

EVALUATING NON-INCINERATIVE TREATMENT OF ORGANICALLY CONTAMINATED LOW LEVEL MIXED WASTE

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ABSTRACT

This investigation examines the feasibility of using non-incinerator technologies to effectively treat organically contaminated mixed waste. If such a system is feasible now, it would be easier to license because it would avoid the stigma that incineration has in the public's perception. As other DOE facilities face similar problems, this evaluation is expected to be of interest to both DOE and the attendees of WM'93.

This investigation considered treatment to land disposal restriction (LDR) standards of 21 different low level mixed (LLM) waste streams covered by the Rocky Flats Federal Facilities Compliance Agreement (FFCA) agreement with the Environmental Protection Agency (EPA). Typically the hazardous components consists of organic solvent wastes and the radioactive component consists of uranic/transuranic wastes. Limited amounts of cyanide and lead wastes are also involved. The primary objective of this investigation was to identify the minimum number of non-thermal unit processes needed to effectively treat this collection of mixed waste streams.

A literature and vendor survey examined the candidate treatment technologies available for developing a nonincinerative treatment system. Based on the available non-incinerator technologies, a system for treatment of their organically contaminated LLM wastes is proposed. The applicability of those treatment technologies to mixed waste streams at Department of Energy's (DOE's) Rocky Flats facilities was evaluated using modified Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) guidelines. The heart of the proposed system consists of volatilization of organic residues from non-combustible wastes coupled with electrochemical wet oxidation of the combustible wastes. While final technology selection for a non-incineration pilot system must await completion of additional work, the proposed system provides a means to examine non-incinerator technologies, their unit operations, cost, advantages, and problems in a way that fairly compares non-incineration and incineration treatment systems. It is concluded that while a non-incineration treatment system may be practical, several component technologies still require demonstration at prototype scale. Furthermore, an integrated system should be constructed and demonstrated before this type of system could be considered as an immediate alternative to proven thermal treatment technologies.

INTRODUCTION

Since its 1989 FFCA with EPA, DOE's Rocky Flats Plant (RFP) has been considering incineration to treat about eight percent of its LLM wastes (wastes contaminated with Resource Conservation and Recovery Act (RCRA) regulated constituents that are also mixed with radioactive constituents, primarily uranium, plutonium and americium). The 718 cubic meters of backlogged LLM being considered for incineration consist of 21 diverse, organically-contaminated waste forms shown in Table I. The organic wastes are primarily spent solvents and used machining oils from manufacturing processes.

The waste matrix can be characterized as either combustible or non-combustible, and the combustible wastes are of

two types, either liquid or solid. This suggests that, at a minimum, two separate treatment trains will be required, one for the combustible wastes and a second for the non-combustible wastes. Based on waste treatment beginning 5 years from now and working off the accumulated inventory over the next five years, treatment rates of $\sim 0.07 \text{ m}^3/\text{hr.}$ and $\sim 0.02 \text{ m}^3/\text{hr.}$ will be required for combustible and non-combustible wastes respectively (based on 60% overall process availability).

However, incineration technologies are not easy to permit, and in some localities, public resistance has stopped or slowed the installation of any waste incineration. The goal of this report is to determine if emerging non-thermal technologies can successfully treat all of these 21 waste forms so that an incinerator is not necessary. The caveat is that if emerging

