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DILEMMA FOR DISPOSAL OF HERBICIDE ORANGE*

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Presentation to a seminar on "Advancements in Pesticides", Helena, Montana, September 16, 1975. Sponsored by the Solid Waste Management Bureau, Montana Department of Health and Environmental Sciences, Helena, Montana and by Region VIII, Environmental Protection Agency, Denver, Colorado.

* The information on disposal options from Final Environmental Impact Statement on "Disposition of Herbicide Orange by Incineration, November, 1974".

DILEMMA FOR DISPOSAL OF HERBICIDE ORANGE

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In 1962 vegetation control systems using herbicides were introduced by the military into the Southeast Asia Conflict. Their use was to remove dense vegetation along highways, canals, lines of communication, and around base perimeter camps; thereby reducing enemy ambush. The herbicide formulation of choice was an equal mixture of the n-butyl esters of 2,4-D and 2,4,5-T. This formulation was labelled Orange because of the orange band around the centers of the 55-gallon drums in which it was transported.

Although severe criticism of the defoliation program was voiced as early as 1964, it was five years later before the program (Operation Ranch Hand) was suspended by the Department of Defense. Initial criticism was directed at Orange as a chemical warfare agent used against crops and the environment of South Vietnam. However, the termination of the program was not based on the above criticism but rather on reports by South Vietnamese newspapers of an increased occurrence of birth defects during June and July 1969 from areas defoliated with Orange Herbicide. These reports elicited far-reaching reactions from governmental agencies, segments of the scientific community, lay groups concerned with environmental problems, and from the communication media. Government sponsored panels of experts, special commissions established by scientific organizations, hearings before subcommittees of the U. S. Congress, and Conferences attended by representatives from industry, government, and universities examined available data and were not able to provide a generally acceptable answer to the central question of whether 2,4,5-T as produced and used constituted a risk for human pregnancy.

In mid-October 1969, a report was released to the press of the findings of a study by Bionetics Research Laboratories, Litton Industries Incorporated. The report documented the presence of defective offsprings from mice and rats treated during early pregnancy with large doses of 2,4,5-T. It was subsequently announced on October 29, 1969, that a series of coordinated actions were being taken by several governmental agencies to restrict the use of the herbicide 2,4,5-T. Additional animal experiments performed early in 1970 confirmed that pregnant mice did deliver some malformed offspring. The question then was one of whether or to what extent, such animal data could be extrapolated to man. On April 14, 1970, the Secretary of Health, Education and Welfare (HEW) advised the Secretary of Agriculture that: "In spite of these uncertainties, the Surgeon General feels that a prudent course of action must be based on the decision that exposure to this herbicide may present an imminent hazard to women of child-bearing age."

Accordingly, on the following day, the Secretaries of Agriculture, HEW, and Interior jointly announced the suspension of 2,4,5-T for "all uses around the home, recreation areas, and similar sites" and "all uses on crops intended for human consumption". Immediately thereafter, the Department of Defense suspended the use of Orange Herbicide in South Vietnam.

The suspension of the use of Orange Herbicide left the Department of Defense with 1.5 million gallons in Vietnam and 860,000 gallons at the Naval Construction Battalion Center, Gulfport, Mississippi. In September 1971, the Secretary of Defense directed the Joint Chiefs of Staff to dispose of the surplus inventories of herbicide in both the Continental United States and Vietnam. The Air Force was assigned the responsibility of finding a disposal method(s) that was (were) ecologically safe and economically feasible. In April 1972, the 1.5 million gallons of herbicide in Vietnam was placed in 55-gallon drums and transported to Johnston Island, Pacific Ocean. The total Orange Herbicide inventory was 2.3 million gallons stored in approximately 40,000 55-gallon drums. Thus, not only is there herbicide to be disposed but also the drums.

The initial method proposed for disposal was incineration at a commercial facility in the United States. The details of this proposed course of action were documented in a draft environmental statement which was filed with the Council on Environmental Quality and the Public in January 1972. The draft statement discussed the studies that were being accomplished but not completed when the statement was filed. Based on the fact that studies were still in progress and the interest evidenced in comments received on the draft statement, the Air Force decided to conduct additional studies on incineration as well as additional investigations of alternative disposal methods.

