a small number of samples of fish, rice, shellfish* (**Figure 18**), *worms, soils and water collected near a community in Rung Sat, which was subjected to Agent Blue missions between* 1964 *and* 1969 *found the As levels within the normal ranges.*

NAS scientists studied the effects of Agent Blue on settlements by interviewing the villagers and reported their findings in a report entitled "Effects of Herbicides on Humans" [27]. *Human reactions to military spraying of tactical herbicides were documented* [30]. *Herbicide spraying including Agent Blue resulted in the displacement of people from their rural homes into government sponsored villages as part of the Diem government's "strategic hamlet" policy and urbanization movement into the slums of Saigon and other larger cities. Only one of* 18 *rural areas increased in population during the* 1960*s. After spraying of tactical* (*Rainbow*) *herbicides and subsequent burning of crops, individuals in every community interviewed reported on who became ill or died after the spraying, or because of eating of herbicide-treated plants or drinking contaminated water. The NAS report* [27] (**Figure 16**) *was translated into Vietnamese for the locals to read. Vietnamese had to live with the consequences and had to undertake remedial action. Financial and technical support from the US* (*funds and training for Vietnamese workers*), *lent professional technical personnel, and equipment.*

Herbicide damage effects included: 1) *loss of potential production at the plant stage before growth and grain production became economically valuable, and* 2)

Figure 17. Tactical herbicides being sprayed on rice paddies and mangrove forests. Published with the copyright permission from Editor of Open Journal of Soil Science.

Figure 18. Shrimp ponds in Mekong Delta. Published with the copyright permission from Editor of Open Journal of Soil Science.

loss of commercial products such as grain, timber and fruit and lack of young plants including seedlings and seeds required maintaining food production. The effects of crop damage were revealed primarily from studies of rural settlements and interviews with villagers. Human reactions to military spraying of tactical herbicides were included in studies on mangrove forests and Vietnamese and Montagnard rice paddies, coconut plantations, gardening, and upland crop areas [27]. *The tactical herbicides were destructive to health and livelihoods of the people whose land was sprayed.*

The As-laden Agent Blue herbicide was used to kill rice food crops and bamboo. Spraying Agent Blue (**Figure 19**) *added a significant amount of water-soluble As to the rice roots, rice grains, water, and soil. The United States and Republic of Vietnam militaries sprayed and dumped bladders of Agent Blue on the rice paddies to desiccate rice plants and then burned the rice residue and seeds. As a result, toxic As-containing aerosols and smoke were released to the atmosphere.*

The goal was to clear out crops and foliage to improve military observation and intelligence, achieve enhanced security, increase availability of troops used for combat, reduce cover for enemy resistance, and reduce United States personnel

Figure 19. Luoi Valley with three temporary US Air Force bases or camps with local buildings and hamlets. Depicts each tactical herbicide mission including Agent Orange, Agent Blue and Agent White spray missions. Re-published with copyright permission from Managing Editor of Open Journal of Soil Science.

casualties [21]. *Between the first test in Kontum base in southern Vietnam on August* 10, 1961, *and the last spraying in October* 1971, *tactical herbicides including Agent Blue were shipped to and sprayed all over South Vietnam. The ongoing U.S. and Vietnam public concern was: Did the extensive use of tactical herbicides including Agent Blue modify the environment of Vietnam beyond the point of recovery? NAS tests showed Agent Blue did not raise the As levels in the groundwater above the* 1970*s drinking water standards* [29].

However, there have been many spikes in the As levels (*above WHO standard*) *in the Mekong Delta groundwater. Arsenic was bio-accumulated in the Vietnamese because of elevated arsenic levels in the drinking water* (**Figure 20**) *and food supply. Medical evidence collected from US veterans and Vietnamese and their offspring* (**Figure 21**) *during the* 55 *years following the Vietnam War suggests there was significant genetic damage* [32]-[34].