TABLE I
Rocky Flat's Solvent Contaminated LLM Waste Forms

Description	Matrix ¹	1992 Inventory	Applicable EPA Codes ²	Expected Generation Rate
Liquid Wastes:				
Analytical Lab Solutions	A	0.6 m ³	D002, D007	0 m ³ /yr.
Cyanide Waste	A	1.1 m ³	F009, D003	0 m ³ /yr.
Excess Chemicals	A	0.4 m ³	D002, P- & U-series	0.2 m ³ /yr.
Miscellaneous Liquids	A	0.4 m ³	F001-3, F005, D002	0 m ³ /yr.
FB Incinerator Oil	O	109.6 m ³	D001, D007-9, F001-3, F005	0 m ³ /yr.
Paints	O	0.4 m ³	D001	0 m ³ /yr.
PCB Liquids	O	0.6 m ³	F001-2	0 m ³ /yr.
Combustible Solid Wastes:				
Organic-Discard Level	WS	8.3 m ³	F001-2	0.1 m ³ /yr.
Solidified Organics	WS	0.2 m ³	F001-3	0.1 m ³ /yr.
Combustibles	WS	319.2 m ³	F001-2, F005	68.0 m ³ /yr.
Filters	WS	29.1 m ³	F001-2, F005, D006-8	65.8 m ³ /yr.
Non Combustible Solid Wastes:				
Cut-off Sludge	DS	7.9 m ³	F001-3, F005	0 m ³ /yr.
Roaster Oxide	DS	82.0 m ³	F001-2	0 m ³ /yr.
Cemented Composite Chips	DS	90.2 m ³	F001-2	0 m ³ /yr.
Insulation	DS	1.6 m ³	F001-2	0.62 m ³ /yr.
Turnings	DS	0.2 m ³	F001-3	0.1 m ³ /yr.
Electrochemical Milling Sludge	WS	1.5 m ³	F006	0 m ³ /yr.
Particulate Sludge	WS	8.9 m ³	F001-3, F005, D001, D006-8	0.2 m ³ /yr.
Used Absorbent (Oil Dri)	WS	0.2 m ³	F001-2	0 m ³ /yr.
PCB Solids	WS	11.5 m ³	F001	0 m ³ /yr.
Soil & Clean Up Debris	WS	43.6 m ³	F001-2	14.7 m ³ /yr.
Totals		717.8 m³		149.8 m³/yr.
Footnotes:				
A - Aqueous Liquid			² U.S.D.O.E., <u>Comprehensive Treatment and Management Plan</u> , June 9, 1992, Rocky Flats Plant, Golden, CO, 1992, pp 3-5 to 3-6.	
B - Organic Liquid				
DS- Dry Solids				
WS- Wet Solids				

technologies cannot treat all 21 of the solvent-contaminated waste forms, then an incinerator remains necessary. This discussion is pivotal for determining the most prudent use of resources for bringing Rocky Flats LLM wastes into compliance with all applicable treatment standards as quickly as is possible.

The stage of technology development is important since if the time required for adequate development is too long, treatment of RFP wastes will not occur in a timely fashion. There are some differences in the way EPA and DOE view the stages of technology development, and EPA's definitions are used in this report. EPA classifies technologies as Available, Innovative, or Emerging.

- Available Technologies are those that are fully proven in routine commercial use and for which sufficient performance and cost information are currently available.
- Innovative Technologies are those for which cost or performance information is incomplete and may require additional full-scale field testing before being considered proven and ready for commercialization or routine use.
- Emerging Technologies are those which require additional laboratory or pilot-scale testing to document the technical viability of the process.

For RFP's purposes, only technologies that are "Available" appear to be mature enough so they can truly be consid-

ered as alternatives to incineration technology now; however, "Emerging" technologies are essential for building a completely non-thermal treatment system, so a non-thermal treatment system is not yet ready for consideration as an immediate alternative to incineration.

CATEGORIZING APPLICABLE TECHNOLOGIES

In an effort to identify innovative and emerging technologies, several databases were searched for key words to locate citations regarding new and emerging technologies. In order to limit the search to new and emerging technologies, the search was confined to 1990, 1991, and 1992 through the month of February. The applicable references and the search strategy details can be obtained from the authors and will be published in the final report. Table II provides a brief description of the categories of technologies identified in the literature search.