In April 1972, the Air Force Logistics Command (AFLC) began an indepth investigation into the feasibility of use, incineration, soil biodegradation, factionation, chlorinolysis and reprocessing as major disposal options. Data to be collected on each method included the parameters of time, cost, and effectiveness of the disposal process. In addition, the physical, biological,managerial and social-political factors for potential sites of disposal were to be assessed. Reports of progress and/or problems encountered were periodically presented to an Ad hoc Committee on the Disposal of Herbicide Orange of the Air Force Scientific Advisory Board. Other disposal options reviewed and discussed with the Ad hoc Committee were return of the herbicide to the manufacturer, deep well disposal, burial in an underground nuclear cavity, sludge burial, microbial reduction, and no disposal action. The last option was to be selected only if the other options were not ecologically acceptable, technology not sufficiently developed for their employment, if excessive capital investment was required, if unacceptable time delay was imminant, or if the socio-political opposition prevented any course of action. The option of "no action" would mean that Orange would be placed into seal storage tanks for permanent storage at both Johnston Island and Gulfport, Mississippi.

In the formulation of an environmental impact statement on the disposal of Orange the following description of action for each option was prepared.

1. Use

Orange Herbicide is not an Environmental Protection Agency (EPA) registered pesticide and cannot be domestically used or sold. The Orange Herbicide stock to be disposed represents a resource of considerable monetary value (a recent estimate is $80-100 million). Orange Herbicide has a potential use on Federal lands as well as on privately owned lands; however, any use would require registration. The prudent disposition of Orange Herbicide for use on privately owned or governmentally owned lands may have a tremendous impact on increasing the availability of certain natural resources, e.g., rangelands and forests.

Undesirable weed and brush species are widespread in every region of the United States. Their combined impact on rangelands and production of commercial timber is enormous. Approximately half of the total land area of the United States is used for pasture and grazing purposes, and weeds and brush are a problem on nearly all these forage lands. Economic losses from weeds on forage lands are virtually incalculable and include low yield of forage and animal products per unit area, reduced livestock gains, and livestock poisoning. Although herbaceous weeds are found on all rangelands in the United States and result in forage losses, brush is the primary problem. Various brush species dominate an estimated 320 million acres of rangelands. More than 80% of 107 million acres of grazing land in Texas alone is infested to some extent with brush. Once established, woody plants such as mesquite (Prosopis spp.) juniper (Juniperus spp.) oak (Quercus spp.), and sagebrush (Artemisia spp.) cannot be eliminated by good grazing practices alone. Measures must be taken to convert brush dominated rangeland to more productive types of vegetation. Brush control and striking improvements in the grazing capacity of rangeland may be obtained most economically by low-rate and low-volume applications of phenoxy herbicides.

Commercial forest land in the United States is estimated at 509 million acres. Although much of this land is not under any form of planned management for production of forest products, management for an increased productivity will soon become essential to meet the needs of the United States population. It is estimated that the total area of forest lands supporting important amounts of undesirable vegetation is approximately 300 million acres, or a land area of potentially commercial timberland equal to roughly the combined areas of Texas, California, and Washington. There are some 4.7 million acres of commercial forest land in western Oregon and Washington on which the land is occupied by vegetation whose presence precludes reestablishment of conifers. Much of the area is in the highest productivity class for growth of forest products.

Concepts of selective brush control have been developed for reforestation with the aid of commercial formulations of 2,4-D and 2,4,5-T. There are presently some 100,000 acres being treated each year with various formulations of these materials, all as the low-volatile esters. Success has been good, especially in operations on the slower-growing brush species.

Thus the purpose for using herbicide Orange on rangelands and reforestation would be to reduce the amount of undesirable vegetation that dominates in selected regions of the United States because of past disturbances and improper grazing and/or timber practices. With the use of herbicide Orange, a more diversified and desirable variety of plant species would become established. This in turn would have a substantial impact on increasing productivity of these regions.

The environmental impact of using herbicide Orange for chemical brush control will vary from region to region and whether it is for range or forest use. However, regardless of the region of use, or for rangeland or reforestation, critical assessments of effects on vegetation, wildlife, domestic livestock, soil microorganism, aquatic life, rangeland or forest waters, and man must be evaluated.

