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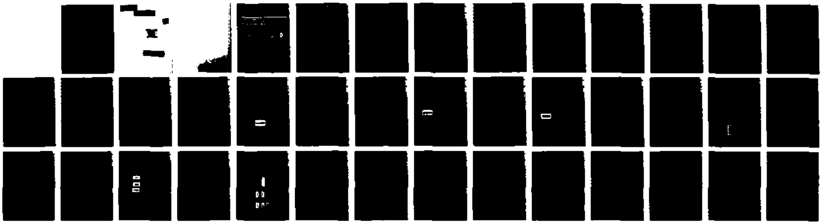

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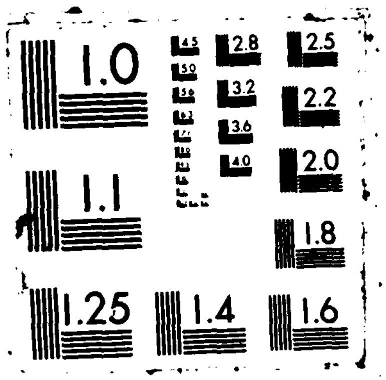
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ECTION AND EVALUATION OF TECHNOLOGIES

Final Report to
United States Army Toxic and Hazardous Materials Agency
February 1987

Evaluation/Selection of Innovative Technologies for Testing with Basin F Materials

(Task Order Number 8)

Final Report

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L.R. Woodland
Principal Investigators

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Under Contract No. DAAK11-85-D-0008 with the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), Process Development Branch, Arthur D. Little, Inc. was issued Task Order No. 8 entitled "Innovative Technology Development for Rocky Mountain Arsenal Environmental Control/Concept Evaluation." Work began on Task Order No. 8 on 25 July '86, and this report presents the results of our concept evaluations and ultimate selection of candidate technologies.

The objectives of Task Order No. 8 directed Arthur D. Little, Inc. to: review the industrial data base for promising hazardous materials treatment technologies; select and ultimately evaluate the candidate technologies with laboratory testing; and prepare a preliminary process design and cost estimate for the most promising technologies.

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Attention was to be directed particularly to three innovative thermal destruction technologies as typified by: (1) in-situ vitrification; (2) circulating bed combustion; and (3) glass furnace incineration. However, we were also instructed to evaluate other technologies which we might consider to be equally innovative. Subsequent selection and evaluation of technologies in laboratory/pilot-scale equipment was to be directed especially to the materials in Basin F at Rocky Mountain Arsenal (RMA).

Based on the conceptualized flowsheets and the criteria for performance of the various technologies, it became apparent that encapsulation and high temperature processes were the leading contenders for future evaluation in small-scale and/or pilot plant tests.

In subsequent discussions with USATHAMA, however, it was pointed out that we had not, as yet, been given the opportunity to review the results of prior work performed by the U.S. Army Engineer Waterway Experiment Station contained in a July 1983 Draft Report (3), "Laboratory-Scale Solidification of Basin F Concentrate -- Rocky Mountain Arsenal." Evaluation of that report indicated that none of the encapsulating agents tried prevented significant leaching of organic components when subjected to the U.S. EPA Extraction Procedure (EP) Toxicity Test and the Battelle Solid Waste Leaching Procedure (SWLP). Based on the measurement of Total Organic Carbon (TOC) in the leachate, it was the investigators' conclusion that the EP and SWLP leachates indicated that the leachates from solidified Basin F liquid concentrate could pose a serious problem. Consequently, at the direction of USATHAMA and RMA Program Management Office personnel, encapsulation was eliminated from further consideration. Furthermore, discussions on the difficulties of verifying low leaching rates from in-situ vitrification coupled with consideration of schedules and funds available resulted in the selection of the following three technologies for laboratory/pilot-scale tests. These were:

- Glassification;
- Fluidized/circulating bed combustion; and
- Soil washing.

In actuality, these three technologies offer one the opportunity to evaluate a spectrum of processes, each offering potentially distinct advantages. Glassification destroys organics and fixes metals under controlled conditions whereby further treatment of residuals may be eliminated; circulating bed combustion destroys organics and offers in-situ acid gas removal, thereby possibly eliminating wet scrubbing; and soil washing offers the possibility of removing organics from soil without having to heat considerable quantities of soil to very high temperatures.

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1.0 INTRODUCTION

Under Contract No. DAAK11-85-D-0008 with the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), Process Development Branch, Arthur D. Little, Inc. was issued Task Order No. 8 entitled, "Innovative Technology Development for Rocky Mountain Arsenal Environmental Control/Concept Evaluation." Work began on Task Order No. 8 on July 25, 1986, and this report presents the results of our concept evaluations and ultimate selection of candidate technologies.

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In approaching this Task Order assignment, we prepared a list of twenty-five steps (milestones) which we initially envisioned to carry out. These are shown in Table 1-1. It was recognized that sequential performance of these actions would not be desirable because some would continue throughout the assignment, e.g., literature and data collection. Consequently, we carried forward work in a number of areas during the concept evaluation and selection of technologies for laboratory/pilot-scale testing with Basin F materials.

TABLE 1-1

TENTATIVE MILESTONE SCHEDULE

Milestone	Week(s)
Kick-off Meeting	0-1
Prepare Resource Utilization Plan	1-6
Review RMA and Technology Literature	1-8
Prepare Matrix Rating Form	4-8
Rank Technologies	8-10
Select Candidate Technologies	10-12
USATHAMA Review of Selection	12-13
Arrange Initial Visits to Tech Developers	12-14
Prepare/Execute Subcontracts with Tech Developers	12-14
Establish Quantities of Basin F Materials to be Shipped	14-15
Establish Sampling Protocols for Basin F Materials	15-16
Arrange for Acquisition/Shipment of Basin F Materials	15-18
Sample/Analyze Basin F Materials	16-18
Prepare Draft Test Plan	15-19
USATHAMA Review of Draft Test Plan	19-20
Revise/Issue Final Test Plan	20-21
Test Technology - 1	20-22
Test Technology - 2	24-26
Test Technology - 3	28-30
Analyze/Evaluate Data	21-32
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Prepare Preliminary Process Design/Cost	30-34
Prepare Draft Final Report	34-38
USATHAMA Review of Draft Final Report	38-40
Revise/Issue Final Report	40-42

Source: Arthur D. Little, Inc.

2.0 BACKGROUND REVIEWS

Our review and compilation of information was directed along the following two paths, i.e., (1) data and information on RMA with particular emphasis on Basin F, and (2) technical and industrial data on innovative hazardous materials management technologies. The results of our reviews are summarized in the following sections.