TECHNOLOGY APPLICABILITY TO RFP WASTE FORMS

There are many processes and approaches available for treatment of hazardous, radioactive, and mixed waste forms but not all are applicable to those at RFP. Some of the key considerations in evaluating technology alternatives are: current stage of development (discussed in introduction), anticipated effectiveness on RFP mixed wastes, probable range of treatable waste forms, cost of application, and

TABLE II
Categories of Technologies

Technology Category	Summary Description
Biotechnology	<ul style="list-style-type: none"> Metabolism of aqueous organic wastes by suitable bio-organisms
Chemical/Physical [UV/Hydrogen Peroxide/Ozone]	<ul style="list-style-type: none"> Strong chemical oxidant (such as chlorine, peroxide, or ozone) is added to the waste stream (either liquid or slurry) to oxidize any organic or inorganic species present.
Electrochemical Oxidation	<ul style="list-style-type: none"> An oxidizing metal ion (such as Ag^{+2}, Co^{+3}, Fe^{+3}, or Ce^{+4}) is generated at the anode of an electrochemical cell containing a strongly acidic solution (nitric or sulfuric) and the organic material to be oxidized. The rate of waste destruction is governed by the rate of coulombic charge transfer between the cell electrodes and the efficiency of mixing between aqueous and organic phases.
Evaporation	<ul style="list-style-type: none"> Thin-film evaporation (TFE) is currently being developed for concentrating remotely handled, transuranic, sodium nitrate based sludges. The TFE process converts a liquid, nitric-acid based waste contaminated with radionuclides and small quantities of various organics and heavy metals, into a thick slurry, a powder, or a fused salt.
Membranes	<ul style="list-style-type: none"> Membrane technology has already been successfully applied to waste treatment on a large commercial scale. In the nuclear industry, reverse osmosis (RO) technology has been applied for the removal of radionuclides from low-level aqueous streams (i.e., garment laundry wash water). Ultrafiltration (UF) is a technology currently used for separating colloidal solids and high molecular weight organics from water. A major drawback of UF technology is it cannot effectively handle organics with molecular weights under about five-hundred. A new type of membrane process currently being developed uses a semipermeable composite membrane to separate volatile organic compounds (VOCs) from air.
Microwave Radiation	<ul style="list-style-type: none"> The use of microwave heating has significant advantages in that the heating source is non-contact so that containment is more easily achieved and maintained. Its principle limitation is that coupling and therefore heating cannot be achieved with some materials. In most other respects, it mimics a glass melter.
Molten Metal Technology	<ul style="list-style-type: none"> Molten Metal Technology uses steelmaking technology to treat hazardous waste by injecting the waste into a molten metal bath. The organic fractions are cracked and converted to carbon monoxide (CO) and hydrogen (H_2) through the water gas shift reaction, the inorganic materials are incorporated into the slag and the metals are reduced and incorporated into the molten metal.
Photolytic or Electron Beam	<ul style="list-style-type: none"> Photolytic processes may be used alone or in conjunction with chemical oxidation to destroy organics. Ultraviolet light helps catalyze the oxidation of organics in water, especially in the presence of transition metal catalysts. Electron beam energy is also being evaluated as a means of promoting the oxidation of organics in water without the need for an auxiliary chemical oxidant or catalyst.
Plasma	<ul style="list-style-type: none"> An electric arc is used to melt the waste. Some types of this technology do not require removing the waste from the storage drum, the drum is melted along with the waste. Slag, molten metal and Off-gases are the byproducts of this technology. Another type of plasma technology, i.e., silent discharge or cold plasma is being investigated as a method for destroying hazardous organic gases/vapors. The mechanism for organics destruction is via oxidation by various free radicals produced in a corona discharge.
Stabilization or Solidification (S/S)	<ul style="list-style-type: none"> The most common type of S/S uses a hydraulic cement (e.g., Portland cement) to encapsulate and immobilize hazardous, low-level radioactive, or mixed wastes. The reduction of waste mobility is directly tied to cement stability and porosity. Organics are captured in the pore structure and may hinder setting by inhibiting/preventing hydration. Volume is increased 1.5 to 2 times for nominal waste loadings. Generally there is no reduction in toxicity for organics, but there may be for heavy metals due to the high pH (>10.5) of the mix during hydration. In polymer encapsulation the waste is surrounded and isolated from the environment until the polymer matrix breaks down with age or waste interaction. Permanence is therefore dependent on polymer selection and waste composition. Reduction in mobility follows the above argument but there is no reduction in toxicity and there is usually an increase in volume due to the added polymer volume.
Supercritical Fluids	<ul style="list-style-type: none"> Supercritical water oxidation (SCWO) is currently being developed to destroy organics, including PCBs and dioxins. Supercritical water oxidizes organics in a medium that has been taken past the supercritical point (i.e. >374°C and 22.0 MPa {3,200 psia}). The firms attempting to commercialize the technology claim to have overcome the severe corrosion problems associated with SCWO. Supercritical carbon dioxide (CO_2) and propane extraction of hydrocarbons from water and soil respectively has been demonstrated at several EPA Superfund sites.
Wet Air Oxidation	<ul style="list-style-type: none"> Wet Air Oxidation (WAO) uses the same basic process as supercritical water oxidation except at milder process conditions. One major drawback of the technology is that the high operating temperatures (~300°C) and pressures (from 2.1 MPa {300 psia} to 20.6 MPa {3,000 psi}) are very corrosive to most metals. An alternative to the wet oxidation process utilizes hydrogen peroxide at ambient conditions to oxidize organic constituents in both mixed and hazardous wastes. This technology is still in the research-and-development stage, but substantial excesses of peroxide appear to be required to accomplish organic destruction at reduced temperature and pressure conditions.