Subsequent industrial development, water treatment plants, and wastewater treatment plants have contributed to dangerous bio-available arsenicals in the surface and groundwater of the Mekong Delta [5] [35]. During the last two decades, thousands of government subsidized tube wells (**Figure 22**) have been built. Shallow groundwater has become the major source of As rich water for irrigation and drinking in Vietnam. Groundwater arsenic in concentrations has measured as high as 3050 ug/L. The Vietnam War's "Operation Ranch Hand" contributed to the crisis of arsenic contamination in South Vietnam upland and lowland rice paddies (**Figure 17**). However, the NAS [27] findings suggest arsenic levels were still below WHO standards. Note that this 1972 report was made before southern Vietnam farmers had not yet started pumping the groundwater to the surface for rice paddies or shrimp ponds. The consequences of decades of using groundwater contaminated with As the expectation would now give a different result.

Figure 20. New water treatment plant on a Mekong River tributary. The goal is to supply treated river water to the villagers rather than potentially polluted and arsenic rich Mekong groundwater previously available via individual tube wells. Re-published with copyright permission from Managing Editor of Open Journal of Soil Science.

Figure 21. Boy club feet and no hands who parents or grandparents were exposed to dioxin TCDD or arsenic during the Vietnam War. Photo credit: picture taken by Ash Annand, Newsmado. Courtesy of the Courier Mail, Brisbane, Australia. Re-published with copyright permission from Managing Editor of Open Journal of Soil Science.

Figure 22. Tube wells in the Mekong Delta. Photo credit: Photograph courtesy of Somnath Chakraborty. (https://www.anandabazar.com/).

Cacodylic acid breaks down in the soil and the resulting inorganic As is believed to bind tightly as arsenate (+5) to soil compounds.

Olson and Cihacek [12] noted in an earlier paper that "*As exists in four forms. Two forms are water soluble, arsenite* (+3) *and arsenate* (+5) *which form water soluble As salts. These two water-soluble forms of As are not tightly bound and can leach from water into plant root zones as well as potentially contaminate groundwater. Complicating this picture is that geological materials in Southeast Asia also tend to be higher in As than in other parts of the world making it difficult to separate anthropogenic As sources from natural As sources. For example, As-rich groundwater* (*from natural and anthropic sources*) *in Southeast Asia is frequently pumped back to the surface* (*after* 1975) *by hundreds of thousands of tube wells* (**Figure 22**). *The water is then used for rice paddies, shrimp ponds and to meet the drinking water and household water needs of* 15 *million Vietnamese living on the Mekong Delta and in the Central Highlands. Despite this clearly observed contamination for the last* 50 *years, the NAS* [27] *report appears to have been the "final word" on the fate of Agent Blue and its active component cacodylic acid*" [12].

4.4. Impacts on Mangrove Forests

NAS [27] studied the effects of defoliation by comparing soil properties (**Figure 4**) in defoliated and non-defoliated mangrove areas northeast of Nam-Can (Ca-Mau Peninsula). The only positive impacts recognized came from the spraying of the mangrove area (**Figure 17**), which increased security from the National Liberation Front because it was easier to clear land for irrigated fields. However, woodcutters recognized that their primary resource was being eliminated.

5. Results

5.1. How Agricultural Herbicides Became Chemical Weapons

Olson and Cihacek [3] identified "*Dr. Ezra Kraus* (**Figure 23**) *was the father of the development of agricultural herbicides as a military and environmental chemical weapon. Dr. Kraus a plant physiologist and Head of the Department of Botany at the University of Chicago suggested on the eve of WWII that weed killers had significant military value as chemical weapons* [36]. *This gave him the notoriety of being first to recognize the modern military value of herbicides even before the recognition by U.S. military officers. Professor Dr. Arthur W. Galston* (*Yale*), *said in later interviews that few scientists who were engaged in biological and chemical warfare projects placed their moral qualms, if any, above the application of scientific knowledge towards destructive military ends in part because of their own sense of national duty to win the 'good war'. The only exception during WWII was when some nuclear scientists tried to prevent the nuclear attack on Japan. However, there is no known evidence available that suggests that civilian and military scientists working on a WWII top-secret herbicide weapons program had any such moral qualms.*"

Figure 23. Ezra Kraus, the father of herbicide (chemical) weapons, in his laboratory at the University of Chicago. Credit line: University of Chicago Library, University of Photographic Archive, Hanna Holbord Gray Special Collections. Individual groups, Informal 5, apfi-03586. Re-published with copyright permission from Managing Editor of Open Journal of Soil Science.