2.1 BASIN F INFORMATION

The USATHAMA Project Officer (Erik B. Hangeland) provided us a number of documents on Basin F and we subsequently obtained other documents from the RMA Information Center for review. In reviewing these documents we were interested especially in obtaining information on the quantities and compositions of the materials at the Basin F site and establishing the time frame for its clean-up. Based on these reviews, as well as discussions with the USATHAMA Project Officer, the RMA Program Management Office and other USATHAMA contractors, we have established the following Basin F information as bases for our evaluations:

(1) The best present estimate of the quantities of Basin F materials to be treated is presumed to be that reported in the April 1986 Draft Report (1) on Task 17, U.S. Army Contract DAAK-11-84-D-0017 by EBASCO Services and is as follows:

	Yd^3
• Standing Liquid (1 million gal)	5,000
• Overburden and Liner	240,000
• Underlying Soils	146,000
• Sewer Debris and Solids	12,000
	403,000*

*Excludes adjoining soils which may have been contaminated by Basin F activities. Estimate is subject to refinement upon completion of Phase II of reference study.

(2) The meager data available on the composition of both the liquids and solids in Basin F shows, as was expected, wide variations in the concentrations of contaminants. Furthermore, the analytic extraction procedures applied to sample cores and samples of the overburden serve only to indicate the likely areal extent and depth of contamination beneath the basin and do not provide any guidance on whether the soils in selected areas might be classified as non-hazardous.

(3) The soils beneath the Basin F liner vary from silt through silty-sand to clay in nature and vary with depths at any location.

(4) The period allowed for clean-up of Basin F is 2.5 years from the time that a treatment/disposal operation is begun.

(5) For the purpose of this assignment, the degree of removal or containment of contaminants for treated residuals either left in place or disposed of on the RMA site can not be specified.

3.0 INFORMATION ON INNOVATIVE TECHNOLOGIES

The most widely utilized technologies for the treatment and disposal of hazardous materials are: (1) securing the materials against leaching and depositing in landfills; and (2) thermal destruction in equipment such as rotary kiln incinerators. These technologies represent two different philosophies, e.g., secure landfilling does not destroy the contaminants but merely reduces their potential for migration into the biosphere to what is deemed an acceptable rate over a lengthened time period, while thermal processes destroy the organic fractions but not, of course, the heavy metals. Therefore, when assessing less well utilized or innovative technologies for application to Basin F, we strove to determine not only the status of their development, but also addressed the expected results of applying the technology including its potential for creating air and water pollution control problems.

Due to regulatory pressures, there has been an accelerating interest in developing technologies for use in the treatment and disposal of hazardous materials. As a consequence, there is an unknown but large number of proposed technologies. Many of these are at the conceptual stages, some have been tested on small laboratory and pilot scales, while a relatively few of the more innovative technologies have reached the stage of being applied to hazardous materials management especially for the clean-up of Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) sites. The interest in innovative technologies has led the U.S. Environmental Protection Agency (EPA) to establish under its Office of Environmental Engineering and Technology the Superfund Innovative Technology Evaluation (SITE) Program. This program is investigating several waste solidification (immobilization) methods, in-situ removal of volatile constituents, gas extraction of hydrocarbons, biological detoxification and five variations of thermal destruction systems such as the circulating bed combustor, infrared incineration, electric pyrolyzer, plasma arc, and so on. Except for the waste fixation technologies, all of the remaining technologies address the destruction of organic substances with varying degrees of fixation of inorganic contaminants such as heavy metals.

Utilizing our staff's knowledge of technologies for hazardous materials treatment, while considering the physical and chemical nature of the Basin F materials to be treated, we began to contact various technology developers and equipment manufacturers. A summary listing of the contacts made is provided in Table 3-1. From these sources we sought to determine the applicability of the technology in question to treat Basin F materials and to establish the status of development and the availability of test facilities.

TABLE 3-1

CONTACTS MADE REGARDING TECHNOLOGIES OF INTEREST

Technology	Technology Supplier	Initial Comments
Advanced Combustion	Advanced Combustion Technologies, Inc.	Have never dealt with hazardous wastes.
Biochemical	Hazardous Organic Disposal, Inc.	In association with Westinghouse uses "accelerated" microbes. No information on test facilities.
	Flow General	Bioaugmentation - Bacterial cultures.
Circulating Bed Combustion	G. A. Technologies, Inc. (Subsequently: Ogden Environmental Services, Inc.)	Pilot plant unit and truck transportable units available.
Electro-Pyrolysis	Westinghouse Electric Corp. (Waste Technology Services Division)	Uses high temperature infrared radiation to melt inorganics and oxidize organics.
Encapsulation	Chemfix Technologies, Inc.	Proprietary encapsulation formulations.
	HAZCON, Inc.	Proprietary encapsulation formualations.
	Stablex Corp.	Proprietary encapsulation formulations.
Extraction	Critical Fluid Systems, Inc.	Carbon dioxide or petroleum extractants--Pilot plants available.
	Resources Conservation Co.	Patented process BEST® (Basic Extractive Sludge Treatment) using triethylamine as extractant. Lab and pilot plants available.

TABLE 3-1 (Continued)

CONTACTS MADE REGARDING TECHNOLOGIES OF INTEREST

Technology	Technology Supplier	Initial Comments
Fluidized Bed Combustion	Waste-Tech Services, Inc. Inc., subsidiary of Bechtel National Inc.	8-inch diameter unit at their facilities and a 2-foot diameter portable unit is available.
Glassification	Penberthy Electromelt Int'l. Inc.	Glass furnace (electrically heated) holding 5-6 tons of glass is available.
	Battelle Pacific Northwest Laboratories	Several small-scale electric melters are available.
Infrared Radiation	Shirco Infrared Systems, Inc.	Have pilot units available for testing at their facilities as well as mobile unit. Uses infrared heat to vaporize and combust hydrocarbons.
In-situ Vitrification	Battelle Pacific Northwest Laboratories	Small crucible-type unit. (Has had one large scale field demo on nuclear wastes).
Organic Stripping	American Toxic Disposal Corp.	Process strips hydrocarbons (e.g., PCBs) but process details not identified. Commercial unit being erected at Gary, Indiana.
Pyroplasma	Westinghouse Electric Corp. (Waste Technology Services Division)	1 gpm units for liquids are available. Unit is ready for testing at Love Canal.
Rotary Kiln Incineration	Environmental Elements Corp.	Transportable, modular incineration process based on European developed rotary kiln technology.