implementability from the standpoint of time required for development, licensing, and public acceptance.

Technology Effectiveness

Effectiveness is essentially selecting the best process(es) available for treatment of a particular mixed waste. A good basis for judging effectiveness is that outlined in the EPA CERCLA guidelines as applied to environmental needs. In "Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA" (EPA 540/G-89/004), the approach to analyzing remediation alternatives for contaminated sites is developed. While it is aimed at Superfund site remediation, the general approach, if suitably modified, is useful for process evaluation.

The general approach first makes a go/no go decision based on whether the technology is protective of human health and the environment and is compliant with the ARARs. If those threshold criteria are not satisfied, the technology is not appropriate for use. Beyond that, there are requirements for compliance with a set of five performance criteria: long term effectiveness and permanence; reduction of toxicity, mobility and volume through treatment; short term effectiveness; implementability; and cost. Details of this approach and examples of items to be considered for each criteria are presented in Table III taken from the above mentioned document.

Modifications to the indicated approach for RFP needs would consist of changes in interpretation of some requirements. For example, Long Term Effectiveness analysis of the magnitude of residual risk for mixed and radioactive wastes, might include evaluating the stability of the waste form for long term storage and identifying a process for separation/destruction of the hazardous waste forms. Similarly, Short Term Effectiveness analysis of worker protection might incorporate ALARA considerations.

Range of Application

This is a key consideration if separate treatment processes for every waste form are to be avoided. Ideally, one process or one process train could be used to treat all the mixed waste forms to meet all effluent and transportation/storage requirements. The number and total volume of waste forms that a process will treat thus becomes a significant criteria.

Cost

Cost will clearly be a significant driver in the selection of waste treatment processes. It is not the only consideration, but a less expensive approach will be favored over a more expensive approach, all other things being equal. The split between capital and operating cost will also be important since it may influence the timing of process implementation through DOE program planning.

Licensability/Public Acceptance

It is clear that technical and cost issues are not the only drivers in the selection of technologies for treating the RFP waste forms. The main driver after technical feasibility favors approaches likely to have regulatory or public acceptance and this should be taken into consideration in the selection process. Public awareness and sensitivity are highlighted by the large number of oversight actions which RFP receives and the inability to permit existing incinerators.

Candidate Technologies

What follows is an examination of some specific candidate treatment technologies using the CERCLA guidance as an evaluation criteria for comparing those options. Table III shows the treatment options evaluated as high, medium or low in the various CERCLA attributes, together with estimates of the percent of inventory and waste generation to which the process might apply.

PROPOSED TREATMENT SYSTEM

To achieve any reduction in volume of the organically contaminated waste forms at the RFP some acceptable method of decontaminating or combusting such wastes will have to be identified. At the same time it is anticipated that regulatory and public support for conventional combustion/incineration methods will be difficult. For this reason, the currently available non-incinerative treatment/destruction technologies were reviewed and a non-incinerative treatment system suitable for the organically contaminated mixed wastes from the RFP is proposed.