"*Before the herbicide weapons program was ready to be deployed on Japan's food supply, rice, and their island forests* (*jungles*), *WWII ended abruptly after United States military use of two atomic bombs. However, after WWII the military scientists at Camp Detrick, Maryland* (**Figure 24**) *continued development of tactical herbicides including Agent Orange and Agent Blue. These tactical herbicide weapons were not used during the Korean War. However, they were used by the U.S. military during the Vietnam War from* 1961 *to* 1971. *By* 1964, *U.S. scientists, with moral and environmental concerns led by Dr. Galston* (*Yale, Cal Tech, and University of Illinois*) *tried to stop the U.S. Government and Military deploying the use of tactical herbicide* (*chemical*) *weapons in South Vietnam during the Vietnam War. The scientist movement and protest were one of many factors that merged and resulted in DOD ordering the military to stop the spraying of Agent Orange in* 1970 *and the other five tactical herbicides in* 1971."

"*After the Second Indochina War and Vietnam War experience, the U.S. military considered tactical herbicides to be a strategic necessity as a deterrent in future conflicts and wanted to keep this chemical weapon in their arsenal. This issue was not settled until* 1975 *when President Ford renounced "first" use concept and said the United States would not be the first nation to use herbicides in war, effectively banning any United States use of chemical* (*herbicide*) *weapons in any future conflicts or wars.*"

How did agricultural herbicides become military and environmental chemical weapons? It was started in secret at the University of Chicago on the eve of WWII. The secrecy (*the U.S. Government and Military were fully aware of the military and environmental chemical weapons program, but the public was not*) *continued during WWII. The funding of research on synthetic herbicides was tightly controlled and research work required total secrecy, or it would not be funded since*

Figure 24. Fort Detrick biological weapons laboratory headquarters in Maryland: Photo credit: Photograph courtesy of Andrew Dutton. Re-published with copyright permission from Managing Editor of Open Journal of Soil Science.

it was conducted during the dark days of WWII. Even the scientific literature was monitored to prevent the disclosure of the secret herbicide weapons program information. This program secrecy was maintained even after WWII. Many scientists and the public are apparently still not aware of this secret WWII chemical weapons program. During WWII, the Office of Strategic Services (OSS) field test site was an area later called Camp Detrick in Maryland. The research was expanded from insecticides to herbicides with experiments on the Beltsville Agricultural Experiment Station (USDA). Even the name of the site (apparently first used by the OSS for research and testing of chemicals) was not identified until 1952 *and was later renamed Fort Detrick in* 1957 *as the program expanded. After WWII ended in* 1946 *the Camp Detrick military scientists did not stop their chemical weapons research. Research continued in secret and the public was not even aware of the biological weapons program until at least* 1957.

The Camp Detrick tactical herbicides were ready for use during the Korea War but were not used since U.S. did not want to be the first country to use herbicide weapons. The "honor" went to British during the Malaysia Conflict defoliants and crop destruction herbicides were employed 1952 *and* 1953 [24]. *The British did defeat the communist insurgency during the* 1948-1960 *Malaysia Emergency. Drawing on the British Malaysian tactics, a western power, U.S. military planners and administration's inner circle advisors included herbicides as part of U.S. military technical superiority arsenal to meet the President's "no combat boots on the ground" directive* [37]. *President Kennedy* (**Figure 25**) *and staff, not wanting to be charged in the World Court with War crimes after the Vietnam War continued to label tactical herbicides as herbicide weapons even though the synthetic herbicides were clearly chemical weapons. During the Vietnam War the military and USDA maintained that herbicides only harmed plants and were harmless to animals and humans* [37]. *This was never true but provided additional cover for the secret herbicide (chemical) weapons program* [38]. *The US was at war and wanted*

Figure 25. President Kennedy portrait. Photo credit: Encyclopedia Britannica. In public domain.