TABLE 3-1 (Continued)

CONTACTS MADE REGARDING TECHNOLOGIES OF INTEREST

Technology	Technology Supplier	Initial Comments
Sintering	Battelle Columbus Laboratories	Battelle is developing process for a client. Equipment available for transport to site. Client not identified.
Soil Washing	MTA Remedial Resources, Inc.	Laboratory froth flotation unit is available. Pilot plants can be assembled at capacities up to 10 TPD.
Supercritical Water	Modar, Inc.	30 gpd (organics) transportable unit (for liquids only) is available. Uses water at 600 deg.C, 3,700 psi.
Synfuels Technology	Mr. E.J. Hoffman Energy Consultant	Proposes use of Synfuels Technology for degradation of organics.
Wet-Air Oxidation	Vertox Corp.	Deep wells (1 to 2 miles in depth) are used with air or oxygen to destroy organics. Pilot plant to be available in early-1987.

Source: Arthur D. Little, Inc.

4.0 SELECTION AND EVALUATION OF TECHNOLOGIES

Our approach to the evaluation of innovative technologies has been the development of conceptual flowsheets for a number of the technologies for which tests with Basin F materials might be carried out in order to better understand the operational limits of the technology in question. Because the operational characteristics of the technologies vary from in-situ treatment through removal, treatment, and disposal of the treated residuals, we believed that it was necessary to develop these concepts in order to gain an appreciation of the operational steps involved. In addition, the development of these flowsheets provided a basis for making qualitative assessments of the likely performance limitations and areas where significant data would be required to make engineering evaluations. Based on literature reviews and our staff's knowledge of hazardous materials treatment technologies, we chose the following for conceptual flowsheet development and comparative evaluation of their merits:

- Encapsulation;
- Circulating Bed Combustion or Rotary Kiln Incineration;
- Glassification;
- In-situ Vitrification;
- Soil Washing;
- Wet-Air Oxidation; and
- Extraction.

Rotary kiln incineration was included for comparative ranking because it is a widely utilized technology and was the reference technology considered in the June 1986 Report (2) by Environmental Science and Engineering, Inc. entitled, "An Accelerated Clean-up Plan for the Contamination at RMA."

In the following sections, the conceptual flowsheets for the technologies are presented along with a brief discussion of their expected operational characteristics and our perception of the additional information that would be necessary for more detailed engineering evaluations.

4.1 ENCAPSULATION

The steps for encapsulation or fixation of Basin F materials within a solid are shown in Figure 4-1. Encapsulation requires excavation of the solids and transportation of the solids and liquids to an area where preparation may be required prior to incorporation into the matrix. The degree of preparation required is unknown; it may be as simple as separating into size fractions with selective preparation of some fractions or it might require additional operations such as grinding and mixing. Additives for forming the matrix might be pozzolanic materials such as cement and/or fly ash as well as proprietary formulations incorporating polymeric substances. The matrix resulting from fixation is presumed to meet regulations for landfill disposal either at the RMA site or, if mandated, at an off-site location. The advantages, disadvantages and unknowns of encapsulation follow:

a. Advantages

(1) Simplicity of operation;

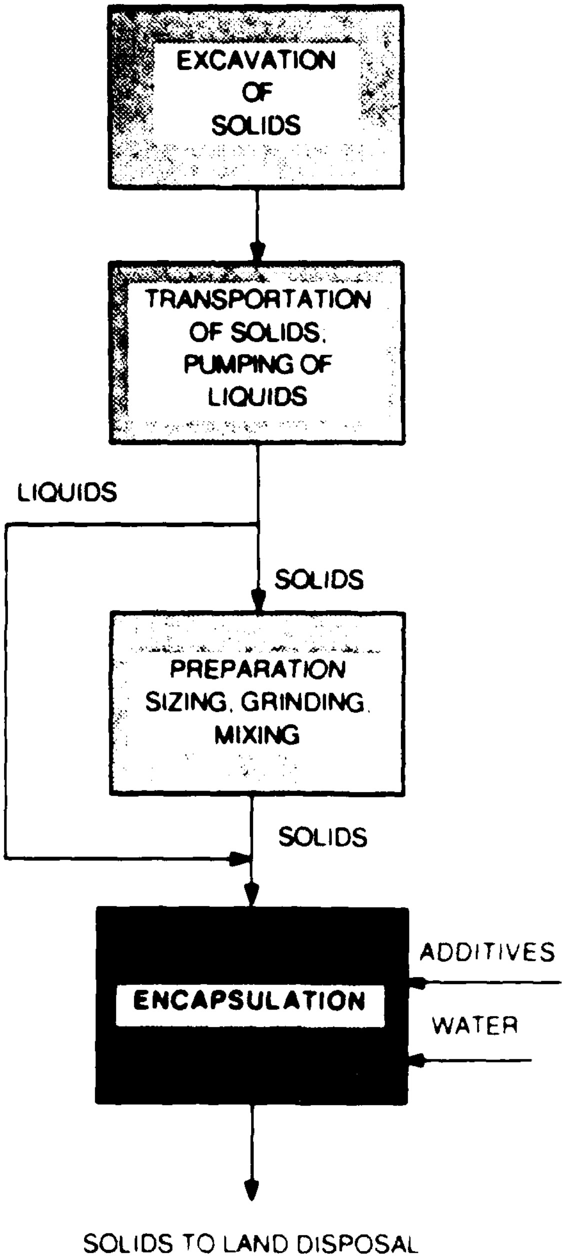

FIGURE 4-1 ENCAPSULATION

Source: Arthur D. Little, Inc.

(2) Limited generation of off-gases or wastewater streams requiring further treatment to meet discharge regulations; and

(3) Equipment for carrying out the operations is readily available through technology transfer from other industries such as chemical manufacture and ore mining.

b. Disadvantages

(1) The organic compounds are not destroyed nor are any of the hazardous components likely to be changed in form or degree of toxicity;

(2) When considered over long-time periods such as hundreds to thousands of years, the encapsulated materials will ultimately enter the biosphere, especially underground water; and

(3) The additives for fixation will increase the volume of the materials requiring treatment.

c. Unknowns

The unknown characteristics of the encapsulation process relate principally to the characteristics of the matrix going to land disposal. Principal among these are:

(1) The best type of encapsulating substances and the quantities required to effectively encapsulate the organics and the inorganic salts;

(2) The physical and chemical properties of the resulting matrix especially its resistance to leaching from groundwater; and

(3) Whether the encapsulated product can be placed directly into a landfill or must be placed in a regulated hazardous materials landfill including long-term monitoring and so on.