A goal of this exercise was to propose a completely non-thermal treatment scheme for the applicable wastes. A conceptual block diagram of such a system is presented in Fig. 1, depicting the interrelationship and material flow between major process components. The alternative technologies and preferred alternative for each major system component are discussed in the following paragraphs.

Feed Preparation

Preparation of materials to be processed is expected at a minimum to consist of the following process steps:

1. Where necessary, remove the materials to be processed from individual waste containers,
2. Gross sorting to separate non-combustibles from the solid combustibles,
3. Initial size reduction of the solid combustible wastes to a size suitable for air classification; to separate any remaining non-combustibles, and
4. Additional shredding of the solid combustibles to permit slurring for aqueous oxidation.

The challenge will be to identify a process train which meets the requirements of OSHA, the goals of ALARA, and which maintains required waste processing rates at maximum reliability.

Combustibles Treatment

Several non-incinerator alternatives for oxidative destruction of organic (combustible) materials have been identified in the technical literature. The available treatment methods include: biological oxidation, chemical oxidation, photolytic oxidation, electrochemical oxidation, wet air oxidation, and supercritical water oxidation.

Four of those processes (biological, chemical, photolytic, and wet air oxidation); are commercially available and demonstrated treatment technologies for hazardous wastes, while the other two, electrochemical and supercritical water oxidation, have only been demonstrated at the small pilot scale to date. Although both wet air and super critical water oxidation have been shown to be very effective methods of oxidizing combustibles, they share the disadvantage of requiring high temperatures and pressures. This results in:

TABLE III
Modified CERCLA Examination of Technologies

Technology	Stage of Development	Technology Effectiveness	Range of Application	Cost	Public Acceptance
Biological Treatment	Available for Hazardous Waste Emerging for Mixed Waste	Good at treatment of some organics, but may not be applicable to specific organics found in RFP wastes	Low applicability to RFP wastes due to the low oxidation potential available	Medium because of problems of disposing of radioactive biomass	High
Cementation	Available	Does not destroy organics	Cannot effectively treat wastes containing high concentrations of organics	Low for process, high for analytical characterization needed to support process	High
Chemical Oxidation	Available for Hazardous Waste Emerging for Mixed Waste	Good at treating some organics, but does not reduce waste volume	Low applicability to RFP waste forms due to the low oxidation potential available	Lower costs than most alternatives	Medium
Electrochemical Oxidation	Innovative for Hazardous Waste Emerging for Mixed Waste	Unknown completeness of organic treatment	May create difficult secondary heavy metal waste forms	Medium	Medium, similar to processes used in metals plating industry
Evaporation	Available	Good means to separate wastes. Could be useful with a destructive treatment process	Does not reduce toxicity of organics	Low for high vapor pressure materials, high for low vapor pressure materials	High
Microwave Solidification	Innovative for Hazardous Waste Emerging for Mixed Waste	Volatilizes organics	Only applicable to inorganic sludge immobilization	Medium	Medium
Photolytic Oxidation	Available for Hazardous Waste Emerging for Mixed Waste	Good for treating some organics, but does not reduce waste volume	Low applicability to RFP waste forms due to the low oxidation potential available	Medium initial cost, high operating cost	Medium
Polymer Encapsulation	Available for Hazardous Waste Emerging for Mixed Waste	Does not destroy organics	Provides for physical immobilization without chemical stabilization of heavy metals	Low	High
Precipitation/Filtration	Available	Good means to separate sludge wastes	Low applicability to the RFP waste forms discussed in this article	Low to Medium	High
Retorting	Available for Hazardous Waste Emerging for Mixed Waste	Good means to separate organics from other media, could be useful with a destructive treatment process	Some cracking of the organics; most likely this process would be used primarily as a separation	Medium, but highly variable depending on temperatures and operating conditions	Low due to high temperatures and similarity to incineration
Steam/ Hot Gas Stripping	Available	Good means to separate organics from other media. Maybe useful with a destructive treatment process	This process would be used primarily as a separation, does not destroy organics	Low	High
Supercritical CO ₂	Innovative for Hazardous Waste Emerging for Mixed Waste	Very good means to separate organics from other media. Maybe useful with a destructive treatment process	This process would be used primarily as a separation, does not destroy organics	Medium	Medium
Supercritical Water	Innovative for Hazardous Waste Emerging for Mixed Waste	Very good treatment of organics	Limited to treating liquid waste forms	High due to need for corrosion resistant materials	Low, due to concerns regarding high temperatures and pressures
Wet Air Oxidation	Innovative for Hazardous Waste Emerging for Mixed Waste	Good at treatment of organics, destruction efficiencies are only 90-95%	Limited to treating liquid waste forms	Medium	Low, due to concerns regarding high temperatures and pressures.