2. RETURN TO MANUFACTURERS

In March 1972, seven manufacturers of herbicide Orange were contacted regarding the possibility of chemically reprocessing Orange Herbicide whereby all impurities, including dioxin, would be extracted or destroyed. Results from all manufacturers were essentially the same; i.e., they did not feel that they were capable of reprocessing the product without extensive investment in equipment and/or development of new processes. Lead time for this type of action would require in excess of 18 months before large scale reprocessing could begin. As a result of EPA's action on 24 June 1974 to cancel the hearings on the possible further restriction of 2,4,5-T, the manufacturers were again contacted (August 1974) via letter to determine if their position may have changed. Manufacturers again indicated that they did not want to reprocess Orange.

3. DEEP (INJECTION) WELL DISPOSAL.

This process would involve injection of the herbicide into a deep subsurface formation. The well hole down into the formation would be lined with casing which has been cemented into place to prevent fluids from rising to the surface outside the casing to a permeable geologic formation. The herbicide drums would be emptied into tanks or vats on the surface where the Orange Herbicide would be diluted and then pumped down the tubing to the permeable formation. The packer tool prevents fluid from returning to the surface inside the casing and impermeable upper and lower formations adjacent to the permeable formation restrict verticle movement. This process has not been approved by state agencies, or the EPA, as deep well injection is not considered environmentally safe or desirable disposal method for waste materials. The policy is to oppose all storage or disposal of wastes in deep wells without strict controls and a clear demonstration that such disposal will not: a) interfere with present or potential use of subsurface water supplies, b) contaminate interconnected surface waters, or c) otherwise damage the environment. Little concrete information is available on what degradation of the Orange would occur at the depths, temperatures, and pressures encountered in deep wells. This coupled with the possibility of subsurface disturbances at a later date which might allow Orange to migrate into formations leading to water supplies or other valuable formations, has prevented any of the firms interested in disposing of Orange in deep wells from obtaining state or Federal permits.

4. BURIAL IN UNDERGROUND NUCLEAR TEST CAVITIES

The Atomic Energy Commission was contacted regarding the possibility of disposing of the Orange by burying it in an earth cavity formed during underground nuclear testing. They advised that a major research, development, and experimentation effort would be required to prove the practicality of this alternative. In view of the time required for this effort, it is not considered a fesible alternative.

5. SLUDGE BURIAL

This technique offered definite promise, but there was a lack of interested and qualified industries to undertake the necessary preliminary investigations. This process involves one concept of destroying the Orange through bacterial action. The proposal envisioned constructing trenches in geologically suited formations on isolated government land. The type of formations picked for the trenches would preclude vertical and lateral movement of the Orange. The trenches would be filled with drums containing the Orange and would then be surrounded by secondary sewage plant sludge, which would provide a growth medium for the bacteria. The tops of the drums would then be mounded with dirt fill and aggragate. Depending upon the type of bacteria selected to decompose the Orange, vents might be required. This process is not considered acceptable because of the time to completely destroy the herbicide is quite lengthy, possibly as long as 10 to 25 years, and because a system of monitoring would be required throughout this time period. The earth covering would require maintenance and additional time might also be required to develop a strain of bacteria that would tolerate high concentrations of Orange.

6. MICROBIAL REDUCTION

This process involves the biological degradation of the herbicide through fermentation. It requires the development of a microorganism to "feed" on the herbicide. From the literature, it seems apparent that microorganisms have developed unbelievable capabilities for handling organic compounds.

However, two factors severely complicate the biological degradation of this refractive material: 1) its insolubility in water and 2) its chemical structure (specifically the number and position of chlorine atoms attached to the aromatic ring). Many investigators have showed that 2,4-D is rapidly decomposed in the soils and that high concentrations have no depreciable effect on the soil population of bacteria, fungi, and actinomycetes. The persistence of 2,4,5-T is usually two to three times longer than 2,4-D and very few microorganisms have been identified as having the ability to break down the 2,4,5-T molecules. Data are available that indicate that mixtures of 2,4,5-T are more rapidly degraded than are single compounds. Very little work has been done on the microbial degradation of TCDD; however, initial data indicate that it is degradable, but with an estimated half life of one year (as a single compound).

The environmental impact of a microbial reducation method is dependent upon the fate of TCDD in a biological treatment facility. It must be established that no TCDD is remaining in the effluent, or a problem of enormous consequences can occur. Thus far no data are available on the fate of TCDD in a biological reduction system. All other aspects of such an alternative can be controlled and minimized to an acceptable level. Monitoring methodology and a failsafe system would be required. Until more data are developed the particular environmental aspects cannot be evaluated. More specific information concerning the process, size of facility, land acreage required, and effluent parameters are needed.

