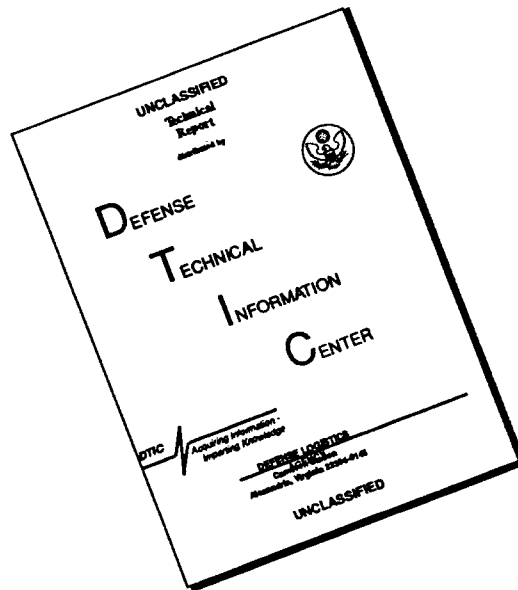


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TASK ASSIGNMENT

33-TS1901-150

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DEPARTMENT OF THE ARMY
Headquarters, Edgewood Arsenal
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C-3610

FOREWORD

This program was conducted for the US Army Manufacturing Technology Directorate at Edgewood Arsenal by AAI Corporation under Contract DAAA-15-75 C-0154, Task Assignment 33-TS1901-150. The purpose of the program was to conduct a systems analysis of the disposal alternatives for waste salts produced and stored at Rocky Mountain Arsenal.

Work performed by AAI was accomplished under the direction of Mr. Robert Epstein of Edgewood Arsenal who supplied the necessary data and technical information. The principal investigators at AAI were A. L. Farinacci, G. B. Bush and H. W. Schuette under the supervision of F. J. Schroeder.

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The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

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I. INTRODUCTION

The U.S. Army's program of demilitarizing lethal chemical agents has produced, and will continue to produce, substantially large quantities of waste salts. At the present time at Rocky Mountain Arsenal, there are approximately 4.2K tons of waste from the demilitarization of mustard agent and over 8.0K tons of waste from the neutralization of GB. The mustard wastes consist largely of various inorganic sodium salts while the GB wastes contain a large percentage of organic phosphorous compounds as well as sodium fluoride and sodium carbonate.

Although the waste salts have been certified free of chemical agent contamination, their characteristics make disposal a relatively complex problem. Tests have shown that the salts are corrosive but less than a Class B poison.⁽¹⁾⁽²⁾ Also, under certain conditions they can cause physical irritation and in significant concentrations, can be toxic to mammals and marine life.⁽³⁾⁽⁴⁾⁽⁵⁾ Other factors which increase disposal problems are the concentrations of heavy metals (particularly cadmium) contained in the salts, the non-biodegradable nature of the wastes which increases the persistence of the problem, and the high solubility of the salts which magnifies the danger of polluting usable ground water. In addition to economic and technical problems associated with disposal of the salts, the matter of public relations cannot be neglected. The salts contain no harmful concentrations of chemical warfare agent, but their mere association with chemical munitions has made them a topic of public concern to be exploited by the news media, environmentalists, and civic associations for years to come.

Edgewood Arsenal has been assigned the problem of determining the safest, most cost effective, and most ecologically sound method of disposing of the wastes. Through research, testing, literature search, and personal contact, Edgewood Arsenal has compiled a bank of data relating to many disposal techniques along with their respective economic, technological, ecological, and legal ramifications. AAI Corporation was assigned the task of assisting the Army in making a selection of the best disposal technique by conducting an ecologically weighted independent systems/cost analysis. This analysis consisted of a qualitative and quantitative compilation and examination of the available data so that an objective decision could be made. It should be pointed out that this analysis was limited only to GB and mustard salt wastes at Rocky Mountain Arsenal and only to options that had been investigated and considered by Edgewood Arsenal. The generation of new technical concepts and data was beyond the scope of this study as was consideration of wastes generated at other demil facilities. In addition, although the scope of the cost and technical data provided was sufficient to allow the comparison of basic options, it was not sufficient to allow the detailed selection of specific variations or contractors.

II. SUMMARY AND RECOMMENDATIONS

This report documents the review and analysis of methods considered for disposing of dried waste salts at Rocky Mountain Arsenal. Many disposal techniques proved inadequate because they were not ecologically sound, not cost-effective, or beyond the state of the art. Those that appeared feasible were subjected to a systems analysis to establish an objective relative comparison. Variables that were considered were cost, schedule, ecological safety, and a relative figure of merit based on how well the disposal method was defined and verified.

Based on available data and information, the following conclusions may be drawn.

(1) For the mustard salts, the only disposal option that appears available in the near term is the use of a chemical waste landfill. The chemical composition of the mustard salts prevents incineration and any reasonably economical industrial use. The high mercury and cadmium content virtually eliminates the possibility of obtaining a special interim permit for ocean disposal. Other possibilities such as electrolytic degradation and sub-ocean floor burial are well beyond the current industrial state of the art but may prove feasible in the future.

(2) For GB salts, the most expedient disposal method for the near term also appears to be the use of a chemical waste landfill. The key words are "expedient" and "near term" because facilities for chemical landfill are immediately available even though other options would have certain long term advantages. For example, incineration of the GB salts with subsequent treatment and landfill of the residue would provide finalized disposal, i.e., no required perpetual monitoring plus elimination of the highly improbable but not impossible long term problems posed by the forever-present salts. Nevertheless, when examining the combined factors of cost, schedule, safety, and current technological and operational availability, chemical landfill emerges as the preferred option. Ocean dumping does not appear to be a wise choice at this time, primarily because of the uncontrolled nature of the method and the uncertainties associated with potential long term problems of introducing cadmium and phosphonates into the environment in such a way that they could become consolidated in the food chain.

Throughout this study, it was observed that there were many factors regarding the disposal options that had not been fully defined or specified. Some of these concern the detailed specification, costing, and scheduling of many of the operations as well as consideration of the effects of potential accidents or improper handling. Where possible, broad process definitions and generalized operating estimates should be scrutinized to avoid overlooking details that could cause subsequent operating delays, safety problems, or cost overruns. As part of any disposal operation, it is suggested that the following items be identified:

(1) detailed analysis of the type, number, availability, cost, and schedule requirements of the men and equipment needed for material handling, loading, transportation, unloading, temporary storage, etc., of drummed and undrummed salts. This includes such details as:

- protective clothing
- type of rail cars and trucks
- special procedures
- responsibility for operation and security
- drum filling and emptying requirements

(2) on-site Army investigation, inspection, and surveillance of:

- contractor facilities and equipment
- contractor operations and maintenance
- contractor security

(3) detailed accident risk and hazard analysis for conditions during pre-operation, operation, clean-up, and post operation follow-up activities. This should include:

- identification of potential accidents and hazards
- probability of accident occurrence
- type, scope and duration of effects to human, animal and plant life
- accident prevention, safety, and recovery methods

(4) specific task definition, responsibility assignment, manpower, costs and scheduling for:

- site preparation
- operation and maintenance
- clean-up (disposition of empty drums, temporary storage facilities, residues, etc.)
- follow-up testing and monitoring
- documentation

(5) analysis of the scope, consequence, and duration of long term effects of disposal including the possibilities of accidents, mishaps, and mishandling in the distant future.

This document presents a summary and consolidation of all of the avenues explored for disposal of the waste salts at RMA. It provides a model for examining and communicating the decision process that was undertaken to analyze the information gathered and supplied. It also provides a framework for adding new data and options if it is deemed necessary in the future. It should be emphasized that the results do not imply that any given method is an ultimate disposal technique but merely better or worse than the others considered in the analysis at this time.

III. TECHNICAL

A. Background

In the past few years, the disposal of "hazardous" wastes has received increasing attention. Through the efforts of environmentalists and the news media, citizens are becoming more aware of the disposal methods that have been employed by government and industry in the past and citizens have become more concerned for their own safety. Many examples of severe and long-term damage to humans and wildlife resulting from careless handling of chemicals and industrial wastes have been widely publicized. Problems such as the Kepone pollution of the James River and Chesapeake Bay, PCB pollution of the Hudson River, and the long-term effects of DDT on animal life have made people fearful of man-made chemicals in the environment and skeptical of industry's ability or desire to control them. In order to allay these fears, state, local, and federal regulations have made the disposal of chemical wastes increasingly difficult. More effort is being applied to define exactly which wastes are dangerous, the specific danger that they pose, and the acceptable methods for their disposal.

The EPA defines hazardous wastes as "wastes or combinations of wastes which pose a substantial present or potential hazard to human health or living organisms because they are lethal, non-degradable, persistent in nature, can be biologically magnified or otherwise cause, or tend to cause, detrimental cumulative effects."⁽⁶⁾ They specify five general categories of hazardous wastes including "toxic chemical" which can be subcategorized as (a) inorganic toxic metals, salts, acids or bases, and (b) synthetic organics. The State of California defines hazardous waste as "any waste material or mixture of wastes which is toxic, corrosive, flammable, an irritant, a strong sensitizer, which generates pressure through decomposition, heat or other means, if such a waste or mixture of wastes may cause substantial personal injury, serious illness or harm to wildlife, during, or as a proximate result of any disposal of such wastes or mixture of wastes"⁽⁷⁾ From these definitions it is interpreted that the waste salts at Rocky Mountain Arsenal could be considered "hazardous" even though they are classified as less than Class B poison. They are highly soluble and persistent, and they have been shown to be irritating, corrosive, and potentially toxic in significant quantities. However, by the above general definitions, many substances, even table salt, could be considered "hazardous".

1. Description of Wastes

a. GB Salts

Large scale neutralization of GB at Rocky Mountain Arsenal was done with NaOH solution. In addition, many washdown and decontamination operations were performed with sodium carbonate solution during various demil operations. The salt solution resulting from the operation has been spray dried and the salts sealed in 55-gallon drums. There are now over 8.0K tons at RMA stored in approximately 41,000 drums..

The waste salts consist primarily of the organic phosphorous compound sodium isopropyl methyl phosphanate (SIMP), sodium fluoride, sodium carbonate, and sodium hydroxide. The proportions vary from lot to lot and there are also other trace elements present. SIMP is not a naturally occurring compound, is not biodegradable, and presents an unknown potential danger if released into the environment. Sodium fluoride is highly corrosive and is regulated by the EPA as well as some state pollution laws as a hazardous compound. The composition of the GB salts is as follows.(8)

<u>Compounds</u>	<u>Per cent</u>
Organic Phosphorous Compounds	32-59
NaF	12-25
Na ₂ CO ₃	8-35
NaOH	2-7

<u>Element</u>	<u>ppm(mg/kg)</u>
Mercury	< 0.1
Cadmium	1.24
Copper	13.20
Zinc	145
Lead	< 0.5
Chromium	< 1
Manganese	1.90
Silver	1
Molybdenum	< 50

b. Mustard Salts

There are concurrently about 4.2K tons of salts at RMA resulting from the incineration of mustard agent, scrubbing of exhaust gases, and spray drying of the brine solution. About 3.6K tons are stored in 55-gallon drums (approximately 19,000 drums) and 600 tons warehoused in bulk form. The major components as well as the trace elements measured are as follows:(9)

<u>Compound</u>	<u>Per cent</u>
NaCl	43.3
Na ₂ SO ₃	23.6
NaH CO ₃	5.9
Na ₂ SO ₄	15.7
Na ₂ CO ₃	11.9
Fe ₂ O ₃	.2

<u>Element</u>	<u>ppm (mg/kg)</u>
Mercury	1.03
Cadmium	16
Copper	53
Zinc	35
Lead	< 5
Chromium	< 25
Manganese	< 0.03
Silver	< 2.5
Molybdenum	< 0.1
Potassium	0.7
Soluble Iron	147
Insoluble Iron	2315

2. Costs

The overall cost of any method of disposal must be given strong consideration particularly in light of technological feasibility. Some disposal options presented in Sections III-B and III-C are techniques that are currently in use, some would require significant modifications to existing systems, and others are virtually untried ideas that have been examined only on paper. The confidence in system costs used in subsequent analyses depends upon the source of those costs. Some are estimates that have been supplied by contractors engaged in waste disposal operations while others are based on purely theoretical conditions. In general, documented costs based on existing operations or equipment have been given more credence than estimates for concepts that would require extensive development.

3. Laws and Guidelines

Aside from the cost and technological factors affecting the selection of a disposal method, it is necessary to consider federal, state, and local laws as well as guidelines and opinions of regulatory agencies. Many technically feasible and economically sound disposal techniques must be eliminated from consideration or viewed with caution because they violate specific regulations or tend to run counter to guidelines for preferred procedures. Because there have been few economic incentives for waste procedures to utilize the most ecologically sound disposal methods, laws have been enacted to specifically prohibit or regulate certain waste handling procedures. For the most part, federal laws have been most stringent with respect to discharge of wastes to the atmosphere and water resources. Up until now, with the exception of radioactive and pesticide wastes, land-based treatment, storage, and disposal have been largely unregulated on the federal level and left to the prerogative of state and municipal governments. However, this is likely to change in the near future. Amendments to existing laws as well as proposed new legislation indicate that legal restrictions will only become more restrictive. Following is a summary of some of the current and pending regulations and guidelines that must be considered in the final selection of a disposal method.

a. National Environmental Policy Act of 1969; (PL 91-190) - This law declares a national policy to promote efforts to prevent damage to the environment and to foster greater understanding and concern for the ecology. It establishes the Council on Environmental Quality and requires all Federal agencies to include an environmental impact statement for proposed major actions which could have significant environmental consequences.

b. Water Quality Improvement Act of 1970; (PL 91-224) - This law amends the Federal Water Pollution Control Act to reinforce prohibition of the discharge of oil into navigable waters of the U.S. and upon other designated waters adjoining the U.S. shoreline. It also gives the power to the President to designate as hazardous and prohibit the discharge of any other material which could present substantial danger to public health or welfare to fish, shellfish, wildlife, shorelines, and beaches.

c. Armed Forces Appropriation Act of 1971; (PL 91-441) - This act specifies that chemical and biological agents must be detoxified prior to disposal. It eases some transportation restrictions on small quantities of agent and provides for emergency transportation and disposal where health and safety are jeopardized.

d. Federal Water Pollution Control Act Amendments of 1972; (PL 92-500) - The basic objective of this act is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters." Toward this end, it authorizes the classification of hazardous materials and the specification of allowable concentrations. It requires the determination of effects of pollutants on human safety and the welfare of fish and wildlife. The act is very comprehensive, specifying target dates for pollution levels and requiring federal permits and grants for the discharge of effluent into the Nation's waters.

e. Marine Protection, Research and Sanctuaries Act of 1972; (PL 92-532) - This act regulates the transportation for dumping and the act of dumping material into ocean waters. It affirms that it is the policy of the United States to regulate the dumping of all types of materials into ocean waters and to prevent, or strictly limit, the dumping into ocean waters of any material which would adversely affect human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities. It specifically prohibits dumping of any radiological, chemical, biological warfare agent, or any high-level radioactive waste except as by special permit and outlines the requirements and conditions for obtaining permits.

f. Clean Air Act of 1970 - This act provides EPA with the power to adopt and enforce air pollution regulations. Using this power, EPA established the National Primary and Secondary Air Quality Standards which set the maximum ambient concentrations for oxidants, CO, NO₂, SO₂, non-methane hydrocarbons, and particulates.

g. Resource Conservation and Recovery Act of 1976 - In addition to providing for financial assistance to state and local governments to aid in

modifying existing disposal techniques, this act prohibits future open dumping on the land and requires the conversion of existing open dumps to facilities which do not pose a threat to the environment. It requires that persons owning or operating facilities for the treatment, storage, or disposal of hazardous wastes to have a permit in accordance with regulations established by the EPA.

4. Other Considerations

Costs, schedules, and laws are absolutes that can be factored into a decision with little difficulty. However, there are other considerations which may be called (with some hesitancy) "moral issues." These deal with somewhat nebulous ecological factors and the ultimate assignment and acceptance of responsibility in the event of an accident. This is particularly true in cases where a great deal of the disposal operation would be handled by contractors, or where special exception permits are required. Regardless of who performs the disposal operations, it should be assumed that the Army will ultimately bear the full brunt of any problems, and would have to accept responsibility for political reasons if not necessarily for legal ones.

A final decision on a detailed method should include verification or establishment of data required for any licensing and permits for disposal operations such as soil samples, bioassays, chemical emissions, dilution/percolation rates, geohydrological conditions, accident scenarios, etc. Information such as this should be obtained even if the disposal operation is carried out by an independent contractor because criteria for operating permits may vary from state to state, and many of the environmental problems that could result from inadequate precautions are long-term and insidious in nature. For example, several people in Perham, Minnesota were hospitalized as a result of ground water contamination from arsenic that had been buried 30 years earlier in a site that was not adequately controlled.⁽¹⁰⁾ Heavy metals and non-degradable pesticides have entered the food chain in some areas and can be consolidated and passed on to humans through wildlife, marine life, and agricultural products. In some cases, the effects do not become apparent for many years, usually after serious damage is done.

Much of the detailed information needed for this level of decision analysis has not been provided for this study and is not necessary for a preliminary selection. However, the specific details have been identified so that they can be considered for future detailed planning of disposal operations.

B. Disposal Concepts

During the past few years many ideas were considered for the destruction or advantageous use of the neutralized GB and mustard salts. Initially all apparent methods were considered to assess their economic, technical, and ecological feasibility. Most were eliminated after a cursory qualitative examination in which their obvious weaknesses became apparent, while others were given significant study before they were either eliminated from consideration or singled out for detailed study. The following section contains a brief description of all of the concepts for disposal or use considered

by the Army in order to serve as a consolidated reference. Those concepts which have been singled out for final consideration are presented in detail in Section III-C.

1. Sale and Recycle by Industry

The ideal method of disposal for demilled GB and mustard residues is industrial recycle. This method was considered, for it was thought that the residues could be used productively by industry instead of being destroyed. Many industries were considered and some were contacted, but most were unwilling to use these residues. Their reluctance is explained by three major problems:

- the relatively small amount of material to be used for a one-time event;
- the complex mixtures of the salts;
- the high corrosiveness of the salts.

A few thousand tons of material is a small amount when it is compared to the amount used in many industries. These industries were usually unwilling to adjust their processes unless a long-term, continuous supply of raw materials were available. The cost of engineering and operating labor for the adjustment would be greater than the profits derived from the use of the demilled salts. Additionally, the residue from the demilled salts usage could cause severe disposal problems.

Each of the demilled salts contains highly corrosive salts, i.e., sodium fluoride in the GB salts and sodium chloride in the mustard salts. Many industries were extremely reluctant to use these materials because of this corrosivity.

a. GB Salts

Some of the industrial applications considered for the GB salts in their unmodified form were:

1) Fire Breaks in Forests⁽¹¹⁾

Unfortunately this method is a type of land dilution. Since there is a definite possibility of contaminating groundwater, the use of this method cannot be recommended.

2) Incorporation into Asphalt Paving⁽¹²⁾

The addition of GB salts to asphalt would weaken the asphalt structure. This weakening would cause a faster asphalt deterioration. There is also a possibility of the salts leaching into the groundwater.

3) Use in Brick Making⁽¹³⁾

A process developed by Tekology Corporation uses inorganic waste material in manufacturing bricks. Tekology Corporation was contacted but was not interested in using this particular waste. Their objections were:

- the amount involved was too small for brick making;
- the salt residues were too fine and uniform;
- the presence of organic material in the GB salts was undesirable.

4) Use in Wallboard⁽¹⁴⁾

The object was to change GB residues to calcium salts which could be mixed with the gypsum used in wallboard fiber. It was learned that this method could not be used because the wallboard would crumble if the sodium content of the gypsum or internal filler were greater than 0.05%. Also, the phosphorus in the GB salt would cause deterioration of the wallboard because oxygenated phosphorus ions would prevent the gypsum from hydrating properly.

5) Use in Manufacture of Plasticizers and Fire Retardants⁽¹⁵⁾

It was felt that the phosphonates in the GB salts could be used in plasticizers or fire retardants. However, the fluorides would be detrimental to the process and would have to be removed. As will be shown later, only about 60 - 80% of the NaF could be filtered from the mixture and the cost would be high. Therefore, this option was dropped from further consideration.

6) Encapsulation of Residues in Clay Aggregates⁽¹⁶⁾

It was suggested that GB residues could be encapsulated in clay aggregates which are used primarily for lightweight concrete. However, this option was found to be unsuitable because P_2O_5 would be formed during the required nodulizing process and its removal would be too costly to make the process economical.

7) Recovery of the Phosphorous⁽¹⁷⁾

Recovery of the elemental phosphorous by burning the residues as raw feed in phosphorous nodulizing kilns was considered by Monsanto Research Corporation, and many phosphorous producers were contacted. By burning the GB salts in nodulizing kilns, they would be reduced to CO_2 , HF, H_2O , and elemental phosphorous. However, several problems existed with this application, one of which was the size of the dried salt particles. Nodulizing kilns work best with large chunks of material. Small salt particles would be "dusted" out of the kiln before the phosphonates could be broken down. Of the phosphorous producers contacted, the following responses were typical.

- Monsanto Corporation - Plant personnel were reluctant to accept the material because of their kiln working process and the likelihood that some of the salts would pollute the nearby river. Notoriety from previous pollution problems made them very sensitive to possible sources of pollution.
- Tennessee Valley Authority (TVA) - TVA would not accept the salts because of the high NaF content.
- Electrophos - The company owner did not want the material because of the possible ecological ramifications.
- Stauffer Chemical Company - Negative response.
- Mobil Chemical Company - The amount of salts at RMA represented about 1.5 times the total annual production of this small company and they were not interested.
- FMC Corporation - This company has a secret process and was not interested; perhaps because they felt that their proprietary process would become known.
- Hooker Chemical Co. - They did not want the salts because of problems created by the handling of secondary residue from their process.

All in all, the use of the GB salts for industrial phosphorous feed stock was rejected by the industry and the option was given no further consideration.

8) Removal of Sodium Fluoride by Filtration

Sodium fluoride filtered from the salts could be sold as a raw material. This option was given particular consideration as an addition to the incineration concept in order to eliminate possible corrosion problems. A study was undertaken by Monsanto Research Corporation to assess the economic and technical feasibility of the technique.⁽¹⁸⁾ They showed that the separation cost would be on the order of \$1.30 - \$3.33 per pound to produce dried NaF. Because the market value is on the order of 15 - 20 cents/lb., the concept is not economically viable. In addition, the filtration is not complete and enough NaF would be left in the salt to cause possible corrosion problems during incineration. For these reasons the idea was dropped from additional consideration.

9) Electrolytic Degradation⁽¹⁹⁾

Electrolytic degradation was an idea examined briefly by the Monsanto Company on the basis of some Russian studies done with this

process. In the Russian process, alkali metal methylphosphonates were decomposed electrolytically to CO_2 and phosphoric acid in strong caustic (48%) with a platinum electrode.

Monsanto suggested that other types of electrodes could possibly be used. After unsuccessfully testing other electrode materials on samples of the demilled GB salts under various conditions, it was concluded that the platinum electrode would have to be used. Even though the initial cost of the platinum electrode would be very expensive, it appears that the platinum could be resold after the degradation was completed. Further investigation would be needed to study the economic and technical feasibility of using this disposal method. Because it is beyond the current state of the art, it was not given detailed consideration.

b. Mustard Salts

1) Use as Deicers on Highways (20)

Rocky Mountain Arsenal contacted the Colorado State Department of Highways concerning the possibility of using detoxified mustard salts as a deicer on mountain highways and roads. According to a letter received by RMA from Colorado State Department of Highways dated October 17, 1973, the sodium sulfite in the mustard salts would damage concrete pavements and concrete bridge decks, so this option was eliminated.

2) Use as Brine in Ice Manufacturing (21)

It was proposed to use the mustard salts instead of sodium chloride as a brine in ice manufacturing. However, the piping system, especially the heat exchangers, needs occasional flushing and the waste water from the flushing would contain dissolved mustard salts. Without special containment or treatment, the mustard salts would eventually enter the environment and therefore this method of disposal could not be considered.

3) Use in Chlorine Manufacture (22)

Monsanto Company and Vulcan Materials were contacted about the possibility of using mustard salts in manufacturing chlorine. Both manufacturers agreed that using mustard salts in the process would cause process and disposal problems.

4) Use in Dyeing Cow Hides

The idea of using mustard salts in the leather dyeing operation was considered and the "42 Products Company" was contacted. However, RMA learned that using mustard salts for dyeing cow and sheep hides would cause a reddish color to appear. This discoloration would prohibit the use of mustard salts for this purpose.

5) Use in Papermaking

Use of mustard salts in pulp and paper manufacturing was considered but had to be eliminated. A letter from Saltcake Sales Corp. dated April 9, 1974 indicated that the high sodium chloride content of mustard salts makes them unsuitable for use in the pulp and paper industry.

6) Extraction of NaCl from Mustard Salts

Most industry representatives contacted indicated that if the sodium chloride could be removed from the mustard salts, numerous methods of disposal or use of the remaining compounds could be found. Various techniques were examined and were very briefly discussed by Monsanto Research Corporation.⁽²³⁾ Elimination of the following options was based exclusively on Monsanto's analysis and recommendation. They are summarized below, merely for convenient reference.

Calcining to $\text{Na}_2\text{SO}_4/\text{Na}_2\text{CO}_3$

This method is neither practical nor applicable for 4000 tons of a mixture of inexpensive common salts. The costs of developing, constructing, and operating this process is extremely high. There is also a danger of air pollution.

Conversion to Calcium Salts and then Calcining

The idea was to treat mustard salts with calcium hydroxide as a way of removing the sodium chloride from the mixture with an inexpensive re-agent. Detailed calculations were performed and the results suggested that the method could be reasonably complete, but laboratory tests showed that the process was incomplete.

Treatment with Sulfuric Acid

It was learned that an expensive pre-treatment process step would have to occur before the sulfuric acid treatment and a large quantity of spent sulfuric acid containing salt impurities would arise in this method.

Removal of Chloride Ion by Ion Exchange

Complete removal or removal of the majority of the chloride ion by ion exchange from a solution containing divalent anions is not possible with the present state of the art.

Fractional Crystallization in Water-Organic Systems to Remove Sodium Chloride

Fractional crystallization from organic-water systems would be very difficult even under ideal conditions.

Separation by Density or Flotation Process

The separation technique depends upon a large difference in density between substances, but sodium chloride has only a very slight difference in density from the other constituents of the mixture. Some of the sodium chloride would be separated but it would be highly contaminated.

Molten Phase Separation

The idea was to cause the sodium chloride to slag, whereupon it could be tapped. The slagging process would only separate the sodium chloride in 75% pure form. In addition, this method would require large amounts of energy and a significant difference in density.

Froth Flotation

This method also requires significant differences in densities of the salts. Very little separation of sodium chloride would occur by froth flotation.

Electrolysis

Converting the sulfites in the mixture to sulfates and the sodium chloride to sodium hypochlorite by the use of electrolysis was considered. Chlorine gas could be obtained from the solution. However, the sulfate and carbonate content would create disposal problems that industrial users did not want to contend with. Because the products were not salable to industry, the concept was eliminated from consideration.

2. Ocean Dumping

Ocean dumping of waste material is closely regulated. The Marine Protection Research and Sanctuaries Act of 1972 (PL 92-532) emphasizes the restrictions placed on wastes disposed in the ocean. Industry has used ocean dumping for the disposal of chemical wastes in the past, but proposed legislation may severely restrict or eliminate future use of the ocean as a disposal sink.

a. GB Salts

The study of the GB salts indicated that the toxicity of the salts is low enough that ocean dumping appears to be a possible disposal option.⁽²⁴⁾⁽²⁵⁾ However, the average cadmium concentration is above the permissible value of 0.60 mg/kg. The estimated concentration of cadmium for the GB salts is 1.24 mg/kg.

An interim special permit could be obtained if there were no feasible present alternative to ocean dumping, but obtaining this permit would be difficult, costly, and time-consuming. The regulations require that certain conditions must occur before issuing an interim special permit. One of these

requirements is an "assessment of the degree of treatment feasible to meet the standards and the development and active implementation of a plan to either eliminate the discharge to the ocean or to bring it within the limits of the criteria in the regulations."⁽²⁶⁾ In addition, costly public hearings would be necessary to obtain an interim special permit. Nevertheless, the fact that a permit may be obtainable and because there are some advantages to ocean dumping, this technique was given detailed considerations in Section III-C.

b. Mustard Salts

A study performed by the U.S. Army Environmental Hygiene Agency (AEHA)⁽²⁷⁾ concluded that the mustard salts were significantly toxic to fish and marine life. The study also showed that mercury and cadmium concentrations in the mustard salts exceeded the maximum allowable for waste disposal under PL 92-532 and indicated that the U.S. Environmental Protection Agency would probably not grant a permit for ocean dumping. AEHA recommended that mustard salts should not be ocean dumped because of the significant toxicity of mustard salts to marine life. For this reason, ocean dumping of mustard salts was dropped from consideration.

3. Ocean Floor Burial

An advanced state-of-the-art concept that received consideration is that of burying the waste salts beneath the ocean floor. An unsolicited proposal outlining the concept was received from Global Marine Development, Inc., of Los Angeles, California.⁽²⁸⁾ The basic concept consists of using a deep sea drilling vessel such as the Glomar Challenger to drill a large-diameter hole (4 - 6 ft.) several hundred feet into the sediment and/or bedrock of an "abysmal basin" on the ocean floor, emplacing the salts, and sealing off the hole. The waste salts could be either encapsulated and simply placed in the hole, or they could be diluted as a brine solution and injected into a porous rock layer similar to a surface deep well injection operation.

The concept has some attractive advantages. Because the burial site would be on the order of 20,000 feet below the ocean surface, there would be virtually no biologic, geologic, or oceanographic activity to upset the long-term stability of the location. The extremely isolated area is safe from human contact and there is no danger to consumable water supplies, but later retrieval of the wastes is possible if desired. The abysmal basins are virtually sterile areas free of life or usable minerals and thus can serve as a dumping ground that would not deplete potentially valuable surface land sites.

Despite the potential safety advantages of the ocean floor burial concept, the probable costs and technical problems detract from the appeal of the system. Although the scientific feasibility of the concept has been illustrated through analysis and the previous extraction of ocean floor core samples, the engineering feasibility of drilling large diameter holes and the emplacement/injection process itself remains to be proved. No firm cost estimates were given for the actual development and operation, but a rough estimate for final operation of \$300 per ton was given during a presentation to Edgewood Arsenal (see Appendix H

This translates to a cost of over \$3.3 million for the RMA salts and does not include feasibility studies, development costs, or contract support costs which are estimated to exceed \$1 million. The highly speculative nature of these costs tends to reduce confidence in the system even more.

It is conceivable that as future waste disposal laws become more stringent and land-based disposal areas become more limited, ocean floor burial operations may be established as a large scale commercial operation to support the chemical process industries. In this event, the engineering technology may become better established and the costs may become significantly lower which could make this type of disposal attractive for government wastes generated in the future. However, the current proposed costs and development uncertainties make the concept unsuitable for the existing RMA salts and the idea was dropped from extended consideration.

4. Landfills

a. Sanitary (ordinary) Landfills

Unfortunately, the term landfill often refers to a sanitary or ordinary landfill. Such sites have been used for years for the dumping of garbage, trash, and some types of industrial wastes. These operations do not control leachate and although this type of landfill may be satisfactory for household wastes and some insoluble industrial wastes, its use for the disposal of the RMA waste salts would be totally out of the question.

b. Chemical Waste (California Class I) Landfills

A chemical waste ("controlled") landfill is one in which the disposed material is prevented from entering the surrounding groundwater by using barriers of impermeable materials. Contamination is contained by using impervious material such as clay, rubber, asphalt, concrete, and plastics - especially Hypalon and polyvinyl chloride. Leachates may be collected by using underground pipes and re-cycled through the landfill or sent to a special treatment plant for final disposal.

Some chemical waste landfills are owned and operated by chemical process companies to dispose of their own wastes but many are owned as separate companies that accept wastes on a contract basis. Chemical landfills present a very convenient, ecologically sound alternative for both GB and mustard salts and are discussed in greater detail in Section III-C.

5. Encapsulation Landfill

If the waste salts could be encapsulated in an inert, impermeable matrix, the rate of pollution released to the environment could be reduced or eliminated entirely and ordinary sanitary landfills could be used for disposal. This concept is used for certain types of particulate wastes scrubbed from flue gases produced by some industrial processes. Some inquiries were made about commercial fixation techniques and some studies were performed but the results

only showed that the concept is not practical with current technology. They are summarized below.

a. GB Salts

1) Disposal in Kiln Dust Cement

The encapsulation of GB salts in kiln dust cement was considered as one of the potential, economically feasible methods for disposal because many cement companies dispose of an average of 100 tons of kiln dust per plant per day.⁽²⁹⁾ This disposal process is accomplished by adding water to the kiln dust, and pumping the mixture into the mining pits where it cures to a concrete-like substance.

Some tests were run by the Portland Cement Association to determine the effects of encapsulating GB salts in various cement mixtures.⁽³⁰⁾ They found that:

- GB residue salts could be added to Type I clinker (55 - 60% C_3S , 16 - 18% C_2S , 10 - 12% C_3A , 7 - 9% C_4AF) in amounts up to 23 - 30% without drastically altering the hydration characteristics of the cement.
- The GB salts had to be acidified to a pH of 10.2 before addition to the clinker to prevent undue retardation of hydration.
- Encapsulation in some cement mixtures caused dimensional instability and excessive expansion.
- Encapsulation did not prevent phosphonate leaching from encapsulated salts.

Based on these results, the use of a cement type matrix cannot be considered for encapsulation.

2) Chemical Fixation

There are companies which provide commercially available fixation processes. One of these companies is Chemfix, Inc., of Pittsburgh, Pa. The Army sent Chemfix two samples of GB salts, one containing sodium fluoride and one without. A letter dated April 7, 1975 from Chemfix said that the demilled GB salts were not compatible with their solidification process. (See Appendix C.)

3) Other Encapsulation Methods

There may possible be other materials such as plastics or glass in which GB salts could be encapsulated for final disposal. Although consideration of these materials is beyond the scope of this study, it is recommended that they be investigated with respect to future disposal problems.

b. Mustard Salts

At the present time, there have not been any studies done for disposing of mustard salts by an encapsulating method.

6. Deep Well Injection

This method involves pumping the wastes into deep wells where they are contained in the pores of permeable subsurface rock, separated from other groundwater supplies by impermeable layers of rock or clay.

The deep well disposal method would require an extensive investigation prior to disposal. The information needed may include maps of the hydrology of the area showing potable water wells, locations of other minerals, fracturing, porosity and engineering details of a proposed well such as type and size of casing, injection procedures, temperature of the material to be injected, and pressures expected.

Deep well disposal has been a State Government responsibility. The Federal Government has been generally inactive in control of groundwater quality, although the EPA has published strong guidelines concerning deep well disposal. Only a few states have specific statutes concerning deep well disposal while some others have regulations concerning industrial disposals which may be used for deep well disposals.

The U.S. Army owns two deep wells but both are out of operation. One is at Rocky Mountain Arsenal and the other is at Newport Army Ammunition Plant. The well at RMA was closed after several years of operation following controversy about the possible relation between deep well injection and earth tremors in the surrounding area.⁽³¹⁾ The Newport Well was closed down after nine years of successful production. This well could be used again because the permit for operation is in good standing and the well is in good physical condition.

Although the technical and economic factors are favorable, deep well injection is not highly desirable as a method for disposal of GB and mustard salts because of negative opinions expressed by environmental and regulatory agencies. The EPA policy has been to consider subsurface storage capacity as a scarce and valuable natural resource and to oppose deep well injection unless all other surface disposal alternatives prove less satisfactory.⁽³²⁾ First of all, there is a possibility of the groundwater being contaminated as a result of the wastes not being contained between impervious boundaries. Secondly, there are few ideal locations for injecting hazardous wastes and State and Federal Governments will only authorize their use when there are no other alternatives. Inasmuch as the Army feels that there are other alternatives and does not want to oppose EPA guidelines, this concept was dropped from consideration.

7. Incineration

a. GB Salts

1) Incineration at Rocky Mountain Arsenal

This method has the advantage that the GB salt remains under U.S. Army jurisdiction during the complete process with incineration residue being landfilled. In addition, transportation costs would be negligible. Because this is such an attractive option, it was subjected to further consideration. A more detailed discussion can be found in Section III-C.

2) Molten Salt

A feasibility study was undertaken by Rockwell International to evaluate the possibility of using the Atomic International Molten Salt Combustion Process to incinerate GB salts.⁽³³⁾ Bench scale tests were performed which demonstrated that the GB salts could indeed be processed successfully. However, there is currently no plant using this process on a scale large enough to be practical. One of the advantages of the molten salt process is that the sodium-carbonate-containing-melt used serves as an automatic scrubbing medium. A big disadvantage is that the volume of residue produced from the process would be larger than the initial volume of GB salts.

A cost estimate for developing a plant large enough to process 1000 lb/hr is on the order of \$1.8 million. This cost does not include the actual disposal operation which could be on the order of three times that of incineration in the RMA bulk furnace because the feed rate is about one third that of the proposed RMA operation. It also does not include transportation and contract support costs. Development of a full scale molten salt incineration plant could be on the order of \$1.5 - 2.0 million greater than that of the RMA bulk furnace process. For this and other reasons, this technique was dropped from current consideration.

b. Mustard Salts

An incineration disposal method is not feasible for mustard salts because of their inorganic composition.

8. Mines and Deep Geological Formation

A ground burial disposal method at or near the surface cannot always be accomplished, particularly in regions with unfavorable geological conditions and/or with a high water table. For these regions other disposal methods must be found for waste disposal, and the possible use of abandoned or deep geological formations has certain advantages.

Mines and geological salt formations have been investigated and are being prepared for use in Europe. For example, West Germany is preparing to convert underground rock salt formations into a permanent dump for highly radio-

active nuclear waste.⁽³⁴⁾ The watertight rock salt formations are the safest method to prevent contamination of natural water reserves.