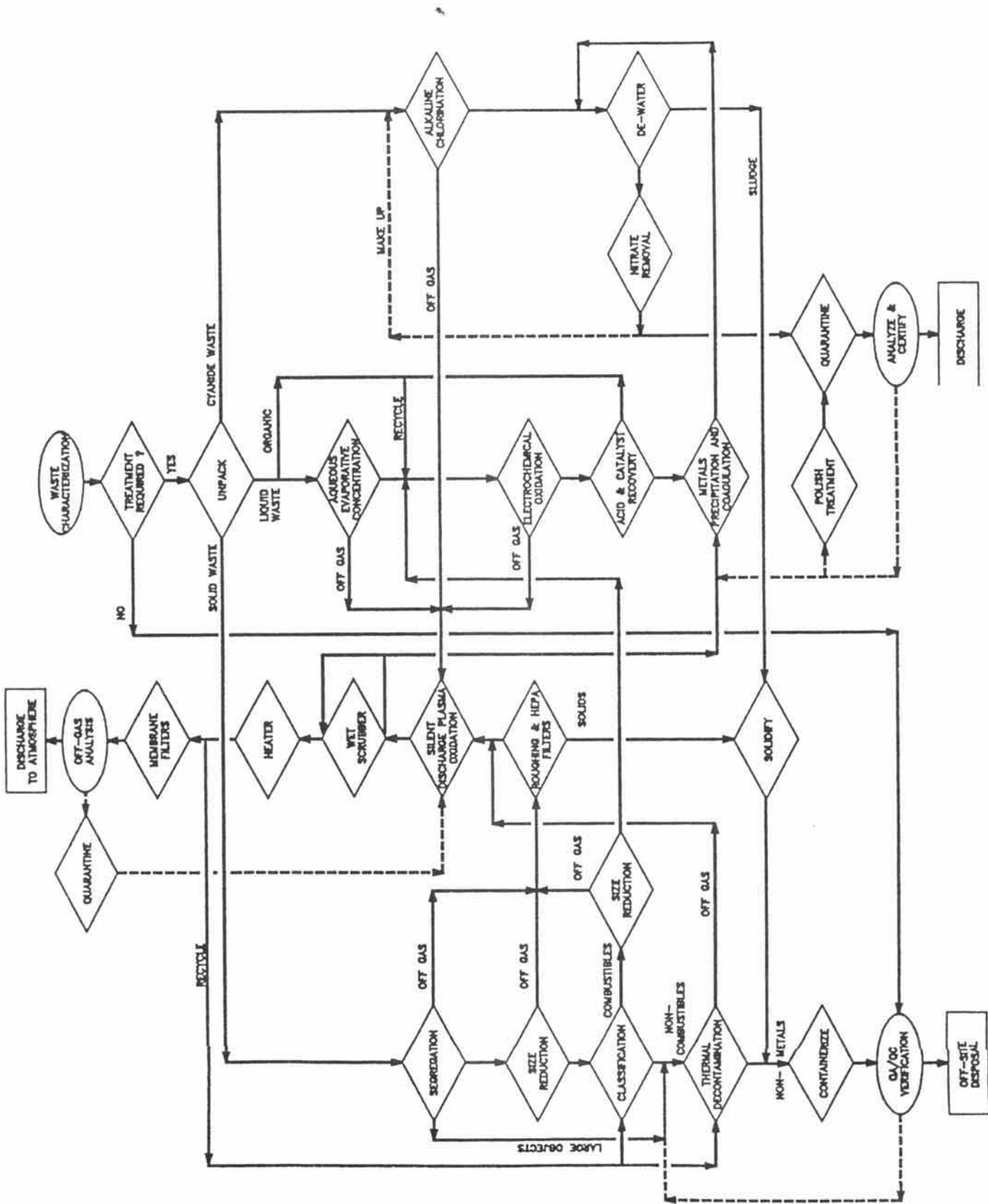


Fig. 1. Conceptual non-incinerative treatment system.