7. FRACTIONATION

Fractionation is the process of converting Orange into its acid ingredients by means of distillation. This would separate the normal butyl esters of 2,4-D and 2,4,5-T and its contaminant TCDD. The 2,4-D and 2,4,5-T would be reformulated for commercial use. TCDD would then be destroyed by chemical, biological or incineration techniques. Actual distillation efficiencies theoretically could approach 90-95%. One investigator stated that any TCDD residue could be destroyed by splitting the ether bonds of the molecule. In the process of fractionation, the dioxin would be isolated or destroyed. A small scale study was funded, but the results were inconclusive. Fractionation is not acceptable because : a) the fate of the dioxin has not been demonstrated, b) in the process, 3% of the Orange processed could not be accounted for, c) standards to control and monitor vapor and fluid emmissions into the environment have not been identified.

8. SOIL BIODEGRADATION

Soil biodegradation is a soil incorporation technique based on the premise that high concentrations of the Orange Herbicide and the contaminant TCDD will be degraded to innocuous products by the combined action of soil microorganisms and soil chemical hydrolysis. The rationale for soil incorporation of herbicide as an ecologically-safe disposal method comes from pertinent laboratory and field studies.

It seems apparent from laboratory studies that microorganisms have developed extensive capabilities for handling organic compounds. Moreover, most organisms seem to have a latent ability for decomposition of halogenated hydrocarbons. However, the amount of active herbicide applied to soil may diminish by means other than biological decomposition; e.g., chemical degradation, absorption, volatilization, leaching, and photodecomposition.

Until recently there was very little information concerning the breakdown of 2,4-D or 2,4,5-T in a soil incorporation site. However, field experiments on the use of soil incorporation as a method of disposing of massive quantities (approximately 1-1/4 million gallons) of 2,4-D and waste by-products has been carried on in eastern Oregon. A trenching technique was employed to simulate subsurface injection. A concentration of 500 lb/A 2,4-D (plus waste) was placed at a depth of 10 inches (5-inch bands on two-foot centers). With this placement the actual concentration of herbicide within these bands was approximately 1250 ppm. Samples taken between trenches and in soil profile segments from the surface down through the point of application indicated minimal vertical and horizontal movement of the herbicide (or phenolic waste) from the site of initial deposition.

Results from this experiment indicated little differences in rates of degradation in the trenched plots or a surface application of 500 lb/A: 95% degradation in 540 days.

Our project group at the United States Air Force Academy has studied the persistence and movement of herbicide Orange and TCDD following soil incorporation at rates of 1,000, 2,000 and 4,000 pounds active ingredient 2,4-D and 2,4,5-T/acre (lb ai/A) in a remote site in western Utah. The precent loss of herbicide over a 330 day sampling period was 78.2%, 75.2% and 60.8% for the 1,000, 2,000 and 4,000 lb ai/A plots, respectively. The calculated half-life of herbicide Orange in alkaline (pH= 8.1) desert soils was approximately 150 days at these massive rates. Data on soil penetration indicated that less than 3.7% of the herbicide was found at depths greater than 18 inches 282 days after soil incorporation of 4,000 lb ai/A. Preliminary data based on levels of TCDD in the formulation (3.7 ppm) and those encountered in the soil profile 265 days following soil incorporation suggested that under these environmental conditions that half-life of TCDD was 88 days. Our USAF Academy team also established biodegradation plots in Garden City, Kansas and Eglin AFB, Florida. Data from these incorporation studies are in agreement with the Utah plots: degradation of 2,4-D, 2,4,5-T and TCDD when applied at massive rates, rapidly occurs and movement of the herbicide in fact is minimal.

It is important that the criteria for selection of a site for soil biodegradation include certain physical, biological, and managerial factors.

(1) Physical Factors: From the standpoint of just physical consideration, the soil incorporation technique provides an array of alternative as to the selection of site. In general:

(a) A minimum of 2,000 acres must be available.
(b) The site must be remote. It cannot be adjacent to land currently in agronomic production.
(c) The land must have a low-use potential, i.e, it should be marginal land. Moreover, the land should not be considered land that will be significantly productive in the foreseeable future.
(d) Water resources must be sufficiently far away so as not to be contaminated.
(e) The topography of the land must be relatively flat with a uniform surface.
(f) The texture of the soil should be sandy-loam or silty-loam with a pH of approximately 8.0.
(g) The area should not be characterized by rock outcrops or areas of marked deflation or dunes. The area should also have minimal surface erosion.
(h) Data should be available on subsurface geology and hydrology.