4.2 CIRCULATING BED COMBUSTION (CBC) AND ROTARY KILN INCINERATION (RKI)

We have chosen to discuss these technologies together because of the similarity of the flowsheets since they are both based on high temperature oxidation of the organic species. Also, this permits highlighting both the similarities and differences between these two technologies.

Excavation of the solids for transport along with the liquids would be required to bring them to the location of the plant. In both circulating bed combustion (CBC) and rotary kiln incineration (RKI) the liquids are assumed to be combined with the solids for further processing; however, the point of combination of the liquids and solids may vary but is not likely to be of great significance. Likely to be of more significance is the high salt content of the liquids and sediment above the basin liner because these can have different effects on the refractories and other operating conditions of the units. The flowsheet depicted in Figure 4-2 indicates the addition of chemicals to the preparation step. The principal reason for this addition is our belief that the small particle size of much of the soils would cause an excessively high dust loading to the off-gas system of the rotary kiln and, consequently, pelletizing might be required before incineration. Conversely, the small size particles would be an advantage in the CBC because solids are elutriated from the bed into the off-gas system. However, larger sized material such as rocks and small stones will likely require removal for separate disposal or size reduction before feeding to the CBC.

Both processes require the use of auxiliary fuel because the energy content of the organics in Basin F is insignificant in comparison with the energy required to maintain the necessary temperatures.

The air pollution control system depicted assumes that acid gas removal and possibly the control of fumes (from phosporus, fluorides, etc.) would be required at least for the rotary kiln incinerator. If in-situ acid gas control can be achieved in the CBC, a dry air pollution control system using bag filters could be used. The resulting residuals will still contain the heavy metals and the inorganic salts; consequently, we have shown alternative pathways to land disposal depending upon whether or not these residuals can meet regulatory requirements without additional treatment or if encapsulation/fixation might be required.

Based on the assumed 2.5 year period for cleanup of Basin F, we expect that a single rotary kiln installation utilizing well developed designs of the cement industry will be capable of achieving the required processing rate. Insofar as we are aware, multiple units of the CBC are likely to be required; however, until the required residence time and destruction efficiencies are determined, we do not know if a single unit similar to those used in the petroleum industry might have the required capacity. The advantages, disadvantages and unknowns of CBC and RKI follow:

a. Advantages

(1) Organics and cyanides are destroyed;

(2) Simplicity of operation (handles liquids and solids simultaneously);

(3) In-situ acid gas control could eliminate water scrubbing for air pollution control (CBC only); and

(4) RKI is presently widely used in hazardous materials destruction.

b. Disadvantages

(1) Energy intensive (RKI likely to be more so than CBC);

(2) Metals and inorganics likely to leach from unencapsulated residuals;

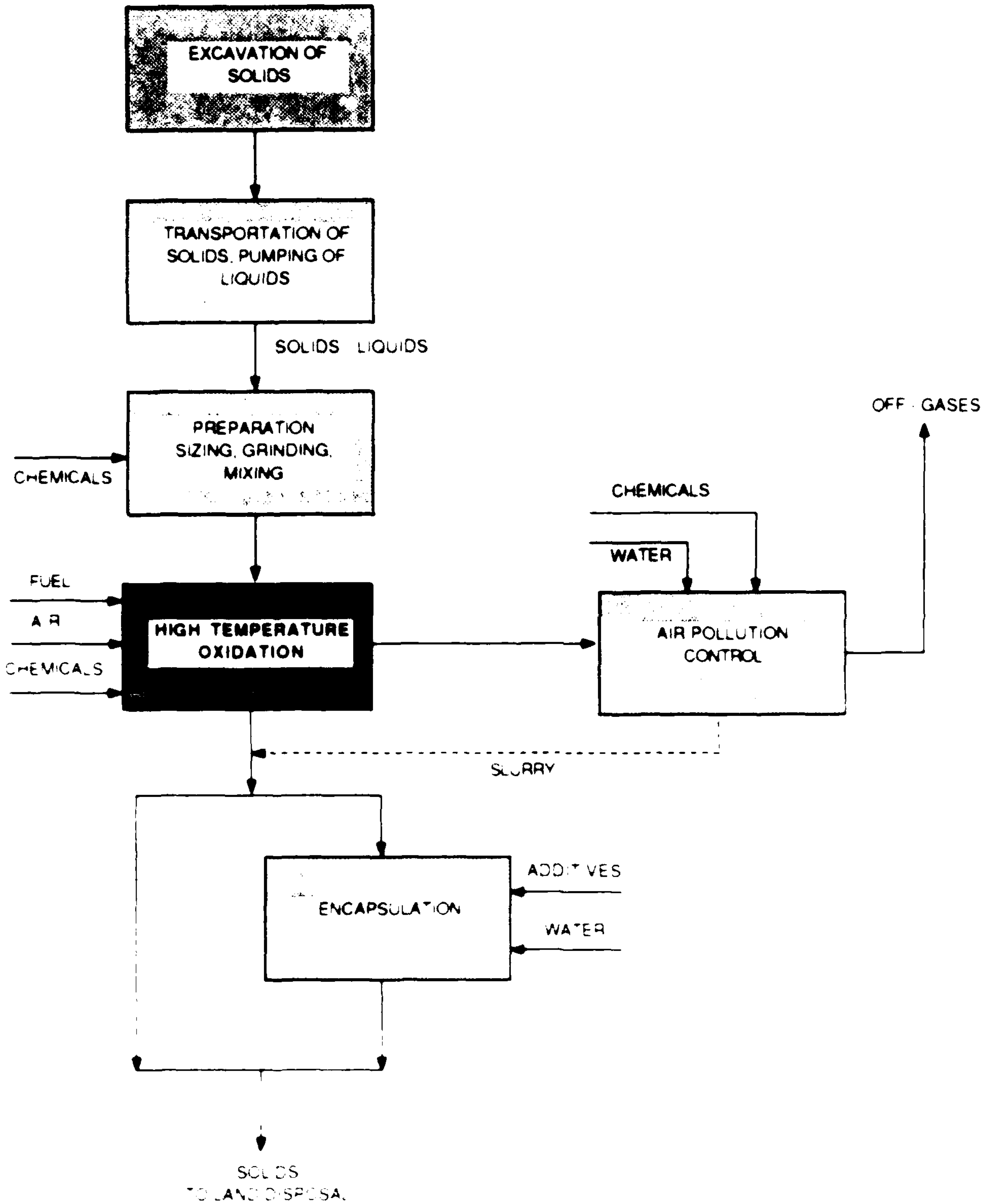

FIGURE 4-2 CIRCULATING BED COMBUSTION OR ROTARY KILN INCINERATION

Source: Arthur D. Little, Inc.