additional weapons in its arsenal as a deterrent. Clearly, the national security issues overrode any potential environmental or human health concerns of the Vietnamese or even our own Vietnam Era veterans. Since 1977 *Veterans have been making benefit claims related to their symptoms believed to be from exposure to TCDD and As.*

GAO documentation shows that quantities of the two components of the tactical herbicide Agent Orange were stored at Kelly Air Force Base in Texas in 1972 [39]. *There were* 38,940 *gallons of* 2,4,5-*T containing TCDD and* 106,260 *gallons of* 2,4-*D stored on the base. Apparently, all the Agent Orange and components,* 2,4-*D and* 2,4,5-*T with an unknown amount of dioxin TCDD was transferred in the early* 1970*s to the USDA, Forest Service as surplus materiel to be sprayed on clear-cut public forest areas* (**Figure 26**) *to kill broad leaf weeds and shrubs to increase the survival of recently planted trees in the Western United States forests. GAO records show that approximately* 173,910 *gallons of the tactical herbicide Agent Blue containing cacodylic acid* (*arsenic*) *were also stored at Kelly Air Force base* [39]. *The fate of this massive amount of Agent Blue, an As based herbicide, was not known in* 2020. *Subsequent information provided by the DoD Agent Orange spokesman* (*personal communication*) *indicated some of the Agent Blue* (*at Fort Kelly and in the distribution supply change*) *was sold to farm chemical companies for use on cotton. Additional quantities were shipped back to the manufacturer, Ansul Chemical Company, for commercial sale. To date, no evidence has been uncovered to suggest that Agent Blue was transferred along with Agent Orange and components to the USDA, Forest Service for grass and narrow leaf weed control on recently clear-cut and re-planted public forests. This is good news. Since As has no half-life and if used by the Forest Service As would have remained in the Western United States forested landscape.*

"*Most Vietnam Veteran lawsuits have been filed in the United States court system where the U.S. Government has been given immunity by the U.S. court system; and in some cases, the chemical companies were sued instead. A*

Figure 26. Spraying of 2,4-D by contractors for the USDA, Forest Service in Oregon. Reprinted with permission from Editor of Open Journal of Soil Science.

US settlement did occur with 52,000 *Vietnam Era veterans or their families if deceased received an average of* $3800.00. *In a Korea lawsuit the international world court system has ruled against the United States Government and provided compensation, to* 5800 *Korean soldiers and their families, who served at the DMZ* (**Figure 27**) *in South Korea were exposed to TCDD at the border fence during the Vietnam War period* [18] [21]. *In* 2020, *a Vietnamese woman who had become a French citizen, filed a suit in a French Court against the United States Government and the international chemical companies including Bayer a Germany company. She requested benefits for treatment of her health problems associated with past exposure to dioxin TCDD during the Vietnam War. The French court, in* 2021, *initially ruled in favor of Bayer* (*Monsanto* (**Figure 28**)) *but the case is currently under appeal* [3]."

5.2. National Academy of Sciences 1974 Report

Olson and Cihacek [12] found "*For the last* 46 *years the NA*S [27] *Part A*: *Summary and Conclusion report appears to have been the* "*final word*" *on the fate of Agent Blue and its active component cacodylic acid. Cacodylic acid breaks down in the soil and thought to bind tightly as arsenate* (+5) *to soil compounds. In a paper* [12], *they explain that the arsenic exists in four forms including two water soluble forms arsenite* (+3) *and arsenate* (+5), *which is a water-soluble arsenic salt, and much of the water-soluble arsenic was not tightly bound and leached from the rice paddy and root zone into the Mekong Delta or Central Highland groundwater potentially contaminating the groundwater. The arsenic rich groundwater* (*from natural and anthropic sources*) *was then pumped back* (*after* 1975) *to the surface by hundreds of thousands of tube wells and the water was then used for rice paddies, shrimp ponds and to meet the drinking water and household water needs of* 15 *million Vietnamese living on the Mekong Delta and in the Central Highlands*."