(2) Biological Factors: The vegetation that characterizes the particular site must be uniform with a ground cover of at least 10-15%. Such a plant community will provide the organic matter and microclimate that supports the growth and maintenance of microflora (e.g., fungi and bacteria). Ideally, the vegetation should be low-growing shrubs, forbs and grasses to facilitate the incorporation equipment.

(3) Management Factors: The management factors that will influence the selection of the site are:

(a) The requirement for established all weather roadbeds to and within the disposal site.
(b) The distance to the disposal site from an off-loading station (e.g., rail to truck).
(c) The requirement for security of the disposal site.
(d) Availability of personnel facilities.
(e) Adequate storage space at the disposal site.

A subsurface injection system would be used to incorporate the herbicide into the soil at a depth of 6-10 inches. The injection would be done by using a conventional agricultural subsoiler, drawn by a heavy industrial tractor. The subsoiler would consist of a verticle blade on which a chisel, or foot, is mounted at an angle of approximately 15° from horizontal. A piece of metal tubing will be attached to the blade (and terminating at the base of the chisel) in such a manner that a piece of hose from the injection pump could be inserted to permit disposition of the herbicide immediately behind the chisel. The equipment, with eight injectors (shanks), should be calibrated to apply 4000 lb/A of Orange. The eight shanks should be on 20-inch centers. During the process of application the overlying vegetative structures will be damaged. To prevent the loss of soil moisture and to reseal the soil (thus minimizing volatility and damage from wind) a soil compactor (cultipacker) will be required and a drought resistant, salt tolerant grass will be planted.

The environmental impact of soil biodegradation would be expressed in two major areas; the most significant of which is the denial of a 1,000 - 2,000 acre tract of land for reclamation or recreation use for a 3-5 year period during biodegradation.

The proposed site would require continuous monitoring during the lifetime of the project. Also occurring will be damage and/or kill of the overlying vegetative structure in the immediate disposal area, drastic alteration of the soil structure, and disturbance and/or temporary destruction of local ecosystems. Adherence to the above site criteria and incorporation method will optimize the soil biodegradation procedure and minimize adverse environmental impact.

9. CHLORINOLYSIS

From the theoretical engineering point of view, chlorinolysis offers an efficient, controlled, and safe method for disposal of the herbicide, as well as other hydrocarbon formulations. Chlorinolysis is a process that breaks down the molecule and adds a chlorine molecule to produce carbon tetrachloride, phosgene, and anhydrous hydrogen chloride, all of which have established commercial value.

Chlorinolysis as a means to dispose of Orange Herbicide was evaluated over a period of almost two years. In July of 1972, discussions and correspondence with the Environmental Protection Agency (EPA) committed the Air Force to pursue the testing and research program necessary to determine the feasibility of converting Orange to salable products by chlorinolysis. In September 1972, a Memorandum of Agreement between the EPA and the Air Force was initiated. The objective of the agreement was the development of a laboratory program to evaluate the practicality of the application of chlorinolysis for the disposal of Orange. The investigation was also to determine the extent of destruction of the impurity dioxin. The information and data obtained in this research was to be utilized by the Air Force to determine whether the proposed concept could be applied and used to dispose of Orange and by the Environmental Protection Agency to determine if it could contribute toward solving the disposal problems of the petrochemical industry. It was agreed that the EPA would manage the research and provide a report containing all data collected, together with conclusions and recommendations. The Air Force agreed to fund the effort in the amount of $35,000. An additional $10,000 was provided for analysis of dioxin. Three drums of Orange containging 14ppm dioxin (analysis by Dow Chemical Company) were provided by the Air Force.

The EPA report, "Study of Feasibility of Herbicide Orange Chlorinolysis" (EPA-600/2-74-006, July 1974), covering only the work of Diamond Shamrock Company was delivered on 2 October 1974. The report covered the results of bench scale tests and concluded, based on these bench scale tests, that chlorinolysis under the proper conditions effectively converts Orange Herbicide and its TCDD contaminant to carbon tetrachloride, carbonyl chloride and hydrogen chloride. Destruction of the TCDD was complete, and preliminary toxicology tests of the recovered carbon tetrachloride on rabbits showed no evidence of TCDD contamination. The report also contained cost estimates which included credit for the sale of chemicals from a 25 ton/day plant. The cost in the worst case was shown to be $11 million and in the best $4 million.