(3) Moderately capital intensive; and

(4) Limited operating experience exists for CBC treating hazardous materials.

c. Unknowns

(1) Nature and type of feed preparation required; and

(2) Efficiency of in-situ acid gas removal for CBC.

4.3 GLASSIFICATION

For purposes of this evaluation, glassification is considered to be carried out in glass-making furnaces. Consequently, the flowsheet shown in Figure 4-3 depicts the excavation of solids followed by the transportation of solids and liquids to the location of the glassification plant. Glass-making furnaces may be heated electrically (Joule heating) or by firing fossil fuels such as gas, oil or coal. Regardless of the furnace type, the liquids could be mixed with the solids and fed to the furnace. Preparation of the the furnace feed, to minimize the amount of glass forming chemicals that would be required to produce a melt with the required viscosity at the operating temperature, would likely require judicious selection among the various clays, sandy-soils, etc. of Basin F. The glass forming chemicals to be added would probably be sodium alkalies. Because the clay may be expected to have high contents of aluminum and other difficultly soluble substances, we expect that perhaps as much as twenty-five weight percent of the furnace feed will be glass formers required to achieve satisfactory operation. For fossil fuel fired furnaces, the fine clays and sands of Basin F may require agglomeration in order to reduce the entrainment of particulates into the off-gas.

Because glassification must be carried out at high temperatures [typically 1200°C (2200°F)], the glass-making operation can generate fumes which are extremely difficult to remove from the off-gases. For this reason, the air pollution control system may require sophisticated equipment such as sonic scrubbers for removal of fumes and small size particulates. Depending upon the relative volatility of chemical species, it might be possible to return the scrubber liquid to the glassification furnace for incorporation of the removed solids into the glass. Certain elements such as mercury would not be expected to remain with the glass so that it might be necessary to remove certain constituents from the recycled slurry.

The chlorides and sulfates present in Basin F material may create problems in glassification because these are not readily incorporated into the glass and are the source of fumes (e.g., sodium chloride will be a liquid with an appreciable vapor pressure at the operating temperature) which tend to exacerbate corrosion in the off-gas handling equipment. At this stage of our investigation, no attempt has been made to evaluate the significance of these constituents.

Because of the addition of glass formers and despite the density of the glass products, it is likely that the volume of the glassified product will be somewhat greater than the volume of materials processed.

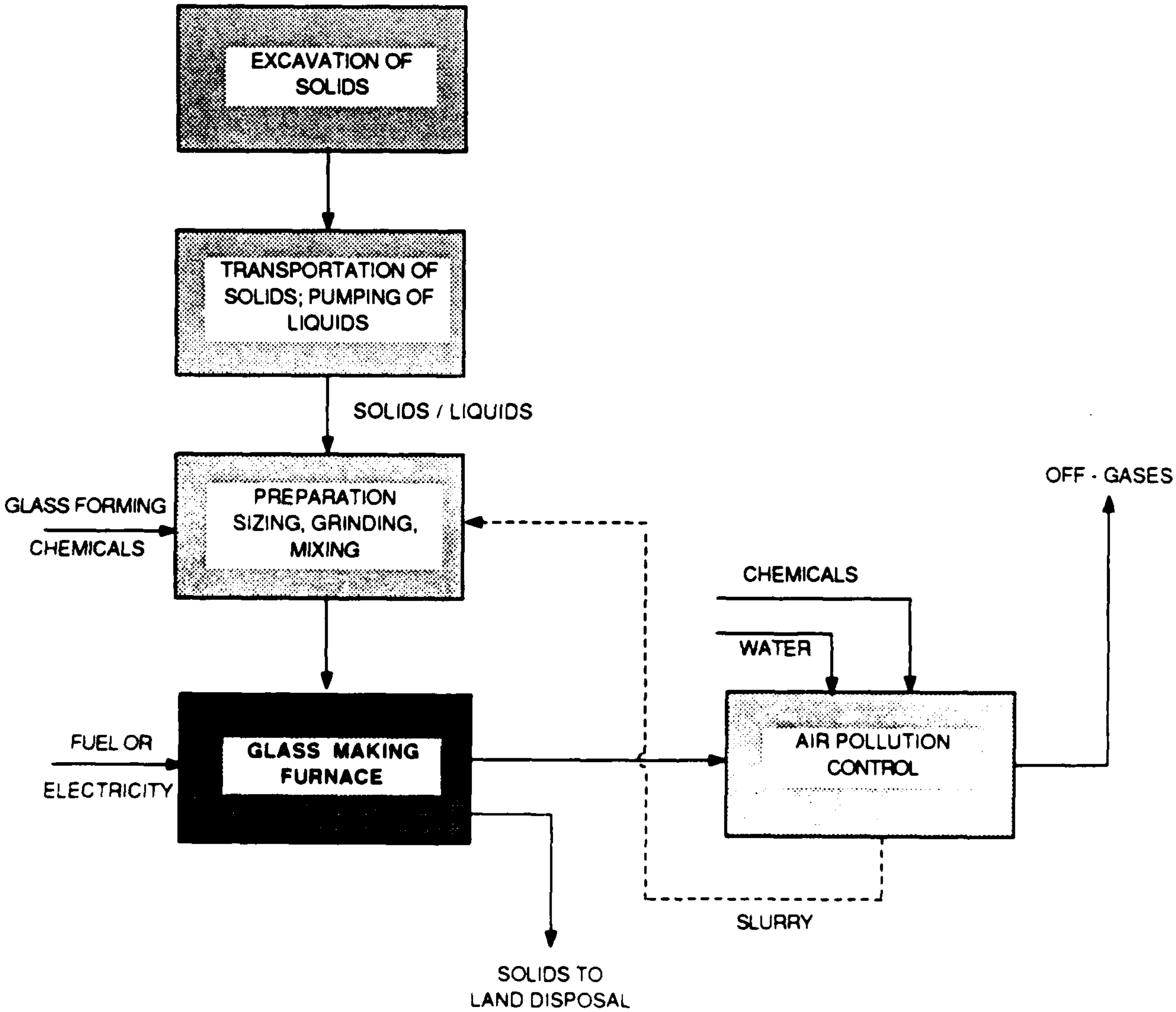

FIGURE 4 - 3 GLASSIFICATION

Source: Arthur D. Little, Inc.