The feasibility of storing hazardous wastes in underground mines in the U.S. was studied by Fenix and Scisson, Inc.⁽³⁵⁾ In their report to the EPA, they concluded that such storage is environmentally acceptable provided that certain precautions relating to site selection, treatment, containerization, and waste handling are followed. They indicate that the design and operation of an underground storage facility is technically feasible and that possible locations for such facilities currently exist. However, they feel that additional research is needed to close existing knowledge and technology gaps, and that this research could cost from 2.3 - 3.2 million dollars. This figure only reflects research and does not even include the actual cost of disposal operations. Because of the knowledge gaps and because the total cost is on the order of twice the estimated total cost of some other disposal methods, this option was dropped from consideration under the scope of this program.

C. Proposed Options

1. Incineration of GB Salts at Rocky Mountain Arsenal

a. Basic Features

An ultimate disposal method for GB salts which has received considerable attention is incineration in one of the furnaces at Rocky Mountain Arsenal. By incinerating the GB salts, the phosphonates would be eliminated, thus reducing the total volume of the wastes. Also, the resulting residue could be treated with lime to form insoluble calcium salts which might be placed in sanitary landfills. Although there are other incineration methods and other furnaces available around the country, performing the operation at the RMA site eliminates the cost, time, and public visibility of transporting the salts outside of Army property.

One disadvantage of the concept is the generation of emissions that must be controlled. In addition, the incineration of the original salts is only a partial solution of the problem. Residues from the incineration must be treated and/or disposed of to complete the overall disposal.

• Equipment/Design Background

Two furnaces at Rocky Mountain Arsenal were considered by the Monsanto Corporation for incineration of the GB salts.⁽³⁶⁾ The bulk furnace was originally used to incinerate hydrazine and mustard liquids. This furnace uses a compressed air-liquid atomizer burner and was designed to burn about 35 gpm of hydrazine and 3 gpm of mustard. Two-ton container furnaces were used to vaporize and incinerate mustard agent remaining in ton containers. This was done by directly heating containers in which holes had been punched. The interior of the ton container furnaces is 4 ft. 3 in. wide by 6 ft. high by 20 ft. 3 in. long. Burners which consume about 200 CFM of natural gas are placed along the furnace walls.

The ton container furnaces and the bulk furnace tie into two existing off gas scrubbing systems. They can be used alternately or in parallel. The older of the two scrubbing systems consists of a quench chamber containing four levels of eight spray nozzles each to cool the incoming furnace gases and an eight-foot diameter packed countercurrent scrubber. The re-circulating scrubbing liquid is caustic soda solution in which the pH is adjusted manually to maintain alkalinity. The furnace gases are conducted to the bottom of the scrubber via a 26-ft. long duct containing spray nozzles to help prevent plugging, and exit from the top. The newer of the two scrubbing systems is similar to the older design except that the height of the quench tower has been increased to 10 feet to accommodate an extra row of eight spray nozzles; a modification has been made in the scrubber packing; and the pH of the scrubber liquid is maintained automatically. For a more detailed description of the existing furnace and scrubbing systems, refer to Appendix A.

b. Process Description

An analysis was undertaken by Monsanto Corporation to assess the limiting factors of the two furnaces and their applicability to incinerating the GB salts with respect to such items as heat release, residence time, flame pattern, refractory stability, combustion temperature and excess air.⁽³⁷⁾ Results were based on past incineration practices with mustard agent and hydrazine and are discussed in detail in Appendix A.

The basic modes of GB salt incineration considered for the two furnace systems were:

- Ton container; batch feed of dried salt in either powder or compacted lump form;
- Bulk furnace; continuous feed of pulverized salt;
- Bulk furnace; continuous feed of brine resulting from the neutralization process

Because all of the salts considered for this study have already been dried and placed in storage, the third mode would require an extra step in re-dissolving all of the salts. The only advantage to be gained by re-dissolving the salts is that it would permit the separation and salvage of some of the NaF contained in the salt mixture. However, it will be shown later that this separation is not economically or operationally worthwhile and therefore the use of brine solution for the incineration process has been dropped from further consideration.

Design of the ton container furnaces would require that the dried salts be fed batch-wise in long pans or continuously on a moving grate. A problem with the use of pans is that of supplying enough oxygen to the salt below the surface. The dried salt could not be piled very deeply in the pans because ash formed on the surface would prevent oxygen from getting through to the bottom, resulting in incomplete incineration. As a result of incineration, a molten NaPO_3 - NaF glass would remain in the pans which would have to be

removed with special handling equipment. There is also the possibility that some unburned salts would remain in the "glass." The use of grates to carry the dried salt material would aid incineration by allowing oxygen to flow up through the dried salts or molten material formed during incineration would fall through the grates. Installation of catch hoppers would involve initial rebuilding of the furnaces. For these reasons, consideration of the use of the ton container furnaces was dropped, leaving incineration of the dried salts in the bulk furnace as the recommended option.

Using their own computer program, Monsanto calculated the heat of combustion of the dried GB salts to be 5981 BTU/lb. (38) This value was used to determine the rate at which the salts could be burned without exceeding the design limits of the furnace or create other problems. For example, a flame temperature of 1800°F was set as a maximum because the melting point of NaF in the salt is 1817.6°F. If the temperature in the furnace reached this point, the refractory lining could become coated with a highly corrosive molten slag. Various salt feed rates and air supply rates sufficient to maintain a temperature below 1800°F were considered. From the standpoint of heat input and residence time for salt particles in the furnace, a feed rate of up to 100 lb/min could be maintained. However, in order to keep the gas flow rate through the scrubbers low enough to assure efficient cleaning, the feed rate would have to be kept lower. The older scrubber system could handle a feed rate of 37.5 lb/min and the newer scrubber system could handle a feed rate of 50 lb/min. If the scrubbers were operated simultaneously in parallel, a feed rate of 87.5 lb/min could be maintained but this was not recommended. A conservative value of 50 lb/min was suggested because it represents a safer level for the furnace. An overall heat and material balance for a feed rate of 50 lb/min (3000 lb/hr) is shown in Table 1.

Materials which would have to be removed from the incineration gases are P_2O_5 gas and smoke; HPO_3 , H_3PO_4 mist from partial or complete hydration of P_2O_5 ; Na_2O , $NaPO_3$, Na_2CO_3 , and NaF dust; and HF gas. The most difficult to collect are P_2O_5 smoke, partially hydrated P_2O_5 acid mist, and HF gas. From design calculations based on a feed rate of 50 lb/min, it was estimated that a liquid recirculation rate of about 230 gpm would have to be maintained in the scrubber. Approximately 94% of the P_2O_5 would be collected but the remaining P_2O_5 acid mist would corrode the existing static precipitator. The problem could be solved with the installation of a high efficiency mist eliminator between the scrubber and precipitator. It is felt that at least 99.7% of the fluoride in the form of HF would be absorbed in the scrubber as long as the pH of the scrubbing solution were maintained between 7.0 and 8.0. For more details see Appendix A.

All of the engineering calculations are based on the assumption that the SIMP would be oxidized to P_2O_5 and Na_2O in the 1800°F flame and that NaF will either remain as solid airborne NaF particles or will react to form HF and Na_2O . However, the high temperature chemistries could cause the P_2O_5 and Na_2O to react and form molten $NaPO_3$ which could settle on the refractory walls and cause corrosive slagging problems. Also, if the temperature exceeded 1817.5°F, the NaF in the salt could be liquified and the highly corrosive salt

Table 1. Operating Conditions for Bulk Furnace
Using Solid Detoxified GB Salt Firing

Fuel rate:	neutralized GB salt	50 lb/min
	SIMP	38.5 lb/min-0.2405 lb.mol/min
	NaF	11.5 lb/min-0.2738 lb.mol/min
Theoretical combustion air:		9.162 lb.mol/min (3289 scfm)
	O ₂	1.924 lb.mol/min
	N ₂ & inerts	7.238 lb.mol/min
Excess air:		10.911 lb.mol/min (3917 scfm)
Percent excess air:		119%
Heat released (@ 25°C) from burning detoxified GB salt:		17,944 Btu/hr
Combustion product temperature:		1800°F (982°C)
Combustion products:		
Quantity & Composition:		
	scfm	7,400
	acfm @ 1800°F	34,000
	CO ₂	0.962 lb.mol/min
	H ₂ O	1.2025 lb.mol/min
	Theory N ₂	7.238 lb.mol/min
	Excess air	10.911 lb.mol/min
	NaPO ₃	0.2405 lb.mol/min
	NaF	0.2738 lb.mol/min
		20.8278 lb.mol/min
Sensible heat content of combustion products above 20°C:		
	CO ₂	1,187,100 Btu/hr
	H ₂ O	1,147,200 Btu/hr
	Theory N ₂	5,645,000 Btu/hr
	Excess air	8,602,200 Btu/hr
	Na ₂ F	372,900 Btu/hr
	NaPO ₃	989,000 Btu/hr
		17,944,000 Btu/hr
Adiabatic saturation temperature of combustion products:		80.1°C

Source: Hedley, W. H., et al; "Disposal of Detoxified Chemical Agents"

could adhere to the refractory walls. Consideration was given to removing the NaF prior to incineration. However, a separate study by Monsanto showed that only about 60-80% of the NaF could be filtered out.⁽³⁹⁾ This would leave 20-40% which would still present a significant corrosion problem. In addition, the least expensive separation technique which also allows for depreciation and a 75% salvage value for equipment, places a cost of \$1.21/lb to separate the NaF. For 1,512,000 lbs that could be recovered, this represents a cost of \$1.83 million. The estimated market value of NaF is 15-20 cents/lb, leaving a net increase in overall cost due to the separation option of over \$1.5 million. Based on this data, the separation of NaF could not be justified from a cost or corrosion elimination standpoint and it was dropped from consideration. However, Monsanto recommended a more complete operation and control study based on bench scale tests.

Pilot tests of incineration of neutralized GB salts with NaF removed were performed at Edgewood and reported by Cavey.⁽⁴⁰⁾ The tests were designed to incinerate NaF-free pulverized dried GB salts in a system that would simulate the bulk furnace at RMA. The purposes were to determine:

- 1) if the phosphorous-carbon bond could be broken;
- 2) if agent GB would be reformed from residual NaF during the incineration;
- 3) if the products of the combustion, e.g., NaPO_3 , condense on and react with the fire brick and cause slagging;
- 4) salt deposits in the furnace in general.

The results showed that:

- SIMP destruction efficiency was 98-99%.
- No organic phosphorous was detected in deposits on furnace walls.
- No GB agent was detected in effluent streams.
- Considerable salt deposits were found on the wall opposite the feed nozzle. These were found to be orthophosphate.

A test brick suspended in the furnace to collect deposits was sent to Monsanto Corporation for analysis and slagging determination. Based on preliminary results from Monsanto, the removal of NaF is not cost effective. These results along with those of additional bench scale tests using GB salts containing their full complement of NaF should be considered before making any decision to utilize the RMA furnaces for incineration of GB salts.

c. Proposed Operation

A flow chart of the proposed operation is shown in Figure 1. Pulverized dried whole GB salts would be fed to the RMA bulk furnace at a rate of 50 lb/min. The feed rate and air supply would be closely controlled to maintain a flame temperature below 1800°F to prevent slagging problems from molten NaF. Removal of the NaF prior to incineration is very expensive and does not eliminate the corrosion and emission problems. It is therefore not recommended. Predicted combustion products of P_2O_5 , Na_2O , Na_2CO_3 , NaF, and HF would be eliminated with the existing packed bed scrubbers, high efficiency mist eliminator and electrostatic precipitator. No air pollution would result because the predicted overall emission recovery is 99.9997%⁽⁴¹⁾. The incineration residue would be treated with lime (calcium hydroxide) to make insoluble land-fillable compounds which would present no soil or water pollution.

The costs for modification of existing equipment, procurement of required additional equipment, and variable costs based on a feed rate of 50 lb/min are presented in Appendix A. A summary of the overall costs to incinerate approximately 8K tons of GB salts is as follows:⁽⁴²⁾

Pilot Scale Testing of Design Concept	\$ 150K
Prepare Contract Scope & Coordination for above	10K
Design Criteria for Production Equipment	20K
Design Contract for Production Equipment	20K
Modification and Installation & Capital Equipment	1,100K
Run-in of Full Scale System	100K
Production Disposal, including disposal of ash or scrubber sludge	400K
Prepare Addendum to M34 EIS	40K
	\$ 1,840K

d. Status

The incineration of the GB salts at RMA is a viable theoretical option although many factors would have to be proved or verified by bench scale tests before modification design factors could be firmly established. Because there are many areas of design and operation that are uncertain and because the costs involved are largely theoretical estimates without basis in actual performance, development of an incineration plant presents a riskier approach than some other disposal techniques.

2. Chemical Waste Landfill; GB and Mustard Salts

a. Basic Features

For years, landfills have been used as a means of disposing of many types of waste materials, including an increasing quantity of hazardous wastes. Because of the pollution danger created by hazardous wastes, restrictions on the types of landfills used for disposal have been developed. Up until now, land-based hazardous waste treatment, storage, and disposal activities have been

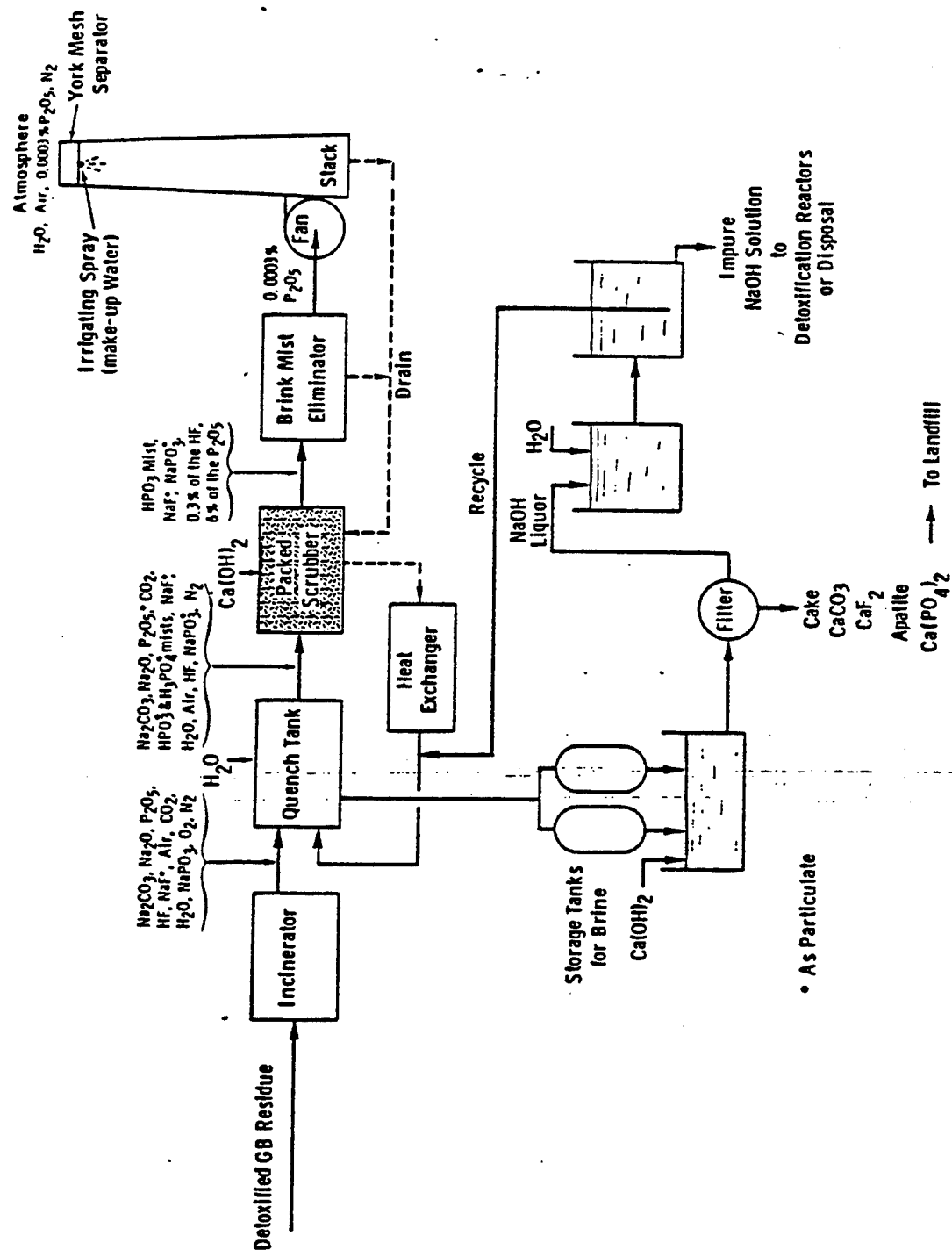


Figure 1. Flow Sheet for Incineration of Detoxified GB Residue at RMA

Source: Hadley, W. H., et al; "Disposal of Detoxified Chemical Agents"

essentially unregulated at the federal level except for radioactive and pesticide wastes. At the state level, Oregon, California, New York, and Minnesota have enacted hazardous waste legislation and rigid federal legislation is pending. These regulations have created the need for "chemical waste" landfills. By design, chemical landfills "provide complete long-term protection from hazardous waste deposited therein, and against hazards to public health and the environment."⁽⁴³⁾ The sites are engineered to prevent direct continuity with surface and subsurface water. Leachates may either be contained by natural or artificial impervious barriers or may be collected in sumps and recycled through the landfill. Test wells around the boundaries of the landfill site are used to monitor for seepage and leachate so that if any problems do develop, they can be corrected before they cause environmental damage. Wastes may be segregated in the landfill or encapsulated in some manner to prevent reactions with each other.

Under current laws, chemical landfills must be licensed by the state in states which have land solid waste disposal laws. Proposed federal legislation would define regulated wastes and parameters for the operation of chemical waste landfills and require permits to operate. The permits could be granted at the state level as long as the state restrictions were as stringent as federal restrictions. In fact, there is a good probability that federal regulations will be based on existing laws of states such as California which have been forerunners in solid waste legislation. As an illustration, the criteria for a California Class I hazardous waste landfill are shown in Table 2.

In general, chemical waste landfills should take advantage of natural geologies, topographic, hydrologic, and climatic conditions wherever possible. Where necessary, engineering design must overcome natural drawbacks. General criteria which should be considered in evaluating a chemical waste landfill site are presented in Table 3. These criteria should be carefully examined because, in spite of careful engineering design, accidents may (and have) occurred. Union Carbide experienced some drainage problems during initial operation of their own chemical landfill.⁽⁴⁴⁾ Rollins Environmental Services experienced some holding basin failures using rubber and clay liners and had to switch to a Hypalon-over-concrete liner.⁽⁴⁵⁾ Examination of the past operating history of any chemical landfill operation's past history, reputation, and system of safeguards is essential. This is especially true with persistent waste materials that would extend the active life of any landfill and present problems many years in the future. For example, one waste disposal company discovered arsenic leaching into its monitoring wells after many years of service since 1953.⁽⁴⁶⁾ Because of the continuous testing, the problem was discovered and corrected before the contaminant entered the city water supply.

Table 2

Criteria for California Class I Landfill⁽⁴⁷⁾

(1) Geological conditions are naturally capable of preventing hydraulic continuity between liquids and gases emanating from the waste in the site and usable surface or groundwaters.

(2) Geological conditions are naturally capable of preventing lateral hydraulic continuity between liquids and gases emanating from wastes in the site and usable surface or ground waters, or the disposal area has been modified to achieve such capability.

(3) Underlying geological formations which contain rock fractures or fissures of questionable permeability must be permanently sealed to provide a competent barrier to the movement of liquids or gases from the disposal site to usable water.

(4) Inundation of disposal areas shall not occur until the site is closed in accordance with requirements of the regional board.

(5) Disposal areas shall not be subject to washout.

(6) Leachate and subsurface flow into the disposal area shall be contained within the site unless other disposition is made in accordance with requirements of the regional board.

(7) Sites shall not be located over zones of active faulting or where other forms of geological change would impair the competence of natural features or artificial barriers which prevent continuity with usable waters.

(8) Sites made suitable for use by man-made physical barriers shall not be located where improper operation or maintenance of such structures could permit the waste, leachate, or gases to contact usable ground or surface water.

(9) Sites which comply with (1), (2), (3), (5), (6), (7), and (8), but would be subject to inundation by a tide or a flood of greater than 100-year frequency may be considered by the regional board as a limited Class I disposal site.

Table 3

Chemical Waste Landfill Selection and Evaluation Criteria
From "Landfill Disposal of Hazardous Wastes:
A Review of Literature and Known Approaches"(48)

(1) Chemical waste landfills ideally should be located in areas of low population density, low alternative land use value, and low groundwater contamination potential.

(2) All sites should be located away from flood plains, natural depressions, and excessive slopes.

(3) All sites should be fenced, or otherwise guarded to prevent public access.

(4) Wherever possible, sites should be located in areas of high clay content due to the low permeability and beneficial adsorptive properties of such soils.

(5) All sites should be within a relatively short distance of existing rail and highway transportation.

(6) Major waste generation should be nearby. Wastes transported to the site should not require transfer during shipment.

(7) All sites should be located an adequate distance from existing wells that serve as water supplies for human or animal consumption.

(8) Wherever possible, sites should have low rainfall and high evaporation rates.

(9) Records should be kept of the locations of various hazardous waste types within the landfill to permit future recovery if economics permit. This will help facilitate the analysis of causes if undesirable reactions or other problems develop within the site.

(10) Detailed site studies and waste characterization studies are necessary to estimate the long-term stability and leachability of the waste sludges in the specific site selected.

(11) The site should be located or designed to prevent any significant predictable leaching or run-off from accidental spills occurring during waste delivery.

(12) The base of the landfill site should be a sufficient distance above the high water table to prevent leachate movement to aquifers. Waste leachability and soil attenuation and transmissivity characteristics are important in determining what is an acceptable distance. Evapotranspiration and precipitation characteristics are also important. The use of liners, encapsulation,

detoxification, and/or solidification/fixation can be used in high water or poor soil areas to decrease groundwater deterioration potential.

(13) All sites should be located or designed so that no hydraulic surface or subsurface connection exists with standing or flowing surface water. The use of liners and/or encapsulation can prevent hydraulic connection.

(14) In arid regions where the cumulative precipitation is less than evapotranspiration, water will not likely accumulate in the landfill or migrate through the soil. Under such conditions, leachate containment precautions (liners, etc.) will not be necessary unless the water table is high or large quantities of liquid wastes are disposed.

(15) Unless leachate generation or escape is prevented in some manner, such as by encapsulation, location in arid regions or naturally impermeable basins, or by immediate cover with an impermeable membrane to prevent infiltration, it will be necessary to line the basin with an impermeable membrane, collect the leachate in headers, and recycle it through the fill or pump it to an appropriate treatment facility.

(16) All liners, cover materials, and encapsulating materials must be tested or have known chemical resistance to the materials it will contain or might otherwise come in contact with. Ideally, such materials should have an effective life greater than the toxic life of the wastes they contain.

(17) Studies will be necessary to determine general site monitoring requirements. Hydro-geological monitoring will be required to detect routine and accidental releases of liquid effluents. A system of observation wells should be installed in aquifers around the site and concentrated in potential water and waste movement paths downgradient from the site. A monthly sampling frequently has been suggested by one source. Downstream monitoring stations and a bimonthly sampling frequency were suggested for surface streams in the site vicinity.

A list of some of the chemical landfills registered with their states or recognized by the Office of Solid Waste Management Programs (OSWMP) of the EPA are presented in Table 4. The list merely represent those companies that were discovered in literature surveyed. It is not all-inclusive and inclusion in the list is in no way meant to imply preference or special consideration for award of contract.

b. Process Description

Several commercial chemical landfill companies were contacted and visited by Edgewood Arsenal Disposal Engineering Division personnel in connection with the disposal of mustard salts. Information gained from these contacts is discussed below. Further information is included in Appendix E. These preliminary contracts were made for the purpose of gathering general operating information and are not intended to imply that any preference be given these particular companies or to exclude consideration of any other qualified waste management contractor.

• Chem-Trol

Chem-Trol Pollution Services in Model City, N.Y., uses a closed-loop type of waste maintenance system. The landfill is a sump with two layers of impermeable clay with a 30-mil welded seam chlorinated polyethylene (Hypalon) liner between the layers. Internal sumps collect leachate which is subsequently treated as required and recycled to the landfill. Chem-Trol has provided the Army with data concerning the leachate treatment process but they have indicated that it is proprietary information. Detailed information is not presented in this report but is available from Mr. Robert Epstein of Edgewood Arsenal.

Chem-Trol is licensed by the state of New York and registers all wastes with them. When a landfill area is filled, it is sealed with a clay cap and registered with the county. They take title to the wastes when they accept them and continuously monitor waste areas by drawing leachate from the internal sumps or standpipes.

Chem-Trol has indicated that they would take the mustard salts but not the GB salts. A trial run of 60,000 lbs (150 drums) of mustard salts is being processed by Chem-Trol under Contract DAAA15-75-M-2935. There is no indication that any problems have occurred.

• Wes-Con Inc.

Wes-Con of Twin Falls, Idaho owns a deactivated Titan Missile Site which has an underground storage capacity of 1.5 million cubic feet. Storage facilities are silos and vaults with side walls and floors of four to thirteen feet of steel reinforced concrete and 110-ton doors to cover the top. Wes-Con is licensed by the Idaho Department of Health and was originally founded to dispose of toxic chemicals and pesticides. It was given a permit on the basis of environmental impact studies that took into account the depth of the aquifer (up to 3000 ft), prevailing winds, wild life, population density, precipitation, and alternate land use.

Table 4

Some Private Commercial Hazardous
Waste Management Companies
(Not inclusive)

1. Rollins Environmental Service, Inc.
3208 Concord Pike
Wilmington, Delaware 19899
2. Chem-Trol Pollution Services, Inc.
P.O. Box 200
Model City, N.Y. 14107
3. Hyon Waste Treatment Services
Chicago, Illinois 60617
4. Conservation Chemical Company
Kansas City, Missouri
5. Nelson Chemical Company
12345 Schaefer Highway
Detroit, Michigan 48227
6. Wes-Con Inc.
Twin Falls, Idaho 83301
7. Nuclear Engineering Company Inc.
Box 156
San Ramon, California 94583
8. BKK Corporation
Wilmington, California 90744

The Army could place the already-drummed salts into the silos or the drums could be emptied and the loose salts dumped into the silos. The first approach would take up more storage space and hence cost more, but has a slight safety advantage because of the added "encapsulation" provided by the drums. The second approach would allow more efficient packing of the salts and salvage of the drums but would expose the salts to the silo walls. If no liquids or liquid wastes are allowed to enter the silo, there should be no problem due to corrosion of or leaching into the silo walls.

● Nuclear Engineering Company Inc.

Nuclear Engineering's Beatty Nevada site is a trench burial landfill leased from the State of Nevada. One section is for radioactive wastes and another for chemical wastes. Each trench is 35 feet deep x 500 feet long x 70 feet wide. The drummed salts would be placed in the trench and the trench mounded with earth to achieve a soil coverage of approximately 15 feet. Each trench is marked with a concrete monument as a record of the type and quantity of the material in the trench.

The site earns its classification as a chemical landfill because of a natural clay liner 180 - 200 feet thick and an annual rainfall of less than 2 inches. The water table in the area is more than 360 feet deep and the nearest civilization is more than 11 miles away. There are observation wells around the waste areas which are monitored once a month along with soil and air tests. Nuclear Engineering is licensed by the State of Nevada and has a 14-year record of safe operation.

Nuclear Engineering also has disposal sites at Robstown, Texas and Sheffield, Illinois. These sites could also be considered for disposal of the salts.

c. Proposed Operation

Use of a chemical landfill presents one of the simplest, most straightforward options. Drummed salts would be loaded on rail cars or trucks at Rocky Mountain Arsenal and transported to the landfill. The landfill company would take title to the salts and emplace them. Mustard salts in bulk storage at RMA may have to be drummed before shipment. Loading and drumming operations may be performed by Army personnel or contractors.

Because of the varieties of landfill operations it is not possible to say exactly how the salts would be handled. It would depend on the particular contractor. In fact, there is no reason to believe that all of the salts would necessarily have to go to the same landfill. Regardless of the landfill, certain precautions would be specified:

- isolation of the mustard and GB salts from other chemicals in the landfill and;
- isolation of the GB salts from adverse environments which could produce hazardous byproducts.

Costs for individual landfills would vary as a result of the different techniques employed. Likewise, there would be variations in transportation costs because the different locations of chemical landfills around the country. For purposes of this study, an average rate for landfill operations will be considered based on data obtained from several contractors (see Appendix E). Shipping costs are based on an average rate for rail shipment (Appendix E), and estimated total distance of 1300 miles (average) for Denver - L.A. and Denver - Buffalo, N.Y. Using an average emplacement rate of \$66/ton, a shipping rate of \$.0564/ton/mile, and estimated support costs supplied by Edgewood Arsenal, (49) the estimated costs for GB and mustard salt disposal by chemical landfill are:

GB Salts

Loading at RMA	\$ 100K
Transportation (average for 1300 mi.)	513K
Contract for controlled landfill	500K
Prepare, coordinate contract	50K
Prepare amendment to EIS	40K
Total	\$1203K

Mustard Salts

Loading at RMA	\$ 60K
Transportation (average for 1300 mi.)	308K
Contract for controlled landfill	300K
Prepare, coordinate contract	20K
Prepare amendment to EIS	40K
Total	\$ 728K

d. Status

The use of chemical landfills is a prime candidate for disposition of the waste salts because of its short-term availability; relative low cost, acceptance by state, local, and federal regulatory agencies; and built-in ecological safety features. In fact, the use of a chemical landfill may be the only economical disposal technique for mustard salts within the current operational state of the art. However, there are some questions and unknowns associated with the chemical landfill disposal option that require further definition. These include such items as:

- verifying that enough chemical landfill contractors will accept the GB salts in significant quantities. (many have already agreed to accept the mustard salts)
- determining the necessity of drumming mustard salts in bulk storage vs. shipping loose salts

- disposition of drums (emplaced in landfill or recovered for scrap)
- determining the need for any special handling in transport or temporary storage

3. Ocean Dump - GB Salts

a. Basic Features

Dumping of chemical wastes into the ocean is a disposal technique that has been employed by the chemical process industry for many years. Because the demilled agent salts are highly soluble and many of their constituents are similar to those in ocean water, releasing them into the ocean appeared to be a very simple and economical disposal technique. The salts would be shipped via rail to an ocean port where it would be turned over to a private dumping contractor. The contractor would then proceed with the dumping operations according to government specifications and regulations. However, federal legislation enacted in the past few years has severely restricted ocean dumping practices and reduces the straightforward simplicity of the system.

Ocean dumping is regulated by the Federal Water Pollution Control Act, Water Quality Improvement Act of 1970, Federal Water Pollution Control Act Amendments of 1972, and Marine Protection, Research, and Sanctuaries Act of 1972. The Marine Protection, Research and Sanctuaries Act forbids the dumping of any material in the ocean (except dredged soil which is controlled by the Corps of Engineers) without an EPA permit. Certain materials such as chemical warfare agents and radioactive materials, are absolutely prohibited. Some, such as cadmium and mercury are prohibited in all but trace quantities specified by regulation. Others, such as inorganic fluorides and organic phosphorous compounds require special care and the proof that they will not cause harm to marine life based on bioassay tests. Because of the nature of the compounds comprising the waste salts, an interim special permit would be required. This type of permit would be granted in the case where no other feasible alternatives were currently available.

b. Process Description

Preliminary bioassay tests were performed by the U.S. Army Environmental Hygiene Agency to determine if the wastes would be safe to ocean dump. (50) (51) The mustard salts were found to be significantly toxic in concentrated form. In addition they had a cadmium content on the order of 26 times greater than the minimum allowed by the EPA and a mercury content about 40% over the limit. It was felt that these conditions would be too severe to grant an interim special permit. The GB salts could be toxic in concentrated form but dilution to 4.5 mg/l in the dumping zone would prevent harm to the algae, fish and shrimp examined in the preliminary bioassay. The only metal component that is above the allowable trace concentration is cadmium. However, the average of all the lots of GB salts sampled is only about twice the allowable limit and it is felt that this is not too extreme for the granting of a special interim.

permit. In fact, by singling out the few production lots with very high cadmium levels for special handling and disposal, it may be possible to bring the overall average cadmium level for the remaining quantity closer to the regulatory limit. This idea was tested with the sample analysis done by AEHA which is representative of 50% of the GB salts. (Appendix D) In this sample distribution for example, lot #39 accounts for only 3.91% of the total quantity of salts but because of the high cadmium level, accounts for over 50% of the cadmium. Revised overall cadmium levels were estimated by eliminating selected lots from the distribution (Appendix D). By eliminating lot numbers 26, 30, 33, and 39 (about 5% of the total), the average cadmium concentration would be reduced to .67 mg/kg, very close to the EPA limit. If lot numbers 8, 9, 10, 26, 27, 30, 33, 35, 38, and 39 were eliminated (approximately 12% of the total), the average cadmium level would be reduced to .49 mg/kg. The eliminated lots could be given special handling, e.g., placed in a chemical landfill. Before any decision could be made concerning the segregation of certain production lots, an analysis of a sample distribution representative of all of the salts would be necessary.

Several towing and dumping services were contacted by the Army to determine if they would accept the task and to obtain cost estimates. Some indicated that they had the equipment to handle the waste salts. It was assumed that those accepting the job would comply with all dilution specifications and regulatory requirements.

c. Proposed Operation

Before any material can be dumped, a permit must be obtained from the EPA. The permit application would be based on a comprehensive Environmental Impact Statement which, in turn, would require a detailed bioassay for the marine life indigenous to the selected dump site. Selection of the dump site would require examination of factors such as prevailing ocean currents, nearby commercial fishing grounds, etc. In addition, public hearings would likely be required to justify the overall benefit and need for ocean dump disposal.

As with chemical landfill disposal, the salts would be loaded on rail cars by Army personnel at Rocky Mountain Arsenal, transported to a pre-determined port, and released to a private contractor for dumping. Dilution and handling requirements would be specified as part of the dumping contract. Maintaining proper dilution levels would reduce or eliminate short term harm to marine life. Possible long term effects of cadmium levels would have to be examined and addressed in the EIS.

Cost of transportation is based on an average rail shipping rate of \$.0564/ton/mile for 1450 miles. The rate is the same as that used for the chemical landfill options (Appendix E). The distance of 1450 miles is selected as an average estimate from Denver to either east or west coast. Costs could vary, depending on the port used for the dumping site. A summary of costs, including estimates provided by Edgewood Arsenal for backup and support costs is as follows.

Load at RMA	\$ 75K
Transportation to port (average to east or west coast)	573K
Unload at port	75K
Ocean Dump, including loading barges	150K
Bioassays	25K
Prepare permit application	15K
Prepare, coordinate contract	50K
Prepare amendment to EIS	40K
Prepare, respond to public hearings	20K
	<u>\$1023K</u>

d. Status

Ocean dumping is a very attractive disposal technique because of its relative simplicity, low cost, and permanence. However, current legislation makes obtaining a permit difficult and future laws may make it impossible. Changes in ocean dumping laws must be monitored closely between now and the time a final disposal method is selected.

The analysis presented later for ocean dumping of GB salts is based on estimates provided by the Army. Much of this data is of a preliminary nature, particularly where bioassays, ecological and legal documentation, and in-process monitoring are concerned. In contrast to the other disposal options which take place under government control or which are permanently monitored or controlled, ocean dumping represents an intentional, overt addition of waste material to the ecological system. Even though safety to the environment must be demonstrated through the process of obtaining a permit, the open dumping of wastes into the ocean is more apt to arouse the sensitivities of environmentalists. For this reason, it is felt that some of the analyses, data reporting and public relations may be more extensive than expected and their eventual costs higher than shown.

4. Proposed Options Summary

From preliminary review of available data and information, three disposal methods are feasible for the GB salts but, for the mustard salts, only the chemical landfill option appears feasible in the near term. For this reason, only the GB disposal options are subjected to a complete systems analysis (Section IV). However, even though chemical landfill is the choice by default for the mustard salts, knowledge gap ratings are derived and cost and schedule data are presented later along with the evaluation for GB salt disposal for comparative purposes.

a. Advantages and Disadvantages

A summary of some of the advantages and disadvantages of the proposed options given final consideration is shown in Tables 5, 6, and 7.

Table 5
Advantages and Disadvantages of
GB Salt Incineration
In Bulk Furnace at Rocky Mountain Arsenal

Advantages	Disadvantages
1) Reduces the volume of organic waste. 2) Resultant waste can be made insoluble and less hazardous so that it can be dumped in a conventional landfill. 3) The resultant wastes will not have to be monitored when placed in a landfill. 4) No transportation will be required because the salts are already at RMA. 5) One incinerator at RMA could be used to incinerate residues from other sites in the future.	1) Expensive and time-consuming because it would require construction or modification of equipment. 2) Pilot testing would be required. 3) Potential P_2O_5, HF, HC_1 and NO_x air pollution that would have to be scrubbed. 4) HF formed from NaF is highly corrosive. (Note: removal of NaF prior to incineration is not cost effective because the cost of removal is much greater than its value.) 5) Some small amount of GB gas could be given off during incineration. 6) 55-gallon containers must also be disposed of as a separate operation. 7) Residues could build up in furnace and require special cleaning operations.