Owing to the uncertainties associated with developing this technique to a full scale plant capable of processing 2.3 million gallons of Orange in a timely and economical manner. Partial or total chlorinolysis was not selected as the method of disposal even though it is satisfactory from an environmental point of view.

10. INCINERATION AT SEA

One of the most viable options for the destruction of Orange Herbicide is via incineration on a ship at sea. Since September 1972, a ship the "Vulcanus" (registered in Rotterdam, Netherlands) has been equipped to carry certain hazardous liquid chemical cargoes from northern European ports and approved by participating countries to incinerate the waste cargo in prescribed areas of the North Sea. Additionally, U. S. Companies have suggested shipboard incineration and have indicated a willingness to investigate it.

The ship is a double hulled and double bottom tanker with an overall length of 331.4 feet, a beam of 47.2 feet and a draft of 22.9 feet. Her construction complies with the latest Inter-Governmental Maritime Consultative Organization (IMCO) regulations of bulk carriage of dangerous chemicals at sea. Because of her size, the vessel is able to operate and continuously man the incineration process. Two diesel engines drive the single propeller to give service cruising speeds of 10-13 knots.

The vessel's cargo tank capacity of 3,503 cubic meters (CBM) (925,493 gallons) is divided into 15 cargo tanks ranging in volume from 115 cbm to 574 cbm. None of these tanks are in contact with the vessel's hull and/or bottom. The engine room is separated from the cargo tanks by double bulkheads, the pump room and generator room being situated in between.

The incineration system consists of two combustion chambers installed right aft of the upper deck. Each of the bricklined incinerators has a maximum outer diameter of 5.50 meters (m), and inside diameter of 4.80 m and a total height, including the stack, of 10.45 m. The volume of each combustion chamber is calculated to be 87.9 cmb. Each chamber has three burners with rotating cup fuel injection systems which provide vortex turbulence and distribution of fuel feed throughout the whole chamber.

Incineration could be conducted in a designated area 50-60 miles clear of normal shipping lanes and on the open tropical sea downwind of Johnston Island. Gas or diesel oil would be used to bring the chambers to the required combustion temperature, normally 1400°C (2552°F); the maximum operating temperature is reported as 1650°C. Only when the required temperature is reached would the feed pumps allow waste to enter the combustion chambers. Waste feed flow and air would be carefully controlled to insure complete combustion. Once the required temperature was obtained, the chambers would be fed solely by the undiluted Orange. The Orange could be pumped to each of two chambers at a rate of 10-12 tons per hour for a total daily pump rate of about 576 tons. Therefore, about 22-26 days of continuous incineration would be required to burn the entire Orange stock (2.3 million gallons). The vessel's capacity of about 925,000 gallons of Orange would require three voyages; 925,000 gallons of Orange would be burned during each of the first two voyages, and the remaining 380,000 gallons of Orange plus any solvents used in drum cleaning would be burned during the third voyage.

The data accumulated, together with theoretical considerations and applied thermochemistry, clearly indicate that the production of incomplete combustion products can be minimized to insignificant levels. Destruction, efficiencies of 99.9% or better appear feasible for this incinerator project. This would result in a total discharge of 0.05 pounds or less of TCDD via the exhaust streams over the duration of the project. (The average concentration of TCDD in the herbicide is about 2 mg/kg and the total amount of TCDD in the entire Orange stock is approximately 50 pounds.) The commercial incinerator test program indicates that if any TCDD were present in the exhaust stream, it was analytically nondetectable. Incineration would convert the Orange herbicide to its combustion products of carbon dioxide, hydrogen chloride, and water which will be released to the atmosphere. In addition, a relatively small amount of elemental carbon and carbon monoxide would be generated in the incineration process and discharged to the atmosphere. With proper concern for the environment in which such incineration would take place, incineration is an environmentally safe method of disposal of Orange Herbicide.

Ecological monitoring is neither required nor feasible for the following reasons: a) the ship will complete the project within a month and always be moving and operating over a large area of the open tropical sea; and b) the predicted impact will be very minimal and transient for this incineration option. A dispersion zone model utilizing "worst case" analyses techniques was used to estimate mass concentrations of unburned Orange and Hydrogen chloride in the air and water environment in the vicinity of the discharge, and a meteorological model was applied to predict the atmospheric concentration of unburned Orange and hydrogen chloride at sea level downwind of the discharge location. Predicted results from these models revealed that there would be no significant environmental impact upon either the air or ocean environment.