As mentioned earlier, a variety of energy sources can be used for glassification; however, the energy consumption will be among the highest of any of the technologies considered because of the necessity to melt the constituents. Based on the experience of the glass-making industry, we expect that a minimum of two glass-making furnaces, each equal in size to some of the largest now in operation, would be required to meet the 2.5 year processing cycle. The advantages, disadvantages and unknowns of glassification follow:

a. Advantages

(1) Organics and cyanides are destroyed;

(2) Metals and most inorganics will be fixed;

(3) Simplicity of operation (handles liquids and solids simultaneously);

(4) Based on well understood and developed technology;

(5) Minimal water usage and wastewater treatment required; and

(6) Glass product will be highly leach resistant.

b. Disadvantages

(1) Energy intensive;

(2) Requires significant addition of chemicals, thereby increasing volume of materials for ultimate disposal;

(3) Moderate to high capital investments; and

(4) Requires, potentially, sophisticated off-gas treatment to meet air pollution regulations.

c. Unknowns

(1) Controllability of melt properties (viscosity, etc.); and

(2) Capability for dealing with chlorides, sulfates and volatile metal species.

4.4 IN-SITU VITRIFICATION

As its name implies, in-situ vitrification does not require the excavation and transport of materials to a processing facility. By placing electrodes into the soils and creating a pathway for the flow of electrical current, the temperature can be raised to a level where the naturally occurring constituents along with inorganic contaminants are vitrified into a monolith. Water is evaporated and organic compounds are either oxidized or vaporized. The site preparation is minimal requiring only the placement of the electrodes and the installation of a cover from which water and other vaporized substances can be withdrawn for treatment in an air pollution control system.

The flowsheet depicted in Figure 4-4 assumes that organic species would volatilize and not be destroyed; consequently, a thermal oxidation step is shown to ensure their destruction. The expected low off-gas flow rates might permit the use of a low energy oxidative process such as catalytic oxidation. Because there are likely to be acid gases from the resulting oxidation, a wet scrubbing system is shown and it is presumed that the slurry from scrubbing could be mixed into the next area selected for vitrification. Because in-situ vitrification is limited to the volume that can be treated between the array of electrodes, it would be necessary to carry out the vitrification in increments across the Basin F area. The number of increments as well as the maximum number of simultaneous operations that would be necessary to meet the 2.5 year treatment schedule can not be predicted with any degree of accuracy at this time. In-situ vitrification has been carried out in pilot plant equipment and an on-site demonstration with radioactively contaminated soils has been performed at Department of Energy's (DOE's) Richland, Washington site. The principal advantages, disadvantages and unknowns are listed below:

a. Advantages

(1) Minimum site preparation is required;

(2) Minimum exposure of personnel to the site materials;

(3) Minimum amounts of removal and transport of contaminated materials;

(4) Destroys organics and fixes metals and, most likely, the inorganic solids;

(5) Minimal usage of water;

(6) No off-site transport required;

(7) Simplicity of operation; and

(8) Low to moderate capital investment.

b. Disadvantages

(1) Likely high operating costs because of the cost of electricity;

(2) Limited experience; and

(3) Step-wise operations would be required.

c. Unknowns

(1) Uniformity of vitrification;

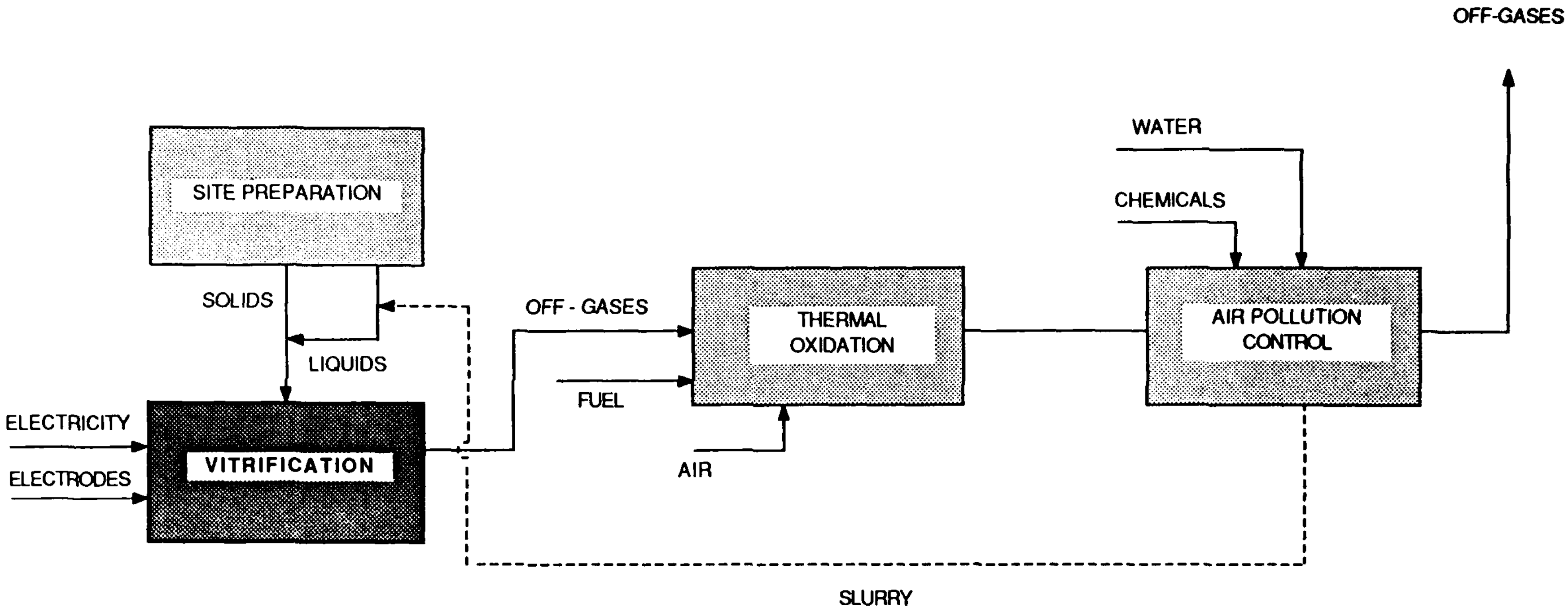

FIGURE 4 - 4 IN - SITU VITRIFICATION

Source: Arthur D. Little, Inc.

(2) Stability and leach resistance of vitrified matrix and procedures to prove leach resistance of the vitrified mass to regulators;

(3) Type of air pollution control system required; and

(4) Future use limitations that might be placed on the area.