Table 6
Advantages and Disadvantages of
Chemical Landfill Disposal of
Mustard Salts and GB Salts

Advantages	Disadvantages
1) Continuous monitoring and control of leachates.	1) Does not really "dispose" of the salts in the sense that it "returns them to the earth in harmless form".
2) Appears to be the most ecologically safe method in the near term.	2) Requires a perpetual commitment of money and manpower.
3) Accepted by the EPA and state agencies.	3) Prevents a certain portion of land from ever being used for any other purpose.
4) Able to retrieve it if a better method of disposal is found.	4) May require an encapsulation method to permanently stop or decrease the leaching rate.
5) Chemical landfills are known to be successful for handling hazardous wastes.	5) Further costs could occur for such things as: re-encapsulation of the wastes, replacement of liners, pipes, pumps, etc.
6) Known contractors are ready to accept the waste immediately.	6) Requires transportation outside of government controlled areas.
7) Salts may be able to be land-filled in their original containers.	7) Handling of wastes would be required especially during transportation.
8) Monitoring equipment would detect leachates before widespread contamination occurs.	8) GB salts must not be subjected to any type of acid because hazardous by-products could be produced.
9) Indications are that both GB and mustard salts can be landfilled.	9) The number of ideal landfill locations is finite.
10) Relatively economical approach in the near term.	
11) Accessibility to the disposal site is limited and protected.	

Table 7

Advantages and Disadvantages of
Ocean Dump of GB Salts

Advantages	Disadvantages
1) Once dumped, the waste requires no further monitoring or control.	1) Adds heavy metal (cadmium) in concentrations that exceed the federal dumping restrictions.
2) Permanent disposal.	2) Possibility of the heavy metals entering the food chain.
3) Equipment for disposal is probably readily available.	3) Special permits from the EPA are needed to dump into the ocean.
4) Relatively economical approach.	4) "The EPA does not promote a policy of dispersion or dilution but rather one of containment" "Pollution Engr." April, 1976 pg. 301.
	5) No control over the wastes after they have been dumped.
	6) Requires several transportation, loading, and unloading applications.
	7) Requires direct personnel contact via opening of drums before disposal.
	8) Public disapproval of ocean dumping.
	9) Water in the surrounding dumping area will be contaminated for a period of time.
	10) Salts must be spread out over a large area to prevent high concentrations.
	11) 55-Gallon containers must be disposed of independently.
	12) Complete bioassay on the effect of GB salts on marine life must be completed.
	13) EPA will probably not issue a permit unless there is no other alternative.

b. Knowledge Gaps

Knowledge gap values are assigned to factors or items which relate to the process definition, development, operation, and safety of the disposal methods. They are not confidence factors in the statistical sense, but they do provide insight into the amount of confidence someone might have in the disposal method based on the degree to which each aspect of the method has been verified. The values applied should not be confused with the probability of success for solving or resolving the indicated knowledge gaps, but rather the level of progress that has already been made, the extent to which it has been verified or documented, and the source of documentation. The numerical ranges used for assigning knowledge gap values are:

- .75 - 1.0 Based on actual or experimental conditions with like or similar material; contractor-supplied data.
- .50 - .75 Analytically derived or established; estimated based on published fixed rates or data.
- .24 - .50 Documented supposition; basic ideas and order-of-magnitude estimates.

The arithmetic average of the values provided in knowledge gap tables 8, 9, 10, and 11 are used to compute the relative figure of merit for the options used in the systems evaluation matrices discussed in the following section.

TABLE 8

TECHNOLOGICAL & DEVELOPMENT KNOWLEDGE GAPS

	Ocean Dump GB Salts	Incin. at RMA GB Salts	Chem. Landfill GB Salts	Chem. Landfill Mustard Salts
1. Process Definition				
a. loading and unloading equipment	.50	.50	.50	.50
b. process feed/emplacement equipment	.70	.65	.90	.90
c. residue handling equipment	.50	.65	.80	.90
d. chemical/thermal reactions	.80	.75	.70	.90
e. technical feasibility	.75	.85	.90	.95
f. process/emplacement rate	.75	.80	.90	.95
g. operating instrumentation and controls	.65	.65	.85	.90
h. contamination controls (i.e., filters and scrubbers, dilution controls, etc.)	.65	.80	.85	.90
i. emissions/contamination monitoring	.50	.80	.95	.95
j. secondary waste disposal (ash, empty drums, etc.)	.50	.60	.75	.75
k. transportation/logistics requirements	.60	.75	.60	.60
l. failsafe measures/equipment	.35	.50	.80	.85
2. Responsibility Assignment				
a. equipment modification/fabrication	.75	.75	.75	.75
b. engineering/design	.75	.75	.75	.75
c. pre-operation	.75	.85	.85	.85
d. operation/emplacement	.75	.85	.85	.85
e. post-operation/clean-up	.75	.85	.85	.85
f. transportation/logistics	.60	.85	.60	.60
g. material handling	.60	.85	.75	.75
3. Development/Preparation Schedules	.50	.65	.50	.50
4. Development/Preparation Costs	.75	.75	.85	.85
Average of Total System	.64	.74	.77	.80

TABLE 9
OPERATIONS KNOWLEDGE GAPS

	Ocean Dump GB Salts	Incin. at RMA GB Salts	Chem. Landfill GB Salts	Chem. Landfill Mustard Salts
1. Process Definition				
a. loading and unloading equipment	.50	.50	.50	.50
b. process feed/emplacement equipment	.70	.65	.90	.90
c. residue handling equipment	.50	.65	.80	.90
d. chemical/thermal reactions	.80	.75	.70	.90
e. technical feasibility	.75	.85	.90	.95
f. process/emplacement rate	.75	.80	.90	.95
g. operating instrumentation and controls	.75	.65	.85	.90
h. contamination controls	.75	.80	.85	.90
i. emissions/contamination monitoring	.50	.80	.95	.95
j. secondary waste disposal	.50	.60	.75	.75
k. transportation/logistics requirements	.60	.75	.60	.60
l. failsafe measures/equipment	.35	.50	.80	.85
m. downtime	.25	.25	.25	.25
n. maintenance/repairs	.50	.65	.75	.75
o. training	.75	.50	.75	.75
2. Operating Schedule				
a. loading/unloading	.50	.50	.50	.50
b. transportation	.50	.75	.50	.50
c. process/emplacement	.50	.75	.60	.60
3. Operating Costs				
a. loading/unloading	.50	.50	.50	.50
b. transportation	.75	.75	.75	.75
c. process/emplacement	.50	.65	.85	.85
Average of Total System	.58	.65	.71	.74

TABLE 10
CLEAN-UP KNOWLEDGE GAPS

	Ocean Dump GB Salts	Incin. at RMA GB Salts	Chem. Landfill GB Salts	Chem. Landfill Mustard Salts
1. Process Definition				
a. secondary residue/waste				
(1) quantity	.75	.75	.75	.75
(2) components	.75	.75	.75	.75
(3) disposal method	.75	.75	.75	.75
b. handling equipment	.50	.50	.50	.50
c. post-operation testing and monitoring	.50	.65	.95	.95
2. Clean-Up Schedule				
a. loading/unloading	.50	.50	.50	.50
b. transportation/handling	.50	.50	.50	.50
c. process	.50	.50	.50	.50
3. Clean-Up Costs				
a. loading/unloading	.50	.50	.50	.50
b. transportation/handling	.50	.50	.50	.50
c. process	.50	.50	.50	.50
Average of Total System	.57	.58	.61	.61

TABLE 11
SAFETY KNOWLEDGE GAPS

		Ocean Dump GB Salts	Incin.at RMA GB Salts	Chem. Landfill GB Salts	Chem. Landfill Mustard Salts
1.	Site Location	.50	.90	.70	.70
2.	Security				
	a. pre-operational	.60	.75	.60	.60
	b. operational	.50	.80	.75	.75
	c. post-operational/clean-up	.50	.75	.75	.75
3.	Inspection/Surveillance/Monitoring Procedure				
	a. pre-operational	.80	.90	.80	.80
	b. operational	.70	.75	.80	.80
	c. post-operational/clean-up	.75	.50	.90	.90
4.	Worst Case Accident Scenario (Effects/Scope)	.50	.50	.60	.60
5.	Corrective/Recovery Procedures	.50	.60	.70	.70
6.	Contamination/Environment Containment Method	.50	.75	.95	.95
7.	Process/Emplacement Procedure	.75	.75	.90	.90
8.	Operator Safety (Protective clothing, etc.)	.65	.65	.65	.65
9.	Short-Term Effects				
	a. animal life	.85	.85	.95	.95
	b. plant life	.70	.85	.95	.95
10.	Long Term Effects (Greater than 10 years)				
	a. animal life	.40	.70	.65	.65
	b. plant life	.65	.65	.65	.65

(continued)

TABLE 11 (Continued)

SAFETY KNOWLEDGE GAPS

		Ocean Dump GB Salts	Incin.at RMA GB Salts	Chem. Landfill GB Salts	Chem. Landfill Mustard Salts
11.	Effects of Geo-Physical and/or Climatic Conditions	.50	.65	.90	.90
12.	Demonstration of Technical Feasibility	.80	.80	.95	.95
13.	Demonstration of Operational Feasibility	.85	.80	.85	.95
	Average of Total System	.63	.73	.79	.79

IV. SYSTEMS ANALYSIS

A. General

The purpose of conducting a mathematical systems analysis is to provide an objective quantified framework for examining the various disposal options. Through the Army's own efforts and the work of outside contractors, a significant amount of data and information has been gathered relating to the technical, economic, ecologic, and legal aspects of various disposal methods. Often, the technique employed in analyzing such data and making a final decision results from study; mental weighing of many pros and cons; and finally selecting one on the basis of some feeling of what is best. Under these conditions, decision makers frequently cannot truly explain their decision process. They point to individual bits of data to justify their position but cannot actually delineate all of the information that they processed or define the relative importance that they placed on particular data. On the other hand, a systems analysis based on a prescribed mathematical model requires strict specification and definition of:

- all of the variables considered
- all of the aspects of the systems
- relative merit or confidence of the data
- relative weight or importance of the variables

Because the math model requires detailed specification and quantification of variables, it is a useful tool for isolating areas that have not been defined completely. It tends to force objectivity in handling the variables. It is also a technique for communicating to others the factors, rationale, and relative importance applied to various data. In this way it is possible for other parties to see the procedure that was followed in arriving at the decision.

The scope of the analysis under this program was limited to concepts and data which had been provided by the Army. The purpose was to document and analyze the available concepts on the basis of current data but not to generate new concepts or information. In many cases, only rough estimates were provided. This was usually true in instances where the details of the options were not fully defined. Some of the areas where a more detailed definition of costs, schedule, and safety are needed were pointed out in the discussion of knowledge gaps. For this reason, the systems analysis based on existing data can at best be described as a "coarse grid" analysis. Nonetheless, the results do help to give a relative comparison of the preferred options and if more detailed data is obtained at a later date, the analysis and results can be refined.

B. Math Model

The primary variables in the mathematical framework used to evaluate the proposed disposal options are cost, schedule, ecological safety and a combined figure of merit which is basically a measure of the confidence placed in

the system's ability to do the desired job safely and within cost and schedule limitations. Cost and schedule considerations are absolutes but the degree of confidence placed in these absolutes will affect the confidence in the final decision and therefore the relative merit of the system. The combined figure of merit is based strongly on the knowledge gap values discussed earlier plus ecological safety.

- Costs

In general, costs used in the analysis were based on values provided by Edgewood Arsenal which were developed through their own estimates or those of independent contractors. Transportation costs were updated and revised on the basis of more recent shipping data. Some of the cost data provided is at least a year old. Also, some of the projected programs extend over a period of several years. No attempt was made to adjust costs for inflation or to discount future costs to the present. It is felt that this will not be a problem within the scope of this analysis. It must be remembered that the systems analysis model is a comparative tool for rating options with respect to each other. Although absolute values for cost and schedule in this report may give some order of magnitude estimate of actual dollars and time, they would best be viewed as values relative to each other.

Total system costs are considered as the sum for three process phases: development, operation and clean-up. Each of these cost areas consists of individual components as delineated in Figure 2. In most cases, the cost estimates provided by the Army were of an all-encompassing nature and not a detailed breakdown. After some discussion between Edgewood and AAI personnel, it was felt that they would be adequate for a preliminary comparative analysis. Numerical data is presented in Section IV-C.

- Schedule

As with the cost estimates, schedule estimates were provided by Edgewood Arsenal and are specified for development, operation, and clean-up. In most cases, these are ballpark estimates and have not been broken down in the detail illustrated in Figure 2. Although they may be good enough for this comparative coarse grid analysis, a more detailed task by task breakdown should be undertaken if an absolute budgetary cost estimate becomes necessary. It must be remembered that time is money and that time estimates that do not consider areas of potential delays, downtimes, inflationary influences, etc., can result in cost estimates that are grossly in error.

- Safety

Two general safety areas must be considered in conjunction with any disposal system; the safety of the operating personnel and the safety to the environment. A considerable amount of effort was expended in trying to establish a method of rating the proposed options with respect to ecological safety. Most of the techniques centered about trying to score the potential risk of various disposal techniques presented by normal operation or accident.

Items		Schedule (Months)	Cost (K \$)
I. DEVELOPMENT/FINAL DEFINITION PHASE			
A. Government Effort			
1. Program & technical management (planning/contract)			
2. Engineering and scientific (specs, design criteria background investigation, preliminary site selection, soil tests, bioassay, etc.)			
3. Documentation (EIS, permits, licenses, background data, etc.)			
4. Government furnished material & equipment			
5. Technical support (bench scale tests, mockups, etc.)			
6. Contingency (public relations)			
Sub Total			
B. Contractor Effort			
1. Program and technical management			
2. Engineering and scientific (specs, soil tests, bioassay, design, prototypes, compatibility tests, life cycle tests, etc.)			
3. Documentation (licensing permits, manuals, etc.)			
4. Purchase parts and material			
5. Fabrication and Installation			
6. Installation testing and training			
7. Contingency			
Sub Total			
Total Development/Final Definition			
II OPERATIONAL PHASE (Government or Contractor)			
A. Systemization/Preparation			
1. Site preparation			
2. Set-up and pre-op (pilot test or dry run if necessary)			
3. Training			
4. Maintenance and corrections			
5. Site support (lab tests, on-site inspectors, etc.)			
6. Material cost (repairs, modifications, expendables)			
7. Transportation and handling (loading, transport, unload)			
8. Contingency			
Sub Total			
B. Operations			
1. Site support (monitoring, material handling, inspectors, etc.)			
2. Operations (processing, feeding, dumping, emplacing, etc.)			
3. Materials cost (expendables)			
4. Rebuild and modification			
5. Maintenance			
6. Contingency			
Sub Total			
Total Operational Phase			
III. CLEAN UP			
1. Post-op monitoring (short term)			
2. Retro-fit/clean up of facility/equipment			
3. Transportation of secondary waste			
4. Processing and/or disposal of secondary waste			
5. Contingency			
Total Clean Up			
TOTAL SYSTEM			

Figure 2. Desirable Cost and Schedule Breakdown.

Attempts were made to examine and evaluate the possible modes of damage to human life, non-human animal life, and plant life; the potential physical damage caused by various concentrations; the duration of possible exposure; and the legal and public ramifications of exposure. It soon became apparent that such a method of scoring such factors was not going to give meaningful results because:

- the proposed options that were being given final consideration were designed specifically to prevent potentially harmful concentrations from entering the environment;

- the proposed opinions were designed to comply with federal, state and local laws and guidelines;

- any assessment of problems which could be caused by accidents would involve establishing the probability of occurrence of various accident scenarios and this was beyond the scope of the program;

- the severity and duration of any accident would depend largely on characteristics of each particular disposal site (soil type, water tables, ocean currents, prevailing winds, proximity of inhabited areas, etc.) and an exact disposal site has not been selected for some of the options.

However, it became obvious that there were certain desirable safety features that a good disposal method should possess and that these features were better defined, proved, and implemented with certain methods than with others. The degree to which the safety features have been verified is addressed by the safety knowledge gap ratings (Section III-C.4.b) and an "ecological safety factor." The value of the ecological safety variable for each option is simply the number of desirable features that the option possesses according to Table 12. The ecological safety knowledge gap values and the value of the ecological safety factor variable form the basis of evaluating the ecological desirability of proposed options.

The primary variables of cost, schedule, ecological safety, and figure of merit are manipulated to arrive at a final evaluation score as described below and summarized in Figure 3.

- Relative Figure of Merit

For each disposal option, an individual figure of merit is found for cost and schedule for the development, operation, and clean-up process phases. This is done by multiplying the average knowledge gap score for the given process phase by the ratio of the absolute value for the given phase to the total value for the option. For example, the individual figure of merit for development cost of incineration at RM_A would be the average knowledge gap score for development of the incineration method multiplied by the development costs for incineration divided by the total cost of incineration. This procedure is summarized in Block A of Figure 3.

TABLE 12

ECOLOGICAL SAFETY FACTORS

An ideal Disposal System should possess the following safety features. The proposed options are rated on the basis of how completely each of the options could satisfy these features	OCEAN DUMP GB SALTS		INCIN. AT RMA GB SALTS		CHEM. LANDFILL GB SALTS	
	Yes	No	Yes	No	Yes	No
1. Can be isolated from inhabited areas.	X			X	X	
2. Could be removed from vicinity of usable commercial areas (farms, factories, fishing grounds, etc.).	X			X	X	
3. Would not degrade aesthetics of surrounding area.	X		X		X	
4. Would provide positive control of wastes or by-products in the disposal site.		X	X		X	
5. Would not allow wastes or by-products to enter usable water/food chain.		X	X		X	
6. Would not require transportation outside of controlled area,		X	X			X
7. Would prevent noxious fumes & gaseous by-products from leaving disposal site,	X		X		X	
8. Would be currently acceptable to regulatory agencies.	X		X		X	
9. Would not destroy current or future value of resources associated with disposal site,	X		X			X
10. Would utilize in-process controls to insure that the design safety parameters are satisfied,	X		X		X	
11. Would allow simple in-process surveillance to verify that design safety parameters are maintained.		X	X		X	
12. Would allow simple post operative monitoring/testing to assess effects of disposal.		X	X		X	

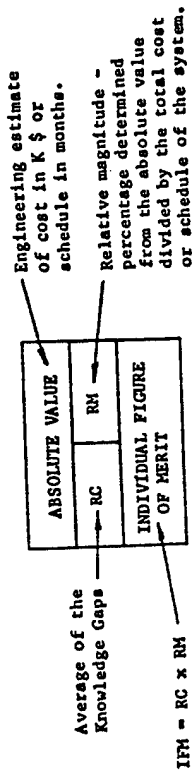
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TABLE 12 (Cont'd)
ECOLOGICAL SAFETY FACTORS

	OCEAN DUMP GB SALTS		INCIN. AT RMA GB SALTS		CHEM. LANDFILL GB SALTS	
	Yes	No	Yes	No	Yes	No
13. Would utilize positive security measures (fences, barriers, etc.) to prevent human and animal contact to wastes or by-products.		X	X		X	
14. Would eliminate short term risk.	X		X		X	
15. Would eliminate long term risk.		X	X			X
16. Would attract a minimum amount of public/media attention.		X	X		X	
Ecological Safety Factor (Total "Yes")	8		14		13	

A

A relative "figure of merit" is found by weighting average "Knowledge Gap Scores" by the relative magnitude of the values to which they relate. That is, if "development cost" is 40% of the total cost, the individual "figure of merit" is $(.40) \times (\text{Average Knowledge Gap Value for Development})$



B

Options	Develop Schedule	Develop Costs	Operational Schedule	Operational Costs	Clean up Schedule	Clean up Costs	Safety	COMBINED FIGURE OF MERIT
	V_{DS}	V_{DC}	V_{OS}	V_{OC}	V_{RDS}	V_{RDC}	V_S	

A combined figure of merit for each option is calculated by adding the six individual figures of merit and dividing by two to equally account for cost and schedule. This average is multiplied directly by the safety knowledge gap value. The multiplication is done because it is felt that if virtually nothing is known for sure about the safety of a technique, the overall confidence in that technique should be severely downgraded.

$$\text{COMB. FIG. MERIT} = \frac{V_{DS} + V_{DC} + V_{OS} + V_{OC} + V_{RDS} + V_{RDC}}{2} \times V_S$$

C The combined figures of merit, total costs, total schedules, and ecological safety factors are summarized in the expected value matrix.

EXPECTED VALUE MATRIX

OPTIONS	COMBINED FIGURE OF MERIT	TOTAL COST	TOTAL SCHEDULE	ECOLOGICAL SAFETY FACTOR

D The absolute values are normalized so that they become nondimensionalized ranking values between zero and one. Each column is normalized to the "best" value which is a minimum in some cases and a maximum in others. The highest value of "combined figure of merit" and "ecological safety factor" is divided into all of the other values in their respective column. For cost and schedule, each absolute value is divided by the largest respective value in each column.

RANKING FACTORS MATRIX

OPTIONS	FIGURE OF MERIT	TOTAL COSTS	TOTAL SCHEDULE	ECOLOGICAL SAFETY
A		B	C	D

E Values in the evaluation matrix are found by multiplying the "ranking factors" by weighting factors and summing.

EVALUATION MATRIX

OPTIONS	FIGURE OF MERIT	TOTAL COSTS	TOTAL SCHEDULE	ECOLOGICAL SAFETY	TOTAL EVALUATION FACTORS
	$(W_1)(A)$	$+(W_2)(B)$	$+(W_3)(C)$	$+(W_4)(D)$	E

Figure 3. Evaluation Model Schematic

A combined figure of merit for each option is calculated by adding the individual figures of merit and dividing by two to give equal weight to cost and schedule. The average is multiplied by the average of the safety knowledge gap values. The multiplication has the effect of applying a heavy weight to safety because if most of the factors concerning safety are only in the realm of speculation, the combined figure of merit which reflects the overall confidence of the system will be greatly downgraded. Block B of Figure 3 illustrates this procedure.

The combined figures of merit, total cost, total schedule and ecological safety values are normalized so that they become non-dimensionalized ranking values between zero and one (Block D in Figure 3). Each variable is normalized with respect to the "best" value for that particular variable which is a maximum in the case of combined figure of merit and ecological safety factor but a minimum for cost and schedule.

The variables are fully combined into a total evaluation factor by multiplying each variable by a weighting factor and summing. The weighting factors establish the relative importance of the primary variables with respect to each other. For this analysis, the following weighting factors were used:

$$W_1 = 4$$

$$W_2 = 2$$

$$W_3 = 1$$

$$W_4 = 3$$

Once the total evaluation scores are calculated they can be normalized with respect to each other to establish a total ranking order.

The entire process is illustrated with the numerical data and carried through to completion in Section IV-D.

C. Data

Estimated costs and schedules for the proposed options are summarized in Figures 4 and 5. Data was taken from information provided by Edgewood Arsenal (Appendix E) with some modification of transportation costs. As mentioned earlier, the costs and schedules provided for this study are order-of-magnitude values and should be used for comparative rather than budgetary purposes.

The averages for the knowledge gap values are summarized in Figure 6. It should be remembered that these values represent the degree to which the exact system has been defined and resolved, not the probability of finding solutions to unknown areas. A score of 1.0 would indicate that every aspect of the system has been defined in detail and verified by testing or operation.

COST AND SCHEDULE

Items	Ocean Dump CB Salts		Incineration at NMA CB Salts		Chemical Land Fill CB Salts		Chemical Land Fill Phostor Salts	
	Schedule (Months)	Cost (K \$)	Schedule (Months)	Cost (K \$)	Schedule (Months)	Cost (K \$)	Schedule (Months)	Cost (K \$)
DEVELOPMENT/FINAL DEFINITION PHASE								
A. Government Effort								
1. Program & technical management (planning/contract)		50		10		50		20
2. Engineering and scientific (specs, design criteria background investigation, preliminary site selection, soil tests, bioassay, etc.)	3	12.5 (initial bioassay)		20				
3. Documentation (EIS, permits, licenses, background data, etc.)	9	55		40	9	40	9	40
4. Government furnished material & equipment				150				
5. Technical support (bench scale tests, mockups, etc.)		20						
6. Contingency (public relations)								
Sub Total	12	137.5		220	9	90	9	60
B. Contractor Effort								
1. Program and technical management				20				
2. Engineering and scientific (specs, soil tests, bioassay, design, prototypes, compatibility tests, life cycle tests, etc.)				1100				
3. Documentation (licensing permits, manuals, etc.)								
4. Purchase parts and material								
5. Fabrication and installation								
6. Installation testing and training								
7. Contingency								
Sub Total				1120				
Total Development/Final Definition	12	137.5	36	1340	9	90	9	60
OPERATIONAL PHASE (Government or Contractor)								
A. Systemization/Preparation								
1. Site preparation				100				
2. Set-up and pre-op (pilot test or dry run if necessary)								
3. Training								
4. Maintenance and corrections								
5. Site support (lab tests, on-site inspectors, etc.)								
6. Material cost (repairs, modifications, expendables)								
7. Transportation and handling (loading, transport, unload)	9	723			12	613	12	368
8. Contingency								
Sub Total	9	723		100	12	613	12	368
B. Operations								
1. Site support (monitoring, material handling, inspectors, etc.)								
2. Operations (processing, feeding, dumping, emplacing, etc.)	3	150	9	300	12	500		300
3. Materials cost (expendables)								
4. Rebuild and modification								
5. Maintenance								
6. Contingency								
Sub Total	3	150	9	300	12	500		300
Total Operational Phase	12	873	9	400	12	1113	12	668
I. CLEAN UP								
1. Post-op monitoring (short term)								
2. Retro-fit/clean up of facility/equipment	3	12.5 (final bioassay)						
3. Transportation of secondary waste			3	100				
4. Processing and/or disposal of secondary waste								
5. Contingency								
Total Clean Up	3	12.5	3	100				
TOTAL SYSTEM	27	1023	48	1840	21	1203	21	728

Figure 4. Cost and Schedule

Figure 5. Total Cost and Schedule Summary

	Development		Operation		Clean-up		Totals	
	<u>Cost</u> K \$	<u>Schedule</u> Months	<u>Cost</u> K \$	<u>Schedule</u> Months	<u>Cost</u> K \$	<u>Schedule</u> Months	<u>Cost</u> K \$	<u>Schedule</u> Months
Ocean Dump GB Salts	137.5	12	873	12	12.5	3	1023	27
Incineration at RMA GB Salts	1340	36	400	9	100	3	1840	48
Chemical Landfill GB Salts	90	9	1113	12	?	?	1203	21
Chemical Landfill Mustard Salts	60	9	668	12	?	?	728	21

Figure 6

Summary of Knowledge Gap Factors

Phase	Ocean Dump (GB Salts)	Incin. at RMA (GB Salts)	Chemical Landfill (GB Salts)	Chemical Landfill (Mustard Salts)
Technological and Development	.64	.74	.77	.80
Operations	.58	.65	.71	.74
Clean-up	.57	.58	.61	.61
Safety	.63	.73	.79	.79

D. Evaluation Matrices and Options Comparison

The computations for the system's Math Model are summarized in Tables 13, 14, 15, and 16. Only the options for GB salts are carried through to completion because there appear to be no option for the mustard salts other than chemical landfill.

TABLE 13

COMBINED FIGURE OF MERIT

OPTIONS	DEVELOPMENT SCHEDULE	DEVELOPMENT COST	OPERATION SCHEDULE	OPERATION COSTS	CLEAN-UP SCHEDULE	CLEAN-UP COSTS	SAFETY	COMBINED FIGURE OF MERIT
Ocean Dump; GB Salts	12 [.64] [.44] .28	137.5 [.64] [.13] .08	12 [.58] [.44] .26	873 [.58] [.85] .49	3 [.57] [.11] .06	12.5 [.57] [.01] .01	.63	.37
Incineration at RMA GB Salts	36 [.74] [.75] .56	1340 [.74] [.73] .54	9 [.65] [.19] .12	400 [.65] [.22] .14	3 [.58] [.06] .03	100 [.58] [.05] .03	.73	.52
Chem Landfill GB Salts	9 [.77] [.43] .33	90 [.77] [.07] .05	12 [.71] [.57] .40	1113 [.71] [.93] .66	0 [.61] [0] 0	0 [.61] [0] 0	.79	.57

TABLE 14
EXPECTED VALUE MATRIX

OPTIONS	COMBINED FIGURE OF MERIT	TOTAL COST	TOTAL SCHEDULE	ECOLOGICAL SAFETY FACTOR
Ocean Dump GB Salts	.37	1023	27	8
Incineration at RMA GB Salts	.52	1840	48	14
Chemical Landfill GB Salts	.57	1203	21	13

TABLE 15

RANKING FACTORS MATRIX

OPTIONS	COMBINED FIGURE OF MERIT	TOTAL COST	TOTAL SCHEDULE	ECOLOGICAL SAFETY FACTOR
Ocean Dump GB Salts	.65	1	.78	.57
Incineration at RMA GB Salts	.91	.56	.44	1
Chemical Landfill GB Salts	1	.85	1	.93

TABLE 16

EVALUATION MATRIX

OPTION	$(W_1)(A) + (W_2)(B) + (W_3)(C) + (W_4)(D)$				RANKING TOTAL SCORE
	A COMBINED FIGURE OF MERIT	B TOTAL COST	C TOTAL SCHEDULE	D ECOLOGICAL SAFETY FACTOR	
Ocean Dump GB Salts	2.6	2.0	.78	1.71	3
Incineration at RMA GB Salts	3.64	1.12	.44	3.0	2
Chemical Landfill GB Salts	4.0	1.7	1	2.79	1
Chemical Landfill Mustard Salts	Choice by Default				

For this study:

$$W_1 = 4 \quad W_3 = 1$$

$$W_2 = 2 \quad W_4 = 3$$

E. Conclusions

Based on the available data and the model described earlier, the best overall currently available disposal technique for GB salts is the use of a chemical waste (controlled) landfill as indicated by the ranking in Table 16. Incineration of the GB salts at Rocky Mountain Arsenal would be slightly better from the ecological standpoint because it would provide finalized disposal with no long-term monitoring requirements, and ocean dumping would provide a less expensive option. However, when considering the combination of cost, schedule, safety, and current technological and operational availability, the use of a controlled landfill becomes the best overall method.

As a result of the preliminary analysis, chemical landfilling of the mustard salts appears to be the only available method at this time.

It must be remembered that the systems analysis model used gives comparative results among options considered based on the variables specified earlier. Changing the variables or their relative weight could change the results. It must also be remembered that no claim is made that chemical landfill is the ultimate disposal method but only the best available at this time and under the constraints imposed by this analysis.

It should also be repeated that the cost and schedule estimates used in this analysis are rough estimates and should not be used for funding purposes without further investigation and updating to reflect current labor, material, and service costs.

V.

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APPENDIX A

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Hedley, W. H., et al; Monsanto Research
Corp.; March, 1975.

APPENDIX B

ESTIMATED COSTS FOR INCINERATION OF DEMILLED GB RESIDUES AT ROCKY MOUNTAIN ARSENAL

The report on incineration of demilled GB residues was prepared by Mr. B. B. Crocker, Sr. Engineering Fellow, Corporate Engineering Department, Monsanto Company, St. Louis, Missouri, as a result of the visitation to RMA on 3 April 1974. The report is included *in toto*. It contains an abstract, and discusses properties of the dried salt, available equipment at RMA, capabilities of the existing facilities, incineration of salt solutions, and estimated costs.

1. Abstract

This report discusses the possibility of incinerating neutralized GB salt produced at Rocky Mountain Arsenal. Existing equipment which is used for incineration at Rocky Mountain Arsenal is described, consisting of a bulk liquid incinerator and two batch furnaces for incinerating the contents of ton cylinders. Off-gas scrubbing equipment present is also described.

It is concluded that incineration of powdered, spray-dried, detoxified GB salt in the present bulk furnace would be much preferred to use of the ton container furnaces and that a suitable incineration rate in the bulk furnace would be 3,000 lb/hr of dried powdered residue when using the new scrubbing system.

Pollutants resulting from the incineration are P_2O_5 and HF. The existing packed scrubber will successfully recover 99.7% of the HF (effluent quantity released = 1 lb/hr) if L (liquid rate) = 1800, G (gas rate) = 800, and the scrubbing liquid pH is maintained at 7.0-8.0. The addition of a high efficiency Brink Mist Eliminator is required to reduce the P_2O_5 effluent to 0.31 lb/hr (99.997% overall recovery).

It is also feasible to fire the bulk furnace with a 28.9% solution of neutralized GB salt. This requires burning 8690 cfh of 1000 Btu/cf natural gas in addition to the heating value of the salt itself. Due to the scrubbing system limitations, the feed rate of demilled GB solution must be reduced to 2550 lb/hr of detoxified GB salt. Incinerating the solution could result in appreciable operating cost savings over continuing to spray dry the solution first.

The design conditions for the bulk furnace have been set to maintain a flame temperature not in excess of 1800°F, slightly below the melting point of sodium fluoride, to prevent coating the refractory with molten material. The major uncertainty regarding use of the bulk furnace is a question concerning the

composition of detoxified GB salt combustion products. As long as the combustion products consist of P_2O_5 , Na_2O , Na_2CO_3 , NaF , and HF , no difficulties are anticipated. To the extent that P_2O_5 and Na_2O might react in the flame to produce $NaPO_3$ (melting point 1600°), a severe refractory slagging problem could ensue for which no cure is foreseen. It is recommended that a bench scale test of possible slagging problems be conducted before proceeding with plant modifications.

The cost of converting existing equipment at Rocky Mountain Arsenal to incinerate detoxified GB salt is of the order of \$1,025,000.

2. The Problem

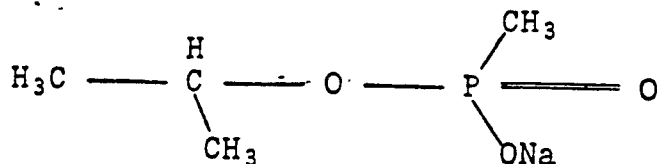
The Army Materiel Command has a disposal problem in connection with disposal of GB - a chemical warfare material. The first step in detoxification is to react and neutralize the GB with $NaOH$. The resulting mixture is a solution which they can spray dry in existing equipment at Rocky Mountain Arsenal to produce a fine granular powder. The resulting powder analyzes about 77% sodium isopropyl methyl phosphonate solids and about 23% sodium fluoride. Over the next three years, the government will have prepared about 7000 tons of this material.

The fine powder from the spray drying operation has been run through a compaction roll in an attempt to produce lumps of the material. The product contains long, thin, agglomerated fingers of the crude detoxified GB salt interspersed in uncompacted fine powder. The yield of agglomerated fingers is probably around 50%.

The purpose of agglomerating the powder is to obtain lumps which might be further processed in some ore-treating process (such as cement manufacture, phosphate nodulizing, etc.) where the phosphonate solids could be oxidized by heating to CO_2 , H_2O , and P_2O_5 . The addition of the spray-dried fine powder to such an operation might cause an extreme dusting problem. However, the present compacted product is also not acceptable for the same reason. Screening and recycling of the fines to the compaction roll might result in a product suitable for disposal in this fashion.

The best way to dispose of the phosphonate molecule is by combustion or incineration. Since the Rocky Mountain Arsenal presently contains equipment designed for incineration of waste organic liquids, it was felt that this equipment might possibly be used for incineration of the detoxified GB salt. Accordingly, Monsanto Research Corporation as an Army Materiel Command contractor was asked to study this problem and report on the feasibility of using the existing incineration equipment at Rocky Mountain Arsenal. This study has not been made, and it is the purpose of this report to present the results of this study.

The molecular structure of the phosphonate salt is:



sodium isopropyl methyl phosphonate

For incineration of the neutralized GB salt mixture, it would be possible to take the material in any one of several forms as follows:

1. The present partially compacted product.
2. The spray-dried product without compaction.
3. The spray drier feed solution - a 28.9% dissolved solids (in water) solution of the dried product.
4. A more concentrated solution or slurry by using some subsequent treatment in place of spray drying.

3. Properties of Dried Neutralized GB Salt

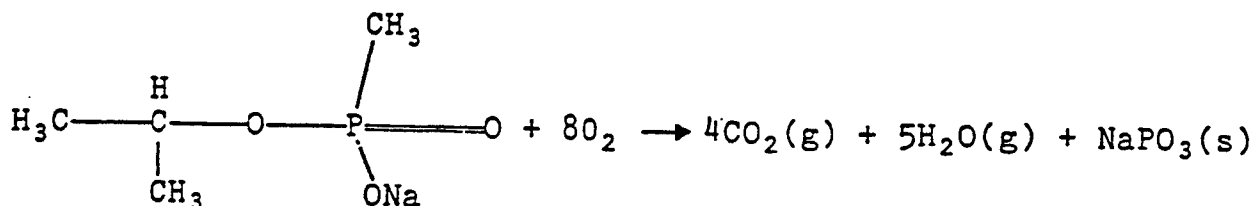
As previously indicated, the neutralized GB salt is composed of roughly 77% sodium isopropyl methyl phosphonate (SIMP) and 23% sodium fluoride (NaF).

a. Sodium Isopropyl Methyl Phosphonate:

Molecular weight: 160.08

The heat of combustion of SIMP was estimated using Monsanto's physical property estimation computer program E0052 which gave $\Delta H_c = -690.849$ Kcal/gram mole. This program makes use of Handrick's method of summation of the contribution to combustion heat of individual structural groups. R. C. Reid estimates that Handrick's method estimates ΔH_c to within about 2%.

The combustion of SIMP would occur in accordance with the following reaction:



b. Sodium Fluoride

Molecular weight:	41.99
Melting point:	992°C (1817.6°F)
Heat of fusion:	7780 cal/g mole
Heat of capacity of solid:	$9.66 + 4.50 \times 10^{-3} T(^{\circ}\text{K})$ cal/g mol - °K
Heat capacity of liquid:	16.0 cal/g mol - °K

Based on the above data, the heat released in burning a mixture of the above materials at 25°C is 5,981 Btu/lb of the dry mixed salts. Theoretical air for combustion of 1 pound of the mixed salts is 0.03848 lb mols of O₂ and 0.14476 lb mols of N₂.

4. Possible Incineration Equipment Available at Rocky Mountain Arsenal

The Rocky Mountain Arsenal has available several different incineration devices which have been used in the past and are being used for incinerating various materials. These are a bulk furnace liquid incinerator, and ton container incinerators (2). A common combustion product scrubbing system is available to control release of effluents.

a. Bulk Furnace

The bulk furnace was originally built to incinerate hydrazine remaining from use in rockets. More recently, it has been adapted to the incineration of mustard liquids.