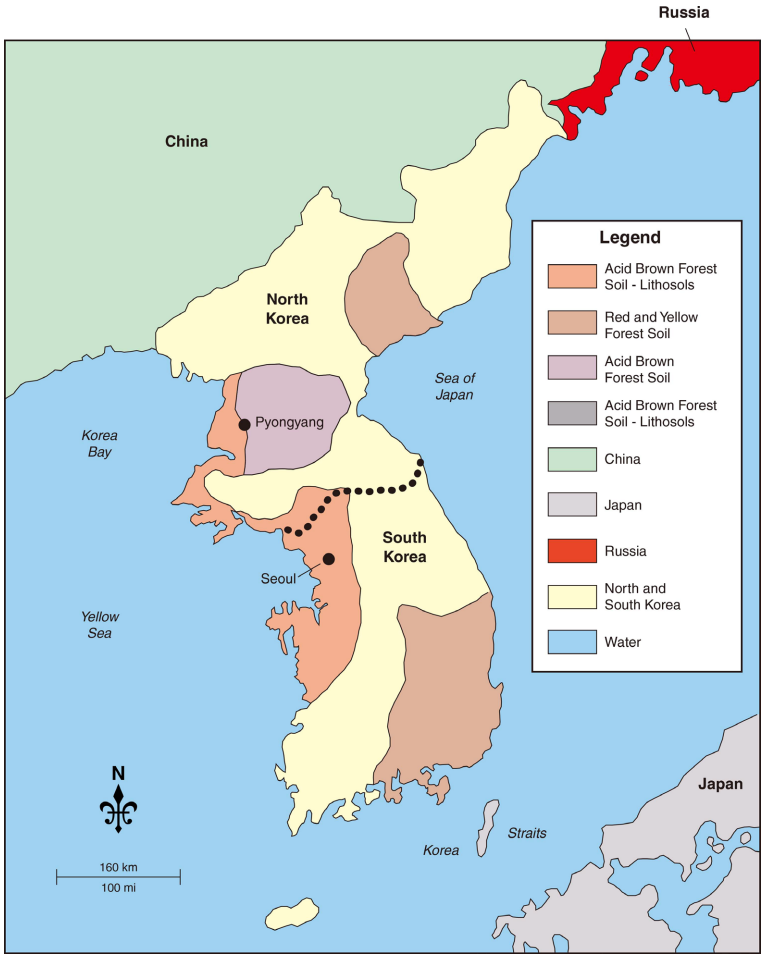

Figure 27. Soils on Korea Peninsula. The location of the DMZ with soil tunnels is shown. Map created by Cruz Dragosavac. Re-published with copyright permission from Managing Editor of Open Journal of Soil Science.

Figure 28. A black and white photograph taken in the 1950s at Monsanto Chemical Plant in Nitro, West Virginia. Photo Credit: Terry Humphreys. Pinterest. Re-published with copyright permission from Managing Editor of Open Journal of Soil Science.

"*The National Academy of Sciences Part A*: *Summary and Conclusions report* [27] *states*: '*Cacodylic acid, the active component in Agent Blue, is a non-selective herbicide killing a wide variety of herbaceous plants. It is a non-volatile, highly soluble organic compound which is broken down in soil, mostly to inorganic arsenate bound as insoluble compounds which also exist naturally in the soil. Acute and chronic toxicity studies in a variety of animals indicates a low to medium toxicity rating. No teratological studies, nor toxicity studies in man seem to have been reported*'. *While the author and our committee have great respect for the National Academy of Sciences* (*NAS*) *and their field work and research in South Vietnam its scope was limited. The NAS study* (1971-1972) *was conducted after President Nixon ordered the stop of herbicide spraying and completed just before he ordered in January* 1973 *the withdraw of soldiers from the American Vietnam War. Furthermore, the study was conducted mostly from the air due to the unstable political environment on the ground. This gave little chance for scientist boots on the ground. It is now time for a fresh look. Their findings and a re-assessment of the fate of Agent Blue, cacodylic acid, and arsenic including both water soluble and inorganic arsenate and arsenite makes this clear. In addition, there has been recent research* [31] *studying the effects of feeding chickens' organic arsenic* (*non-toxic*) *supplements and their ability to convert it into inorganic arsenic* (*toxic Group-A carcinogen*). *As a result of these findings the use of organic rich chicken feed was banned in the United States. The feed had been used to make chickens more marketable* (*more plump, redder and prevent certain chicken diseases*). *Arsenic is a heavy metal and thought to be a carcinogen and dangerous* [12]."