1. increasingly severe corrosion potential requiring the use of exotic alloy construction, and
2. significant potential for a breach of containment in the event of a maximum credible pressure vessel failure.

The remaining four treatment alternatives are essentially ambient treatment processes (i.e. $< 100^{\circ}\text{C}$ @ atmospheric pressure). Biological destruction has the disadvantages of being very slow, not being applicable to all of RFP's organic wastes and not resulting in complete destruction of those wastes. Chemical oxidation also has the disadvantage of not being applicable to a broad spectrum of organic wastes. However, it is well suited to the safe destruction of certain organic contaminants such as cyanide wastes and inexpensive to implement; therefore it should be included in the treatment scheme for such wastes. To date, photolytic oxidation (either uncatalyzed or catalyzed) has only been demonstrated to be effective in the destruction of dilute aqueous wastes (i.e. < 10 g/l total organic) contaminated with a limited spectrum of organics.

While, Electrochemical oxidation is at present a developing technology for destruction of a broad spectrum of wastes, it appears to be the best available candidate for destroying combustible wastes. It is not without its own problems which include:

1. Slow oxidation rate and high energy demand,
2. Potential secondary contamination as a result of catalyst loss, and
3. High corrosion potential, necessitating use of corrosion resistant alloys, glass, or polymers.

Nevertheless, it is concluded that these problems can be solved in a time frame consistent with RFP's waste treatment needs if adequate priority and resources are available to overcome these engineering hurdles, and to modify the process so that is adequate for radioactive materials.

Non-Combustibles Decontamination

Alternatives for removing organic contaminants from non-combustible substrates have been extensively studied and reported on in the technical literature. However, to be suitable for treatment of the RFP's mixed waste streams it is essential that: 1) the treatment remove organic contaminants to or below LDR levels, and 2) secondary residues which could limit land disposal not be introduced as a result of such treatment. There are three general treatment methods meeting these requirements: steam/hot gas stripping, retorting, and super critical fluid extraction.

All three of those processes are commercially mature technologies at the present time. Although super critical fluid extraction has come to maturity during the past five years, it is considered the least appropriate of the three technologies, due to the significant potential for a breach of containment in the event of a maximum credible pressure vessel failure.

The distinction between retorting and steam/hot gas stripping is a subtle one depending on how the substrate is heated to accomplish organics volatilization. In the former case it must be supplied by resistive, inductive, or microwave heating, while in the latter case it is supplied by the circulating steam/hot gas stream. For maximum decontamination flexibility it is proposed that a system utilizing microwave heating with provision for Hot Nitrogen circulation for contaminant

transport be utilized. Such a system has the following advantages:

1. The rate of substrate heating is not limited by the gas circulation rate, and
2. By product liquid waste requiring treatment is minimized.

If steam were found beneficial to the rate or extent of contaminant removal it could be introduced by adjusting the moisture content of the waste being processed. However, this has the associated disadvantage of reducing the rate of substrate heating and thereby the rate of decontamination and producing a larger waste stream due to the added water.

Waste Water/Sludge Treatment

The treated water/sludge leaving the chemical/electrochemical oxidation cells is expected to be free of hazardous organic residues. However, it is expected to contain hazardous metal and/or nitrate residues which will have to be removed prior to being discharged. It is anticipated that metals removal will be by means of hydroxide precipitation and chemical coagulation to accomplish solids/liquid separation.