The bulk furnace is a horizontal cylindrical refractory lined furnace with a steel external shell. A compressed air-liquid atomized burner is mounted on the end of a small combustion chamber which is positioned axially at one end of the furnace on the horizontal centerline of the furnace. Combustion products make a 90° turn upwards at the back of the furnace and leave through a radial outlet on the top of the furnace. The combustion products, in passing through this outlet, enter a refractory lined horizontal breeching which conducts the gases to the off-gas cooling and scrubbing system.

The horizontal furnace shell is lined with 9 in. of insulating fire brick (type unknown) and 4-1/2 in. of 70% alumina fire brick. The dimensions of the furnace inside the refractory are 9 ft I.D. by 16 ft 11 in. long.

The combustion chamber on the firing end of the furnace is lined with M-28 insulating fire brick and 70% alumina castable. Inside the refractory, it is 5 ft 4-1/2 in. I.D. by 4 ft 3 in. long. There is a 2 ft dia. opening on the back of the combustion

chamber where the liquid atomizing burner is mounted. Secondary air enters the combustion chamber in an annulus surrounding the burner.

The operating conditions and limitations in the past have been:

1. The furnace was designed to burn 35 gpm of hydrazine.
2. In recent operation, the furnace has been used to burn a maximum of 3 gpm of mustard liquids. This has been stated to be the maximum permissible heat input without overheating the refractory in the breeching. This breeching refractory is of lower quality than the refractory in the furnace and is said to be good only to 2200-2300°F. As an operating parameter, they limit off-gas temperature to a maximum of 2200°F, but normally run with an off-gas set point of 1900°F. All of the heat is supplied, while operating, by combustion of the liquid which is being incinerated.
3. The capabilities of the secondary air fan are unknown. An actual operating test conducted when burning 2 gpm of mustard showed the combustion air being utilized as 4500 scfm.
4. Mustard is dichlorodiethyl sulfide, $\text{CH}_2\text{Cl}-\text{CH}_2-\text{S}-\text{CH}_2-\text{CH}_2\text{Cl}$. When pure, it has a sp. gr. of 1.2741 @ 20°C (10.6 lb/gal), a melting point of 14.4°C, and a boiling point of 217.5°C. In storage, some polymerization of mustard occurs which has a higher melting point. In addition, the mustard reacts to some extent with the steel ton cylinders in which it is stored to produce FeS solids. Thus the mustard liquid being burned is a slurry containing about 30% solids. This mustard has a density of about 12 lb/gal.

b. Ton Container Furnaces

Some of the mustard cylinders will not empty completely due to the presence of solids and polymerized material. These must be further decontaminated before disposal. This is done by punching triangular shaped holes in the portion of the cylinder which is up while it is held in a horizontal position. The cylinders are then placed in a small long horizontal furnace with a vertical sliding end door. The furnace might be considered to resemble a large muffle furnace. Once inside, the end door is closed, and the furnace is heated to 1000°F by burning natural gas. The contents of the cylinders become hot, vaporize (and crack). The vapors burn primarily as they come out of the cylinders. Final decontamination may occur by internal burning as oxygen diffuses into the cylinder. The ton cylinders of mustard are 30 in. diameter x 7 ft long.

The ton container furnaces are built of refractory. They are 4 ft 3 in. wide inside by 6 ft 0 in. high from the hearth to the beginning of the overhead arch. The overall length of the furnace is 20 ft 3 in., but only the first 10 feet are considered to be the portion where ton cylinders would normally be placed, the last half being allowed to insure complete incineration of the gases.

The heart is constructed of 2300°F castable refractory. The walls and roof are made of brick. The exact grade is unknown, but it is presumably of material at least equivalent to the hearth in refractoriness.

The furnace has a total of six Maxon wide-range premix burners, located three in each side wall. The burners near the loading door are placed about 2/3 of the way up the side wall and burn above the top of the cylinders. These three burners are all located on one side of the furnace and are spaced equally along the first 10 feet of furnace length. The remaining three burners are in the opposite side wall equally spaced over the last 10 feet of the furnace, and vertically, are positioned just above the hearth. All six burners consume a total of 200 cfm of 1000 Btu natural gas. There are also two 6 in. dia. air inlets in the side walls to provide combustion air for the material contained in the cylinders. These inlets are located near the hearth and close to the lengthwise center of the side walls.

Frequently, only one ton cylinder is placed in the furnace at a time, even though two can be handled about as well when placed end to end in the furnace. A fairly long cycle time is required for completion of the incineration process. There are three phases to the cycle: heating of the cylinders to 1000°F, vaporization and oxidation of their contents, and cooling of the furnace and charge before opening to the atmosphere. Overall cycle time is in the neighborhood of 10 hours so that only two batches are processed in a 24-hour day. There are two identical furnaces of this type at Rocky Mountain Arsenal. The combustion products issue from the furnaces at the end opposite to the charging door. They connect to the same breeching as the bulk furnace.

c. Combustion Gas Treatment

There are two parallel off-gas scrubbing systems which are fed from opposite ends of the breeching at Rocky Mountain Arsenal. They are referred to as the "old system" and the "new system." They may be used alternately, or in parallel if needed to handle the total quantity of combustion products being released. The scrubbing system was designed to remove the contaminants produced when burning mustard which are primarily SO₂ and HCl. It might also be partially effective in removing oxides of nitrogen produced during the combustion.

In the old system, the hot gases (around 1900°C) enter a quench tank which is a vertical tank, 6 ft dia. x 9 ft high. The gas inlet nozzle which is on top of the vessel (with downward flow) projects into the vessel one foot. It is 3 ft 6-1/2 in. I.D. and has a 3-1/2 in. thick castable lining. The vessel itself is constructed of Hastelloy B and is unlined. There are four levels of spray nozzles installed in the tank through nozzles in the vessel side wall to cool the hot gas. There are eight nozzles spaced at 45° about the vessel at each level, giving a total of 32 spray nozzles. The nozzles are Spray Engineering Co. (Sprayco) No. 111F80 and are operated with a recirculated dilute brine caustic system at around 30 psig. The first row of nozzles is pointed downward at around 30° to keep from spraying liquid on the refractory lining of the inlet duct. The remaining rows of spray nozzles are directed radially inward.

The gas outlet is on the side of the vessel at the bottom and is mounted radially on the vessel. It is 26-3/4 in. I.D. There is a 6 in. brine drain nozzle on the bottom of the quencher for removal of the spray liquid.

In the "old system" the quenched gas is conducted to the bottom of a packed scrubber with a long sloping duct about 26 ft in length and containing two bends. It contains 10 duct sprays spraying vertically downward in the duct from its top. These spray nozzles are the same as those used in the quench tank and have been added in an attempt to prevent pluggage in this duct-work which has only a mild slope.

The scrubbing tower in the "old system" is an 8 ft dia. packed countercurrent scrubber containing 10 ft 11-3/4 in. of 1 in. glass Raschig rings. The scrubbing liquid is distributed over the packing with a Norton model 1837, 93 in. dia. polypropylene weir through the gas space 4 ft 6 in. from the distributor to the top layer of the packing. The packing support is a Norton Model 801-R2, 93 in. Hastelloy B perforated multibeam support plate. The tower itself is constructed of carbon steel. Originally, the interior walls were covered with a protective coating, but we were told that the carbon steel is now exposed in many places. The scrubbing liquid is the same recirculated brine caustic solution used in the quencher. Gas to be scrubbed enters the bottom through a side inlet radial nozzle below the support plate and leaves at the top.

In the "new" scrubber system flow and design are similar, but certain modifications and improvements have been made. The quench tank is still 6 ft dia., but its height has been increased to 10 ft. There are five levels of spray nozzles entering through the side walls rather than four. There are still eight equally spaced spray nozzles at each level, but the spray nozzles are Spraying Systems Co. 3/8G1550. The gas leaves through a duct on the center of the bottom which is 30-1/8 in. I.D. and which is

much steeper and shorter in connecting to the bottom of the scrubber. Both gas and spray liquid leave the quench tank through this one duct. Little pluggage problem is encountered in this duct and there are no duct sprays. When not specifically mentioned, other design features are similar to the "old system." There is a Hastelloy B damper in the duct connecting the quench tank and scrubber on the "new system" which is used to control gas flow.

The scrubber in the new system is 9 ft dia. and is packed with 8 ft 11-3/4 in. of 1 in. glass Raschig rings with another 2 ft 1 in. of 1-1/2 in. porcelain rings on top of the glass rings. The liquid distributor and support plates are similar to those in the "old" scrubber except for diameter. The liquid falls 4 ft 6 in. through the gas space between the distributor plate and the top of the packing.

There is no mist eliminator following either scrubber. The exit gases from the scrubbers are conveyed through carbon steel ductwork to a common electrostatic precipitator some distance away and located outside of the building. The precipitator is a five stage (five compartments in series) grid or plate type precipitator with horizontal flow between the plates. The precipitator internals are carbon steel. The precipitator is energized at 50 kV from the rectifiers. The gases passing through the precipitator are exhausted to the atmosphere.

In the recirculating liquid system, caustic soda is added to maintain an alkaline pH. Control of pH is manual in the old system and automatic in the new system. The recirculated brine passes through a large stainless steel heat exchanger which cools the brine going back to the quench tank and scrubbers. Therefore, the operation is not strictly adiabatic and within reason, it is possible to drop the exit gas temperature somewhat below the adiabatic saturation temperature of the incoming gases. Considerable difficulty with fouling and pluggage of the tubes of this heat exchanger is encountered. The deposit on the tanks appeared to be largely iron compounds.

The surplus brine produced is stored in storage tanks until disposed of. The brine from the mustard incineration is evaporated to dryness in a spray drier. The spray-dried solids have been collected and retained in storage and have not yet been disposed of in a permanent manner.

5. Analysis of Capabilities of Existing Incineration Facilities

Initial consideration of the incineration equipment available indicates that it should be feasible to replace the liquid fuel burner in the bulk furnace with a pulverized fuel burner and to burn the spray-dried (and uncompacted) neutralized GB salt in the bulk furnace. The major questions relate to the

rate at which this furnace would burn the detoxified GB salt, and whether this rate would permit disposal in a reasonable time period.

Combustion of the detoxified GB salt in open pans in the ton container incinerators does not appear nearly as attractive initially because of the low exposed surface area and the difficulty of getting oxygen to the surface of the burning particles.

In consideration of the off-gas scrubbing system, the possible pollutants will be NaF dust, HF, P₂O₅, and NaPO₃ smoke. It will be necessary to consider the capabilities of the system to recover these materials.

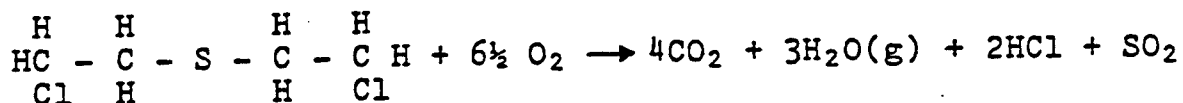
Each of these areas has been investigated and will be discussed separately on the following pages.

a. Bulk Furnace Capability

In considering the adaptation of the bulk furnace to incineration of detoxified GB salt, it is necessary to determine what are the limiting factors of the present furnace in regard to items such as heat release, residence time, flame pattern, refractory suitability, combustion temperature, and excess air as these items may affect incineration capacity, equipment serviceability, and completeness of combustion. Since ready answers to these factors are not available, it was necessary to make calculations on the bulk furnace concerning its past uses to discover what some of these limiting factors might be.

(1) Combustion of Mustard Liquid

Liquid mustard has been burned most recently in the bulk furnace at rates of 2 to 3 gpm. Mustard would be oxidized in accordance with the following equation:



Using Monsanto's physical property estimation computer program (based on Handrick's method), we estimate the heat of combustion of mustard as $\Delta H_c = -670.04$ Kcal/g mole or 7581.6 Btu/lb. At 12 lb/gal, 2 gpm is 24 lb/min. Thus the heat released due to combustion would be 10.9 M Btu/hr.

When 2 gpm of mustard was being burned, 4500 scfm of combustion air was used. The theoretical air for combustion is 1676 scfm, so approximately 168% excess air was being used. With this mixture, the theoretical flame temperature in the furnace (neglecting heat losses) calculates to be 1830°F; not a bad check on the reported normal operating temperature of 1900°F.

The maximum capacity of the secondary air fan is not known, nor is the air quantity which is used when the maximum mustard feed rate of 3 gpm exists.

However, if we assume that the secondary air flow is increased to maintain essentially the same flame temperature, combustion air flow would be 6750 scfm. This sets one possible limit on the capacity of the secondary air blower.

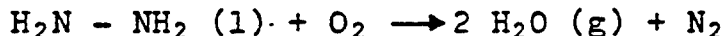
The total volume of the furnace and burner combustion chamber is 1172.6 cubic feet. When burning 3 gpm of mustard, the heat of combustion release is 16.4 M Btu/hr or a heat release rate in the furnace of 13,965 Btu/cf. This is a fairly low heat release rate for a liquid fuel. It does not appear that combustion space is the factor which limits the incineration rate to 3 gpm.

Another check on combustion space or combustion efficiency is residence time. The volume of the combustion products when burning 3 gpm of mustard is 7024 scfm or 33,690 acfm at 1900°F. This gives a residence time of 2.09 seconds which is decidedly ample for burning a liquid fuel.

The statement has been made that the 3 gpm input rate is limited by the off-gas temperature becoming too high for the breeching refractory when the fuel input is increased. However, since there is adequate combustion space, this high off-gas temperature could be avoided by using more secondary air to keep flame temperature down if it were available. Therefore, the real limitation must either be lack of secondary air blower capacity, or lack of system exhaust gas handling capacity which limits the amount of secondary air which can be used.

(2) Combustion of Hydrazine

Liquid hydrazine was originally burned in the bulk furnace at a rate of 35 gpm. Hydrazine may be oxidized as follows:



The heat of combustion of hydrazine at 25°C in accordance with the above equation is $\Delta H_c = -127.6558$ Kcal/g mole or 7,170.5 Btu/lb. A burning rate of 35 gpm is 294.76 lb/min for a heat release rate of 126.8 M Btu/hr.

The amount of excess air that was used in burning the hydrazine is not known. Assuming a flame temperature of 2100°F, the excess air required is 156%. Under these conditions, total combustion air requirements would be 40,235 scfm. This appears to be a rather high secondary air quantity to expect to obtain from a blower which now may be limiting the capacity of the operation to perhaps an availability of 6750 scfm.

There may be two possible explanations for this:

- (a) The present secondary air blower might not be the fan which was used previously when hydrazine was being burned.
- (b) When hydrazine was burned, there would be no pollutants produced other than oxides of nitrogen from the combustion operation. Therefore, it seems likely that the gases were released to the atmosphere without scrubbing and that the through-put of the present scrubbing system is the limiting factor in burning mustard. Subsequent calculations on the scrubbing system do, in fact, indicate that its sizing corresponds rather closely with the quantity of gas produced from burning 3 gpm of mustard, so that it is highly probable that exhaust system capacity is limiting the amount of secondary air that can be used.

Calculation of the heat release volume available in the bulk furnace when burning hydrazine indicates the heat release rate was 108,150 Btu/cf. This is a considerably higher figure than obtained with mustard, again indicating that combustion space is not the limiting factor in burning mustard. This hydrazine heat release figure is close to what one might anticipate as a top heat release capability for this incinerator. The literature reports maximum heat release rates in combustion chambers burning light oils of 100,000 Btu/cf.

The volume of combustion products (assuming a 2100°F flame temperature) is 46,840 scfm or 243,720 acfm at 2100°F. This gives a residence time in the furnace of 0.29 second -- very close to the recommended design residence time of 0.3 second for complete combustion in an incinerator.

Based on these two figures of heat release and residence time, we can conclude that the bulk furnace was being operated essentially at its maximum capacity when it was burning hydrazine.

(3) Design Parameters for Detoxified GB Salt

Since the sodium fluoride in the detoxified GB salt has a melting point of 1817.6°F, it would be desirable to stay below this temperature in the bulk furnace in order to avoid coating the refractory lining with a molten corrosive slag. Therefore, we should design for a maximum flame temperature of not over 1800°F. The excess air required to limit flame temperature to 1800°F is 119%. This quantity of excess air has been assumed as one of the basic design parameters.

With a heat of combustion for the total neutralized GB salt mixture of 5,981 Btu/lb, we can calculate the quantity of detoxified GB salt that can be burned for various combustion chamber heat release rates. We can also calculate the quantity of combustion

air required, the volume of the combustion products produced and the residence time in the incinerator. All of these can be used to pick various limiting features in the process. These results have been tabulated in Table B-I along with the length of operating time required to consume 7000 tons of detoxified GB salt.

A number of comments can be made concerning the data in Table B-I:

- (a) Heat release rates of 100,000-200,000 Btu/hr cu ft are entirely feasible in a combustion space burning gaseous fuels. Somewhat lower heat release rates are used with liquid fuels because of their somewhat slower rate of combustion. Heat release rates as high as 100,000 Btu/cf can be achieved with light fuel oil. With heavy oils, the peak rate drops to around 80,000 Btu/cf. Often combustion chambers are designed for heat release rates of 40,000-45,000 Btu/cf with liquid fuels. These lower rates would apply in situations where turbulence is not high, or where water cooled walls are present which might quench the flame. With combustion of solid fuels like coal, heat release rates up to 35,000-45,000 Btu/cf may be used. Where the coal has an ash with a low fusion point, these rates may be dropped as low as 15,000-25,000 Btu/cf in order to prevent coating the walls with fused particles.

On the basis solely of heat release, one might safely go as high as 100 lb/min of detoxified GB salt in the present bulk furnace.
- (b) The amount of combustion air available from the secondary air blower is unknown, but it is believed that as much as 6750 scf are being used when burning 3 gpm of mustard. Assuming this is the maximum secondary air available, this might limit the capacity of the bulk furnace to 46.8 lb/min of detoxified GB salt. However, when burning hydrazine, it appears that more combustion air was available.
- (c) Minimum residence time required for complete incineration of gaseous and volatile liquid fuels is 0.3 second at 1300°F or above. Solid combustibles, depending on particle size and composition, may require somewhat longer. Typical burning times for coal particles of various diameters are tabulated below:

Table B-I. Operating Factors in Incinerating Dry Detoxified GB Salt at Various Disposal Rates

Detoxified GB Salt Combustion Rate, lb/min	Heat Release, Btu/hr-cu ft	Combustion Air, scfm	Residence Time, sec	Exhaust Volume, scfm	Time to Incinerate 7000 Tons Hours	Years*
37.5	11,500	5,405	2.8	5,535	6222	0.78
46.8	14,300	6,750	2.2	6,905	4986	0.62
50	15,300	7,205	2.1	7,380	4667	0.58
63	19,300	9,080	1.6	9,295	3703	0.46
81.7	25,000	11,775	1.3	12,055	2856	0.36
100	30,600	14,410	1.0	14,760	2333	0.29
150	45,900	21,620	0.7	22,135	1556	0.19
200	61,200	28,825	0.5	29,515	1167	0.15
325	99,500	46,840	0.32	47,960	718	0.09
345	105,600	49,720	0.30	50,915	496	0.06

* Assuming 8000 hours of operation per year.

Table B-II. Burning Times for Coal Particles

Coal Particle Size			
<u>Microns</u>	<u>U.S. Mesh</u>	<u>Inch</u>	<u>Combustion Time, Sec</u>
44	325	0.00173	0.27
74	200	0.00291	0.47
100	150	0.00394	0.82
149	100	0.00587	1.4

The above data are average for coal particles. Coal with high volatile content will tend to burn faster. Detoxified GB salt, because of its comparatively short, simple structural nature, should tend to be quite volatile (or crack) and burn more readily than the data above indicate.

However, small particle sizes are advantageous in combustion of a solid aerosol mixture. In burning pulverized coal, it is often good practice to grind to coal to 80% minus 200 mesh. The exact particle sizes of the spray-dried detoxified GB salt are not known. It is quite fine and it is likely that it could be burned in the bulk furnace directly as produced. However, to be sure of burning completely, a small mill to grind the salt to around 325 mesh has been included in the equipment cost. With fine grinding of this salt, any feed rate up to 100 lb/min should certainly produce adequate burning in the bulk furnace.

- (d) In design of the packed scrubber (which is discussed later in this report) it is desired to keep the gas mass velocity after cooling and humidification to around $G = 800$ lb/hr sq ft or less. This corresponds to a burning rate for the residues from GB of 50 lb/min for the new scrubber and around 37.5 lb/min for the old scrubber. If both scrubbers were run in parallel, combustion rates of up to 87.5 lb/min might be handled.

Assuming adequate combustion air is available, a detoxified GB salt feed rate to the bulk furnace of 50 lb/min would be a thoroughly conservative rate as far as the furnace is concerned, and it is recommended. This is about the maximum rate that could be handled with the new scrubbing system. Whenever the old scrubbing system was substituted, it would be necessary to cut the feed rate back to around 40 lb/min to avoid excessive pressure drop in the old scrubber.

Using both scrubbers simultaneously, it would be possible to operate the bulk furnace at rates up to 87.5 lb/min. However, this constitutes a less conservative situation for the furnace, and would require higher cost gas handling equipment following the present scrubbers than has been included in the cost estimate. This situation, while possible, is not recommended.

An overall heat and material balance for operating the bulk furnace at a 50 lb/min feed rate is found in Table B-III.

(4) Uncertainties in Bulk Furnace Application

The above recommendation to burn 50 lb/min of powdered detoxified GB salt in the bulk furnace is a safe, conservative recommendation as regards engineering calculations. However, the high temperature chemistries of some of the species which may be present are not subject to calculation and could result in processing difficulties. It has been assumed that the SIMP will be oxidized to P_2O_5 and Na_2O in the flame at $1800^\circ F$ and that the NaF will either remain as solid airborne NaF particles or will react to produce HF and Na_2O .

The assumption of P_2O_5 and HF species represents the worst situation in regards to recovery of pollutants in the scrubbing system, and adequate modifications to the scrubbing system to handle these difficulties have been recommended.

However, there may be the possibility that P_2O_5 and Na_2O will react in the flame to give molten $NaPO_3$ (m.p. $1160^\circ F$) which will settle out in the furnace, coat the refractory walls, and give a corrosive slagging problem in regard to the furnace refractories. To the extent this occurs, the off-gas cleanup problem becomes easier and there might not even be a need for a Brink high efficiency mist eliminator to capture H_3PO_4 mist escaping from the packed scrubber. But, if any appreciable amount of $NaPO_3$ is formed, it could result in fluxing of the refractory lining from the bulk furnace in a fairly short period of time (measured in weeks).

Since this difficulty cannot be determined by calculation, it is recommended, before conversion of the bulk furnace is commenced, that a small simulated bench scale furnace be operated for a short period of time to observe any slagging tendencies. A small quantity of detoxified GB salt could be burned in a small 70% alumina refractory tube. The outside of the tube might be wrapped with an electric heating element to maintain the wall at $1800^\circ F$. If no condensation or slag accumulation occurs, there should be no problem with operation of the bulk furnace as proposed.

b. Ton Container Furnace Capability

Conceivably, neutralized GB salt could be burned batchwise in the present ton container furnace. One of the problems in burning the detoxified GB salt completely is the matter of getting oxygen to the surface of the particles. The product could be placed in a large pan or tray in the furnace. However, as it became hot, oxygen would get to the material only on the surface of the pile. As the neutralized GB salt was consumed, leaving a sodium fluoride ash behind, the material underneath in the pan would tend to

Table B-III. Operating Conditions for Bulk Furnace
Using Solid Detoxified GB Salt Firing

Fuel rate:	neutralized GB salt	50 lb/min
	SIMP	38.5 lb/min-0.2405 lb.mol/min
	NaF	11.5 lb/min-0.2738 lb.mol/min
Theoretical combustion air:		9.162 lb.mol/min (3289 scfm)
	O ₂	1.924 lb.mol/min
	N ₂ & inerts	7.238 lb.mol/min
Excess air:		10.911 lb.mol/min (3917 scfm)
Percent excess air:		119%
Heat released (@ 25°C) from burning detoxified GB salt:		17,944 Btu/hr
Combustion product temperature:		1800°F (982°C)
Combustion products:		
Quantity & Composition:		
	scfm	7,400
	acfm @ 1800°F	34,000
	CO ₂	0.962 lb.mol/min
	H ₂ O	1.2025 lb.mol/min
	Theory N ₂	7.238 lb.mol/min
	Excess air	10.911 lb.mol/min
	NaPO ₃	0.2405 lb.mol/min
	NaF	0.2738 lb.mol/min
		20.8278 lb.mol/min
Sensible heat content of combustion products above 20°C:		
	CO ₂	1,187,100 Btu/hr
	H ₂ O	1,147,200 Btu/hr
	Theory N ₂	5,645,000 Btu/hr
	Excess air	8,602,200 Btu/hr
	Na ₂ F	372,900 Btu/hr
	NaPO ₃	989,000 Btu/hr
		17,944,000 Btu/hr
Adiabatic saturation temperature of combustion products:		80.1°C

become smothered with the ash. So, if a pan were piled deep with material, we do not believe that the material on the bottom would ever become completely oxidized. The presence of unincinerated salt from GB remaining in the ash could present a disposal problem in regard to the residue.

Based on experience with burning coal in a pile where the air enters the pile from the top, rather than traveling through the pile from a grate below, we do not believe that this product can be burned much farther than to a depth of 4-6 inches. It is difficult to burn coal containing only 10% ash to a depth greater than this. The detoxified GB salt can be considered as a solid fuel with 23% ash.

The use of this salt in lumps would facilitate the penetration of oxygen until there is too great an accumulation of ash on the surface. Therefore, the present compacted material would be a preferable feed to the spray-dried material without compaction. The removal of the fines from the compacted detoxified GB salt would even be preferable.

To achieve maximum burning surface in the ton furnace, the detoxified GB salt might be charged batchwise into a 4 foot wide by 14 foot long pan, with sides perhaps 12-18 inches high. The salt would be filled to a depth of 4-6 inches. Assuming a 6 inch depth, a single pan charge would be 1820 pounds. The pan would be placed in the furnace and the furnace heated. A maximum achievable burning rate for coal on a traveling grate stoker is 400,000 Btu/hr sq ft. Without air actually being blown through the material to be burned, it is unlikely that more than 1/5 of this burning rate would be achieved, or a burning rate of 80,000 Btu/hr sq ft. This means that the maximum incineration rate for the detoxified GB salt is 13.375 lb/hr sq ft. For the above size pan, the burning rate is 750 lb/hr of salt. A period of 2.4 hours would be required for complete oxidation of the charge once burning temperature is reached.

One can visualize a batch cycle which allows 2 hours for furnace heatup, 2-1/2 hours for oxidation, and 1 hour to cool down for a total cycle time of 5-1/2 hours. With two furnaces in use, this would permit a total of about eight batches per day or an incineration of 14,560 lb/day. Total amount of detoxified GB salt which could be incinerated in a normal year would be around 2430 tons. To incinerate 7000 tons would require 2.9 years.

At the completion of each batch, the pan would probably contain a NaPO_3 -NaF glass which would have to be removed. Its removal in the molten state would result in the need for special handling equipment. Its removal from the pan after solidification might be difficult and time consuming. To the extent it contained any unincinerated detoxified GB salt, its disposal could become a further problem. Compared to incineration in the bulk furnace, this does not appear to be an attractive alternative.

(1) Continuous Approaches

The above method might be made continuous by installing a series of small articulated pans (perhaps 4 ft long x 12 in. wide) on an endless belt which would travel through the furnace and recycle. The returning pans at one end of the furnace would be filled with fresh detoxified GB salt from a distributing feeder while the residue would be dumped from the pans at the opposite end. The capacity of the furnace would be greater because no time would be lost to heating up and cooling down of the furnace. It would always stay hot.

The furnace capacity of a single furnace with such a device would be about 730 lb/hr or 17,520 lb/day. Approximately 2.4 years would be required to incinerate 7000 tons of the salt using one furnace. The time could be reduced to half if conversions were made to both furnaces.

The residue discharged from the pans on the belt would likely be a molten glass. Facilities to catch this glass and solidify it into a disposable form would be required. Potential problems revolve around the possibility of the glass containing unoxidized residue from the salt. There is also a question of the glass viscosity and how rapidly and cleanly the pans would discharge. The simplest device would be to fasten the pans to an endless chain belt which would return the pans through the furnace upside down. However, if the glass were sufficiently viscous that the pans did not discharge cleanly, they might continue to drip glass onto the floor of the furnace throughout the return trip, creating a buildup in the furnace which might be difficult to clean out.

Greater capacity could be obtained in the ton furnaces by charging the detoxified GB salt onto a traveling grate or similar device where combustion air is blown through the bed. In this case, the burning rate could be as high as 400,000 Btu/hr sq ft of grate surface or perhaps 4000 lb/hr of product burned per furnace. Daily incineration for one furnace would be 48 tons per day, and 7000 tons could be incinerated in around 0.44 year.

Problems that would be encountered are:

- (a) Fines in the present compacted, detoxified GB salt would spill through the grate openings. Without undergrate dust hoppers, the furnace would have to be shut down frequently for cleanout of accumulated material. Installing undergrate hoppers would essentially require rebuilding of the furnace.
- (b) If the compacted salt were screened and only pelletized lumps fed, the spillage problem would be minimized. However, small pieces near the end of the burning process could still fall through the grates and cause a cleanout problem.

- (c) To the extent sodium phosphates are produced during the burning process, a molten slag could develop which could stick to the grates, coat them up, or even leak through into moving parts beneath where it could freeze and bind them up. It could also coat burning product particles and prevent complete burnout of combustibles, or even form incompletely burned clinkers on the grate. Either of these last possibilities could be a real problem.

Our general appraisal is that the bulk furnace is a much more promising disposal device.

5. Off-Gas Scrubbing System

Materials which must be removed from the off-gases are P_2O_5 gas and smoke; HPO_3 and H_3PO_4 mist from partial or complete hydration of P_2O_5 ; Na_2O , $NaPO_3$, Na_2CO_3 , and NaF dust and fine particles; and HF gas. The exact distribution of materials between these species is unknown and cannot be predicted with confidence. The most difficult of these materials to collect are P_2O_5 smoke, partially hydrated P_2O_5 acid mist, and HF gas. Therefore, if all of the off-gas compounds containing these materials are assumed to be in this form, and the scrubbing system is made adequate to recover these materials, it should be capable of efficient collection regardless of the species.

Design calculations were made on the scrubber system for handling the off-gases from the bulk furnace operated at a 50 lb/min of detoxified GB salt incineration rate using only one scrubber. For the old scrubber, incineration rate would need to be cut to 37.5 to 40 lb/min because of the smaller cross section of the packed scrubber and to prevent excessive pressure drop across the packing. (The old packed scrubber will not flood even at the 50 lb/min incineration rate.)

(1) Quencher

Referring to the flow quantities shown in Table B-III, the inlet gas to the quencher from the bulk furnace will be 7400 scfm at an actual temperature of 1800°F. The actual inlet velocity will be around 4810 ft/min.

In being adiabatically saturated, the gas will be cooled to 80.1°C and 15.8 lb moles/min of water will be evaporated into the gas stream.

With the recirculation of the scrubbing liquid through the 316 stainless steel heat exchanger, the gas can be cooled somewhat below the adiabatic saturation temperature to perhaps 5-70°C. This will reduce the amount of evaporated moisture and reduce the gas velocity through the packed scrubber somewhat, improving its scrubbing efficiency slightly. However, this

subcooling of the gas is not necessary as the system has been checked for satisfactory performance at the adiabatic saturation temperature..

At the adiabatic saturation temperature, the quantity of gas leaving the quencher is shown in Table B-IV.

Table B-IV. Data on Off-Gases from the Quencher

<u>Component</u>	<u>Lb mols/min</u>	<u>Lb/min</u>
CO ₂	0.962	42.33
Theory N ₂	7.238	202.66
Excess air	10.911	316.42
H ₂ O	17.0266	306.48
NaPO ₃	0.2405	24.53
NaF	<u>0.2738</u>	<u>5.48</u>
Total	36.6519	897.90
Volume @ Standard Conditions 13,082 scfm		
Actual volume @ 1 atm 16,916 acfm		
Water evaporated in quencher: 15.82 lb mol/min		
285.09 lb/min (34.2 gpm)		

(2) Packed Scrubber

The gas mass velocity through the new scrubber is $G = 842$ lb/hr sq ft. A liquid rate for efficient scrubbing of $L = 1800$ lb/hr sq ft should be maintained. This would require a recirculation rate to the new scrubber of 1908.5 lb/min of water (about 230 gpm). The pressure drop through the packing for the gas is expected to be about 0.9 inch of water per foot of packing. For 1 inch Raschig rings, the height of a transfer unit, H_{OG} , is expected to be less than 1.5 ft for something over 7 transfer units in the packed scrubber.

Both P₂O₅ and HF will tend to attack the glass Raschig rings. The preferred material would be 1 inch carbon Raschig rings and money has been included in the cost estimate for new tower packing. However, for a short term operation, and if the pH is kept sufficiently alkaline, it may be that the attack on the glass rings will not be too rapid.

It is anticipated that some corrosion of the steel shell will also occur.

The circulation rate required in the old scrubber to maintain a liquid rate, $L = 1800$, is 1508 lb/min (about 180 gpm).

(3) P₂O₅ Recovery

Essentially no P₂O₅ smoke particles (which will be below 1 micron in size) will be collected in the quencher although essentially all P₂O₅ particles will be at least partially hydrated here to HPO₃ mist particles. The mist particles leaving the quencher will have a median size range from 0.8 to 1.0 micron.

Monsanto has little experience in recovery of P₂O₅ and phosphoric acid mist in a packed bed with alkaline scrubbing liquor, nor is there any reported information in the literature. Scrubbing efficiency is well known in neutral and mildly acidic solutions. All of the P₂O₅ and acid mist entering the scrubber is particulate (not gaseous) and collection in a packed bed occurs by a combination of impingement and Brownian diffusion. It is not anticipated that these collection techniques would be influenced appreciably by scrubbing with liquor of alkaline pH.

Based on Monsanto experience, we would expect about 94% collection of the P₂O₅ in a packed scrubber with 11 ft of 1 in. Raschig rings. If all of the phosphorus in the detoxified GB salt is in the form of P₂O₅, the entering quantity to the packed scrubber will be 1024.5 lb/hr at a concentration of 592 mg P₂O₅/scf. The exit quantity would be 61.5 lb/hr and the exit concentration would be 35.5 mg/scf.

A plume released to the atmosphere containing this much P₂O₅ or acid mist will be very opaque because the particle sizes will all be submicron. The trail from such a plume would extend for at least 10 miles. Therefore, further collection is necessary.

The present electrostatic precipitator could collect the mist, but the carbon steel internals would be quickly corroded. Therefore it is recommended that a Brink high efficiency glass fiber mist eliminator in a stainless steel shell be installed following the packed scrubber. Such a mist eliminator, plus stainless steel ductwork, a stainless steel exhaust fan, and a 100 foot tall stainless steel stack with York mesh entrainment separator at the top have been included in the estimated cost of process alternations.

The high efficiency Brink mist eliminator should be designed for 99.5% collection on 1 micron size particles. Accordingly, the P₂O₅ quantity in the effluent from the stack will be 0.31 lb P₂O₅/hr. This should provide only a barely discernible trace of P₂O₅ in the plume following the dissipation of any condensing water vapor in the effluent.

The Brink mist eliminator should be equipped for an irrigating spray for washing water soluble particles from the elements. In this manner, the mist eliminator will serve as a total final collector for any other particulate matter getting through the packed scrubber such as NaF or sodium phosphate particles.

Due to the high water vapor content of the effluent, it is anticipated that the effluent will have a highly visible condensing steam plume on the stack during most of the year's operation.

(4) Fluoride Recovery

If the spray in the quencher is maintained with a neutral or alkaline pH, a certain amount of the HF will be recovered in the quencher. The exact amount will depend on the pH, the ratio of liquid to gas, the size of the spray particles, and the residence time. However, for this study, collection of the HF in the quencher has been neglected and the design of the packed scrubber checked to see that at least 99.7% of the fluoride would be collected in it.

Assuming that all of the fluoride in the detoxified GB salt enters the scrubber in the form of HF, the inlet quantity is 328.6 lb/hr. The inlet mol fraction (y_1) = 0.00746. The partial pressure of HF in the inlet gas is 5.67 mm of mercury. For desirable pollution control, it is believed that the HF concentration in the outlet gas must be reduced to no more than 1 pound per hour. This is a mol fraction in the outlet gas (y_2) = 2.28×10^{-5} . The partial pressure of HF in the outlet gas will be 0.017 mm of mercury.

To achieve such a low outlet partial pressure of HF, it is absolutely essential that the scrubbing be countercurrent and that there be no back pressure of HF above the incoming scrubbing solution. This means that the scrubbing solution pH must be maintained in the pH range of 7.0-8.0. If the pH becomes appreciably more alkaline than 8.0, CO_2 will start to be absorbed with attendant increase in caustic consumption. The control of pH can be with either sodium or calcium alkalies. However, the use of calcium would require the addition of a settling thickener to remove solids from the recirculating stream.

With a recirculation rate L of 1800 and assuming all fluoride is in the form of HF, the weight concentration of HF in the leaving liquid from the scrubber would be 0.285% HF. The vapor pressure of HF above this solution at 80°C is 0.123 mm of mercury, and the equilibrium back pressure of HF in the gas y_2^* is 1.614×10^{-4} .

Operating the scrubber in the fashion described requires 5.9 transfer units to reduce the HF outlet quantity to 1 lb/hr. The paced scrubber, when operated in the fashion described, will actually have 7 transfer units.

6. Possibility of Incinerating Detoxified GB Salt Solution

The neutralized GB salt solution which is presently fed to the spray drier runs 28.9% dissolved salts and the remainder water. A considerable savings in operating cost could result if this solution could be sprayed directly into the bulk furnace and burned, instead of being spray dried and having the resultant powder burned.

Calculations for this case were therefore made and it was found that this could be done if some supplemental fuel were supplied to help evaporate the water. The same design parameters were used as discussed in the preceding pages of this report. The limiting factor was found to be the off-gas handling capability of the packed scrubber. Accordingly, this was set at $G = 800$ lb/hr sq ft which limits the combustion rate to 42.5 lb/min of dissolved, detoxified GB salt or 147 lb/min of solution.