4.5 SOIL WASHING

Use of detergent and flotation chemicals in a dilute water slurry for effecting removal of organics from contaminated soils has been demonstrated in the laboratory for a number of hazardous materials. The effectiveness of removal will vary with the nature of the contaminant and, probably, the type of washing agents. The flowsheet shown in Figure 4-5 presumes that after excavation and transport of the solids, a preparation step would be necessary to control the maximum particle size going to the froth flotation unit. Countercurrent washing of the solids is shown in order to remove the detergent that would remain in the slurry stream from flotation. The effects of dissolved salts in the recycled water stream is unknown and their removal might be required. If so, the water handling system will increase in complexity.

This flowsheet presumes that the major portion of the organics (possibly in the 90-95% range) would remain in the froth which, after foam breaking, would enter a wastewater treatment system. Alternatively, the liquid stream from foam separation might be incinerated. Because the froth flotation units typically operate with a low concentrate of solids, e.g., in the low percent ranges, (soil washing will require a large volume of circulating water); therefore the water treatment system may need to be more extensive than depicted. Regardless, the removed organics must be further treated or destroyed to meet environmental regulations.

The technology for handling the large volumes of liquids and mass of solids has been developed to a point where the quantities involved from Basin F would be relatively small compared with those presently processed in plants beneficiating mineral ores. The advantages, disadvantages and unknowns of soil washing are as follows:

a. Advantages

(1) Low energy usage;

(2) Moderately capital intensive; and

(3) Technology transfer for handling large tonnage should be readily effected.

b. Disadvantages

(1) Will not remove all the organics;

(2) Does not destroy or reduce hazardousness of contaminants; and

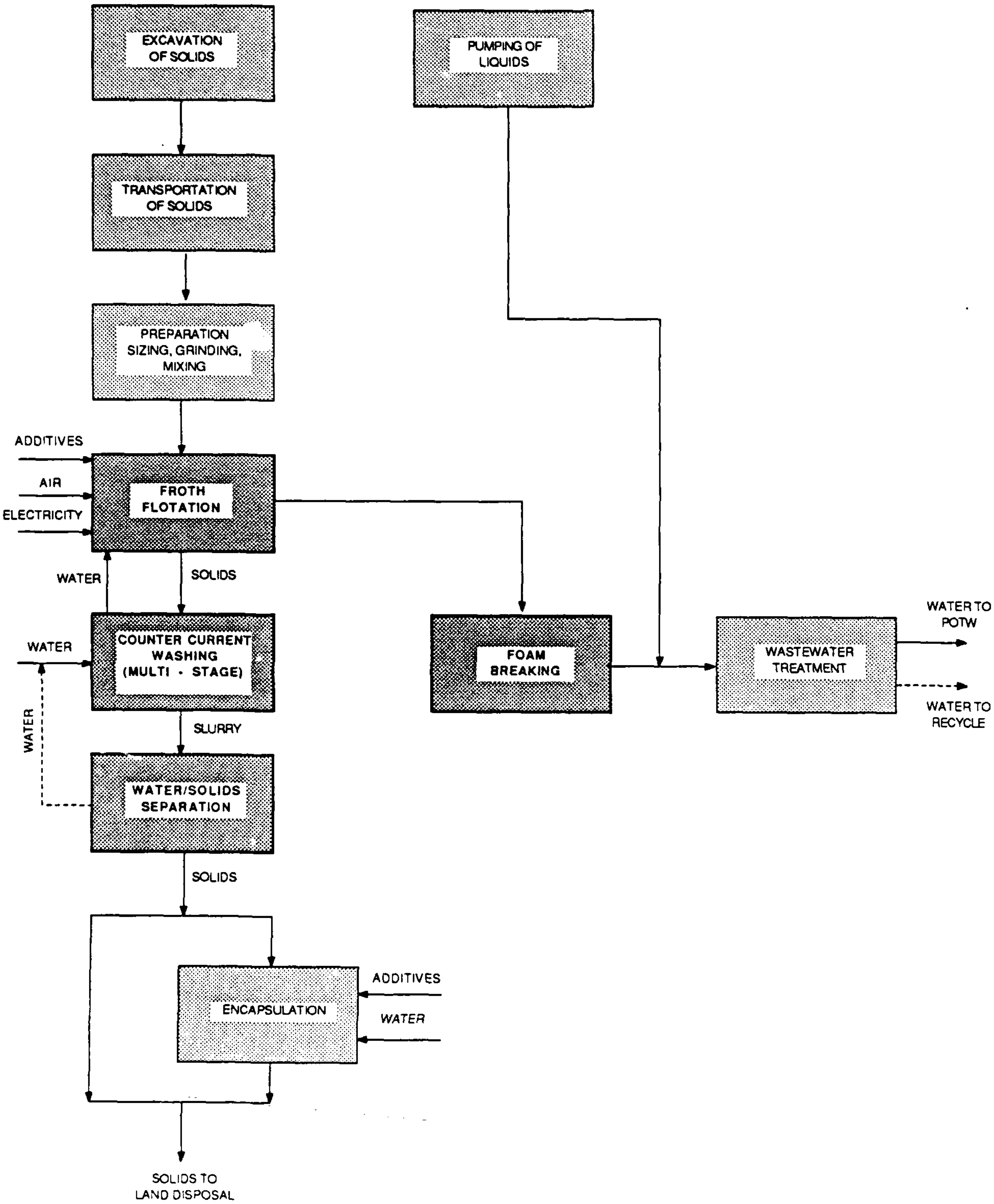

FIGURE 4 - 5 SOIL WASHING

Source : Arthur D. Little, Inc.

(3) May require extensive wastewater treatment systems.

c. Unknowns

(1) Effectiveness of washing for removal of organics;

(2) Quantities and types of detergents required; and

(3) Effects of soluble inorganic salts in recycled water system.

4.6 WET-AIR OXIDATION

The oxidation of organics in water at relatively low temperatures and under moderate pressures has been widely used for treating sewage sludges and some industrial hazardous materials. The energy content of many of these wastes is sufficient to maintain operating temperatures without the use of auxiliary fuel. A pumpable slurry of the waste to be oxidized is contacted with air (oxygen is also a possibility) under pressure (typically under 500 psig) to effect the oxidation. This oxidation is most often performed in pressure vessels; however, a recent variation utilizes a deep well (from one to two miles deep) in which the hydrostatic column of water maintains the pressure. Air is entrained into the slurry as it goes down one of two concentric pipes. The oxidation is carried forward in both the downward flow and the upward flow. Obviously, the heat released may be transferred from one pipe to another and the necessity of high pressure pumping of slurries is eliminated.