However, improved chemical coagulation chemistry continues to be investigated in an effort to reduce the quantity of by-product sludges produced as a result of treatment. Nevertheless it is anticipated that the equipment and methods currently used in this portion of the process will continue to be used.

In addition it is anticipated that RFP will identify and implement a process for nitric acid recovery or nitrate destruction to reduce by-product salt production in the waste evaporators. The proposed alternative treatment process would utilize such waste water treatment facilities as are in existence rather than propose alternative facilities.

Offgas Treatment

Offgases from the entire treatment system will have to be appropriately HEPA and probably membrane filtered to remove particulate contaminants prior to discharge. The technology and equipment for accomplishing this at ambient temperatures is well established. In addition off gases from the thermal decontamination and aqueous oxidation cells may have to be treated for tramp volatile organic, and acid vapor (HCl , H_2SO_4 , & HNO_3) removal prior to discharge. Four methods are available for such treatment, namely: aqueous reagent scrubbing, solid sorbents, selective catalytic oxidation/reduction, and silent discharge plasma. All of the processes described above except silent discharge plasma are commercially mature technologies being employed in certain commercial markets. These are not described in any greater depth in order to keep this paper brief.

Waste Fixation/Stabilization

Some of the by-product wastes and sludges produced as a result of waste processing will require fixation/stabilization to meet disposal site waste acceptance criteria. The RFP is actively evaluating three technologies for fixation/stabilization of other waste streams, namely pozzolanic stabilization, polymer encapsulation, and microwave melting. The by-product wastes from the proposed process are expected to be similar to other waste streams for which waste fixation/stabilization technology has been or is being developed. For that reason a further analyses of available alternatives is not considered

necessary. In other words, those systems which are available would be utilized by the proposed treatment process.

CONCLUSIONS

The proposed treatment system contains three unit processes which are not fully developed treatment technologies at present, namely electrochemical oxidation, silent discharge plasma oxidation and nitrate removal/recovery technology. Lack of time or complete development of the first two technologies would preclude implementation of the proposed treatment system for RFP mixed wastes. Complete development of nitrate removal/recovery technology is considered less critical to overall system performance than the other two technologies, since existing developed alternatives could be implemented if necessary (such as anion exchange and/or evaporative concentration). Our understanding of the current level of development of the two critical technologies is summarized in the following paragraphs.

Electrochemical Oxidation

Several organizations (Lawrence Livermore; Delphi Research, Inc.; and AEA Technology of the UK) are actively pursuing research and development of electrochemical oxidation. To the best of our knowledge AEA Technology has carried the development of this process further than the other organizations. They have had a completely integrated laboratory prototype system (2,000 Amp capacity corresponding to a treatment capacity of ~0.14 kg/day of Chemical Oxygen Demand) in operation for the past several years. They also have: 1) demonstrated its effectiveness in destroying a wide range of organics including cellulose and PCBs, 2) examined the key engineering design and scale up parameters for such a system, and 3) are preparing to design and construct a larger demonstra-

tion unit. However, it remains unclear whether acid and catalyst recovery technology have been adequately developed for long term operation at significantly expanded scale.

Silent Discharge Plasma Oxidation

Since the mid '80s this technology has received considerable attention from various researchers as a means of oxidizing vapor phase organics. Los Alamos has an ongoing research program to investigate its use for destruction of chlorinated volatile organics. They have operated a laboratory prototype system at 100 standard liters/minute of air flow containing up to 1,000 ppm of chlorinated volatile organics. At a feed concentration of 1000 ppm, discharge concentrations of <100 ppb have been obtained with residence times of less than one second. Los Alamos is currently working with the Electric Power Research Institute (who provided some of the research funding) to commercialize this technology. To date, the long term operability and performance of this system for broad spectrum organics destruction is unproven.

In addition to completing development of the component technologies, an integrated demonstration of the proposed low temperature treatment system would be necessary for it to be considered a practical alternative to proven higher temperature treatment alternatives. The latter would be expected to identify critical unit process interactions, component reliability/maintainability, overall system operability, and effluent quality control issues. Thus the time delay required for both critical technology development and integrated system demonstration may preclude serious consideration of any currently unproven treatment system.