The incineration rate is 2550 lb/hr of salt, requiring 5490 hours or 0.69 year to incinerate 7000 tons.

Supplemental heat which must be supplied is 3.41 cf of 1000 Btu/cf natural gas per lb of dissolved salt incinerated. It has been assumed that the natural gas would be burned with 20% excess air, but that no excess air would be provided for the detoxified GB salt. Fuel oil could be used for the supplementary fuel as readily as natural gas. Flame temperature has again been limited to 1800°F.

The modifications to the gas scrubbing system would remain the same. The cost of handling the liquid solution has not been estimated in detail. Presumably, liquid salt solution storage tanks would have to be provided instead of a solid residue storage and feeding system. Burner changes would still be required, but there would be no need for a detoxified GB salt grinding mill. The overall capital cost of modifications to burn the solution should be about the same as has been estimated for the dry salt -- perhaps an insignificant amount less.

Table B-V lists operating parameters for the bulk furnace when burning 42.5 lb/min of detoxified GB salt in a 28.9% water solution.

Table B-V. Operating Conditions for Bulk Furnace
Using 28.9% Detoxified GB Salt Solution Feed

Detoxified GB soln. feed rate	147 lb/min
SIMP	32.73 lb/min
NaF	9.77 lb/min
H ₂ O	104.50 lb/min
Fuel rate - natural gas:	8690 cfh
Combustion air:	4487 scfm (20% excess air for natural gas only)
Combustion temperature:	1800°F
Combustion products:	
Quantity & composition:	
scfm	6958
acfm @ 1800°F	31,962
CO ₂	1.2385 lb.mol/min
Theory N ₂	9.2689 lb.mol/min
Excess air	0.7853 lb.mol/min
H ₂ O	7.6522 lb.mol/min
NaPO ₃	0.2044 lb.mol/min
NaF	0.2327 lb.mol/min
	19.3820 lb.mol/min
Adiabatic saturation temperature of combustion products:	90.65°C
Water evaporated (adiabatically) in quencher:	374.1 lb/min - (44.9 gpm)
Volume of cooled gases leaving quencher:	14,412 scfm

7. Estimated Costs of Process Modifications

The costs of modifying the existing equipment at Rocky Mountain Arsenal in connection with using the bulk furnace to incinerate spray-dried detoxified GB salt have been developed. These costs are to be considered only as order of magnitude costs since Monsanto has little information as to where the new equipment would be specifically located, building or piping modifications that might be required, or any knowledge of Rocky Mountain Arsenal installation costs or construction procedure requirements. To develop these approximate costs, the present purchase costs of the new equipment items have been estimated and the installed costs have been obtained with the use of a multiplier of 5-1/2 to cover foundations, piping, building items, erection, contractor overhead and profit, and engineering costs.

The equipment modifications required are:

- Salt unloading hopper
- Unloading hopper screw conveyor
- Unloading elevator
- Unloading area dust collector and exhaust fan
- Salt feed bin
- Salt airlock screw feeder with variable speed drive
- Salt grinding mill
- Burner airveyor and burner
- Carbon Raschig rings for one packed scrubber
- High efficiency Brink mist eliminator
- Stainless steel exhaust fan with flow control damper
- Stainless steel stack and York mesh demister

A rough breakdown of equipment cost by groups is:

Unloading hopper, conveyors	\$ 12,000
and elevators	
Unloading area dust collector and fan	12,000
Feed bin and feeder	6,500
Grinding mill	2,500
Burner piping and burner	8,000
Carbon Raschig rings for scrubber	13,500
316 SS H.E. Brink mist eliminator	82,000
Exhaust fan	13,000
316 SS stack and York mesh demister	<u>37,000</u>

Total equipment cost \$186,500

Installed cost including auxiliaries,
erection, overhead, engineering, and
contingencies \$1,025,000

The scrubbing system modifications have been priced for modifying only one scrubbing system. If it were desired to operate both scrubbing systems in parallel to permit higher incineration rates, items beginning with the carbon Raschig rings on would have to be doubled in cost.

8. Additional Calculations

After completing the calculations summarized in the preceding seven sections in this Appendix (Appendix B), it was suggested that similar calculations should be done for a different composition of demilled GB residue which contained a significant amount of sodium carbonate. Four separate salt compositions have been considered and the corresponding associated costs have been estimated. Based on the information available to us, the following salt compositions have been considered.

- | | |
|----------|---|
| Case I | 23% NaF, 77% SIMP |
| Case II | 23% NaF, 77% SIMP as an aqueous solution containing 28.9% salt |
| Case III | 15% NaF, 60% SIMP, 25% Na_2CO_3 |
| Case IV | 15% NaF, 60% SIMP, 25% Na_2CO_3 as an aqueous solution containing 28.9% salt. |

a. Combustion Products

Insufficient data is available to calculate the exact nature of the combustion products. However, by applying the data available, estimating other data, and comparing these systems with reactions reported in the literature, the following are likely possibilities.

(1) The combustion of SIMP will produce NaPO_3 which has a melting point of 627°C . In turn, this will react in the melt with NaF forming the monofluorophosphate, $\text{Na}_2\text{PO}_3\text{F}$ (M.P. 635°C). The monofluorophosphate is unstable in the melt forming a variety of decomposition products, e.g. $\text{Na}_4\text{P}_2\text{O}_7$, Na_3PO_4 , and other polyphosphates as non-volatiles and HF and F_2 as volatiles in the presence of water vapor and oxygen, respectively.

(2) The addition of Na_2CO_3 to the system should reduce the evolution of HF to some extent. Carbon dioxide will be produced in a melt reaction of the non-volatiles; all combinations of NaPO_3 , Na_2CO_3 , and NaF have low melting point eutectics. But the mixture of reaction products are likely to have higher melting points.

(3) In general, both systems will form mist-like, molten-salt droplets at the proposed operating temperature of 1800°F in the combustion chamber. The vapor pressures appear to be sufficiently low that an insignificant amount of non-volatiles

will be carried over as vapor. The entrained droplets will be carried over to the quencher where the salts will dissolve; the remainder will condense on the furnace exhaust and walls, forming a molten slag which will accumulate at the base of the furnace.

The nature of the slag will depend on the initial salt composition, furnace temperature, and extent of melt reaction. However, both fluorine and phosphates will be present in the slag.

b. Combustion Chamber Refractory

The furnace slag as described above is highly corrosive to common refractories. Where only phosphates are present, zircon refractories have been used, e.g. in the manufacture of "calgon." According to Charles Taylor and Sons, phosphate calcining furnaces where fluorine gas is driven off at about 2600°F have a refractory life of about 3 months when high alumina brick is used. They recommend either zirconium brick or "Tiger Brick", a hard burned, clay free mullite. Even with these corrosion resistant refractories, their useful life would probably not exceed one year.

Before any decision is made regarding refractory installation, the material should be tested in the laboratory to determine the products of combustion and their effect on the proposed refractory.

c. Economics

The capital costs for the equipment necessary to perform the incineration of 1) spray dried solid feed, and 2) aqueous solution feed were estimated separately as slightly different equipment will be required to handle each. The total project fixed capital estimate includes new equipment, modifications to existing equipment, and an estimate of the value of existing equipment.

To process spray dried solids:

New equipment and modifications*	\$1,100,000
Existing equipment	520,000
Total fixed capital	\$1,620,000

To process 28.9% aqueous solution

New equipment and modifications*	\$ 920,000
Existing equipment	480,000
Total fixed capital	\$1,400,000

*Includes 9" zircon refractory lining in furnace

The capacity of the scrubber was taken as the limiting factor for determining production capacity; for purposes of calculation the maximum gas flow allowed in the scrubber was 800 lb/hr-ft². The results of the calculations are as follows.

	Case I	Case II	Case III	Case IV
Incineration Capacity, Mlb/yr on solids basis	19.4	19.0	25.7	17.6
Operating Cost, M\$/yr	690	690	570	610
Unit Cost, \$/100 lb Solids	3.55	3.63	2.22	3.47

More details are given in the following section.

Temperatures and compositions are given for each of the four cases. The quenched gas composition refers to the composition of gases going to the scrubber assuming:

1. All of the fluorine is present as HF.
2. All of the carbonate is converted to CO₂.
3. None of the gases are absorbed in the quencher.
4. The scrubber efficiency is the same as previously described by B. B. Crocker in his report dated May 10, 1974.

Calculations were made initially on the basis of 100 lb/min of solids, then factored down to "actual operation" reflecting the limiting gas flow of 800 lb/hr-ft² in the scrubber.

The economics are based on the following assumptions.

1. On stream operation -----7884 hr/yr
2. Repairs -----10% of fixed capital
3. Factory supplies -----10% of repairs
4. Payroll charges -----16% of labor + supervision
5. Controllable Overhead -----30% of direct conversion costs
6. Non-controllable Overhead -----2% of M&E capital costs
7. Clothing and laundry -----15/man-month
8. Supervision -----10% of labor (Case I)
9. Operators & labor -----6.00/hr
10. Depreciation -----Not considered
11. Materials and Services

Caustic (50%) -----3.21/cwt NaOH
 City Water ----- .30/ccf
 Natural Gas ----- 1.07/mcf
 Electricity ----- 3.00/ckwh

PLEASE NOTE THAT NUMBERS PRINTED DO NOT INDICATE
 ACCURACY, MERELY AN ABSENCE OF ROUND-OFF.

SUMMARY -- CASE I

COMPOSITION, PERCENT

NAF 23.00
 GO 77.00
 NA2CO3 0.0
 WATER 0.0

FURNACE TEMP. 1800.0 DEG. F.

100 LB/MIN (BASIS) ACTUAL OPERATION

WATER EVAP. IN QUENCHING, LB/MIN. 507.48 208.08

QUENCHED GAS COMPOSITION

H2O, LB/MIN 545.87 223.83
 CO2, LB/MIN 84.68 34.72
 N2, LB/MIN 838.34 343.75
 O2, LB/MIN 154.63 63.41
 HF, LB/MIN 10.96 4.49
 TOT, LB/MIN 1634.48 670.20

SATURATION TEMP.= 76.91 DEG. C.

EXCESS AIR

O2, LB/MIN 154.63 63.41
 N2, LB/MIN 509.01 208.71
 AIR, LB/MIN 663.64 272.12

FACTOR= 0.410

SOLID COMBUSTION RATE, LB/MIN 100.00 41.00

SIMP COMBUSTION RATE, LB/MIN 77.00 31.57

GAS FLOW IN SCRUBBER, LB/HR-FT2 1951.04 800.00

ESTIMATE OF COSTS

PRACTICE

50 PCT. CAUSTIC 3620336.0 LUS/YR
ELECTRICITY 16400.0 CKWH/YR
CITY WATER 33796.8 CCF/YR
FUEL GAS 0.0 MCF/YR

MATERIALS

DOLLARS/YEAR

CAUSTIC

116212.0

DIRECT CONVERSION

ELECTRICITY 49200.0
CITY WATER 10139.0
FUEL GAS 0.0
LABOR-MFG 136799.9
SUPERVISION 13680.0
PAYROLL CHARGES 24076.8
REPAIRS--M AND E 158752.8
FACTORY SUPPLIES 15076.0
LABORATORY 6000.0
CLOTH. AND LOY. 1980.0

TOTAL

416511.4

INDIRECT CONVERSION

CONTROLLABLE-F.I.E. 124953.4
NON-CONTROLLABLE-F.I.E. 31752.0

TOTAL

156705.3

TOTAL MFG COST

609429.5

YEARLY PRODUCTION=19396448.0 LR/YR

UNIT COST(\$/100 LB SOLIDS)= 3.554

SUMMARY -- CASE II

COMPOSITION, PERCENT

NAF 23.00
GB 77.00
NA2CO3 0.0
WATER 71.10

FURNACE TEMP. 1800.0 DEG. F.

100 LB/MIN (BASIS) ACTUAL OPERATION

WATER EVAP. IN QUENCHING, LB/MIN.

591.43 237.55

QUENCHED GAS COMPOSITION

H2O, LB/MIN
CO2, LB/MIN
N2, LB/MIN
O2, LB/MIN
HF, LB/MIN
TOT, LB/MIN

914.06 367.13
132.21 53.10
597.84 240.12
13.54 5.44
10.96 4.40
1668.61 670.20

SATURATION TEMP. = 88.96 DEG. C.

FUEL, SCFH

371.71 149.30

FUEL COMBUSTION PRODUCTS

O2, LB/MIN
N2, LB/MIN
CO2, LB/MIN
H2O, LB/MIN

13.54 5.44
268.51 107.85
47.53 19.09
36.22 15.35

FACTOR = 0.402

SOLID COMBUSTION RATE, LB/MIN

100.00 40.17

SIMP COMBUSTION RATE, LB/MIN

77.00 30.93

GAS FLOW IN SCRUBBER, LB/HR-FT2

1991.77 800.00

ESTIMATE OF COSTS

PRACTICE

50 PCT. CAUSTIC 3546296.0 LUS/YR
ELECTRICITY 15200.0 CKWH/YR
CITY WATER 35670.7 CCF/YR
FUEL GAS 70624.9 MCF/YR

MATERIALS

DOLLARS/YEAR

CAUSTIC 113836.0

DIRECT CONVERSION

ELECTRICITY 45600.0
CITY WATER 10701.2
FUEL GAS 75568.6
LABOR-MFG 97199.9
SUPERVISION 13680.0
PAYROLL CHARGES 17740.8
REPAIRS--M AND E 140079.8
FACTORY SUPPLIES 14008.0
LABORATORY 6000.0
CLOTH. AND LDY. 1440.0

TOTAL

422018.2

INDIRECT CONVERSION

CONTROLLABLE-F.I.E. 126605.4
NON-CONTROLLABLE-F.I.E. 28016.0

TOTAL

154621.3

TOTAL MFG COST

690475.5

YEARLY PRODUCTION=18999776.0 LB/YR

UNIT COST(\$/100 LB SOLIDS)= 3.634

SUMMARY -- CASE III

COMPOSITION, PLRCENT

NAF 15.00
GB 60.00
NA2CO3 25.00
WATER 0.0

FURNACE TEMP. 1800.0 DEG. F.

100 LB/MIN (BASIS) ACTUAL OPERATION

WATER EVAP. IN QUENCHING, LB/MIN. 302.54 212.01

QUENCHED GAS COMPOSITION

H2O, LB/MIN 420.09 228.63
CO2, LB/MIN 76.36 41.56
N2, LB/MIN 610.04 336.36
O2, LB/MIN 109.80 59.76
HF, LB/MIN 7.15 3.89
TOT, LB/MIN 1231.43 670.20

SATURATION TEMP.= 79.32 DEG. C.

EXCESS AIR

O2, LB/MIN 109.80 59.76
N2, LB/MIN 361.42 196.70
AIR, LB/MIN 471.21 256.45

FACTOR= 0.544

SOLID COMBUSTION RATE, LB/MIN - 100.00 54.42

SIMP COMBUSTION RATE, LB/MIN 60.00 32.65

GAS FLOW IN SCHUBBER, LB/HR-FT2 1469.93 800.00

ESTIMATE OF COSTS

PRACTICE

50 PCT. CAUSTIC	0.0	LBS/YR
ELECTRICITY	16400.0	CKWH/YR
CITY WATER	31982.5	CCF/YR
FUEL GAS	0.0	MCF/YR

MATERIALS	DOLLARS/YEAR
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CAUSTIC	0.0
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DIRECT CONVERSION

ELECTRICITY	49200.0
CITY WATER	9594.8
FUEL GAS	0.0
LABOR-MFG	136799.9
SUPERVISION	13680.0
PAYROLL CHARGES	24076.8
REPAIRS--M AND E	158759.8
FACTORY SUPPLIES	15876.0
LABORATORY	6000.0
CLOTH. AND LOY.	1900.0

TOTAL	415967.2
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INDIRECT CONVERSION

CONTROLLABLE-F.I.E.	124790.1
NON-CONTROLLABLE-F.I.E.	31752.0

TOTAL	156542.1
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TOTAL MFG COST	572509.3
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YEARLY PRODUCTION=2574480.0	LB/YR
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UNIT COSTS/100 LB SOLIDS=	2.224
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SUMMARY -- CASE IV

COMPOSITION, PERCENT

NAF 15.00
GR 60.00
NA2CO3 25.00
WATER 71.10

FURNACE TEMP. 1800.00 DEG. F.

100 LB/MIN BASIS, ACTUAL OPERATION

WATER EVAP. IN QUENCHING, LB/MIN. 636.80 237.11

QUENCHED GAS COMPOSITION

H2O, LB/MIN 970.15 361.23
CO2, LB/MIN 146.98 54.73
N2, LB/MIN 655.54 244.09
O2, LB/MIN 20.12 7.49
HF, LB/MIN 7.15 2.66
TOT, LB/MIN 1799.94 670.20

SATURATION TEMP. = 88.64 DEG. C.

FUEL, SCFM

552.26 205.63

FUEL COMBUSTION PRODUCTS

O2, LB/MIN 20.12 7.49
N2, LB/MIN 328.92 148.54
CO2, LB/MIN 70.61 26.29
H2O, LB/MIN 56.78 21.14

FACTOR = 0.372

SOLID COMBUSTION RATE, LB/MIN

100.00 37.23

SIMP COMBUSTION RATE, LB/MIN

60.00 22.34

GAS FLOW IN SCHUBBER, LB/HR-F12

2148.54 800.00

ESTIMATE OF COSTS

PRACTICE

50 PCT. CAUSTIC	0.0	LBS/YR
ELECTRICITY	15200.0	CKWH/YR
CITY WATER	28999.0	CCF/YR
FUEL GAS	97271.9	MCF/YR

MATERIALS

DOLLARS/YEAR

CAUSTIC

0.0

DIRECT CONVERSION

ELECTRICITY	45600.0
CITY WATER	8699.7
FUEL GAS	104080.9
LABOR-MFG	97199.9
SUPERVISION	13600.0
PAYROLL CHARGES	17740.8
REPAIRS--M AND E	140079.8
FACTORY SUPPLIES	14008.0
LABORATORY	6000.0
CLOTH. AND LOY.	1440.0

TOTAL

448529.1

INDIRECT CONVERSION

CONTROLLABLE-F.I.E.	134558.7
NON-CONTROLLABLE-F.I.E.	28016.0

TOTAL

162574.6

TOTAL MFG COST

611103.7

YEARLY PRODUCTION=17613472.0 LB/YR

UNIT COST(\$/100 LB SOLIDS)= 3.470

APPENDIX B

Hazardous Waste Management/Statement of Non-Toxicity

- 1) Environmental Information, "Hazardous Wastes and Their Management."
- 2) Statement of Non-Toxicity.

HAZARDOUS WASTES AND THEIR MANAGEMENT

One of the serious drawbacks of the technological era is the steadily increasing amount of hazardous wastes being produced daily by industry, agriculture, government, hospitals, and laboratories. All radioactive waste material is regarded as hazardous. In addition about 10 percent, or at least 10 million tons per year of all waste material generated by industry is considered hazardous. To protect human health and the natural environment it is imperative that we use safe handling and disposal techniques for these wastes.

What are hazardous wastes?

They are wastes that pose a substantial danger, immediately or over time, to human, plant, or animal life and which, therefore, must be handled or disposed of with special precautions. They may be chemical, biological, flammable, explosive, or radioactive substances. They are mostly liquids but also occur as gases, solids, and sludges. Some specific examples: arsenic-bearing flue dusts from the smelting of metallic ores, pesticide wastes, oily sludges from the petrochemical industries, obsolete munitions, radioactive waste from nuclear power plants.

How are they disposed of now?

Radioactive wastes are stored and monitored according to Federal and State regulations until decayed into harmless substances--a process that takes from several months to hundreds of thousands of years.

The most common methods of disposing of other hazardous wastes are dumping on the land, burial in the land, injection in deep wells, and dumping in the ocean. Sometimes explosives are detonated and burned in the open. And some organic chemicals, biological wastes, and flammable materials are incinerated. Each of these commonly used disposal methods is a potential threat to public health and the environment.

Some industrial firms and other sources of waste are processing and disposing of their hazardous materials safely. In fact, a hazardous waste management industry has developed in the past few years, but at present it is handling only about six percent of the Nation's needs.

What harm can come from improper disposal of hazardous wastes?

A number of instances of serious harm are on record. Some examples: Arsenic buried 30 years ago near Perham, Minnesota, contaminated a new well drilled near the site; several persons were hospitalized. In Waynesboro, Tennessee, chemical wastes at a city dump got into a spring that rises under the dump and then empties into a creek; once used as a source of drinking water, as well as for watering cattle, fishing, and recreation, the creek is now polluted for at least 10 miles and is not fit for any of these purposes. At a New Jersey landfill, a bulldozer operator was killed in 1974 when drums of chemical wastes exploded.

Are there regulations that apply to disposal of hazardous wastes?

The disposal of wastes on land is essentially unregulated except in the case of radioactive wastes. The Clean Air Act covers the burning of toxic materials. The Federal Water Pollution Control Act of 1972 deals with the discharge of hazardous materials into lakes and streams. And the Marine Protection, Research and Sanctuaries Act of 1972 (Ocean Dumping) regulates ocean disposal operations. As the antipollution laws protecting air and water are implemented, many hazardous substances, sometimes in greatly concentrated form, are being diverted to the land. Unless the right precautions are taken, however, these substances can leak from the land into water and air, or they can stay on the land as unsuspected sources of potential danger. Some 25 States have some regulatory provision for controlling hazardous waste disposal but few are comprehensive or fully implemented. The U.S. Environmental Protection Agency (EPA) has proposed that the Congress enact hazardous waste management legislation which would establish a nationwide Federal and State regulatory program.

What really should be done with hazardous wastes?

To safeguard public health and the environment, and also conserve resources, maximum use should be made of existing technology to

- * Reduce the amount of hazardous waste generated in the first place.
- * Concentrate wastes (through evaporation, precipitation, other techniques) at the source to reduce handling and transport problems.
- * Stimulate "waste exchange"--one factory's hazardous wastes can become another's feedstock; for instance, acid and solvent wastes from some industries can be utilized by others.
- * Recapture and recycle metals, the energy content, and other useful resources contained in the wastes.

- * Destroy some hazardous wastes in special incinerators.
- * Detoxify and neutralize other waste, destined for land disposal; most nonradioactive wastes can be rendered harmless.
- * Build specially designed landfills, cut off from groundwater and properly monitored and secured, for hazardous materials that have to be buried in the ground.

Such a program will require construction of new treatment facilities at industrial plants. It will require a system of regional treatment and disposal facilities across the Nation, especially designed for dangerous wastes that industry cannot dispose of safely.

Switching to environmentally sound treatment and disposal will generally mean higher costs to those sources producing dangerous waste that, in turn, may mean higher prices for consumers of some products. But the alternative cost--the environmental and health damage we will incur if dangerous materials continue to be discarded irresponsibly--is infinitely greater.

Is there more information available on this subject?

Yes. EPA has published Report to Congress: Disposal of Hazardous Wastes, which was prepared in response to the 1970 Congressional mandate to study the problem of hazardous wastes and submit a report and recommendations for action. Another EPA publication, Hazardous Wastes, gives a brief, basic description of the problem and what can be done about it. These publications and other information can be obtained from the Office of Solid Waste Management Programs (AW-562), U.S. Environmental Protection Agency, Washington, D. C. 20460.

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DEPARTMENT OF THE ARMY
HEADQUARTERS, EDGEWOOD ARSENAL
ABERDEEN PROVING GROUND, MARYLAND 21010

SAREA-MT-E

Dr. William Hedley
Monsanto Research Corporation
Dayton, OH 45407

Dear Dr. Hedley:

Enclosed is a draft of a statement on non-toxicity of the demilled GB salt residue. We would like you to review this, compare it to the one you gave us during your visit to Edgewood Arsenal on 23 Jul 74, and comment on its use in your efforts to have Monsanto use the salts in the phosphorous manufacturing process.

Sincerely yours,

Robert I. Epstein

ROBERT I. EPSTEIN
Contract Project Officer

1 Incl
as stated

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Statement of Non-Toxicity

Representative samples of salt residues produced by the detoxification of the agent GB will undergo laboratory testing to demonstrate that the salts have no toxicity attributable to the presence of chemical agent GB. Sodium fluoride, a common chemical of commerce, is the most toxic material in the residue salts. Therefore, the GB residues should be treated as if they were entirely composed of sodium fluoride. They should be handled by the procedures that have been established and the precautions that are recommended for handling sodium fluoride.

The agent is treated (detoxified) with strong alkali solution. The alkali solutions are spray dried at approximately 2000°F to obtain the dry salts which are stored in 55 gallon drums.

As an example, if 10 ng/ml of GB were present in the salt brine, it would be necessary to maintain intimate skin contact with a minimum of 44,900 gallons of a 28.9% solution of the salts to absorb the LD₅₀ (Lethal Dose, 50% fatality). This low toxicity would be reduced even further by the spray drying operation. Water and GB have similar volatility, and they are completely miscible. Residual traces of agent that may have been present prior to the spray drying operation would be removed during the evaporation of the water because it would volatilize with the water and/or it would be entrained by (carried along with) the water.

The extremely low agent toxicity of these salts can be demonstrated further. Assume that none of the residual agent (assuming a solution concentration of 10ng/ml) is removed during the evaporation of the water. Absorption of the agent LD₅₀ from the salts would require intimate skin contact with each particle of each piece in 275 drums of salt (solids capacity of 50 gallons). The toxicity ratio (ratio of the LD_{50's}) of sodium fluoride to GB in these salts would be 4,000,000 : 1. There would

be 14,000 LD_{50's} of sodium fluoride per drum of salt and only 0.0036 LD_{50's} of GB.

Personnel at Rocky Mountain Arsenal and Monsanto Research Corporation have handled considerable quantities of the residue salts (both fine and large pieces) without an exposure or incident of any kind. A dust mask should be used in the absence of a hood or good vacuum removal system because sodium fluoride dust is toxic by inhalation (threshold limit value; TLV; 0.2mg/m³).

APPENDIX C

Encapsulation Techniques

- 1) Portland Cement Association, Report on the feasibility of using cement or clinker with and without kiln dust added to encapsulate GB residue salts, Contract No. CR-7051.
- 2) Chemfix, Inc., "Use of GB salts in the Chemfix Waste Solidification Process" - April 7, 1975.

(1)

PORTLAND CEMENT ASSOCIATION

Old Orchard Road, Skokie, Illinois 60076 / Area Code 312 / 966-6200

Research and Development
Construction Technology Laboratories

Contract DAAA 15-75-M-1363

REQ NO.

WO 45-SV-4357-20

August 19, 1975

Mr. Robert Epstein
Edgewood Arsenal
S.A.R.E.A. M-T-E
Aberdeen Proving Ground, Md. 21010

Dear Mr. Epstein:

The work performed by PCA (Contract No. CR-7051) on the feasibility of using cement or clinker with and without kiln dust added to encapsulate G.B. residue salts has been completed.

The aims of this project consisted of the following studies:

- (1) Ascertain the level of G.B. residue that could be added to cement without drastically altering the hydration characteristics of the cement.
- (2) Provide a mix design (cement, clinker, a combination of cement plus kiln dust; or clinker plus kiln dust) that would have volume stability (no excessive expansion) when G. B. residues were added.
- (3) Determine the optimum water-to-cement ratio that would produce a paste in which the least amount of F^- , P_2O_5 and SO_3 could be leached out.
- (4) Produce a mix design (including type of cement, water-to-cement ratio and highest level of G.B. salt addition) that had optimum strength development at 1-28 days.

It appears from our present results that it is possible to encapsulate the G.B. residue salts using a Type I clinker (C_3A content 10-12%) with additions of either G.B. -1 or G.B. -2 residues added (level 23-30%) without drastically altering the hydration characteristics of the clinker.

Since salts in the G.B. residue (due to the high pH (i.e. 14) of the solution of G.B. salt in water) retard the cement hydration, the residue had to be acidified to a pH of 10.2 before addition to the clinker. An amount of 98% sulfuric acid was

PORTLAND CEMENT ASSOCIATION

Mr. Robert Epstein

- 2 -

8/14/75

added such that the SO_3 level of the system was brought to 4.11%. In some cases, this amount of H_2SO_4 did not decrease the pH to as great an extent as in other cases, but it was judged that higher H_2SO_4 addition levels would be likely to cause volume instability in the hardened cubes.

For the same reason, if cement is used instead of clinker the SO_3 content of the mix is excessive and expansion of the paste cubes is large enough to cause their complete destruction. This expansive reaction is caused by the interaction of the sulfate in the system with the tricalcium aluminate in the cement.

The complete report on this work including Tables I-VI is attached.

If there are any questions concerning this report, please contact us.

Sincerely,

C. H. Weise

Senior Research Chemist
Basic Research Department

C. H. Weise/js

encl.

Copy to - W. E. Kunze
E. Hognestad
N. R. Greening

CR-7051/4330

Objective

The aim of the work performed by PCA in 1975 was to study the feasibility of using cement or clinker with and without kiln dust added, to encapsulate G.B. residue salts. The purpose of this encapsulation is to render the G.B. salts harmless to the environment (water pollution). The G.B. residue salts studied are nominally composed of 15% sodium fluoride, 25% sodium carbonate, and 60% sodium isopropyl methylphosphonate. (Monsanto analysis of G.B. -1) The three forms of the salts studied are:

- (1) G.B. -1 a very fine powder F^- level 5.50%
- (2) G.B. -2 large lumps, F^- level 0.53%
- (3) G.B. -3 brine solution (28% solids) F^- level 3.83% (solids basis)
(F^- contents determined in PCA laboratories)

Experimental

Descriptions of the cements, clinker, and kiln dusts used in this work follow:

The four major phases in portland cement are:

- C_3S tricalcium silicate*
- C_2S dicalcium silicate
- C_3A tricalcium aluminate
- C_4AF tetracalcium aluminoferrite

An additional phase appears in regulated-set cement; this is $C_{11}A_7 \cdot CaF_2$.

- (1) Type I - #1 Cement

Potential compound composition: 53% C_3S , 20% C_2S , 9.3% C_3A and 7.1% C_4AF .

- (2) Type I - #2 Clinker

55-60% C_3S , 16-18% C_2S , 10-12% C_3A , 7-9% C_4AF (Estimate based on X-ray diffraction pattern of clinker.)

*Cement Chemists' shorthand notations:

- C = calcium oxide (CaO)
- S = silicon dioxide (SiO_2)
- A = aluminum oxide (Al_2O_3)
- F = ferric oxide (Fe_2O_3)

- (3) Regulated-Set Cement
potential compound composition:
49% C_3S , 12% C_2S , 19% $C_{11}A_7 \cdot CaF_2$, 2.6% C_4AF
- (4) Type S Cement (shrinkage-compensating cement)
potential compound composition: 53% C_3S , 9.3% C_2S ,
19% C_3A , 5.8% C_4AF
- (5) Kiln Dust #1
(10.93% free or unreacted CaO)
medium amounts of SiO_2 , $CaCO_3$ and K_2SO_4 (Based on X-ray
diffraction pattern)
- (6) Kiln Dust 2
(5.72% free or unreacted CaO)
large amount of $CaCO_3$, medium amounts of SiO_2 and K_2SO_4
(based on X-ray diffraction pattern)
- (7) Calcium aluminate cement (refractory cement)
Large amount of CA , medium amount CA_2 , C_2AS and
small amount of $C_{12}A_7$ (Based on X-ray diffraction pattern)

The oxide analysis of samples #1, 3, 4, 5, and 6 appear in Table I.

The cements and clinkers chosen for the experimental work had varying aluminate contents in order to ascertain what effect the aluminates (C_3A , or $C_{11}A_7 \cdot CaF_2$) had on the cement hydration when G.B. residue salts were added. From the exploratory work discussed in our progress report of April 16, 1975, it was observed that the G.B. residue salts have a stronger retarding effect on the silicate phases (tricalcium silicate and dicalcium silicate phases in cement) than on the aluminate phases. This is demonstrated by the strength development data in Table II.

The two kiln dusts used (#1 and #2 in Table I) had different free lime contents. Kiln dust was added in order to supply lime for reaction with the sodium fluoride present in the G.B. residue salts. The reaction of lime with NaF produces calcium fluoride, which is much less soluble in water.

Preparation of 1" Paste Cubes

In order to study strength development from 1-28 days, also to determine the amount of leaching of F^- , P_2O_5 and SO_3 by water during a seven day or twenty-eight day period, 1" paste cubes were made at five water/solids ratios.

The cube series appearing in Table II were mixed with a hand mixer for 1 minute, allowed to stand 1 minute and remixed an additional two minutes. This mixing cycle will eliminate false set if it occurs. After mixing, the paste was placed in three gang 1" cube molds and vibrated on a small vibrating table to release any entrapped air. The paste samples in the three gang molds were placed in a moist room for curing. The 1" cubes were removed from the molds after 1 day hydration. One cube was placed in a sealed plastic bottle with 65 ml H_2O (to completely surround the cube) for leaching experiments. The remaining cubes were placed again in the moist room for further hydration to 3, 7 and 28 days; 2 months, and later ages. Compressive strengths were determined on these moist-cured cubes at designated times (Table II).

Preparation of 1" x 11" Paste Bars

For the volume stability data, 1" x 11" paste bars were made using G.B. -1 salt (23% by weight) and G.B. -2 salt (23% by weight) plus kiln dust (25% by weight, #25). A water/cement ratio of 0.4 was used. Paste bars were stored in water and length measurements were made with a comparator at 7 days, 28 days and two months. Weight losses of the cubes were also determined at 7 days, 28 days and two months. These weight losses are probably due to a leaching of F^- , P_2O_5 or SO_3 from the specimens during storage in water. The results are given in Table III.

Results.

X-ray Diffraction of Hydrated Pastes

X-ray diffraction patterns were run on 60-day hydrated cubes from cube series #2 and #5 (Table I).

Hydration products in #2 were ettringite ($C_3A \cdot 3CaSO_4 \cdot 3H_2O$), calcium hydroxide ($Ca(OH)_2$), calcium hemi-carboaluminate (hydrated $C_3A \cdot 1/2CaCO_3 \cdot 1/2Ca(OH)_2$) and a small amount of calcium silicate hydrate (CSH). Also, a large amount of $CaCO_3$ was present together with a small amount of calcium fluoride. Cube series #5 showed the same hydration products as cube series #2

except that less tricalcium silicate and dicalcium silicate had hydrated.

The G.B. salts appear to retard the silicate hydration, while the tricalcium aluminate (C_3A) hydration is less affected.

A more detailed group of X-ray diffraction patterns were run on 7 day and 28 day hydrated cubes from the various series. Data appear in Table IV.

The hydrated phases are similar to those reported on the 60 day hydrated pastes. The major hydrated products present are:

- (1) calcium hydroxide
- (2) Ettringite
- (3) Calcium hemi-carboaluminate
- (4) small amount of calcium silicate hydrate.

In samples #6, #7 (28 days), #9 (7 and 28 days) and #10 (7 days), another hydration product probably a sodium calcium silicate hydrate, was present. (See footnote to Table IV.)

Lines for unhydrated tricalcium silicate and dicalcium silicate appeared in the X-ray diffraction patterns. Traces and small amounts of tricalcium aluminates were indicated. In some cases, lines for calcium carbonates and sodium carbonate were observed.

Chemical Analysis

F^- contents on cube series #1, #2 and #5 appear in Table V. F^- , P_2O_5 , and SO_3 (ppm) were determined on leachings from the following samples: 6, 7, 8, 17, 18, 19, 20, 21, 22, 23, 26, 27, 28 and 29 (Table VI). Na_2O , K_2O , SO_3 , total CaO , and free CaO contents were determined for the two kiln dusts used in the experimental work. (Table I).

F^- contents were run on all three G.B. residues used (Table I).

P_2O_5 contents were run on cubes #21 and #22 previously leached for 28 days (Table I).

General Comments on the Study

(1) The results suggest that a Type I clinker can be used in conjunction with G. B. Residues #1 and #2, provided the pH of the G. B. residue in water is reduced from 14 to approximately 10.2 - 11.0 (#18, #21, Table II). When sulfuric acid is used for neutralization, it brought about a far more satisfactory strength development than was achieved using hydrochloric acid (#15, Table II). A possible difficulty with the use of sulfuric acid lies in the greater expansive potential of the high sulfate systems. Therefore, the use of clinker, which is relatively sulfate free, rather than cement, which contains sulfate in the form of gypsum, reduces this expansive potential. The expansive force occurring in cement paste or concrete is due to the interaction of sulfate ions with the aluminate fraction of the cement (tricalcium aluminate $(3CaO \cdot Al_2O_3)$). The hydration product from this reaction is Ettringite (calcium sulfoaluminate).

(2) The G. B. -2 residue has one advantage in that it has a lower F^- content. In the present work, it was necessary to reduce the large lumps to material passing a 30 mesh screen to facilitate incorporation into 1" paste cubes. In concrete, where more mass is involved, it may be possible to eliminate this particle reduction step. We do not recommend the G. B. -3 residue form (brine) as the solids level is too low (28%) and additional dried G. B. -1, G. B. -2 or G. B. -3 residue had to be added before neutralization with H_2SO_4 to bring the G. B. solids level in the paste to 23%.

The neutralization reaction using G. B. -3 generated considerably more heat and required much more precaution in handling. (Table

II example #23).

(3) Addition of kiln dust intended to provide CaO to react with the sodium fluoride present and produce a less soluble form of F^- . (CaF_2) was not advantageous to either strength development or volume stability. As shown in Table III, the expansion of the 1" x 11" paste bars with kiln dust (#25) was almost double that of the bar containing no dust (#24).

(4) The leaching experiments (Tables V and VI) demonstrate that a considerable amount of phosphonate is leached from the cubes, (50% during a 28 day period). Of importance is the fact that leaching experiments were begun under very severe conditions. The one inch cubes were placed in water after 1 day hydration. The amount of cement hydration during that time was not sufficient to produce an impermeable structure. The more impermeable structure resulting from further hydration would be expected to reduce the levels of phosphonate, F^- and SO_3 in the leach water. This indicates that a longer curing period for the 1" paste cubes (28 days) before being placed in water would reduce significantly the amounts of material leached from the paste cubes. The results from the cube series placed in water 14 additional days (#26, #27, #28, #29 Table VI) confirm this.