11. INCINERATION ON JOHNSTON ISLAND

If incineration at sea is not approved by EPA (e.g., if a permit for incineration at sea were not approved) then an alternate incineration option would be the construction of an incinerator facility on Johnston Island. Incineration on Johnston Island would require a higher efficiency owing to the ecology of the Atoll. (A complete ecological survey was conducted of Johnston Island by the Smithsonian Institution in order to document the areas of concern.) The facility on Johnston Island would probably be designed to incinerate about 206 drums of herbicide per day. At this rate, approximately 200 burn days would be required to incinerate all 2.3 million gallons of the Orange stocks.

Thermal decomposition research using differential thermal analysis was conducted to determine the temperatures required for complete combustion of Orange Herbicide and a test program was conducted in a commercial incinerator to document the feasibility of destroying undiluted Orange Herbicide by means of combustion. Particular emphasis was placed on the ability to destroy the low quantity of TCDD (low miligram per kilogram concentration, mg/kg) present in the herbicide. Extensive sampling, utilizing time-weighted and concentration techniques, was conducted to evaluate the unscrubbed combustion gases, the scrubbing liquid used to cool and scrub the combustion gases, scrubbed effluent gases, and any solid residues deposited in the system. Program objectives were outlined to determine, among other things, engineering data relative to controlling and monitoring the incineration process, the composition of the combustion products, and the toxicity of discharged scrubber water to several aquatic organisms.

For a system operating at combustion chamber temperatures of 2400-2800°F; dwell time equal to or greater than 0.14 seconds; fuel to air mass ratio of about 0.1; and excess air greater than 30%, it can be stated that: a) combustion gas and scrubbed effluent gases are free to undetectable levels. ($\sim 0.20 \times 10^{-3}$ μg/l for each compound) of herbicide esters, acids, and TCDD; b) about 10% of the carbon dioxide and greater than 99.9% of both the hydrogen chloride and carbon particulates are removed from the combustion gases via an alkaline scrubber;

c) combustion pyrolyzates are unchlorinated hydrocarbons whose total concentrations average less than 0.50 µg/l; d) alkali scrubbing removes a small fraction of the pyrolyzates from the combustion gases, and with gaseous condensation in presence of chlorine, converts some of the pyrolyzates into chlorinated hydrolyzates; e) total unchlorinated pyrolyzates average less than 13.0 µg/l and total chlorinated hydrolyzates average less than 3.0 µg/l in the spent scrubber water; f) carbon particulates contain no detectable levels of any type of hydrocarbon and the mass of these particulates was less than 0.5% of the carbon in the herbicide; g) carbon dioxide, carbon monoxide, and heat of combustion gases are not environmentally significant; and h) dispersions of scrubbed effluent gases into the atmosphere have no effect on tomato plant bioassays and attest to the lack of phytotoxicity of the gases.

12. INCINERATION IN THE CONTINENTAL UNITED STATES (CONUS) ROCKY MOUNTAIN ARSENAL, COLORADO

An incineration system has been constructed, installed, and operated at the U. S. Army Rocky Mountain Arsenel (RMA) in Colorado which, by technical investigation, appears to be capable of incinerating the Orange in an environmentally safe manner. The RMA incinerator is used to destroy mustard agent and many of the problems associated with the incineration of mustard and Orange are similar. The problems arise from the similarity between mustard and Orange as regards certain physical and chemical properties and environmental impact. These problems include: fuel conditioning, high temperature incineration, acceptable effluents, real time monitoring and drum disposal. The problems are handled at RMA; but, the facility is necessarily of considerable value, and the waste feed rate of ∿2 gallons per minute (gpm) requires considerable time to incinerate a given quantity of material. The information below regarding the RMA facility has not been reviewed by the U. S. Army, nor has any action been taken to contract the RMA facility for Orange incineration. Incineration of 2.3 million gallons would require approximately 27 months. The RMA system can operate at >2,000°F with a stay time of 2-6 seconds. Although no actual Orange incineration data is available, it is felt that such operating conditions will adequately destroy the herbicide and TCDD. In addition a caustic scrubber installed on the system will provide additional treatment of the combustion gas. The elimination of the liquid discharge, the slow rate of incineration, the cumbustion gas treatment, the monitoring systems installed, and the drum cleaning capability make this option extremely attractive.