5.3. Emergence Scientific-Technological Elite and Its Management

The term "scientific-technological elite" was first coined by President Dwight D. Eisenhower [40] in his farewell address; it was over shadowed and lost to the public eye with Eisenhower's other phrase, the "military-industrial complex". He used in his last public message to inform Americans of two new hazards which would require forbearance to control. The proceedings in this paper outline one incident where these two hazards converged, were misapplied, and contributed lasting damage to the environment and caused human suffering as a consequence. What were the circumstances that enabled a solitary scientist like Dr. Ezra Kraus, a botanist, to be credited as the father of chemical weapon?

Dr. Kraus, head of a college department, recognized the cleverness of his department and other researchers use of chemistry to manipulate the growth of plants [3] [18]. The coincidence of WWII, which drove the government's emphasis on maximization of American technology investing funds for better labs and recruiting the best researchers to win the "good war" enabled Dr. Kraus to benefit his department. A practical decision as Department Head. The convergence of full national mobilization with a single shared goal of winning is rare. The employment of two atomic bombs preempted mass use of the new plant killing chemicals.

It was nearly two decades before circumstance enabled pulling off the shelf, a refined formulation, now 2,4-D and 2,4,5-T to be employed as a tactical weapon. This time, the catalyst which mobilized a nation, was not another world war threating our way of life, but the fear of communism ideology replacing our democratic ideals worldwide, one country after another. The trigger was Sputnik being launched overhead.

Technology was embraced as the answer to America to recover after falling behind the communists when they launched Sputnik. Dr. Kraus's greatest legacy was his graduate students he and other WWII contracted researchers trained. By 1960 a third generation of researchers were readily employed by the government on various projects. The planners for the counter Indochina operation pointed to the British use of herbicides. Despite the British less than successful experience with the herbicides, the US planners moved forward. Apparently felt they could better employ the weapon.

After Agent Orange defoliants and crop destruction mixtures were validated in 1961 by the United States-Vietnamese Combat Development and Test Center (CDTC) in Saigon, which Vice President Johnson had consulted with President Diem (Republic of Vietnam) on its establishment during Johnson's visit in May that year. After this the planners went to work. President Kennedy, as a peacemaker, [41] encouraged President Diem to use not his past authoritarian methods, but to follow US military and civilian advisors outreach programs to benefit the Vietnamese people. Rather, a new version of the British Malaysian resettlement programs was imposed [37]. Diem, fell out of favor by 1963 and was disposed. Shortly afterward President Kennedy was assassinated. This tragedy took the last safety mechanism off the herbicide weapon. President Lyndon Johnson, in a tragic Aristotelian action [41], took the reins and the military planners went to work. The first military proposal to use defoliants and crop destruction chemical was to cover one-half of the Vietnamese countryside. Because of expense this was toned down to ten percent. Then, 1965, President Johnson triggered on the herbicide weapon by directing "Operation Rolling Thunder" to bomb the North Vietnamese and Viet Cong soldiers. Employing the herbicides was a tactical component of the bombing. The US fully engaged with maximum production of these herbicides, turning the sprockets on full with eleven manufacturing sites [18]. To increase production even more the reaction temperatures were raised which inadvertently created more contaminant, dioxin, by several fold. In the end one out of five hectares of Vietnam had at least one dose of the chemical.

Dr. Arthur W. Galston was one of the young researchers during WWII. United States was fortunate for his moral character which drove him to confront the use of his discovery to hurt humankind. If President Nixon had not been informed of the hazard the damage from the misuse of the chemicals may had been greater. Circumstances also took Dr. Galston a different employment direction where he eventually taught bioethics at Princeton University. The lesson learned; however, must be to recognize the crises that mobilize nations must have processes which

will determine the long-term hazards of a weapons use and ensure controls will mitigate any effects. Waiting for protests to get "boots on the ground" to evaluate new technology impacts on the environment and humans' results in too great of damage. The world is becoming exceedingly complex and use of new technology constructed by scientists and military must have the hazards better acknowledge first and plans to send science teams into the battlefield to research the affect and develop recommendations to mitigate potential harm. This must be part of planner's postwar recovery plan. Future human endeavors will have to deal with this problem. Again, President Eisenhower [40] foresaw this in his last address to the American people and gave this last advice as president [37].