(5) The flocculating agent* used in sample #26 resulted in a reduction in amount of phosphonate leached at 7 days, relative to the corresponding sample without flocculating agent (No.22). Relatively insignificant increases in F^- and SO_3 occurred, but the compressive strength was appreciably reduced. In the work completed, only two flocculating agents were used. There may be others whose effects would be more advantageous.

*A flocculating agent settles suspensions, and it was hoped that

its use would reduce the leachability of the phosphonate, fluoride and sulfate. . . .

(6) Calcium hydroxide addition to the G. B. salts either before or during mixing with cement did not reduce retardation in set and strength development. This negative result is puzzling, that the sodium fluoride and sodium carbonate should have been converted to the less soluble calcium salts, and consequently be removed from solution. It may be that these precipitates coated the hydrating cement grains and reduced water access to them.

Recommendations: Sulfate-Resistant Clinkers

(1) It may be worthwhile to work with a Type II or Type V clinker (sulfate-resistant clinker) with G. B. residue salts neutralized to a pH of 11.5 to 12. This recommendation is based on the observation that a Type I clinker may be used with added G. B. residue salts if the pH of the salt in water is reduced from 14 to a lower level. Furthermore, in the work completed, the pH level was reduced, but at the same time the SO_3 level was maintained at 4.11%. However, the amount of SO_3 in the system may still be too high, resulting in higher than normal expansions (Sample #24 Table V). Normal expansions generally run between .07 and .09% in paste bars. This level of expansion will not cause destruction of the bars. As the expansion in the Type I cement - G. B. salt bars is still increasing (2 month values, Table V), there may be some destructive action at a later date.

(2) Use of G. B. Brine

Further experimentation with G. B. -3 (brine solution) may be of value. This material may possibly be used if some of the water is evaporated and then caused to react with gypsum instead of sulfuric acid. This process would take a longer period of time than neutralization with sulfuric acid.

(3) Increased Curing

In order to evaluate the effects of decreased paste permeability due to hydration it may be of value to start the leaching experimentation after 28 days of curing. Investigation of the use of water-reducing admixtures to achieve decreased permeability would also be of value.

(4) Flocculating Agents & Admixtures

Owing to the alkalinity and high alkali content of G. B. salts, it may be of interest to examine reactive siliceous admixture, or other flocculating agents which can tolerate very high pH levels.

(5) There appears to be another expansive reaction besides that attributable to ettringite formation (Example Nos. 6, 7, 9 & 10 Table IV). The identity of the new phase similar to sodium calcium silicate hydrate should be established.

Partial Chemical* Analysis of Clinkers, Kiln Dusts, G.B. Residue Salts and Leached Cubes

* Fluoride: determined by Orion Specific Ion Electrode.
phosphorus: determined by a calorimetric procedure.
sulfate: determined gravimetrically. Other elements

Table II

Compressive Strengths (psi) of 1" Paste Cubes with G.B. Salts Added

Cube Series	Cement	Cement wt. (g)	G.B. Salt wt. (g)	Water/Solids	Compressive Strength, psi				
					1 day	3 days	4 days	7 days	28 days
1	Type I, #1 (control)	100	none	0.50	1500	3200	-	5500	7200
1A	Type I, #1 (control)	130	none	0.65	640	1800	-	3300	-
2	Type I, #1	100	30 (G.B.-1)	0.50	170	240	-	450	1200
3	Type I, #1	75	25 (G.B.-1)	0.50	120	-	310	515	805
			(+ 5.5 g Ca(OH) ₂)						
4	Type I, #1	55	25 (G.B.-1)	0.50	190	-	395	575	775
			(+ 20 g kiln dust)						
5	Type I, #1	100	30 (G.B.-2)	0.50	30	65	-	230	40
6	Reg-Set	100	30 (G.B.-1)	0.50	600	-	840	970	500
7	Type S	100	30 (G.B.-1)	0.50	200	-	420	520	75
8	Type I, #1	100	30 (G.B.-1)	0.50	80	-	250	370	740
			(+ 5.5 g Ca(OH) ₂ in 65 ml water)						
			(G.B.-1 added to above solution prior to mixing with cement)						
							5.5 mo.	-	1200

(continued on next page)

Table II (continued)

Compressive Strengths (psi) of 1" Paste Cubes with G.B. Salts Added

Cube Series	Cement	Cement wt. (q)	G.B. Salt wt. (q)	Water/Solids	Compressive Strength, psi			
					1 day	3 days	4 days	7 days
9	Type I-#1	100	30 (G.B.-1) (+34.8 g $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ in 65 ml H_2O) (G.B.-1 added to above solution prior to mixing with cement)	0.50	-	-	100	1080
								1780 (3 mo.*)
10	Type I-#1	100	30 (G.B.-1) (pH of G.B. salt and water lowered from 14 to 10.2 by adding H_2SO_4 ($\text{SO}_3 = 4.11\%$) prior to mixing with cement)	0.50	380	830	-	1300
								1280 (3 mo.*)
11	Reg-Set	100	30 (G.B.-1) (8.5 g $\text{Ca}(\text{OH})_2$ added to water and G.B.-1 salt prior to mixing with cement. $\text{Ca}(\text{OH})_2$ added would balance both the Na_2CO_3 and NaF .)	0.50	250	300	-	360
								700 (3 mo.*)
12	Type I-#1	100	30 (G.B.-1) (8.5 g $\text{Ca}(\text{OH})_2$ added to G.B.-1 salt in water prior to mixing with cement) ($\text{Ca}(\text{OH})_2$ added would balance both the Na_2CO_3 and NaF)	0.50	170	300	-	500
								835
13	Calcium Aluminate Cement (control)	50	none	0.50	4700	6100	-	5800
								5.5 mo. 1350

(continued on next page)

Table II (continued)

Compressive Strengths (psi) of 1" Paste Cubes with G.B. Salts Added

Cube Series	Cement	Cement wt. (g)	G.B. Salt wt. (g)	Water/Solids	Compressive Strength, psi			
					1 day	3 days	4 days	7 days
14	Calcium Aluminate Cement	50	15 (G.B.-1)	0.50	110	225	-	270
15	Type I-#1	100	30 (G.B.-1)	0.50	130	325	-	610
			(HCl added to reduce pH of G.B.-1 and water from 14.0 to 10.2)					
			(added HCl = 8.70% Cl ₂)					
16	Type I-#1	100	30 (G.B.-1)	0.50	55	265	-	520
			(HCl added same as (15) but 3.96% Ca(OH) ₂ also added)					
17**	Type I-#2	100	30 (G.B.-3) dried	0.50	soft	1110	-	1340
18	Type I-#2	100	30 (G.B.-1)	0.23	1010	1610	-	1810
			(pH of G.B.-1 residue lowered from 14 to 10.1 with H ₂ SO ₄)					
19	Type I-#2	50	15 (G.B.-3) dried	0.23	700	-	-	2150
20	Type I-#2	130	none added (12.6 g of gypsum added - 4.11% SO ₃)	-	2600	6400	-	10000
21	Type I-#2	100	30 (G.B.-2)	0.31	495	1800	-	2300
			(pH of G.B.-2 residue in H ₂ O lowered from 14 to 10.4 by addition of H ₂ SO ₄)					

(continued on next page)

Table II. (continued)

Compressive Strengths (psi) of 1" Paste Cubes with G.B. Salts Added

Cube Series	Cement	Cement wt. (g)	G.B. Salt wt. (g)	Water/Solids	Compressive Strength, psi			
					1 day	3 days	4 days	7 days 28 days 60 d
22	Type I-#2	100	30 (G.B.-1) (25 g kiln dust added) (pH of G.B.-1 in H ₂ O lowered from 14 to 12 by addition of H ₂ SO ₄)	0.29	1265	1800	-	2200 3400 -
23**	Type I-#2	150	45 (G.B.-3) (Additional dried G.B.-3 residue had to be added to brine solution of G.B.-3 then pH lowered from 14 to 13 by addition of H ₂ SO ₄)	0.31	680	1000	-	1475 2300
24	Type I-#2	307.7	92.3 (G.B.-1) (pH of G.B.-1 residue in H ₂ O lowered from 14 to 11 by addition of 2.5 ml of 98% H ₂ SO ₄)	0.31	(1" x 11" paste bars made for volume stability tests - Table IV)			
25	Type I-#2	258	77.4 (pH of G.B.-2 residue in H ₂ O lowered from 14 to 10.2 by addition of 2.5 ml of 98% H ₂ SO ₄) (65.4 g kiln dust added)	0.31	(1" x 11" paste bars made for volume stability tests - Table IV)			
26	Type I-#2	100	30 (G.B.-1) (1% Separan added (flocculating agent) (pH of G.B.-1 residue in H ₂ O lowered from 14 to 10.2 by addition of 2.5 ml of 98% H ₂ SO ₄)	0.31	715	1125	-	1340 1875 -

(continued on next page)

Table II (Continued)
Compressive Strengths (psi) of 1" Paste Cubes with G.B. Salts Added

Cube Series	Cement	Cement wt. (g)	G.B. Salt wt. (g)	Water/Solids	Compressive Strength, psi			
					1 day	3 days	4 days	7 days
27	Type I-#2	100	30 (G.B.-1) (1% Drewfloc added (flocculating agent) (pH of G.B.-1 residue lowered as in #26)	0.31	525	715	-	930
28	Type I-#2	100	42.85 (G.B.-1) (30% level) (pH of G.B.-1 residue lowered as in #26 and #27)	0.31	480	905	-	1370
29	Type I-#2	100	30 (G.B.-2) (25 g klin dust added) (pH of G.B.-2 residue lowered as in #26, #27 and #28)	0.29	300	1335	-	1290
								1570

* Expanded and fell apart.

** Cube series, #17-#29 clinker used instead of cement.

*** This was necessary to maintain the water to cement ratio and the level of addition of G.B. salts used in the previous samples.

Table III

Expansion and Weight Loss of 1" x 11" Paste Bars

Sample No.	G. B. Residue Used	G. B. % Added	Water/Cement = 0.4 (Stored in Water)			
			Expansion % 7d	Expansion % 28d	Expansion % 7d	Wt. Loss % 28d
24	G.B. -1	23%	.056	.112	.151	2.1
						2.9
						3.1
25	G.B. -2 +25% Kiln Dust #2	23%	.127%	.235	.286	1.1
						.8
						.8

*Wt. Loss is due to the F⁻, P₂O₅, and SO₃ being leached from the 1" x 11" bars.

Table IV
X-ray Diffraction Results on 1" Cube Series

Cube Series	Hydration Time (days)	Amts. of Hydration Products				Amts. of Unhydrated Phases				
		Calcium Silicate Hydrate	Ca(OH) ₂	Ettringite	Calcium Hemihydrogen phosphate	C ₃ A	C ₃ S	C ₂ S	CaCO ₃ and Na ₂ CO ₃ **	
6*	28	small	small	medium	medium	none	small	small	large	
7*	28	small	medium	small	medium	small	med.	med.	large	
8	7	small	large	trace	medium	tr.	med.	med.	large	
8	28	small	large	small	medium	small	"	"	"	
9*	7	small	trace	trace	trace	tr.	lg.	lg.	"	amt.
9*	28	small	trace	trace	trace	none	med.	med.	"	"
10*	7	small	large	trace	trace	tr.	lg.	lg.	"	"
10	28	small	large	trace	trace	sm.	sm.	sm.	"	"
12	7	small	large	trace	medium	sm.	med.	med.	"	"
17	28	small	medium	trace	large	sm.	med.	med.	"	"
18	28	small	medium	trace	medium	sm.	med.	med.	"	"
20	7	small	large	medium	trace	tr.	tr.	sm.	trace	
	(control)									
	(no G.B. residue added)									
21	7	small	large	trace	small	sm.	med.	med.	large amt.	
22	7	small	medium	trace	medium	sm.	med.	med.	"	
23	7	small	medium	trace	medium	sm.	lg.	med.	"	

* Another hydration phase having major lines at 8.6° and 17.4° 2θ appeared in the X-ray patterns of these samples. No positive identification was made, but the phase may be a sodium calcium silicate hydrate of the approximate composition Na₂Ca₂Si₁₂O₇·H₂O.

** Some Na₂CO₃ also appeared in the X-ray diffraction patterns of these samples except #20, the control sample.

Table V

Chemical Analysis for F⁻* Present in Water Extracts

<u>Cube Series**</u>	<u>Cement</u>	<u>G.B. (salt used)</u>	<u>Time in Water</u>	<u>F⁻ (ppm)</u>	<u>Time in Water</u>	<u>F⁻ (ppm)</u>
1	Type I (control)	none	1 day	0.125	7 days	0.125
2	Type I	G.B.-1	1 day	26	7 days	29
5	Type I	G.B.-2	1 day	5	7 days	7

*Fluoride analysis by specific fluoride ion electrode.

**Cube series used in leaching experiments correspond to cube series Numbers (Table I)

Table VI
Chemical Analysis for F⁻, P₂O₅, SO₃ Present in Water Extracts

<u>Cube Series</u>	<u>Cement Used</u>	<u>G.B. Salt Used</u>	<u>Water/Clinker</u>	<u>Time in Water (d)</u>	<u>F⁻ (ppm)</u>	<u>P₂O₅ (ppm)</u>	<u>SO₃ (ppm)</u>
6	Reg-Set	G.B.-1	0.65	7	30	1400	5453
7	Type S	G.B.-1	0.65	7	21	1900	4567
8	Type I-#1	G.B.-1	0.65	7	12	2400	3400
17	Type I-#2	G.B.-3	0.65	4	7.5	7000	160
17	"	"	0.65	28	2.6	3800	0.00
18	Type I-#2	G.B.-1	0.30	7	20.2	12500	2900
18	"	G.B.-1	0.80	28	8.7	3800	285
19	Type I-#2	G.B.-3	0.30	7	18.3	6600	2260
20	"	none	0.40	7	<1.0	<25	0.00
21	"	G.B.-2	0.40	7	2.7	13000	1775
21	"	G.B.-2	0.40	28	3.7	14660	1750
22	Type I-#2	G.B.-1	0.40	7	17.3	10500	3820
22	"	G.B.-1	0.40	28	23.0	14250	5400
23	Type I-2	G.B.-3	0.40	7	28.8	13100	3675
26	Type I-2	G.B.-1	0.40	7	24.0	9760	3150
26*	Type I-2	G.B.-1	0.40	21	9.6	4089	1338
27	Type I-2	G.B.-1	0.40	7	24	13180	3450
27*	Type I-2	G.B.-1	0.40	21	9.6	4089	646
28	Type I-2	G.B.-1	0.40	7	31	16445	5000
28*	Type I-2	G.B.-1	0.40	21	23.1	4089	692
29	Type I-2	G.B.-2	0.45	7	3.7	11710	3300
29*	Type I-2	G.B.-2	0.45	21	1.3	2468	154

* 7-day cubes placed in water for an additional 14 days.

DENVER BOARD OF WATER COMMISSIONERS - QUALITY CONTROL LABORATORY

FINISHED WATER QUALITY SUMMARY - 1974

(Results are expressed in mg/l or Units*)

PARAMETERS	STANDARDS		SOUTH PLATTE SYSTEM			HOFFAT SYSTEM **		
	EPA	DEQ	MIN	MAX	AVG	MIN	MAX	AVG
Alkalinity as CaCO_3	---	---	56	87	72	17	37	25
Aluminum	---	0.50	0.020	0.100	0.015	0.025	0.450	0.298
Arsenic	0.05	0.05	0.000	0.000	0.000	0.000	0.000	0.000
Cadmium	0.01	0.005	0.000	0.000	0.000	0.000	0.001	0.000
Calcium	---	---	24.1	36.8	28.8	8.4	16.4	11.8
Chloride	250	50	17	39	27	2	6	4
Chromium	0.05	0.05	0.000	0.000	0.003	0.000	0.012	0.003
Color*	15	10	3	10	7	4	12	8
Copper	1.0	0.20	0.002	0.015	0.007	0.003	0.010	0.006
Fluoride	2.5	0.8 to 1.2	0.99	1.30	1.10	0.17	3.10	1.20
Hardness as CaCO_3	---	---	86	129	101	30	69	41
Iron	0.3	0.1	0.010	0.030	0.050	0.020	0.035	0.054
Lead	0.05	0.025	0.000	0.003	0.001	0.000	0.005	0.002
Mercury	---	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Magnesium	---	---	5.1	11.2	7.9	0.73	6.8	2.9
Manganese	0.05	0.01	0.004	0.003	0.005	0.001	0.007	0.004
Molybdenum	---	---	0.000	0.160	0.055	0.000	0.000	0.000
Nitrate as "N"	10	1.0	0.00	0.20	0.10	0.00	0.10	0.05
pH*	6.0 to 8.5	7.2 to 8.0	7.5	7.9	7.7	7.3	8.0	7.5
Potassium	---	---	1.22	2.20	1.98	0.45	1.00	0.75
Phosphate as "P"	---	0.50	0.00	0.08	0.03	0.00	0.11	0.03

At the request of Mr.
Epstein the Denver Water
Standards are enclosed.

FINISHED WATER QUALITY SUMMARY - 1974

(continued)

(Results are expressed in mg/l or Units*)

PARAMETERS	STANDARDS		SOUTH PLATTE SYSTEM			MOFFAT SYSTEM		
	EPA	DWR	MIN	MAX	AVG	MIN	MAX	AVG
Radioactivity (Gross Alpha*)	---	---	0.0	1.2	0.4	0.0	1.8	0.7
(Gross Beta*)	1000	1000	0.0	17.1	7.6	71.2	87.4	80.1
Residue (Total)	500	250	136	214	177	25	91	58
Sodium	---	---	11.1	44.1	21.2	1.59	3.80	2.70
Sulfate	250	100	43	55	48	14	40	25
Temperature (°C)	---	---	3	20	11	6	20	13
Turbidity (JTU)	5	---	0.24	0.63	0.42	0.26	1.10	0.69
Zinc	5	0.5	0.001	0.029	0.006	0.000	0.018	0.006

PARAMETERS WITH LIMITED DATA

(Results of other parameters are available upon request)

Barium	1.0	0.5	0.047	0.022
Lithium	---	---	0.005	0.001
Nickel	---	---	0.001	0.000
Silica as SiO ₂	---	---	4.8	3.3
Strontium	---	---	0.230	0.063

** The Moffat System was in operation from April 1 to December due to construction during the first three months of the year.

April 7, 1975

Department of the Army
c/o Commander, Edgewood Arsenal
Aberdeen Proving Ground, Maryland 21010

ATTN: SAREA-MT-E/R. Epstein

RE: Chemfix Waste Solidification Process
Samples #SW 894A75 & B75
Demilitarized GB Brine with & without NaF

Gentlemen:

Chemfix has completed an exhaustive series of solidification tests on your submitted samples of GB brine. Unfortunately, these samples are not particularly compatible with the Chemfix solidification process because of the high sodium, organic and water content. The successful sample from Monsanto Research was a cake which we slurried with a minimum of water before Chemfix treatment.

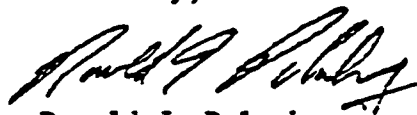
Would it be possible to mix any of the below with the waste as a filler before treatment without incurring the risk of releasing or activating GB or other toxicogens in the waste? Also, how much supernatant liquor can we decant before treatment?

1. Fullers earth, kaolin, or bentonite
2. Calcium, aluminum, or iron salts (eg: sulfates or hydroxides)
3. Flyash
4. Silicas

If these are acceptable additives, we could begin a short development program to find a formula for solidification at a cost to the Army of \$15/hr for 32 hrs or \$480. If this is an acceptable approach, please let me know. We will then need additional samples. The sample with NaF was the more compatible; we would prefer to work with this one.

Thank you for your interest in Chemfix.

Sincerely,



Ronald J. Polosky
Technical Director

RJP/cks

THE ULTIMATE WASTE DISPOSAL PROCESS AND SERVICE

APPENDIX D

Cadmium Content of GB Salt Samples and
Estimates with Selective Elimination of
Certain Production Lots.

12 MAY 1

HSE-EW-A/WP

SUBJECT: Investigation of the Toxicity of GB Salts to Marine Organisms -
Water Quality Biological Study No. 99-040-75/76

Project Manager for Chemical Demilitarization
and Installation Restoration

AIRM: DACTA-DR

Aberdeen Proving Ground, MD 21010

1. REFERENCES.

a. Letter, AMDC-O, Office of the AMC Program Manager for
Demilitarization of Chemical Material, 5 May 1975, subject: Bioassay of
Demilitarized GB Salt.

b. Letter, HSE-EW-A/WP, this Agency, 12 February 1976, subject:
Preliminary Marine Toxicity and Metals Concentration Data on GB Salts - Water
Quality Biological Study No. 99-040-75/76.

c. Report, HSE-EW-A/WP, this Agency, 8 April 1976, subject: Water
Quality Biological Study No. 99-040-75/76, Investigation of the Toxicity of
GB Salts to Marine Organisms, 5 May-10 December 1975.

d. Title 40, Code of Federal Regulations (CFR), 1975 ed., Chapter 1,
Subchapter H, Ocean Dumping.

2. As previously reported in reference 1c, the toxicity of GB salts to
marine fish, shrimp and diatoms is low enough that ocean dumping appears to
be a viable technique for disposal. However, cadmium concentrations are
markedly variable among demilitarization lots. As previously reported in
reference 1b, the average concentration exceeds the permissible maximum of
0.60 mg/kg (reference 1d). The basis of this calculation is the analysis of
cadmium in 33 samples taken from production lots representing approximately
50 percent of the expected total 14,000,000 pounds of salts (see inclosed
Table). Assuming a value of "0" for laboratory reports of "non-detectable"
(detection limit 0.10 mg/kg), the estimated concentration of cadmium in the
entire production is 1.24 mg/kg.

REF: A/WP
SUBJECT: Investigation of the Toxicity of Cu Salts to Marine Organisms -
Water Quality Biological Study No. 99-040-75/75

3. Before any further studies required under law (reference la) are conducted, a preliminary opinion regarding ocean disposal should be solicited from the US Environmental Protection Agency (USEPA). The existing data in references lb and lc, are sufficient for this purpose. This Agency can provide support should technical representation to USEPA regarding this study be required.

4. This letter completes the study requested in reference la. Further interpretation or consultation may be obtained from the Chief, Water Quality Engineering Division, AUTOVON 534-3919/3296. Requests for additional studies should be submitted through command channels to Commander, USA Health Services Command, ATTN: HSPA-H, Ft San Houston, TX 73234.

FOR THE COMMANDER:

1 Incl
as

A. D. KNEESSY, P.E.
COL, MSC.
Director, Environmental Quality

CF:
HQA (DASG-HCH)
Cdr, HOC (HSPA-H)
Cdr, HMA
Cdr, HRCOM (DRCSG)
Cdr, EWA (SAREH-DV)

INVESTIGATION OF THE TOXICITY OF CB SALTS TO MARINE ORGANISMS -
 WATER QUALITY BIOLOGICAL STUDY No. 99-319-75/75

TABLE CADMIUM CONCENTRATIONS IN CB SALTS

Sample No.*	Production Date	Number Drums†	Percent of Production	Cadmium Concentration (mg/kg)
1	10-16-74	468	2.45	ND‡
2	9-17-74	460	2.41	3.2
3	3-4-75	639	3.34	1.0
4	2-19-75	609	3.19	0.7
6	1-2-75	270	1.41	2.0
8	1-14-75	445	2.33	3.0
9	2-4-75	360	1.33	2.4
10	2-17-74	104	0.54	2.7
11	3-23-74	124	0.65	2.0
12	9-4-74	249	1.30	1.3
13	10-1-74	468	2.45	1.2
14	3-20-75	254	1.33	0.7
15	11-15-74	696	3.64	ND
16	11-9-74	696	3.64	0.7
17	11-3-74	77	0.40	ND
18	4-14-75	556	2.91	ND
19	7-2-75	1415	7.40	ND
20	8-1-75	1178	6.16	ND
21	7-20-74	26	0.14	0.3
22	6-1-75	390	2.06	1.0
23	4-16-74	20	0.15	1.3
24	11-22-74	539	2.82	0.8
25	5-6-75	1235	6.46	0.3
26	1-18-74	94	0.49	3.9
27	5-15-74	129	0.67	3.3
28	7-2-74	77	0.40	1.5
29	8-6-74	81	0.42	0.3
30	3-21-74	115	0.60	3.9
31	4-2-75	505	2.64	0.2
32	6-21-74	1519	7.96	ND
33	2-9-74	10	0.05	7.1
34	7-14-75	1937	10.44	ND
35	6-21-74	18	0.09	3.3
36	12-6-74	218	1.14	2.1
37	10-19-74	582	3.04	2.0
38	4-4-74	275	1.44	3.4
39	5-20-75	747	3.91	14.3
40	8-19-75	1467	7.67	1.1

*Sample containers 5 and 7 not used

†1 drum = 350 lbs

‡Detection limit, Cadmium, ND <0.1 mg/kg

Table D-1. Cadmium Concentrations in GB Salts
Eliminate Sample Nos. 8, 9, 10, 26, 27, 30,
33, 35, 38, 39 (Ref. Col. Kneessy Letter
May 12, 1976)

Sample No.	Production Date	Number Drums	Percent of Production	Cadmium Concentration (mg/kg)	Percent of Cadmium Concentration
1	10-16-74	468	2.78	ND	-
2	9-17-74	460	2.73	0.2	0.55
3	3-04-75	639	3.80	1.0	3.8
4	2-19-75	609	3.62	0.7	2.53
6	1-02-75	270	1.60	2.0	3.2
8	1-14-75				-
9	2-04-75				-
10	2-17-74				-
11	8-23-74	124	0.74	2.0	1.48
12	9-04-74	249	1.48	1.3	1.92
13	10-01-74	468	2.78	1.2	3.34
14	3-20-74	254	1.51	0.7	1.06
15	11-15-74	696	4.14	ND	-
16	11-08-74	696	4.14	0.7	2.90
17	11-08-74	77	0.46	ND	-
18	4-14-75	556	3.30	ND	-
19	7-02-75	1415	8.41	ND	-
20	8-04-75	1178	7.00	ND	-
21	7-20-74	26	0.15	0.3	0.05
22	6-01-75	390	2.32	1.0	2.32
23	4-16-74	28	0.17	1.3	0.22
24	11-22-74	539	3.20	0.8	2.56
25	5-06-75	1235	7.34	0.3	2.20
26	1-18-74				-
27	5-18-74				-
28	7-02-74	77	0.46	1.5	0.69
29	8-06-74	81	0.48	0.3	0.14
30	3-21-74				-
31	4-02-75	505	3.00	0.2	0.6
32	6-21-74	1519	9.02	ND	-
33	2-08-74				-
34	7-14-75	1997	11.87	ND	-
35	6-21-74				-
36	12-06-74	218	1.30	2.1	2.73
37	10-18-74	582	3.46	2.0	6.92
38	4-04-74				-
39	5-20-74				-
40	8-19-75	1467	8.72	1.1	9.59
		$\Sigma 16823$	$\Sigma 99.98$		$\Sigma 48.8$

% of Total Samples Used

$$\frac{48.8}{100} = 0.488$$

$$\frac{16,823}{19,120} \times 100 = 88\%$$

$$\sim 0.49$$

Estimated cadmium concentration is 0.49 mg/kg

Table D-2. Cadmium Concentrations in GB Salts
Eliminate Sample Nos. 26, 30, 33, 39
(Ref. Col. Kneessy Letter May 12, 1976)

Sample No.	Production Date	Number Drums	Percent of Production	Cadmium Concentration (mg/kg)	Percent of Cadmium Concentration
1	10-16-74	468	2.58	ND	-
2	9-17-74	460	2.53	0.2	0.51
3	3-04-75	639	3.52	1.0	3.52
4	2-19-75	609	3.35	0.7	2.35
6	1-02-75	270	1.49	2.0	2.98
8	1-14-75	445	2.45	3.0	7.35
9	2-04-75	360	1.98	2.4	4.75
10	2-17-74	104	0.57	2.7	1.54
11	8-23-74	124	0.68	2.0	1.36
12	9-04-74	249	1.37	1.3	1.78
13	10-01-74	468	2.58	1.2	3.10
14	3-20-75	254	1.40	0.7	0.98
15	11-15-74	696	3.83	ND	-
16	11-08-74	696	3.83	0.7	2.68
17	11-08-74	77	0.42	ND	-
18	4-14-75	556	3.06	ND	-
19	7-02-75	1415	7.79	ND	-
20	8-04-75	1178	6.49	ND	-
21	7-20-74	26	0.14	0.3	0.04
22	6-01-75	390	2.15	1.0	2.15
23	4-16-74	28	0.15	1.3	0.20
24	11-22-74	539	2.97	0.8	2.38
25	5-06-75	1235	6.80	0.3	2.04
26	1-18-74				-
27	5-18-74	129	0.71	3.3	2.34
28	7-02-74	77	0.42	1.5	0.63
29	8-06-74	81	0.45	0.3	0.14
30	3-21-74				-
31	4-02-75	505	2.78	0.2	0.56
32	6-21-74	1519	8.37	ND	-
33	2-08-74				-
34	7-14-75	1947	11.00	ND	-
35	6-21-74	18	0.10	3.3	0.33
36	12-06-74	218	1.20	2.1	2.52
37	10-18-74	582	3.21	2.0	6.42
38	4-04-74	275	1.51	3.4	5.13
39	5-20-75				-
40	8-19-75	1467	8.08	1.1	8.89
		$\Sigma 18154$	$\Sigma 99.96$		$\Sigma 66.67$

% of Total Samples Used

$$\frac{18,154}{19,120} \times 100 = 95\%$$

$$\frac{66.67}{100} = 0.667$$

$$\sim 0.67$$

Estimated cadmium concentration is 0.67 mg/kg

APPENDIX E

Chemical Landfill Disposal

- 1) Position paper on Controlled Landfill Disposal of Waste Salts.
- 2) BKK Corporation, Wilmington, California, Landfill Disposal, (Contractor Letter).
- 3) Chem-Trol Pollution Services, Landfill Disposal of Mustard Salts, (Visit Report and Correspondence).
- 4) Nuclear Engineering Co., Beatty, Nevada Landfill Disposal of Mustard Salts, (Visit Report and Correspondence).
- 5) Wes-Con, Inc., Twin Falls, Idaho, Disposed Mustard Salts by Encapsulation, (Visit Report and Correspondence).
- 6) Emplacement and Transportation - Estimated Costs for Chemical Landfill.

(1)
SAREA-MT-E

Position Paper on Controlled Landfill Disposal of Waste Salts

Cdr, USAHEA Col.

Cdr, Edgewood Arsenal

22 JUL 1976

Attn: HSE-E/HP/Mr. Kneessy

Mr. Epstein/mjn/2893

1. Reference is made to Letter, HSE-E/HP, USAHEA, 29 June 1976, SAC.
2. Subject document has been revised to accommodate comments you furnished in referenced letter.
3. Request you review the inclosed position paper and indicate your concurrence by 30 July 1976.

FOR THE COMMANDER:

The new interagency agreement on waste disposal by the Army has produced and for some time will continue to produce large quantities of waste salts. The 1 Incl was a disposal of these salts is a Chief, Disposal Engineering Division Manufacturing Technology Directorate quantity (11,000 tons at Rocky Mountain Arsenal) of waste salts. The waste salts are a single landfill. They contain small but significant amounts of heavy metals. Some of the salts have been disposed by the Environmental Protection Agency for disposal. The salts are getting into the water table and are getting into the water table - the origin being local in some cases.

Of immediate concern are the salts from the disposal of waste salts at Rocky Mountain Arsenal. There are presently 11,000 tons of mixed sodium salts in the off-gases, and spray drying the off-gases. The disposal of the waste salts at Rocky Mountain Arsenal will produce, on the order of 100,000 tons of mixed orthophosphorous, sodium phosphate, and sodium carbonate salts which are disposed from cooling CO with spray drying and spray drying the salts.

POSITION PAPER
ON
CONTROLLED LANDFILL DISPOSAL OF WASTE SALTS

I. Objective.

The objective of this paper is to assess the methods presently available to the Army for waste salt disposal and recommend a procedure for implementation.

II. Discussion.

The demilitarization of lethal chemical agents by the Army has produced and for some time will continue to produce large quantities of waste salts. The ultimate disposal of these waste salts is a problem because: there is a large quantity (11,000 tons at Rocky Mountain Arsenal in FY 77); they are mostly soluble, precluding simple landfill disposal; they contain small but significant amounts of heavy metals; some components in the salts have been proposed by the Environmental Protection Agency for designation as hazardous substances (relative to those substances getting into the nation's waters); and because of the nature of the salts - the origin being lethal chemical agents.

Of immediate concern are the salts resulting from demil operations at Rocky Mountain Arsenal. There are presently stored at Rocky Mountain Arsenal approximately 4,200 tons of mixed sodium salts produced from incinerating mustard, scrubbing the off-gases, and spray drying the scrubber solution. The current demil operation at Rocky Mountain Arsenal will produce, by October 1976 approximately 7,000 tons of mixed organophosphorous, sodium fluoride, sodium carbonate salts which are produced from demilling GB with sodium hydroxide and spray drying the resulting brine.

The Army has been investigating techniques for the ultimate disposal of the waste salts. As a result of contractual efforts⁽¹⁾ ⁽²⁾ and in-house studies, we have narrowed the viable options for the Rocky Mountain Arsenal salts to three methods, contract disposal including controlled landfill, ocean dump, and incineration/separation. These are discussed in detail below.

Environmental regulations which impact on the disposal of the waste salts include Title 40, Code of Federal Regulations (CFR), 1975 ed. Chapter 1, Subchapter H, (Ocean Dumping); the Federal Water Pollution Control Act Amendments of 1972; the Resource Recovery Act of 1970, which amended the Solid Waste Disposal Act of 1965; the Safe Drinking Water Act of 1974; and the Clean Air Act Amendments of 1970.

III. Salts from Demil of Mustard.

There are approximately 4,200 tons of mixed sodium salts which were produced from the mustard demil program at Rocky Mountain Arsenal and now stored there. Approximately 3,600 tons are in 55 gallon drums and 600 tons in bulk form in warehouses. The salts result from incinerating the mustard, scrubbing the exhaust gases with sodium hydroxide, and spray drying the brine solution. Analyses of the brine input and salt output from the spray dryer have always been negative for mustard within the limit of the colorimetric method of analysis, which was less than 0.5 micrograms/gram.

Chemical analyses of a composite salts sample which was performed by USAEHA during an investigation as to the feasibility of ocean dumping the salts⁽³⁾, showed the following major compounds.

<u>Compound</u>	<u>Percent</u>
NaCl	43.3
Na ₂ SO ₃	23.6
NaH CO ₃	5.9
Na ₂ SO ₄	15.7
Na ₂ CO ₃	11.9
Fe ₂ O ₃	.2

In addition, the following metals were measured: (4)(3)

<u>Element</u>	<u>ppm(mg/kg)</u>
Mercury	1.03
Cadmium	16
Copper	53
Zinc	35
Lead	< 5
Chromium	< 25
Manganese	< 0.03
Silver	< 2.5
Molybdenum	< 0.1
Potassium	0.7
Soluble Iron	147
Insoluble Iron	2315

While there are no restrictions on shipping these salts, there is a specific restriction on their disposal imposed by the Denver Region of the EPA. That region requested publication of a "notice of concern" on an Invitation for Bid (IFB) which DSA published in September 1975⁽⁴⁾ when

we were attempting to sell the salts. The notice of concern stated that application of the salts to the unrestricted environment, such as highway de-icing, where uncontrollable movement of the salts to an airborne state or to the ground and/or surface waters results, would be deemed unsatisfactory by EPA. They also stipulated that the salts would not be disposed of in a sanitary landfill, but land disposal in a landfill (controlled, or class I type) specifically designed to receive special wastes would be satisfactory.

IV. Salt from Demil of GB.

There is a current demil operation being conducted at RMA in which the Army will produce approximately 7,000 tons of waste organophosphorous salts. The salts result from reacting GB with a solution of sodium hydroxide to produce a salt solution, which is spray dried and packed in 55 gallon drums. The operation is to be completed by October 1976.

The major components in these salts are:

<u>Compounds</u>	<u>Percent</u>
Organic Phosphorous Compounds	32-59
NaF	12-25
Na ₂ CO ₃	8-35

In addition, the following metals were measured: (5)(6)(7)

<u>Element</u>	<u>ppm(mg/kg)</u>
Mercury	< 0.1
Cadmium	1.24
Copper	13.20
Zinc	145

<u>Element</u>	<u>ppm(mg/kg)</u>
Lead	< 0.5
Chromium	< 1
Manganese	1.90
Silver	1
Molybdenum	< 50

The only restriction on shipping the salts or brine from demil of GB is that they have to be handled as a corrosive, and appropriately packaged and labelled. Prior to March 1975, they were shipped as a Class B poison because they contain sodium fluoride. However, the Biomedical Laboratory, EWA, conducted toxicity tests and established the salts and brine as a corrosive material rather than a Class B poison⁽⁸⁾. The Office of Hazardous Materials, Department of Transportation, concurred in this classification.⁽⁹⁾

V. Disposal Options

A. Controlled Landfill

A Controlled Landfill is one at which complete protection is provided for all time for the quality of ground and surface waters from all wastes deposited there and against hazard to public health and wildlife resources. Geological conditions are capable of preventing vertical and lateral hydraulic continuity between liquids and gases emanating from the wastes in the site and useable surface or ground waters. Leachate and subsurface flow into the disposal area are contained within the site. These and additional conditions are used by the State of California to define what they call a Class I landfill. This term - Class I landfill

is becoming generally accepted throughout the industry and in other states as well. Other synonymous terms that are used include Secure, Scientific, Chemical, and Hazardous Waste Landfills.