Based on technical and environmental considerations, incineration in the CONUS in units such as the RMA facility could be safely accomplished. Unfortunately incineration units of sufficient capacity are located near centers of populationsand industry, and these areas are already marginally acceptable from a polution viewpoint because of presently occurring degrees of air pollution. Furthermore, local and state governments are generally opposed to the importation of waste for disposal within their areas of jurisdiction. For the above reasons, incineration in the CONUS is not considered a viable alternative.

13. REPROCESSING

Reprocessing of Herbicide Orange would convert it into commercial products (n-butyl esters of 2,4-D and 2,4,5-T) containing acceptable levels of TCDD. The process would differentially destroy the TCDD or concentrate it into a readily disposable waste. To date (September 1975) three chemical companies have submitted process descriptions in support of bids to reprocess the herbicide. The basic processes proposed all basically attempt to selectively separate the valuable components of Herbicide Orange from the TCDD contaminant. Classical chemical methods, i.e., solvent extraction, distillation or absorption, would be employed to concentrate the TCDD. The TCDD impurity would then be disposed of by incineration. The process descriptions have been evaluated by EPA and the Army Environmental Hygene Agency. The processes appear promising with respect to 2,4-D and 2,4,5-T recovery as well as satisfactory destruction of the dioxin contaminant. However, sufficient processing questions have been raised (e.g., disposal of dioxin wastes and in-process destruction) to warrant a mandate for pilot studies (up to 150 gallon capacity). The objectives of the pilot study would include: (1) confirmation of process claims, (2) determination of impact of scale-up unit on process efficiencies, (3) evaluation of dioxin destruction and disposal, (4) estimation of possible dioxin contamination of the environment.

The Scientific Advisory Board's Ad hoc Committee on Disposal of Herbicide Orange met for a final assessment of all research data and a discussion of options in March 1974. Rough estimates for the cost of each major viable option were presented.

TREATMENT	ESTIMATED COST ($ Million)
Complete Incineration	3.657
Complete Biodegradation	2.235
Fractionation and Incineration	4.031
Fractionation and Biodegradation	2.754
Complete Chlorinolysis	11.462
Fractionation and Chlorinolysis	9.033
Reprocessing/Hemogenous Mixing/Sale	2.153

Although these data suggested that the reprocessing option was most viable, there were no assurances given by EPA that once selected, registration of appropriate inventory would follow. The use option (as Orange Herbicide) was not considered in the final analysis for two reasons (1) no registration existed for the n-butyl ester of 2,4-D and 2,4,5-T and (2) the market for a n-butyl ester formulation was thought to be minimal. Moreover, field tests with Orange Herbicide in western Oregon in 1973 drew an unusually and controversial reaction from the public. Newspapers in the area (and throughout the Country) generally carried a very derogitory view of the use of this chemical (as Orange) in reforestation programs.

Biodegradation of the herbicide in an isolated area in western Utah appeared feasible. However, newspaper coverage in the Fall of 1973, also made this option "politically" sensitive. The suggestion in the newspapers that the Air Force was seeking a site to "dump" 2.3 million gallons of toxic surplus herbicide from Vietnam made the selection of an appropriate location impossible. For similar reasons, the incineration of Orange within the Continental United States (CONUS) appeared unrealistic.

The obvious option was considered to be incineration outside the CONUS. Since some of the European Countries had used specially designed ships for incineration at sea, this option was considered the "most likely to succeed". As a consequence, the Environmental Health Laboratory at Kelly AFB, Texas, was tasked with preparing an environmental impact statement for the incineration of Herbicide Orange. The final statement "Disposition of Orange Herbicide by Incineration" was released in November 1974.

Destruction of Herbicide Orange is pending final evaluation of reprocessing and a review of the status of 2,4,5-T Herbicide by the Environmental Protection Agency. If the latter two actions are negative, then the Air Force will seek a permit for ocean incineration of Orange. Destruction of the herbicide by incineration could begin in the Spring of 1976.

It is ironic that such large quantity of herbicide, so widely used in the United States, and so critical in World Agriculture, will be destroyed because it was used in a highly controversial military conflict. When given the option of whether to use it for the benefit of mankind or destroy it as a symbol of protest against war and the abuse of our environment, the American public has choosen the latter.