"*It is the task of statesmanship to mold, to balance, and to integrate these and other forces, new and old, within the principles of our democratic system-ever aiming toward the supreme goals of our free society*" President Dwight D. Eisenhower's Farewell Address (January 17, 1961) [40].

6. Discussion

Olson and Cihacek [12] reported "*The National Academy of Sciences: Part A Summary and Conclusions report* [27] *suggests that the fate of Agent Blue, the cacodylic acid the active component in Agent Blue, and the water soluble arsenite and arsenate* (+3 *and* +5) *was assumed to be tightly bound to the soil compounds in the root zone. However, this was not often the case. In this paper they explained that arsenic is a water-soluble arsenic salt, and much of the water-soluble arsenic is actually leached from the rice paddy and root zone into the Mekong Delta or Central Highland groundwater potentially contaminating shallow groundwater. More recent toxicology studies have shown that the arsenic in drinking water and the food supply can and does bioaccumulate in humans. Other studies have shown that the organic arsenic can be ingested by chickens and become inorganic arsenic a hazardous carcinogen. The supplying of organic arsenic rich feed to chickens is now banned in the United States. It is now well known that arsenic does not have a half-life and once introduced into the South Vietnam environment it continued to exist. The Mekong Delta and Central Highlands drinking water and the food supply, including rice, shrimp, and fish, contain trace amounts of arsenic which can be bioaccumulated over decades.*"

"*The* 1974 *NAS report* [27] *was only a* 2*-year study with most of the focus on Agent Orange dioxin TCDD and the Mangrove Forest damage. An environmental study of the impact of Agent Blue, the arsenic-based rice killing herbicide, on the environment, animals and humans are now long overdue. It does appear that the U.S. military veterans were less exposed to arsenic than the Vietnamese civilians since they did not normally drink the contaminated local water without an attempt to filter to remove the contaminated soil particulate matter, and then chlorinated the water to kill the pathogens. However, there was apparently no attempt to remove the pesticide contaminants such as arsenite, arsenate, and dioxin TCDD. If present the dioxin TCDD would probably have been removed with the*

filtered sediment or particulate matter. The Republic of Vietnam military and Vietnamese civilians did drink the untreated local surface and groundwater and the civilians have continued to drink the treated and untreated water and food with trace amounts of arsenic for the last 50 *years. The U.S. military veterans had limited exposure, usually one year, to Agent Blue, cacodylic acid, arsenic, and dioxin TCDD and had a much lower risk of bioaccumulating arsenic. However, some U.S. Vietnam veterans were exposed directly to Agent Blue, cacodylic acid and arsenic during the handling of the Agent Blue barrels and the transport and distribution process as well as from the spraying on the rice paddies, mangrove forests and the perimeter military base fences.*"

"*It is not clear to this day if the VA medical doctors treating the Vietnam veterans for the last* 50 *years knew much about Agent Blue, the arsenic-based herbicide. Evidence suggests they probably did not, and they apparently made no attempt* (*prior to* 2022) *to measure the arsenic levels in the Vietnam veterans since dioxin TCDD was their focus. Rather than determining whether any of the health issues were linked to Agent Blue and arsenic, the medical doctors apparently lumped Agent Blue exposed veterans in with the other veterans exposed to Agent Orange, Agent Pink, Agent Purple and Agent White which contained dioxin TCDD but not arsenic. Agent Orange plus Agent Purple, Agent Green, Agent Pink and Agent White were applied more widely and frequently than Agent Blue by a factor of* 10 *or* 20 *based on all Rainbow herbicide shipment records. Therefore, Agent Blue, the arsenic-based herbicide, was less of a medical concern and not everyone was aware that Agent Blue did not contain dioxin TCDD. If the Agent Blue military handlers, spraying Agent Blue on rice paddies, Mangrove forests and military base perimeter fences, were exposed to arsenic they might have been grouped with the Agent Orange dioxin TCDD exposed U.S. military veterans working in Operation Ranch Hand.*"