There are a number of companies which operate controlled landfills. The Office of Solid Waste Management Programs, EPA, while not endorsing any, did publish a list of some 20 sites which provide controlled landfill capability. We visited three of these, in connection with possible disposal of the salts from demil of mustard; Chemtrol Pollution Services, Model City, N.Y., Wes-Con Missile Site, near Grandview, Idaho, and Nuclear Engineering Company near Beatty, NE. All of them, as well as others we had corresponded with, offer an ecologically sound method for disposal of the salts. Two of the companies have specific approvals from their respective state environmental offices for disposal of the RMA salts from demil of mustard in their facilities. We have copies of the approved letters from Idaho for the Wes-Con site⁽¹⁰⁾ and from Nevada to Nuclear Engineering⁽¹¹⁾. Controlled landfills that the Army will utilize for disposal of the wastes from demil operations will be those which operate under the cognizance of their respective state environmental agencies. The company which operates the controlled landfill would take title to the wastes and be responsible from then on for their control. The companies have various arrangements with their respective states for perpetual care. For instance, Nuclear Engineering has a fund set up with the state of Nevada where they pay a certain lump sum every five years and monthly payments to the state for every cubic foot of material buried.

The cost of disposal in a controlled landfill can be estimated with a fair degree of accuracy. For large quantities of wastes (such as several

thousand tons of salts) the cost for disposal once the material is delivered to a site is approximately \$1 to \$2 per ft³. Waste salts in 55 gallon drums with 400 lb salt per drum would cost approximately \$70 per ton. The cost of shipping by rail is roughly \$60 per ton for 1,000 miles.

For comparison with other disposal options, assuming the landfill is 1,000 miles from RMA, the cost for controlled landfill disposal of 7,000 tons of demilled GB salts is estimated as:

Loading at RMA	\$100K
Transportation	420K
Contract for controlled landfill	500K
Prepare, coordinate contract	50K
Prepare amendment to EIS	<u>40K</u>
	\$1,110K

Scheduling of controlled landfill disposal would require approximately nine months to prepare and coordinate an addendum to the M34 EIS, and prepare and award a contract for the disposal. Three to twelve additional months could be required for the actual disposal, depending on the contractor selected and the rate he could accept the material. This rate could be lower than normal capacity due to the desire to maintain a low visibility and not attract undue public attention to the Army's waste.

Controlled landfill disposal of the demilled mustard salts is estimated as:

Loading at RMA	\$ 60K
----------------	--------

Transportation	220K
Contract for controlled landfill	300K
Prepare coordinate contract	<u>20K</u>
	\$600K

B. Ocean Dump

Ocean Dumping as a means of disposal of waste materials is closely regulated. The Marine Protection, Research and Sanctuaries Act of 1972, Public Law 92-532 (Title 40CFR, Chapter 1, Subchapter H, Ocean Dumping), established a program for issuance of permits by EPA for dumping in the ocean of all materials (other than dredged spoil, which is controlled by the Corps of Engineers). The Act also established criteria for granting of permits. Certain materials are absolutely prohibited from ocean dumping, such as chemical warfare agents. Other materials are prohibited such as mercury or cadmium and its compounds, in other than trace quantities. The concentration which must not be exceeded is specified in the regulations. Certain materials are defined as requiring "special care." Included in this category are inorganic fluorides and organophosphorous compounds. The presence of these materials requires proof in the form of bioassay tests, that they will not cause adverse effects on marine life. Based on the criteria, general, special, interim special, emergency, or research permits can be applied for.

In the case of waste salts from the RMA mustard and GB demil operations, only the special or interim special permits would apply. General permits are used to regulate such activities as dumping of galley wastes, removal of wrecked vessels from navigation channels, and burial at sea.

An emergency permit will be issued only when there is a marked degree of urgency, there is danger to human health, and there is no feasible alternative. Research permits are used to conduct research into the impact of materials on the marine environment. A special permit regulates all materials not covered by the general permit. In the event the criteria described in the regulations are not met, an interim special permit may be granted if there is no feasible present alternative to ocean dumping.

To evaluate the feasibility of requesting a permit to ocean dump the waste salts from the RMA mustard and from the GB demil operations, the US Army Environmental Hygiene Agency conducted studies on these materials. The study of the salts from mustard demil⁽³⁾ showed that the salts are significantly toxic to fish, shrimp larvae and algae to warrant very high dilution in the mixing zone to meet the requirements of PL 92-532. Also, the mercury and cadmium concentrations in the salts exceed the maximum allowable per PL 92-532. The study concluded that a request of the US EPA to grant an ocean dump permit is "contraindicated."

The study of the salts from GB demil⁽⁵⁾⁽⁶⁾⁽⁷⁾ indicated the toxicity of the salts is low enough that ocean dumping appears to be a viable technique for disposal. However, cadmium concentrations, which were variable among demil lots, showed an average which exceeds the permissible of 0.60 mg/kg. The estimated concentration of cadmium for the entire 7,000 tons of salts (samples were taken from production lots representing 50 percent of the expected total) was 1.24 mg/kg. This would preclude the obtaining of a special permit, but an interim special permit would still be a possibility. However, obtaining such a permit would be difficult, costly, and

time consuming. The regulations stipulate that certain conditions must be met for an interim special permit, including an assessment of the degree of treatment feasible to meet the standards and the development and active implementation of a plan to either eliminate the discharge to the ocean or to bring it within the limits of the criteria in the regulation. Also, coordination with EPA by the Pollution Abatement Officer, LTC R. Hanson, in the Office of the Proj Mgr for CDIR, surfaced that pursuing a permit would almost certainly require public hearings. While the Army expects to conduct the disposal in an open manner, including writing an addendum to the M34 EIS, public hearings would undoubtedly result in increased costs, schedule delays, and unwanted publicity.

The cost for ocean dumping (7,000 tons of waste salt from demil of GB, for comparison) is estimated as:

Load at RMA	\$100K
Transportation to port (1,100 mi)	500K
Unload at port	100K
Ocean Dump, including loading barges	100K
Bioassays	25K
Prepare permit application	15K
Prepare, coordinate contract	50K
Prepare amendment to EIS	40K
Prepare, respond to Public Hearings	<u>20K</u>
	\$950K

Scheduling of ocean dump disposal is estimated as requiring 27 months, including 18 months to prepare and obtain approval for a permit (included in

that time is 9 months to prepare and coordinate an addendum to the M34 EIS). An additional 3 months is estimated for the initial bioassay. The disposal itself is estimated at 3 months, and the final bioassay 3 months after that.

C. Incineration/Separation

Incineration as a means of disposal of the waste salts from demil of GB is an option since the salts contain approximately 50 percent organics. The waste salts from demil of mustard contain no organics, only various sodium salts, and are not candidates for incineration.

The feasibility of incinerating the salts from demil of GB, both whole salts and after separating out the sodium fluoride portion of the salts, was investigated by EWA⁽¹⁾⁽²⁾. Although we showed on Pilot Scale that we could filter out most of the sodium fluoride, the projected cost for the process compared to the value of the saleable sodium fluoride⁽¹²⁾ made it obvious it was not an economical approach. For a return of \$60 per ton, it would cost \$4,000 per ton, including capital equipment.

As far as this project is concerned, therefore, incineration as a disposal option refers to burning the whole salts from demil of GB followed by disposal of the residue in a landfill. The incineration would be done in the existing equipment at RMA (modified as necessary) which was used for burning bulk quantities of the chemical agent mustard. Pollutants resulting from the incineration would be P_2O_5 and HF. A packed scrubber would remove the HF and a Brink Mist Eliminator would remove the P_2O_5 , to maintain effluent discharges to the air in accordance with requirements of the Clean Air Amendments of 1970 and the Colorado Air Pollution Control Regulations. Other residues produced from the incineration and scrubbing would be treated with calcium hydroxide to make insoluble

calcium fluoride, calcium carbonate, and apatite. This material could be disposed of in a sanitary landfill. State authorities in Colorado and federal authorities at the Solid and Hazardous Waste Research Laboratory of the EPA stated⁽¹⁾ that this was a satisfactory method for disposing of detoxified waste salts.

The cost and time for this method of disposal of the salts from demil of GB is considerably greater than for the two previously described methods. Although it is planned that the existing equipment at RMA would be used, extensive modification to that equipment would be required. It is estimated the installed cost of new and modified equipment would be approximately \$1,100,000. A breakdown of the estimated cost, based on a 1 year production disposal operation for 7,000 tons is estimated as:

Pilot Scale Testing of Design Concept	\$ 150K
Prepare Contract Scope & Coordination for above	10K
Design Criteria for Production Equipment	20K
Design Contract for Production Equipment	20K
Modification and Installation, & Capital Equipment	1,100K
Run-in of Full Scale System	100K
Production Disposal, including disposal of ash or scrubber sludge	400K
Prepare Addendum to M34 EIS	<u>40K</u>
	\$1,240K

The time required to implement this disposal is estimated as 48 months, including 12 months for the actual disposal and 36 months to accomplish the piloting, design, modifications, and run-in shown above.

D. Other Options Considered

We studied other disposal methods for the waste salts, which we determined to be either not feasible, not cost effective, not ecologically desirable, or not fully developed to be used at this time.

Among the disposal methods not feasible was sale/recycle to industry since we could not consummate a sale after several attempts. Methods which we found to be not cost effective include molten salt combustion, and electrolytic conversion of the salts to useful products. We judged deep well disposal not ecologically desirable compared with more positive separation of the salts from the environment. Methods we judged not fully developed for our application (cost effectiveness to be assessed when further developed) include encapsulation in an inert matrix, such as the Chemfix and TRW methods, under ocean floor burial, fluid bed combustion, and burial in abandoned salt mines or salt domes. Removal of the cadmium from the demilled GB salts and then pursuing ocean dump disposal was considered, but this was also judged not sufficiently developed at the present time for our application. We have received a letter from Battelle, Pacific Northwest Laboratories, suggesting the concept but saying it was not off the shelf and would have to be developed. We would assess the cost effectiveness when the process was further defined.

VI. Summary.

A comparison of the three disposal options for the waste salt from RMA Mustard and GB demil are summarized in the following table:

	<u>Controlled Landfill</u>	<u>Ocean Dump</u>	<u>Incineration</u>
<u>Salts from demil of mustard</u>			
Cost	\$600K	—	—
Schedule	12-18 Months	—	—
Environmental Assessment	Acceptable	Not Acceptable	—
<u>Salts from demil of GB</u>			
Cost	\$1,100K	\$1,000K	\$1,840K
Schedule	12-21 Months	27 Months	48 Months
Environmental Assessment	Acceptable	Not Acceptable	Acceptable

Based on the above, it is concluded that the salts from demil of mustard should be disposed of under a disposal contract which will include controlled landfill, because there appears to be no acceptable and economic alternative. The primary disposal method for the waste salts from demil of GB should be controlled landfill.

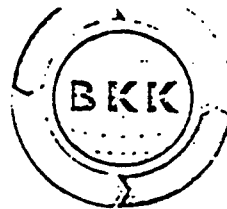
VII. Recommendations.

A. The disposal of the salts from the mustard demil should be initiated so a disposal contract can be awarded in the 1Q FY*77.

B. A contract for disposal of the salts from demil of GB should follow with a target award date in the 4Q FY 77.

(2)

BKK CORPORATION



3031 EAST I STREET • WILMINGTON, CALIFORNIA 90744 • (213) 775-1

March 29, 1976

Department of the Army
Headquarters, Edgewood Arsenal
Aberdeen Proving Ground, MD 21010

Attention: Mr. Sigmund R. Eckhaus *gale*
Chief, Disposal Engineering Division
Manufacturing Technology Directorate
SAREA-MT-E

Gentlemen:

With respect to your letter of March 23, we are pleased to advise that all of the identified materials can be accepted for disposal (via drum burial) in the BKK Class I landfill located in the City of West Covina (County of Los Angeles), California.

Based upon the weight information you provided, it would appear that there are approximately 850 to 900 55-gallon drums involved. Assuming that the Army would provide for delivery--in a single shipment--to the Port of Long Beach, the estimated total cost for pickup, transportation (Long Beach to West Covina), and disposal of these drums would range between \$25,000 and \$30,000. The physical form by which the drums would be delivered (i.e., loose, palletized, or in overseas shipping containers or vans) could obviously influence the cost. Additionally, if the drums were delivered via many shipments (vs. a single shipment), the pickup and transportation cost would be increased slightly.

We would be pleased to provide our services and facilities for your organization's unique waste disposal needs--as we have done for other elements of the U. S. Army and the Department of Defense.

If our transport/disposal capabilities and the estimated costs cited above are acceptable, we would be pleased to examine this matter further with your organization and to provide you with a firm cost proposal. We await your reply.

Sincerely,

BKK CORPORATION

Leonard M. Tinnan

Leonard M. Tinnan
Vice President-Technical

includes
pick-up &
transport
Long Beach to
West Covina
~30 mi.)

$$\left\{ \begin{array}{l} \frac{\$30,000}{900} \approx \$33/\text{drum} \\ \frac{\$33}{\text{drum}} \times \frac{1}{400 \text{ lb.}} \approx 8 \frac{\text{¢}}{\text{lb.}} \end{array} \right.$$

LMT: plb



(3)

DEPARTMENT OF THE ARMY
HEADQUARTERS, EDGEWOOD ARSENAL
ABERDEEN PROVING GROUND, MARYLAND 21010

SAREA-MT-E

24 JUN 1975

MEMORANDUM FOR: DIRECTOR OF MANUFACTURING TECHNOLOGY

SUBJECT: Report of Visit to Chem-Trol Pollution Services Concerning the Disposal
of Mustard Salts in their Facility

1. Purpose of Travel. This travel was made to examine the Chem-Trol Pollution Services facility to decide whether it will be acceptable from an ecological standpoint for ultimate disposal of demilled mustard salts.
2. Itinerary. Edgewood Arsenal, Aberdeen Proving Ground, MD 21010 to Chem-Trol Pollution Services, Inc., 1550 Balmer Road, Model City, NY 14107, and return to Edgewood Arsenal, APG, Md. on 11 June 1975.
3. Individuals contacted.
Walter J. Watson, Technical Sales Coordinator
Edward R. Shuster, Division Manager
Robert A. Stadelmaier, Laboratory Manager
4. Discussion of Problems.
 - a. We are looking for methods for ultimate disposal for the approximately 4,200 tons of demilled mustard salts now stored at Rocky Mountain Arsenal. We had sold the salts but the purchaser defaulted and didn't take over the material. Other options include ocean dumping, but preliminary bioaquatic studies by the AEHA indicated this would be unlikely to be acceptable by the EPA. Another option, conversion of the salts to useful products is being studied but will require some lab work followed by piloting. An investment in production facilities would also be required.
 - b. Chem-Trol offers the possibility of ultimate disposal at their facility. We had sent a sample of the mustard salts to them. They analyzed the material in relation to their processing and determined they could safely and ecologically dispose of all of the mustard salts. They are currently processing a trial run of 150 drums, or approximately 60,000 lbs of the salts under a \$2,400 Contract No. DAAA15-75-M-2935.
 - c. The disposal of our salts would be done in their scientific controlled landfill. The landfill on their property is a sump with two layers of impermeable clay with a 30 mil welded seam chlorinated polyethylene (hypalon) liner between the layers. Internal sumps within each cell are used to collect leachate which is subsequently treated as required. They have analyzed the potential leachate from the salts and have determined how they would treat it. No products leave the closed-loop system. All effluents remain on the Chem-Trol property and are controlled and processed as indicated on the inclosed flow-sheet (incl 1).



24 JUN 1975

SUBJECT: Report of Visit to Chem-Trol Pollution Services Concerning the Disposal of Mustard Salts in their Facility

d. Chem-Trol is a service company specializing in the disposal, recycling, reclaiming, processing, and treating of chemical wastes. They are licensed by the state of New York, and while there are no federal regulations as yet on land-fill disposal of chemical wastes, they coordinate closely with the EPA's solid wastes management personnel in Washington. Their first line of regulation is exercised by the Niagara County (N.Y.) health department. Chem-Trol registers all wastes with them and when a landfill is filled, it is sealed with a clay cap and this fact registered with the County. Monitoring is maintained by sucking out leachate from the internal sumps, or standpipes, and the leachate is treated and recycled as necessary.

e. When Chem-Trol accepts wastes for disposal they take title to the wastes.

f. Estimated costs for 4,200 tons of mustard salts will be \$320,000 plus shipping costs. Shipping cost is estimated at \$300,000. Chem-Trol will give us a more refined estimate for processing, and we will get a shipping estimate from Rocky Mountain Arsenal.

g. Chem-Trol also appears to have capability for disposal of residue from demil of GB in an ecologically sound manner. We will provide them a small sample to study. Arsenic and I.D. Set residue will also be explored for disposing by this method.

6. Summary.

a. Chem-Trol provides process for ultimate disposal of mustard salts (and possibly GB salts as well). This process could result in the disposal of mustard salts at their facility.

b. Chem-Trol exhibits an understanding of the ecology of waste disposal as well as the necessary technology. They maintain control of all products they receive and process so there are no effluents escaping to the environment. With the quantity of residue that will be generated by the Army in their disposal program, the Army may want to consider setting aside land that must be reclaimed in the land reclamation program to establish this type of facility. Chem-Trol expressed an interest in establishing such a facility for the Department of the Army and if desired they could operate the government facility (GOCO).

c. They have licenses from local regulatory agencies as appropriate, and maintain good communication with the EPA so the EPA is knowledgeable of their activities.

d. Chem-Trol can dispose of arsenic, which may be of interest to our nonlethal disposal program as well as the I.D. Kits disposal.

e. Disposal Engineering Division, Manufacturing Technology Directorate will send sample of demilled GB salts to Chem-Trol for their evaluation. This will be accomplished by 30 June 1975.

24 JUN 1975

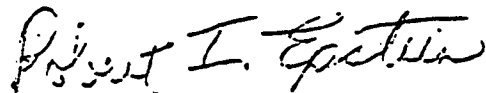
SUBJECT: Report of Visit to Chem-Trol Pollution Services Concerning the Disposal of Mustard Salts in their Facility

7. Recommendations.

a. If sale of mustard salts fails again, dispose of mustard salts from Rocky Mountain Arsenal by Chem-Trol closed loop system at their facility.

b. For future disposal, the Army should consider reserving a site at Rocky Mountain Arsenal or other nearby location, and consider possibility of a government owned scientific landfill. This landfill could be established under a contract with Chem-Trol, to their specifications, and, at least initially, run by them.

1 Incl
as



ROBERT I. EPSTEIN
Project Engineer
Disposal Engineering Division

APPROVED:



SIGMUND R. ECKHAUS
Chief, Disposal Engineering Division

CF:
Chief, Demil/Disposal Ofc (J. Carter)
AMXDC-0 (MAJ Gross)
Chief, Dspo Engr Div

CONTRACT FOR REMOVAL, DISPOSAL OR TREATMENT OF WASTE



Chem-Trol Pollution Services, Inc.
P.O. BOX 200 • MODEL CITY, NEW YORK 14107

CUSTOMER Department of the Army
Commander, Edgewood Arsenal DATE 6/16/75

ADDRESS Aberdeen Proving Ground, Md. 21010

ATTENTION: SAREA - MT-E / MR. Robert Epstein

Chem-Trol Pollution Services, Inc., hereinafter referred to as "Chem-Trol" and the abovenamed customer hereby agree that the following materials will be removed, disposed of or treated on the terms and conditions hereinafter provided.

<u>DESCRIPTION AND/OR COMPOSITION OF MATERIAL</u>	<u>PROCESSING CHARGE</u>	<u>APPROXIMATE VOLUME</u>
Chem-Trol Code 609-B Mixed Sodium Salts Dry Salt residues. Nominally 30% Na_2SO_3 , 30% NaCl , 25% Na_2CO_3 , 10% Na_2SO_4 , balance NaOH , Na_2CO_3 , Fe Hydroxide and water with trace quantities of heavy metals, as per sample, trial shipment, and letters of 2/21/74 and 5/29/75.	\$14.50 per 55 gallon drum	20,000 drums (4,000 tons)

TRANSPORTATION METHOD AND CHARGE

Above Prices are F.O.B. Model City, N.Y. Customer to provide and prepay freight by rail or truck.

METHOD OF DISPOSAL OR TREATMENT

Disposal using Chem-Trol's Closed Loop System, in accordance with State and Federal pollution control regulations.

TERM OF AGREEMENT One time requirement for approximate quantity above, to be received during 1975. Quote valid through July 31, 1975.

TERMS OF PAYMENT: Net 30 Days -- U. S. Funds

This agreement is subject to all of the terms and conditions on the face and reverse side hereof. It shall become a binding contract only when signed and delivered by the customer to Chem-Trol and accepted by an officer of Chem-Trol in writing and a copy of said written acceptance is mailed or delivered to the customer.

CUSTOMER'S SIGNATURE

ACCEPTED BY:

CHEM-TROL POLLUTION SERVICES, INC.

BY

DATE

DATE

CT-14 St. Waste Contract

STANDARD TERMS AND CONDITIONS OF CONTRACT FOR REMOVAL, DISPOSAL OR TREATMENT OF WASTE

PRECAUTIONS - Chem-Trol shall perform its services herein in a careful and workmanlike manner. Chem-Trol agrees to utilize all reasonable precautions in the handling, transportation and disposal of materials so as to avoid injuries to persons and damage to property.

IDENTIFICATION - Customer shall furnish, in writing to Chem-Trol, a reasonable time in advance thereof, (a) a description or identification of the major composition of the waste material to be removed, disposed of or treated, (b) a sample thereof, and (c) customer's existing procedures for safely handling such products.

PACKAGES OR CONTAINERS - Where customer furnishes packages or containers for the materials which are the subject of this contract, customer shall be responsible for and make certain that said packages or containers comply with all laws, rules, regulations and/or ordinances which may be applicable to the safety, packaging, storage or transportation thereof.

COMPLIANCE WITH LAWS AND REGULATIONS - Chem-Trol shall comply with all of the existing requirements of Federal, State and local laws, rules, regulations and/or ordinances applicable to the services to be performed. If any change occurs with respect to any such laws, rules, regulations and/or ordinances, the terms of this agreement shall be renegotiated within ten (10) days after written notice thereof by Chem-Trol to customer; however the services herein are to continue during said negotiations. If such negotiations do not result in an agreed price within said ten (10) days, this contract will be considered terminated unless the parties agree in writing to extend such period of negotiations.

Chem-Trol further agrees to comply with reasonable safety standards adopted by customer for observance at customer's premises. Chem-Trol shall furnish customer with copies of permits or other documents which are required for disposal, removal or treatment of the material which is the subject of this contract.

TITLE TO MATERIALS - Where Chem-Trol provides transportation, title to the materials which are the subject of this contract shall pass from the customer and vest in Chem-Trol at such time as said materials are loaded into the vehicles provided by Chem-Trol. If transportation is not provided by Chem-Trol title to said materials shall pass from the customer and vest in Chem-Trol at such time as said materials have been unloaded at Chem-Trol's plant.

INDEPENDENT CONTRACTOR - At all times herein Chem-Trol shall be considered an independent contractor.

LIABILITY OF CUSTOMER - Customer assumes liability for damages or injuries caused or contributed to by the negligence of customer, its agents or employees.

INDEMNITY - Chem-Trol agrees to take all reasonable precautions to prevent injury to persons or damage to property during the progress of work related to this contract and Chem-Trol shall indemnify and hold harmless customer against such damages or injuries as may arise by reason of services performed by Chem-Trol, its agents or employees pursuant to this agreement. This indemnity shall not indemnify the customer for its own negligence as herein provided.

INSURANCE - Chem-Trol shall carry, at its expense, the following insurance coverage:

Workmen's Compensation	Statutory requirements
Public Liability	
Personal Injury	\$100,000. per person \$300,000. per accident
Property Damage	\$100,000. per accident
Automobile Liability	
Personal Injury	\$100,000. per person \$300,000. per accident
Property Damage	\$100,000. per accident.

Certificates of such insurance shall be furnished to customer on request.

CHANGE IN COMPOSITION OF WASTE MATERIAL - In the event that there is any change in the composition of the waste material identified under this contract as may be revealed by Chem-Trol's analysis, the terms of this agreement shall be renegotiated within ten (10) days after written notice thereof by Chem-Trol to the customer; however the services herein are to continue during said negotiations. If such negotiations do not result in an agreed price within said ten (10) days, this contract will be considered terminated unless the parties agree in writing to extend said period of negotiations.

ACCESS TO PREMISES - Customer agrees that Chem-Trol, its agents and employees shall, during the term of this contract, have reasonable access to customer's premises in fulfilling this contract.

NO LIABILITY - The parties to this agreement shall not be liable to each other by reason of delays or nonperformance caused by circumstances beyond such parties' control, including but not limited to acts of God, fire, storms, strikes, lockouts, work stoppages or delays, labor disputes, transportation embargoes or delays, inability to obtain materials, equipment or transportation, floods, by war or other emergency.

ARBITRATION - Any controversy or claim arising out of or relating to this contract or the breach of it shall be settled by arbitration in Buffalo, New York before one arbitrator in accordance with the rules of the American Arbitration Association and judgment upon the award rendered by the arbitrator may be entered in any court having jurisdiction.

CANCELLATION FOR CAUSE - Either party may cancel this contract at any time without cost or penalty during the term hereof if the other party fails to properly and timely perform their obligations as herein provided and such failure continues for more than seven (7) days after either party has notified the other thereof in writing. Chem-Troi shall have the right to cancel this contract at any time if customer becomes insolvent, makes an assignment for the benefit of creditors or a bankruptcy petition is filed by or against the customer.

ENTIRE AGREEMENT AND CONSTRUCTION - This contract shall constitute the entire agreement between the parties and no modification shall be binding unless in writing and executed by the party to be charged. This contract shall be construed in accordance with the laws of the State of New York.



DEPARTMENT OF THE ARMY
HEADQUARTERS, EDGEWOOD ARSENAL
ABERDEEN PROVING GROUND, MARYLAND 21010

SAREA-MT-E

(4)

21 January 1976

MEMORANDUM FOR: DIRECTOR OF MANUFACTURING TECHNOLOGY

SUBJECT: Report of Visit to Nuclear Engineering Co., Beatty, Nevada,
Concerning the Disposal of Mustard Salts in its Facility
14-16 Jan 76

1. Purpose of Travel. To examine Nuclear Engineering's facility to decide whether it will be acceptable from an ecological standpoint for ultimate disposal of demilled mustard salts.

2. Itinerary. Edgewood Arsenal, Aberdeen Proving Ground, MD 21010 to Nuclear Engineering Co., Beatty, Nevada, and return to Edgewood Arsenal, APG, Md. on 19 Jan 76.

3. Individuals Contacted.

Palmer Berry, Site Manager

4. Discussion of Problems.

a. One of three options for disposing of the approximately 4,000 tons of demilled mustard salts now stored at Rocky Mountain Arsenal is to place them in a permanently controlled environment.

b. Nuclear Engineering Co. offers the greatest potential of ultimate disposal at its facility. Composite analysis of the mustard salts were previously sent to them for review. They determined that they could safely and ecologically dispose of all the mustard salts. Nuclear Engineering Co. has now received approval from each of the State Environmental Protection Service Departments where burial is being considered.

c. Nuclear Engineering Co. now operates three sites which are being considered for the disposal of the demilled mustard salts. The Beatty, Nevada site is leased from the State of Nevada. It now encompasses 80 acres with the option of more land being available when needed. The method of landfill is trench burial with one area for radioactive wastes and another for chemical wastes. The two areas are



AREA-MT-E

21 January 1976

SUBJECT: Report of Visit to Nuclear Engineering Co., Beatty, Nevada
Concerning the Disposal of Mustard Salts in its Facility
14-16 Jan 76

separated by a 470 foot buffer zone. The direction of water flow is such that it does not flow from one area into the second area.

d. Each trench is 35 feet deep x 500 feet long x 70 feet wide. The trench is then filled with stacked drums 31 feet high. (The drums are stacked upright for liquids and sideways for solids). The trench is then filled with earth and a mound of soil made over the trench so the total soil coverage is approximately 15 feet. Each trench is then marked with a concrete monument which represents a specific burial record with the types and quantities of the material in the trench.

e. The site has a natural clay liner of approximately 180 to 200 feet in thickness. The water table is greater than 360 feet deep. The site water well is about 510 feet deep. The area of Beatty, Nevada receives about 2 in/year rainfall. The town of Beatty is 11 miles from the site and has a population of 400.

f. Nuclear Engineering Co. accepts title to all wastes when they contract for disposal. The state of Nevada has a perpetual care fund set up with this firm. Nuclear Engineering pays the state \$500,000 every 5 years in advance and also make monthly payments to the state for every cubic foot of material buried. At the present time, they bury about 30,000 cu. ft./mo.

g. There are observation wells around the chemical and radioactive waste areas to check for migration. They perform well, air, and soil tests once a month. The Environmental Protection Agency performs the same tests once every 3 months. In the 14 years of operation, they have had no migration or leakage of either radioactive or chemical wastes.

h. Nuclear Engineering Co. appears to have the capacity to handle the demilled GB salts as well as arsenic compounds.

5. Summary.

a. Nuclear Engineering Co. can provide ultimate disposal for the mustard salts at its facility. (All disposal by Nuclear Engineering Co. is in drums).

b. A rough cost estimate for disposal of approximately 4,000 tons of salts by Nuclear Engineering Co. is \$285,000. This figure is in the process of being refined with exact specifications as to which site will be used.

AREA-MT-E

21 January 1976

SUBJECT: Report of Visit to Nuclear Engineering Co., Beatty, Nevada
Concerning the Disposal of Mustard Salts in its Facility
14-16 Jan 76

c. They have licenses from local regulatory agencies as required, and maintain good communication with the Environmental Protection Agency so that others are knowledgeable of their operations at all times.

d. Nuclear Engineering Co. can dispose of arsenic, which is of interest to our arsenic disposal program as well as the Ident Kits disposal.

6. Follow-up.

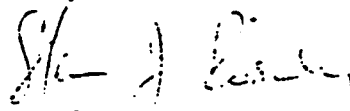
a. Coordinate with Environmental Protection Agency, Region 9, to assess past performance of Nuclear Engineering Co. in landfill disposal operations.

b. Contact Mr. G. S. Williamson, Nuclear Engineering Co. to get more information about the perpetual care program.

c. Consider arsenic disposal in the same landfill.

2 Incl

1. Ltr, State of Nevada to
Nuclear Eng'g Co., 30 Dec 75
2. Drawing, Chemical Wastes Area



STEVEN J. ROSENBERG
Project Engineer
Disposal Engineering Division
Manufacturing Technology Directorate

APPROVED BY:

SIGMUND R. ECKHAUS
Chief, Disposal Engineering Division

CF:
Chief, Demil/Disposal Ofc (M. Stanka)
Proj Mgr for CDIR (N. Coale)



STATE OF NEVADA
DEPARTMENT OF HUMAN RESOURCES
ENVIRONMENTAL PROTECTION SERVICES
CAPITOL COMPLEX
CARSON CITY, NEVADA · 89710

December 30, 1975

G. S. Williamson
General Manager
Nuclear Engineering Company, Inc.
P.O. Box 156
San Ramon, California 94583

Dear Mr. Williamson:

Review of the information concerning the disposal of 4000 tons of Rocky Mountain Arsenal's incinerator wastes indicates that there would be no environmental problems associated with its disposal at the Beatty Burial Site.

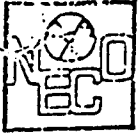
However, I personally hate to see that site filled up with waste materials that are not generally considered hazardous.

Sincerely,

H. LaVerne Rosse
Program Director
Solid Waste Management

dn

xc: John Meder



Nuclear Engineering Company Inc.

WESTERN OPERATIONS HEADQUARTERS ■ P.O. BOX 156, SAN RAMON, CALIF. 94523
PHONE (415) 837-1561

December 22, 1975

Mr. LaVerne Rosse, Public Health Engineer
Division of Health
Consumer Health Protection Services
Capital Complex
Carson City, Nevada 89710

Dear Mr. Rosse,

We have been asked by the Department of the Army to bid on disposing of some 4,000 tons of mixed inorganic salts which were produced at Rocky Mountain Arsenal from the stack gases from their incinerator. The attached October 21st letter from the Army gives details. Also attached is a hazard analysis of the material made by this office.

As you can see, we would be dealing with large volumes of relatively innocuous salts, which should pose no problems when buried in a special trench at Beatty. We are also considering shipping some to Illinois and some to Texas.

Illinois authorities have given us permission, and we expect to receive permission from Texas in a few days.

Normally, we would not consult you on material with this low degree of hazard, but because of the volume involved, it definitely becomes a matter for your attention.

Your concurrence will be appreciated.

Sincerely,

NUCLEAR ENGINEERING COMPANY, INC.

G. S. Williamson
General Manager, Western Operations

GSW:cw

Hazard Ratings of
major ingredients (per Sax)

<u>Constituents</u>	Acute Local		Chronic <u>Local.</u>	Systemic	
	<u>Irritant</u>	<u>Ingestion</u>		<u>Acute</u>	<u>Chronic</u>
Sodium Chloride (43%)	1	1	0	0	0
Sodium Sulfite (24%)	2	2	U	2	1
Sodium Bicarbonate (6%)	Not rated, but used as food additive and as a medicine.				
Sodium Sulfate (16%)	Not rated, but used in food packaging materials.				
Sodium Carbonate (12%)	2	2	1	U	U
Iron Oxide (0.2%)	1	-	0	0	0

Notes:

1. Rating system
 - 0 = No hazard
 - 1 = Slight
 - 2 = Moderate
 - U = Unknown
2. Other than the major ingredients, there are parts per million amounts of various metals (refer to actual analysis).
3. Of these metallic constituents, the worst from a toxicological standpoint are mercury, cadmium and lead. Even though they are in trace amounts, the totals amount to approximately 8, 128 and less than 40 pounds respectively. We can argue with validity that these amounts, distributed throughout 8,000,000 pounds of essentially non-toxic material, and contained within our highly impermeable trench walls, will constitute no threat to the environment.
4. The Army realizes that their analysis totals 101.2% for major components, but they feel that this is within the range of accuracy of the determinations.



DEPARTMENT OF THE ARMY
HEADQUARTERS, EDGEWOOD ARSENAL
ABERDEEN PROVING GROUND, MARYLAND 21010

SAREA-MT-E

21 OCT 1975

Mr. G.S. Williamson
Nuclear Engineering Cor.
P.O. Box 156
San Ramon, CA 94583

Dear Mr. Williamson:

As you requested during your FONECON with Mr. Epstein, Dspo Engr Div, Mfg Tech Dir, Edgewood Arsenal, on 7 Oct 75, we are sending you technical data on the mixed sodium salts we are interested in disposing.

In March 1974, the US Army completed a project at Rocky Mountain Arsenal, Denver, Colo. to demilitarize the chemical agent mustard ($\text{CH}_2\text{CH}_2\text{Cl}_2$) S. The agent was incinerated, and the resulting gases scrubbed with caustic (NaOH). The resulting brine was spray dried to produce a mixture of inorganic sodium salts. Analyses of the brine input and salt output from the spray dryer have always been negative for mustard within the limit of the colorimetric method of analysis, which was less than 0.5 micrograms/gram. Approximately 4,000 tons of salts were produced and are currently stored at Rocky Mountain Arsenal, mostly in 55 gallon steel drums.

The chemical analysis of a composite sample of the salts shows the following major compounds. The composite sample was the representative of all the salts produced in 15 production lots.

NaCl	43 percent
Na ₂ SO ₃	24 percent
NaHCO ₃	6 percent
Na ₂ SO ₄	16 percent
Na ₂ CO ₃	12 percent
Fe ₂ O ₃	0.2 percent



RECEIVED OCT 23 1975

AREA-MT-E
Mr. G.S. Williamson

21 OCT 1975

The following trace metals were measured:

Mercury	1.03 ppm (mg/kg)
Cadmium	16.00
Copper	53.00
Zinc	35.00
Lead	< 5.00
Chromium	< 25.00
Manganese	< 0.03
Silver	< 2.50
Molybdenum	< 0.10
Potassium	< 0.70
Soluble iron	147
Insoluble iron	2315

The pH was approximately 10.0 for concentrations of 10,000 ppm of the mixed sodium salts.

The Army is investigating various disposal options for the salts, including disposal by encapsulation/landfill. We would be interested in your comments regarding possible use of your landfill.

Sincerely yours,



SIGMUND R. ECKHAUS
Chief, Disposal Engineering Division
Manufacturing Technology Directorate



Nuclear Engineering Company Inc.

WESTERN OPERATIONS HEADQUARTERS ■ P.O. BOX 156, SAN RAMON, CALIF. 94583

PHONE (415) 837-1561

November 12, 1975

Mr. Sigmund R. Eckhaus *fm*
Chief, Disposal Engineering Division,
Manufacturing Technology Directorate,
Department of the Army,
Headquarters Edgewood Arsenal
Aberdeen Proving Ground
Maryland, 21010

Dear Mr. Eckhaus:

Your letter of October 21, 1975 asked us for our comments regarding the use of our facilities for the disposal of some 4,000 tons of mixed inorganic salts produced from the demilitarizing of mustard agent at Rocky Mountain Arsenal.

We have given considerable thought to this and believe that there is a very strong likelihood that we could dispose of the material at our Class I Chemical Waste Disposal Sites at Sheffield, Illinois and Robstown, Texas. We also have a site at Beatty, Nevada but, as the nearest rail-head is almost 100 miles distant, we have eliminated it from consideration.

We have not approached the state regulatory authorities in Texas and Illinois but, on the basis of the analysis you have provided, we do not believe they will object on toxicity grounds. The main problem may be due to the volume involved, hence our proposal to split the material between the two states.

With regard to possible costs, we have obtained preliminary freight rates from the railroads involved. On the basis of moving 2,000 tons to Robstown Texas in box-cars and 2,000 tons to Sheffield, Illinois on truck trailers mounted on flat cars, we estimate that the transportation and disposal cost for the 4,000 tons of material will be approximately \$285,000.00.

The estimate is based on the following:

1. The salts will be in 55 gallon steel drums which will be loaded by Arsenal personnel on to flat-car mounted trailers or in to box cars, which will be positioned on the Arsenal rail siding.
2. It may be possible to secure a special commodity rate from the railroads, which could make a significant reduction in the rail costs we have used. It usually takes about 90 days to obtain such a special rate.

3. We have assumed that the two states involved will have no objections to receiving the waste material.

If the forgoing proposal is of interest to you, we will consult with the regulatory agencies involved and will refine our estimate into a firm quotation.

Sincerely,

NUCLEAR ENGINEERING CO., INC.



G. S. Williamson
General Manager, Western Operations

GSW/kh



(5)

DEPARTMENT OF THE ARMY
HEADQUARTERS, EDGEWOOD ARSENAL
ABERDEEN PROVING GROUND, MARYLAND 21010

SAREA-MT-E

14 OCT 1975

MEMORANDUM FOR: DIRECTOR OF MANUFACTURING TECHNOLOGY

SUBJECT: Report of Visit to Wes-Con, Inc. Concerning Disposal of
Demilled Mustard Salts in their Facility, 24-26 Sep 75

1. Purpose of Travel. This travel was made to examine the Wes-Con facility, which is a deactivated Titan Missile Site for possible disposal of demilled mustard salts.

2. Itinerary. Edgewood Arsenal, Aberdeen Proving Ground, MD 21010 to Wes-Con Missile Site, Grandview, Idaho, and return to Edgewood Arsenal, APG, Md. on Monday, 29 Sep 75.

3. Individuals contacted.

Gene Rinebold, President, Wes-Con
Warren Shillington, partner, Wes-Con
N. Ed Barker, Chief, Solid Waste Management, Idaho Dept of Health
and Welfare

Jerry Jankowski, Assistant to Mr. Barker
Mike Stanka, Demil/Disposal Office, Edgewood Arsenal
Ned Coale, Project Managers Office, Edgewood Arsenal

4. Discussion of Problem.

a. Among the options for disposing of the approximately 4,200 tons of demilled mustard salts now stored at Rocky Mountain Arsenal, is to place them in a permanently controlled environment.

b. Wes-Con owns a deactivated Titan Missile Site which has an underground storage capacity of approximately 1,500,000 ft³. The storage area is made up of a series of impenetrable silos and vaults with side walls and floors of four to thirteen feet of steel reinforced concrete and 110 ton doors to cover the top when filled. The silos and vaults, all stripped of salvageable materials, are within 17 acres and consist of:

3 missile silos	40' diameter x 160' deep
3 propellant silos	40' diameter x 35' deep
3 equipment silos	42' diameter x 68' deep
2 antenna silos	38' diameter x 67' deep
1 entry silo	39' diameter x 70' deep



SAREA-MT-E

14 OCT 1975

SUBJECT: Report of Visit to Wes-Con, Inc. Concerning Disposal of
Demilled Mustard Salts in their Facility, 24-26 Sep 75

- 1 powerhouse vault 126' diameter hemisphere
- 1 control center vault 50' diameter hemisphere

c. Wes-con was formed to dispose of toxic chemicals and used pesticide containers. They have a permit to operate by the state of Idaho, and are watched over by the Idaho Department of Health and Welfare.

5. Summary.

a. The Wes-Con facility provides a possible disposal site for the Rocky Mountain Arsenal mustard salts. The volume of 4,200 tons of salts is approximately 85,000 ft³. The salts are in 55 gallon drums. Assuming a 50 percent silo loading efficiency, when the filled drums are dumped randomly in a silo, they would take up about 170,000 ft³. The volume of one missile silo is about 200,000 ft³, so that we expect to have all of the salts contained in one silo.

b. Another option is to empty the drums' contents into a silo, and get essentially 100 percent loading efficiency. This would mean less cost to the Army. In addition, the drums would have salvage value, making it more economically desirable.

c. A rough cost for disposal by Wes-Con is 3 cents per pound or \$250,000. Shipping costs from Rocky Mountain Arsenal to the site ~~are~~ \$2.60/hundred weight, or \$220,000.

d. We talked to N. Ed Baker and Jerry Jankowski of the Idaho Department of Health and Welfare (Idaho's EPA) about this concept. They speak favorably of Wes-Con, and see no immediate objection to the possibility of disposing of our waste there. They requested analytical data on the salts, which is being supplied. They did state that their responsibility is to protect the state of Idaho, and this includes public opinion aspects of the problem. They suggested we also coordinate with Tobias Hedghal, Chief of Solids Waste in the EPA Region X.

e. Wes-Con is extremely public relations oriented, and maintains excellent relations with the Idaho Department of Health and Welfare. They respond immediately to environmentalists' inquiries and offer free pesticide and container disposal to residents of the county, and free disposal under emergency conditions for hazardous material within Idaho when requested by State or Federal agencies, etc.

7. Follow-up.

- a. Send data requested to N. Ed Barker, state of Idaho.

SAREA-MT-E

14 OCT 1975

SUBJECT: Report of Visit to Wes-Con, Inc. Concerning Disposal of
Demilled Mustard Salts in their Facility, 24-26 Sep 75

b. Coordinate with EPA Region X.

Robert I. Epstein

ROBERT I. EPSTEIN
Project Engineer

APPROVED BY:

Sigmund R. Eckhaus

SIGMUND R. ECKHAUS
Chief, Disposal Engineering Division

CF:

Chief, Demil/Disposal Office (M. Stanka)
Proj Mgr for CDIR (Ned Coale)

WES CON, INC.

P. O. Box 564

TWIN FALLS, IDAHO 83301

PHONE 208-733-0897

August 6, 1975

Commander
Edgewood Arsenal
Attention SAREA-MT-E (Robert Epstein)
Aberdeen Proving Grounds
Edgewood, Maryland 21010

Dear Mr. Epstein:

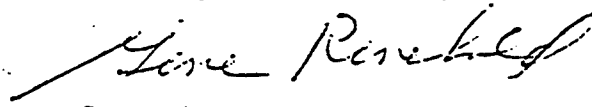
We have tested the samples of your sodium phosphonate salts and these materials, for all purposes, are inert.

You may be assured that WES-CON can encapsulate this material in a legal and safe manner.

We are looking forward to meeting you and any other members of your staff who may wish to inspect our facilities and evaluate our equipment and procedures.

Sincerely,

WES-CON, INC.



Gene Rinebold
President

GR/jl



STATE OF IDAHO

DEPARTMENT OF HEALTH AND WELFARE

DIVISION OF ENVIRONMENT
Statehouse
Boise, Idaho 83720

March 17, 1976

Sigmund R. Eckhaus
Chief, Disposal Engineering Division
Manufacturing Technology Directorate
Department of the Army
Headquarters, Edgewood Arsenal
Aberdeen Proving Ground, Maryland 21010

Dear Mr. Eckhaus:

Gene Rinebold at Wes Con, Inc., has requested that we review your letter of January 7, 1976 concerning the disposal of the chemical riot control agent at the Wes Con facility. Due to the high volatility and toxic chemicals of the riot control agent DM, and the strong wind in Owyhee County, the Division of Environment will not approve the Wes Con facility for the disposal of this material.

Pertaining to another material, as you will recall, the Department of the Army requested permission from this department to dispose of a mixture of sodium salt which resulted from incinerating mustard gas.

This office has completed our technical review of the sodium salt in reference to its suitability for disposal at the Wes Con facility. A copy of the technical review and our recommendations have been sent to the office of Cecil D. Andrus, Governor of Idaho, for their comment and review.

Your office will be notified as soon as the office of the Governor responds. This should be sometime in April as soon as this session of the Idaho legislature adjourns.

Sincerely,

A handwritten signature in dark ink, appearing to read "N. Ed Barker, Jr.", written over a horizontal line.

N. Ed Barker, Jr., Supervisor
Solid Waste Management

NEB/ca

cc: Gene Rinebold, Wes Con, Inc.

WES CON, INC.

P. O. Box 564

TWIN FALLS, IDAHO 83301

PHONE 208-733-0897

June 20, 1975

Commander, Edgewood Arsenal
Attention SAREA-MT-E (Robert Epstein)
Aberdeen Proving Grounds
Edgewood, MD 21010

Dear Mr. Epstein:

Thank you for considering us as a possible disposal site for your plant waste chemicals.

We are prepared to encapsulate this material in a safe and legal manner at your convenience.

You may ship via common carrier if you desire, however, we would prefer to ship with our own truck or a carrier of our choice. The advantage to you, if we assume the transportation responsibility, would be that the title deed (bill-of-lading) will be transferred to us at the time the trucks are loaded on your property. The advantage to us is that we will have control of the material for scheduling, loading, transportation, and unloading. This procedure allows us to utilize our personnel who have extensive training and equipment for handling hazardous material.

The technical data enclosed is quite self explanatory, however, we have made a number of improvements in our procedures which include a complete fire control system, both on the ground surface as well as under ground.

You may select all or any portion or area of our complex for your specific use and, we are prepared to establish any further procedures for safety and containment that you may recommend.

You and any other members of your staff are welcome to inspect our site at any time, and we are prepared to meet with you personally to work out every aspect of the procedures and prices involved.

The following is a partial list of our existing governmental customers:

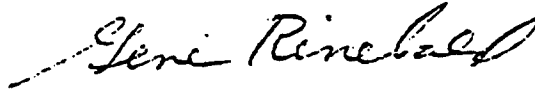
U.S.A.F. Water Port Logistics Office DET2	WA
U.S. Fish and Wildlife	CO
Naval Petroleum Reserve	AL
Dept. of Interior, Bonneville Power	WA, OR, ID
U.S. Forest Service	ID
Veterans Administration Hospital	OR
HQ Dept. of Army DAEN-ZGE	WA, DC
University of Idaho	ID
University of Washington	WA
State of Idaho, Environmental Services	ID
Naval Facilities Engineer Command - Western Div.	CA
Utah Power & Light	UT

Commander, Edgewood Arsenal
Attention SAREA-MT-E (Robert Epstein)
Page 2
June 20, 1975 . .

Thank you again for your interest in our company, we are looking forward to meeting you at the WES-CON SITE.

Sincerely,

WES-CON, INC.

A handwritten signature in cursive script, reading "Gene Rinebold". The signature is written in dark ink and is positioned above the printed name and title.

Gene Rinebold
President

GR/jl
Enclosures



STATE OF IDAHO

DEPARTMENT OF HEALTH AND WELFARE

DIVISION OF ENVIRONMENT
Statehouse
Boise, Idaho 83720

May 5, 1976

Sigmund R. Eckhaus
Chief, Disposal Engineering Division
Manufacturing Technology Directorate
Department of the Army
Headquarters, Edgewood Arsenal
Aberdeen Proving Ground, Maryland 21010

Dear Mr. Eckhaus:

This letter is pursuant to the numerous meetings and your letter of October 14, 1975 requesting Health and Welfare, Division of Environment approval to dispose of 4,000 tons of mixed sodium salt at the Wes-Con facility near Grandview, ID.

The background information and chemical and biological analysis of the sodium salt has been reviewed carefully. The reported relative innocuous characteristics of the sodium salt and the distinctive qualities of the Wes-Con facility indicate that the deposition of the salts at the site should not threaten the environmental quality of the area.

On this basis, the Department of Health and Welfare, Division of Environment will approve the Wes-Con facility for the deposition of the 4,000 tons of the sodium salt subject to the following items:

- 1) If the option of disposing of the sodium salt at the Wes-Con facility is chosen by the Department of the Army, the Department of Health and Welfare, Division of Environment should be notified prior to any shipment and items 2 through 5 below be followed explicitly.
- 2) The Department of the Army has indicated that samples of the salt would be available upon request. A sample of the material should be sent to the Department of Health and Welfare, Division of Environment to be tested at the State lab.

E-44

EQUAL OPPORTUNITY EMPLOYER

Sigmund R. Eckhaus

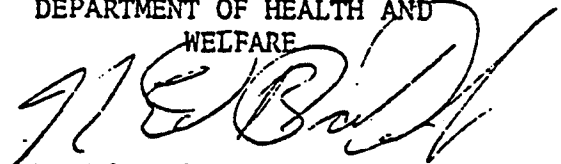
May 5, 1976

Page Two

- 3) Division of Environment personnel work with the Wes-Con officials to determine a suitable unloading and deposition scheme. This would include one area at the site reserved for only this material.
- 4) The Department of the Army has previously indicated that if approval were granted and the Wes-Con site were chosen, transportation would be via a commercial trucking firm. Since the shipment is estimated to be approximately 200 truck loads, these loads must be time phased so as to not attract undue attention.
- 5) The salts should be referred to as sodium salt and not mustard salts or mustard gas residue. This is to minimize any unnecessary public reaction.

Sincerely,

DEPARTMENT OF HEALTH AND
WELFARE



N. Ed Barker, Jr., Supervisor
Solid Waste Management

NEB/br

cc: Gene Rinebold

(6) Estimated Costs for Chemical Landfill

The following costs represent estimates from several commercial landfill operations who responded to inquiries.

BKK Corp. - \$.08/lb (based on estimate of 3/29/76 for 900 drums of mustard salts; includes transport from Long Beach to landfill site in West Covina, Calif.)

Chem-Trol - \$14.50 per drum ~ \$.036/lb (based on estimate of 6/16/75 for 20,000 drums of mustard salts, f.o.b. Model City, N.Y.)

Wes-Con - \$.03/lb (based on estimate of 10/14/75 for 4200 lbs of mustard salts; does not include shipping).

Nuclear Engineering - \$285,000 for approximately 4000 tons; approximately \$.036/lb including shipment to Texas, or Illinois (based on estimate of 11/12/75).

The cost per pound ranges from \$.03 - .08, depending on the amount of shipping included. The average cost per pound for those systems which include no shipping -

Chem-Trol \$.036

Wes Con \$.03

Avg. = .033/lb

= \$66/ton

For 4.2K tons of mustard salts

$$C_F = (4200)(66) = \$277,000$$

Edgewood estimate = \$300,000

For 7000 tons of GB salts

$$C_F = (7000)(66) = \$462,000$$

Edgewood estimate = \$500,000

Costs for Shipping by Rail

A cost estimate as of November 1976 was obtained through the AAI Shipping Department for transporting the drummed salts from Denver to Buffalo, N.Y. a distance of 1500 miles. The cost was \$4.23 per 100 wt. or \$84.60/ton. This is approximately \$0.0564/ton/mile and was used for estimating transportation costs.

Transportation costs - Denver to Buffalo (1500 mi)

Mustard salts:

$$C_T = (4200)(84.60) = \$355,000$$

GB Salts:

$$C_T = (7000)(84.60) = \$592,000$$

Transportation costs - Denver to New York, N.Y. (1800 mi)

Mustard salts:

$$C_T = (4200)(.0564)(1800) = \$426,000$$

GB Salts:

$$C_T = (7000)(.0564)(1800) = \$711,000$$

Transportation costs - Denver to L.A. (1100 mi)

Mustard salts:

$$C_T = (4200)(.0564)(1100) = \$261,000$$

GB salts:

$$C_T = (7000)(.0564)(1100) = \$434,000$$

Average costs from Denver.

Average between Buffalo and L.A.

Mustard salts:

$$\frac{355,000 + 261,000}{2} = \$ 308,000$$

GB salts:

$$\frac{592,000 + 434,000}{2} = \$ 513,000$$

Average between New York and L.A.

Mustard salts:

$$\frac{426,000 + 261,000}{2} = \$344,000$$

GB salts:

$$\frac{711,000 + 434,000}{2} = \$573,000$$

APPENDIX F

Landfill Hazards and Precautions

file: 11/1/75
2) September 75
SRS

DISPOSAL ENGINEERING DIVISION

SAREA-MT-E

6 February 1975

MEMORANDUM TO: CHIEF, DISPOSAL ENGINEERING DIVISION

SUBJECT: Release of GB salts/brine to Contractors.

1. At a meeting I had with LTC Parham and MAJ Gross of the Program Manager's Office on 20 Jan 75, the subject of releasing GB salts and brine to contractors came up.
2. In the meeting, LTC Parham informed me that we can have any competent contractor test our salts/brine, which includes processing, as long as the contractor is informed that he must not treat the materials in acid; that it might produce hazardous byproducts. Salts/brine with the NaF separated out would not have this latter requirement, since there would be no possibility of reforming agent.
3. There was a moratorium on releasing salts/brine, but we received specific relief to send materials to Atomics International, Chemfix, and Portland Cement Association in mid Nov 74. Right after that we were told by LTC Hanson to stop the contractors from processing any of the materials. In early December, we were told by LTC Hanson that we could in fact have the contractors process the materials, if we would have the materials tested for presence of GB and find no trace by the best available test method.

R. I. Epstein

ROBERT I. EPSTEIN
Chemical Engineer
Disposal Engineering Division

APPENDIX G

Deep Well Disposal

Administrator's Decision Statement No. 5
"EPA Policy on Subsurface Emplacement of
Fluids by Well Injection," February 6, 1973.



John F. McGowan

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

THE ADMINISTRATOR

FEB 6 1973

ADMINISTRATOR'S DECISION STATEMENT NO. 5

SUBJECT: EPA POLICY ON SUBSURFACE EMPLACEMENT OF FLUIDS BY WELL INJECTION

This ADS records the EPA's position on injection wells and subsurface emplacement of fluids by well injection, and supersedes the Federal Water Quality Administration's order COM 5040.10 of October 15, 1970.

GOALS

The EPA Policy on Subsurface Emplacement of Fluids by Well Injection is designed to:

1. Protect the subsurface from pollution or other environmental hazards attributable to improper injection or ill-sited injection wells.
2. Ensure that engineering and geological safeguards adequate to protect the integrity of the subsurface environment are adhered to in the preliminary investigation, design, construction, operation, monitoring and abandonment phases of injection well projects.
3. Encourage development of alternative means of disposal which afford greater environmental protection.

PRINCIPAL FINDINGS AND POLICY RATIONALE

The available evidence concerning injection wells and subsurface emplacement of fluids indicates that:

1. The emplacement of fluids by subsurface injection often is considered by government and private agencies as an attractive mechanism for final disposal or storage owing to: (1) the diminishing capabilities of surface waters to receive effluents without violation of quality standards, and (2) the apparent lower costs of this method of disposal or storage over conventional and advanced waste management techniques. Subsurface storage capacity is a natural resource of considerable value and like any other natural resource its use must be conserved for maximal benefits to all people.
2. Improper injection of municipal or industrial wastes or injection of other fluids for storage or disposal to the subsurface environment could result in serious pollution of water supplies or other environmental hazards.
3. The effects of subsurface injection and the fate of injected materials are uncertain with today's knowledge and could result in serious pollution or environmental damage requiring complex and costly solutions on a long-term basis.

POLICY AND PROGRAM GUIDANCE

To ensure accomplishment of the subsurface protection goals established above it is the policy of the Environmental Protection Agency that:

1. The EPA will oppose emplacement of materials by subsurface injection without strict controls and a clear demonstration that such emplacement will not interfere with present or potential use of the subsurface environment, contaminate ground water resources or otherwise damage the environment.

2. All proposals for subsurface injection should be critically evaluated to determine that:
 - (a) All reasonable alternative measures have been explored and found less satisfactory in terms of environmental protection;
 - (b) Adequate preinjection tests have been made for predicting the fate of materials injected;
 - (c) There is conclusive technical evidence to demonstrate that such injection will not interfere with present or potential use of water resources nor result in other environmental hazards;
 - (d) The subsurface injection system has been designed and constructed to provide maximal environmental protection.
 - (e) Provisions have been made for monitoring both the injection operation and the resulting effects on the environment;
 - (f) Contingency plans that will obviate any environmental degradation have been prepared to cope with all well shut-ins or any well failures;
 - (g) Provision will be made for plugging injection wells when abandoned and for monitoring plugs to ensure their adequacy in providing continuous environmental protection.
3. Where subsurface injection is practiced for waste disposal, it will be recognized as a temporary means of disposal until new technology becomes available enabling more assured environmental protection.
4. Where subsurface injection is practiced for underground storage or for recycling of natural fluids, it will be recognized that such practice will cease or be modified when a hazard to natural resources or the environment appears imminent.

5. The EPA will apply this policy to the extent of its authorities in conducting all program activities, including regulatory activities, research and development, technical assistance to the States, and the administration of the construction grants, State program grants, and basin planning grants programs and control of pollution at Federal facilities in accordance with Executive Order 11507.

William D. Ruckelshaus
William D. Ruckelshaus
Administrator

Attachment

Recommended Data Requirements for Environmental
Evaluation of Subsurface Emplacement of Fluids
by Well Injection

RECOMMENDED DATA REQUIREMENTS FOR ENVIRONMENTAL EVALUATION
OF SUBSURFACE EMPLACEMENT OF FLUIDS BY WELL INJECTION

The Administrator's Decision Statement No. 5 on subsurface emplacement of fluids by well injection has been prepared to establish the Agency's position on the use of this disposal and storage technique. To aid in implementation of the policy a recommended data base for environmental evaluation has been developed.

The following parameters describe the information which should be provided by the injector and are designed to provide regulatory agencies sufficient information to evaluate the environmental acceptability of any proposed well injection.

(a) An accurate plat showing location and surface elevation of proposed injection well site, surface features, property boundaries, and surface and mineral ownership at an approved scale.

(b) Maps indicating location of water wells and all other wells, mines or artificial penetrations, including but not limited to oil and gas wells and exploratory or test wells, showing depths, elevations and the deepest formation penetrated within twice the calculated zone of influence of the proposed project. Plugging and abandonment records for all oil and gas tests, and water wells should accompany the map.

(c) Maps indicating vertical and lateral limits of potable water supplies which would include both short- and long-term variations in surface water supplies and subsurface aquifers containing water with less than 10,000 mg/l total dissolved solids. Available amounts and present and potential uses of these waters, as well as projections of public water supply requirements must be considered.

(d) Descriptions of mineral resources present or believed to be present in area of project and the effect of this project on present or potential mineral resources in the area.

(e) Maps and cross sections at approved scales illustrating detailed geologic structure and a stratigraphic section (including formations, lithology, and physical characteristics) for the local area; and generalized maps and cross sections illustrating the regional geologic setting of the project.

(f) Description of chemical, physical, and biological properties and characteristics of the fluids to be injected.

(g) Potentiometric maps at approved scales and isoploth intervals of the proposed injection horizon and of those aquifers immediately above and below the injection horizon, with copies of all drill-stem test charts, extrapolations, and data used in compiling such maps.

(h) Description of the location and nature of present or potentially useable minerals from the zone of influence.

(i) Volume, rate, and injection pressure of the fluid.

(j) The following geological and physical characteristics of the injection interval and the overlying and underlying impermeable barriers should be determined and submitted:

(1) Thickness;

(2) areal extent;

(3) lithology;

(4) grain mineralogy;

(5) type and mineralogy of matrix;

(6) clay content;

(7) clay mineralogy;

(8) effective porosity (including an explanation of how determined);

(9) permeability (including an explanation of how determined);

(10) coefficient of aquifer storage;

(11) amount and extent of natural fracturing

(12) location, extent, and effects of known or suspected faulting indicating whether faults are sealed, or fractured avenues for fluid movement.

(13) extent and effects of natural solution channels

- (14) degree of fluid saturation;
- (15) formation fluid chemistry (including local and regional variations);
- (16) temperature of formation (including an explanation of how determined);
- (17) formation and fluid pressure (including original and modifications resulting from fluid withdrawal or injection);
- (18) fracturing gradients;
- (19) diffusion and dispersion characteristics of the waste and the formation fluid including effect of gravity segregation;
- (20) compatibility of injected waste with the physical, chemical and biological characteristics of the reservoir; and
- (21) injectivity profiles.

(k) The following engineering data should be supplied:

- (1) Diameter of hole and total depth of well;
- (2) type, size, weight, and strength, of all surface, intermediate, and injection casing strings;
- (3) specifications and proposed installation of tubing and packers;
- (4) proposed cementing procedures and type of cement
- (5) proposed coring program;
- (6) proposed formation testing program;
- (7) proposed logging program;
- (8) proposed artificial fracturing or stimulation program;
- (9) proposed injection procedure;

(10) plans of the surface and subsurface construction details of the system including engineering drawings and specifications of the system (including but not limited to pumps, well head construction, and casing depth);

(11) plans for monitoring including a multi-point fluid pressure monitoring system constructed to monitor pressures above as well as within the injection zones; and description of annular fluid;

(12) expected changes in pressure, rate of native fluid displacement by injected fluid, directions of dispersion, and zone affected by the project;

(13) contingency plans to cope with all shut-ins or well failures in a manner that will obviate any environmental degradation.

(1) Preparation of a report thoroughly investigating the effects of the proposed subsurface injection well should be a prerequisite for evaluation of a project. Such a statement should include a thorough assessment of: 1) the alternative disposal schemes in terms of maximum environmental protection; 2) projection of fluid pressure response with time both in the injection zones and overlying formations, with particular attention to aquifers which may be used for fresh water supplies in the future; and 3) problems associated with possible chemical interactions between injected wastes, formation fluids, and mineralogical constituents.

APPENDIX H

Comments on Unsolicited Ocean Burial Proposal.

SAREA-MT-E (10 Nov 75)

SUBJECT: Unsolicited Proposal for Disposal of Hazardous Chemical Residues Beneath the Ocean Floor

TO Chief, Plans Ofc
Attn: SAREA-PL-S

FROM Dir of Mfg Tech

DATE 6 DEC 1975 CMT 2
Mr. Epstein/drw/2260

1. As requested, subject proposal has been reviewed and the evaluation is as follows:

a. Technical Feasibility. The subject proposal presents a plan to perform a feasibility study for the disposal of demilitarized chemical warfare agents underneath the sea bed. The final evaluation of whether this method of disposal of these wastes is feasible is contingent on the results of such a study. Based on the previous work performed by Global Marine Development, Inc. in deep ocean bottom exploration, drilling, and operations including relocating wells after moving from the site, the concept of under sea bed disposal appears technically feasible as follows:

(1) The technology for under sea bed disposal exists but would have to be adapted to this application.

(2) The effect on the ecology must be determined for this mode of disposal.

(3) The legal questions of this mode of disposal must be answered, such as is this a form of ocean dumping for which specific regulations are in effect.

(4) The question of whether national or international agencies exercise jurisdiction over this mode of disposal must be answered.

b. Potential Utility. The potential utility of this method is low in comparison to other disposal options currently being considered and studied. The proposal does not mention predicted costs for ultimate disposal by this method but based on a presentation which Global Marine made to Edgewood Arsenal personnel on 19 Aug 75, the anticipated cost, not including feasibility or development studies, is \$300 per ton or more. Anticipated costs for controlled scientific landfill for comparison is estimated at \$60 per ton. The feasibility and development programs to establish this method would likewise be expensive, estimated in the range of \$1,000,000.

c. Probability of Success. Based on Global Marine's previous work in deep ocean bottom operations, this disposal option has a high probability of success from the technical aspect. Our evaluation of the other aspects is that the probability of success is low. These have to do with completing an environmental impact statement including identifying cognizant agencies and getting their commitments for approval, identifying and solving the legal problems including international legalities, obtaining public acceptance, and proving the ecological effect on the environment. The proposed feasibility study would provide more definitive answers to questions about the probability of success of this method for disposal but the foregoing is our present judgment.

SAREA-MT-E (10 Nov 75)

5 DEC 1975

SUBJECT: Unsolicited Proposal for Disposal of Hazardous Chemical Residues Beneath t
Ocean Floor

d. Applicability to Present Requirements. The proposed method for disposal of wastes generated by the demilling of chemical warfare agents is applicable to our present requirements. Currently, there are approximately 4,200 tons of salts from the demil of mustard at RMA and there soon will be approximately 7,000 tons of residue from other demil operations at various CONUS and OCONUS sites. Presently there appear to be viable means for disposing of the salts from RMA but no firm commitment has yet been made. Until a commitment is made, and also for the future demil, we are still investigating disposal options.

2. No funding for a contract will be requested at this time. We feel it will be more advantageous to the Government to complete work on disposal methods we're presently studying, such as ocean dumping, scientific controlled landfill, and incineration. If no viable methods are ultimately determined, then under sea bed disposal should be pursued.

FOR THE DIRECTOR:

wd all incl

SIGMUND R. ECKHAUS
Chief, Disposal Engineering Division

AUTHOR RE
GRP LDR H
DIO CHIEF R

DISPOSITION FORM

For use of this form, see AR 340-15; the proponent agency is The Adjutant General's Office.

S-10 Dec 75

REFERENCE OR OFFICE SYMBOL

SUBJECT

SAREA-PL-S

Unsolicited Proposal for Disposal of Hazardous
Chemical Residues Beneath the Ocean Floor

TO Dir of Mfg Tech
Attn: SAREA-MT-E

FROM Chief, Plans Ofc

DATE 10 Nov 75
Mr. Couch/tj/3037

1. Subject proposal from Global Marine Development Inc., is forwarded for review and evaluation (incl 1). A copy of the signed Memorandum of Understanding is also inclosed (incl 2).
2. Request that your evaluation be based upon the following criteria:
 - a. Technical feasibility.
 - b. Potential utility.
 - c. Probability of success.
 - d. Applicability to established requirements.
3. Your reply, if favorable, should state whether you plan to request funding for a contract, the fiscal year of funding, and if sole-source procurement will be recommended.
4. It is requested that your reply reach us by 10 December 1975.

FOR THE CHIEF:

2 Incl
as


FRANKLIN L. COUCH, Jr.
QRI Program Manager

H-4

DA FORM 2496
1 FEB 62

REPLACES DD FORM 86, EXISTING SUPPLIES OF WHICH WILL BE
ISSUED AND USED UNTIL 1 FEB 63 UNLESS SOONER EXHAUSTED.

☆ U.S. GPO: 1974-239

APPENDIX I

Mustard Salts; Sales and Industrial Use.

- 1) Colorado State Department of Highways -
"Use As A Deicer" - Letter dated October 17, 1973.
- 2) 42 Products Company; Use in dyeing cow hides,
Letter dated December 12, 1973.
- 3) Saltcake Sales Corporation; Use in the pulp and
peper industry; Letter dated April 9, 1974.
- 4) Letter from EPA concerning Road De-Icing.

STATE DEPARTMENT OF HIGHWAYS

(1) CHAS. E. SHUMATE

EXECUTIVE DIRECTOR

DIVISION OF HIGHWAYS
LAURENCE C. BOWER
CHIEF ENGINEER

STATE OF COLORADO



COLORADO STATE PATROL
COL. C. WAYNE KEITH
CHIEF

4201 EAST ARKANSAS AVENUE • DENVER, COLORADO 80222 • (303) 757-9011

October 17, 1973

Gerald G. Watson
LTC, CMIC
Department of the Army
Headquarters Rocky Mountain Arsenal
Denver, Co 80240

Dear Col. Watson:

Reference your letter of October 1, 1973 concerning the Division of Highways using the salts generated by the demilitarization of the toxic agent at Rocky Mountain Arsenal.

We would like very much to have been able to use this material, but we have found the sodium sulphite to be very damaging to our concrete pavements and concrete bridge decks.

We are encountering some damage using salt with a very low sodium sulphite content.

We thank you for the offer and we certainly wish we could help you by using this material.

Sincerely,

CHAS. E. SHUMATE
Executive Director

By

E. N. Maase
Chief Engineer

ENH/RWP/h



(2)

DEPARTMENT OF THE ARMY
HEADQUARTERS ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO 80245

SARRM-L-P

12 December 1973

Mr. Frank Rogers
42 Products Company
P. O. Box 1081
Scottsbluff, Nebraska 69361

Dear Mr. Rogers:

Please reply as soon as possible with the results of your experiment to use Mustard Salt from this installation for dyeing cow hides.

A sample of the salt was sent to you on 26 October 1973.

Sincerely yours,


RAYMOND J. ERNST
Contracting Officer

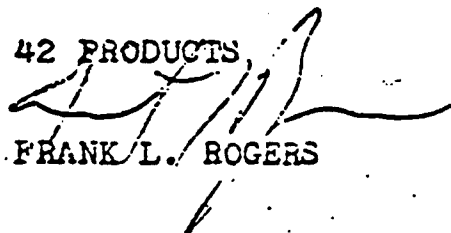
SIR:

WE HAVE TESTED THIS MATERIAL AND HAVE FOUND THAT THE CONTENT OF 3.8 of FE2 O3 CAUSES A REDDISH COLOR TO APPEAR AND THIS IS DEFINATELY PROHIBITIVE IN THE PROCESSING OF SHEEP & COW HIDES.

WE ARE STILL RESERCHING THE USES OF THIS MATERIAL & IF YOU HAVE OBTAINED ANY BUYERS WE WOULD BE INTERESTED IN THE PRISING SO WE MAY HAVE SOME BASE TO GO BY.

THANKING YOU ,

42 PRODUCTS


FRANK L. ROGERS

(3) SALTCAKE SALES CORPORATION

P. O. BOX Q 16 ARCADIA ROAD
OLD GREENWICH, CONNECTICUT 06870
TELEPHONES: 203-637-4394. ~~XXXXXXXX~~

~~XXXX~~

~~XXXXXXXXXXXX~~

~~XXXXXXXXXX~~
~~XXXXXXXXXX~~
~~XXXXXXXXXX~~

9 April 1974

Department of the Army
Office of the AMC Program Manager for
Demilitarization of Chemical Materiel
Aberdeen Proving Ground, MD 21010

ATTENTION: Colonel Sampson H. Bass, Jr.

Gentlemen:

We refer to your letter of 2 April 1974 concerning the disposition of the inorganic mixed sodium salts resulting from disposal of the chemical warfare agent Mustard ($\text{CH}_2\text{CH}_2\text{Cl}$)₂S).

After reviewing the chemical composition of the mixed sodium salts indicated in the attachment to your letter, we are of the opinion that because of the high concentration of sodium chloride (NaCl) this material would be unsuitable for use in the pulp and paper industry, which is the market served by Saltcake Sales Corporation, and thus from our standpoint would not have any commercial application.

In regard to the salt by-product produced from the disposal of chemical warfare agent GB ($\text{CH}_3(\text{C}_2\text{H}_5\text{O})\text{FPO}$), we are not in a position to comment on the commercial application or salability of this material.

Very truly yours,

SALTCAKE SALES CORPORATION


Daniel E. Jackson

DEJ:rmn

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION VIII
1080 LINCOLN STREET
DENVER, COLORADO 80203

Mr. Henry L. T. Koren OCT 15 1974
Deputy Undersecretary of the Army
Department of the Army
Washington, D. C. 20310

Dear Mr. Koren:

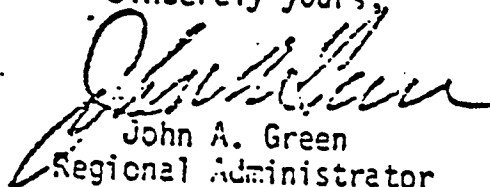
The Region VIII Office of the Environmental Protection Agency has been in contact with Major Robert Hansen of Edgewood Arsenal regarding proposals for the disposal of salts from the mustard gas demilitarization operation, stored at the Rocky Mountain Arsenal.

My staff was under the impression that a number of alternative disposal methods were under consideration, including ocean disposal. Depending on the manner of disposal and the nature of the material, such a disposal action could be considered a significant action in terms of National Environmental Policy Act criteria.

I am thus concerned to learn that a commitment has been made to dispose of these salts to a commercial firm. The end-use contemplated for these salts is for de-icing purposes on roads. No information is available to EPA through NEPA activities as to whether any such determination of environmental significance has been made. If an environmental analysis has been done, I would request that such an evaluation be made available to the Region VIII office. Considering the potential use of these salts on highways, one outstanding question comes to mind. I feel that it is essential to know what the nature of the trace materials in the salts is, and in what concentrations. I am particularly concerned that trace metals generally considered hazardous could become airborne as fugitive dust. Automobiles quickly pulverize sand and salts on roadways in the winter months, creating air pollution problems.

It would be premature to suggest that an environmental impact statement be written at this point on the disposal method, but I feel that it is important to evaluate the above-mentioned issue before a final commitment has been made. I would appreciate any quantitative information your office could provide, including an environmental assessment of the proposed action.

Sincerely yours,


John A. Green
Regional Administrator

APPENDIX J

Deep Mines and Geological Formations.

Germans Seal Nuclear Waste By Dumping In Salt Mines

Remlingen, West Germany (AP)—Somewhere in Lower Saxony, West German scientists are preparing to convert underground rock salt formations into a permanent dump for highly radioactive nuclear waste.

Government experts say they believe the facility could set an international example in safe disposal of nuclear garbage, one of the trickiest technical problems of the atom age. Several proposed sites for the nuclear waste repository have been kept secret for fear of triggering local protests.

Political Dynamite
Officials say final site selection will be made soon and announced next year—at the risk

active contamination of natural water reserves.

Safest System Known
"It's the safest system in the world today," said a Research Ministry spokesman.

He said "no final repository system has yet been chosen in the United States. Only very low-activity waste is buried in shallow trenches and covered with earth."

Other countries with waste problems have suggested that West Germany's underground salt caverns make it an obvious choice as a sort of international garbage dump for radioactive waste, he said.

"God forbid," he commented, adding that the Bonn gov-

ernment has pointed out that these countries also have geological structures offering suitable underground storage possibilities—such as salt mines in the United States and granite formations in France.

Buried In Salt
Reporters inspecting the mine here were shown how low-level waste is stored in casks, which are rolled into vast salt caverns 2,500 feet underground and covered with salt. When full, the caverns are sealed.

Medium-level fluid or slime waste is mixed with cement or bitumen, poured into casks and transported in shielded 9.2-ton containers to a section of the mine where they are lowered

down a shielded shaft to a cavern 1,670 feet below the surface.

There is no human access to this cavern, which is monitored by closed-circuit TV.

High-Level Waste
Even greater precautions will have to be taken at the proposed final depository for the high-level waste output of the fuel recycling plant, officials said.

Present plans foresee mixing the "hot" waste with molten glass and allowing it to harden in blocks.

The waste is so radioactive that three years after sealing, the temperature of the glass

blocks would still measure roughly 572 degrees at their surface and double that at their core.