"*There is little information available to assess the exposure of the military veterans to Agent Blue, cacodylic acid and arsenic. Even when DoD funded the clean-up in* 2018 *of the dioxin TCDD hotspots in Vietnam, such as Bien Hoa airbase where three thousand soil samples were collected, these samples were not checked for arsenic. Arsenic levels in the soil were not the focus of the clean-up effort due to cost of analysis and the focus on Agent Orange dioxin TCDD. Therefore, no arsenic data was provided in the* 870*-page USAID report* [42] *which summarized the Hatfield field sampling and their research report. There is still a need to determine if arsenic levels in Central Highlands and the Mekong Delta are still adversely affecting Vietnamese civilian health after more than* 55 *years. There is a growing set of water quality data that shows significant spikes in arsenic levels at specific locations in the Mekong Delta and in the Red River Valley* (*Hanoi*) *which was not sprayed with Agent Blue during the Vietnam War so the cause or causes remain unknown in most cases* [12]."

7. Summary and Conclusions

Conducting environmental impact studies during a war has limitations since they

are often funded by government, conducted from the air, and the access is restricted by the ongoing war and the host military. Often the scientists do not have boots on the ground, cannot go where they want, sites are off limits, and their personal safety is often at risk. In the case of the US funded scientific study conducted in 1971 and 1972, a key finding was that the application of arsenic (1,132,400 kg) to the Mekong Delta is harmless since arsenic occurs naturally in the soil and anthropic As in solution becomes attached to soil particle surfaces. However, what was overlooked by National Academy of Sciences was the cation exchange capacity of soils. As is water soluble and can leach into the groundwater. The As temporarily attached to the soil particles can be replaced by other cations and released into the soil water and eventually leach into the groundwater. After the Vietnam War ended in 1975, the Vietnamese dug 700,000 tube wells in the Mekong Delta and brought the As rich groundwater back to the soil surface. The water was used in shrimp ponds (local food), rice paddies (local food), and to meet the household and drinking water needs of the 20,000,000 Vietnamese and Cambodians living on the Mekong Delta. The high As levels and spikes are often above the Vietnam standard of 50 ppm and the WHO standard of 10 ppm (used in all countries that do not have their own standard) and require mitigation. As has no half-life, is water soluble, is toxic, and can cause cancer.

Post-war, the authoritative study by the National Academy of Science [27] on the Rainbow herbicides and their use in South Vietnam had little scientific information about Agent Blue and the soil-chemical processes of natural and anthropic As, and seriously underestimated short- and long-term persistence of As in soil, sediments, and water. They assumed, without teratological studies or toxicity studies in humans, that because As was naturally occurring in the soil, it was not harmful to animals or humans. We know otherwise today. "*As in groundwater poses a massive and growing human health threat*" throughout Southeast Asia, especially the Mekong and Red River Deltas of Vietnam [43]. Human exposure by way of inhalation (airborne As) contaminated drinking water, and food supplies grown in As contaminated soil and water can result in acute arsenical poisoning with carcinogenic and genotoxic potential [31].

The primary objective of this research study was to describe how it is possible for a country to fund and carry out environmental impact studies during rather than decades after the war. There is considerable risk to the scientists conducting these environmental and human health impact studies especially when scientist boots on the ground are required to validate the findings. This historical assessment of the Vietnam War addressed the failures and success of environmental and human impact studies conducted during that war. Many unanswered questions remain about the persistence of herbicides with TCDD and in soil, sediments, and water environments and present-day human health and generational effects that are legacies of the herbicides previously used as military and environmental chemical weapons. The United States and other countries, including Russia and Ukraine, need to learn the historical lessons from United States use of herbicides, containing

TCDD and/or As, as chemical weapons during the Vietnam War.

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Conflicts of Interest

The author declares that there is no conflict of interest.

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