Regardless of the method of carrying out the oxidation, all available data indicates that complete conversion of the organic carbon to carbon dioxide is not achieved with the concurrent results that the effluent water from the oxidation must be treated before it could be discharged. When odor forming chemicals such as organic sulfur compounds are present, the separated off-gases may require treatment to prevent public concerns about odors. For the Basin F materials, the flowsheet envisioned for wet-air oxidation is depicted in Figure 4-6. Because of the high inert solids content of these materials and the low concentration of oxidizable substances, wet-air oxidation would require an auxiliary energy source such as fuel oil. The type of wastewater treatment system required might be relatively sophisticated and would depend upon the nature of the oxidized organics remaining. Obviously, wet-air oxidation will not remove metals; consequently, the treated solids may require encapsulation or disposal into secure landfills.

When carried out in pressure vessels, multiple units will be required. The use of deep-wells may also require more than one installation. A summary of the advantages, disadvantages and unknowns of wet-air oxidation are listed below:

a. Advantages

(1) Low energy use.

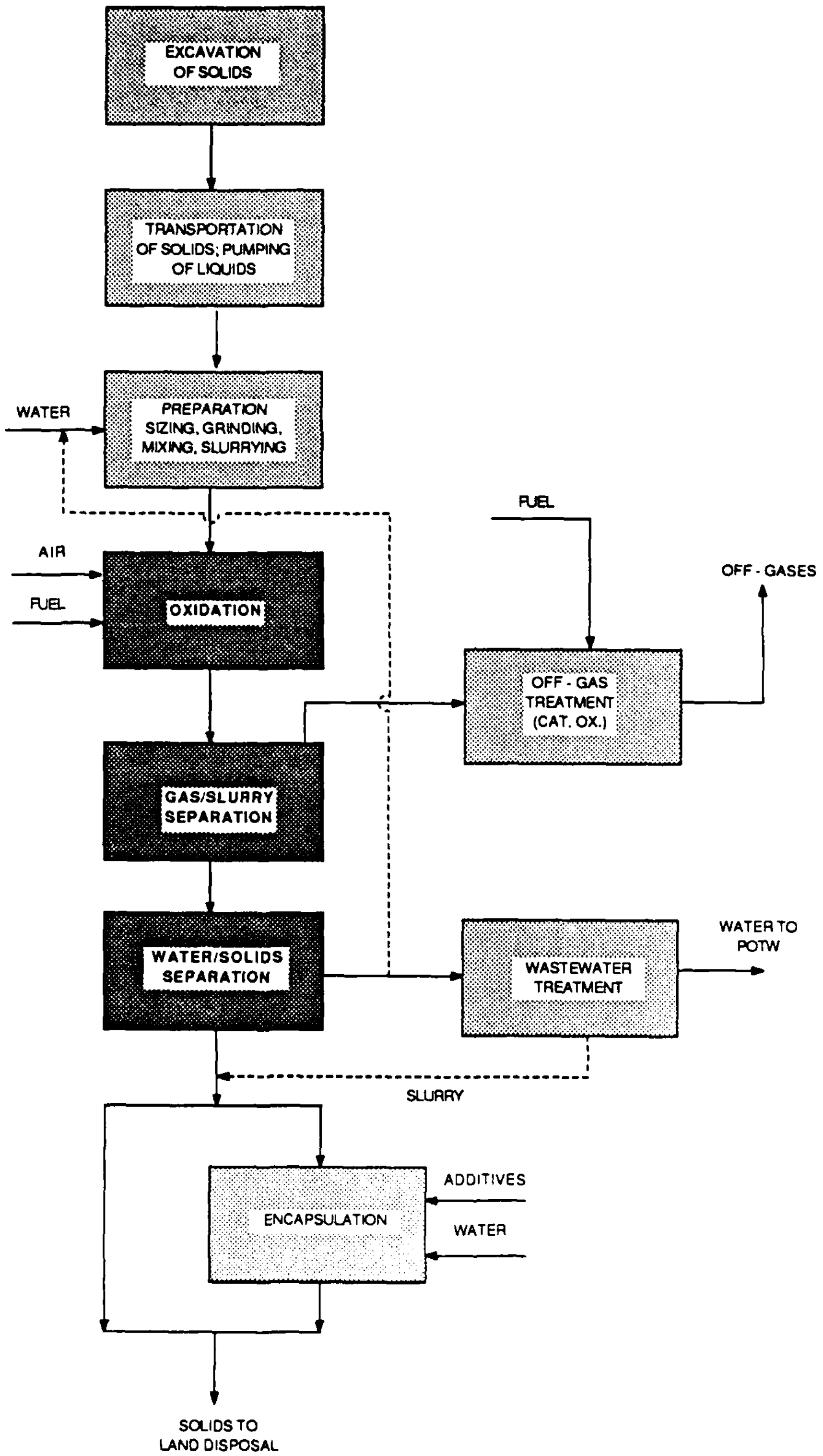

FIGURE 4 - 6 WET AIR OXIDATION

Source : Arthur D. Little, Inc.

b. Disadvantages

(1) Incomplete destruction of organics may require extensive wastewater treatment;

(2) Soluble inorganics may exacerbate problems with recycled water, thereby increasing complexity of wastewater treatment; and

(3) Capital intensive if carried out in pressure vessels.

b. Unknowns

(1) Effectiveness of oxidation;

(2) Type of feed preparation required;

(3) Operability with high concentrations of inert but abrasive solids;

(4) Type and extent of wastewater treatment required for recycle and discharge.

4.7 EXTRACTION

Removal of organic contaminants through extraction with various solvents is receiving increasing attention. The solvents may vary from super critical water systems to supercritical gases or may use various organic liquids. Operating temperatures and pressures for the various systems can vary over wide ranges but energy requirements are generally low. The flowsheet shown in Figure 4-7 presumes that the liquids and solids in Basin F would be treated separately because a number of installations would be required and, consequently, design and operating conditions could be adjusted accordingly. After preparation of the solids, contact with the solvent in an appropriate contactor followed by separation of solids and removal and recycle of solvent is performed.

The contactors might be continuous, countercurrent operations for low or atmospheric pressure operations but might require batchwise extractors for high pressure operations. It is presumed that the removed organics would be destroyed in a thermal oxidation system equipped with appropriate air pollution control equipment. Because acid gases will occur from thermal oxidation a wet scrubbing system is shown. For the extractants most often considered, i.e., petroleum liquids, carbon dioxide, triethylamine, etc., there would be no removal or fixation of the metals. Consequently, the disposal of the residual solids might require encapsulation or disposal into secure landfills rather than being directly returned to the land at RMA. The state of development of this technology varies from laboratory through pilot-scale with a few commercial installations, including a recently announced installation of 100 tons/day to treat oily sludges, in operation. The advantages, disadvantages and unknowns of extraction can be summarized as follows:

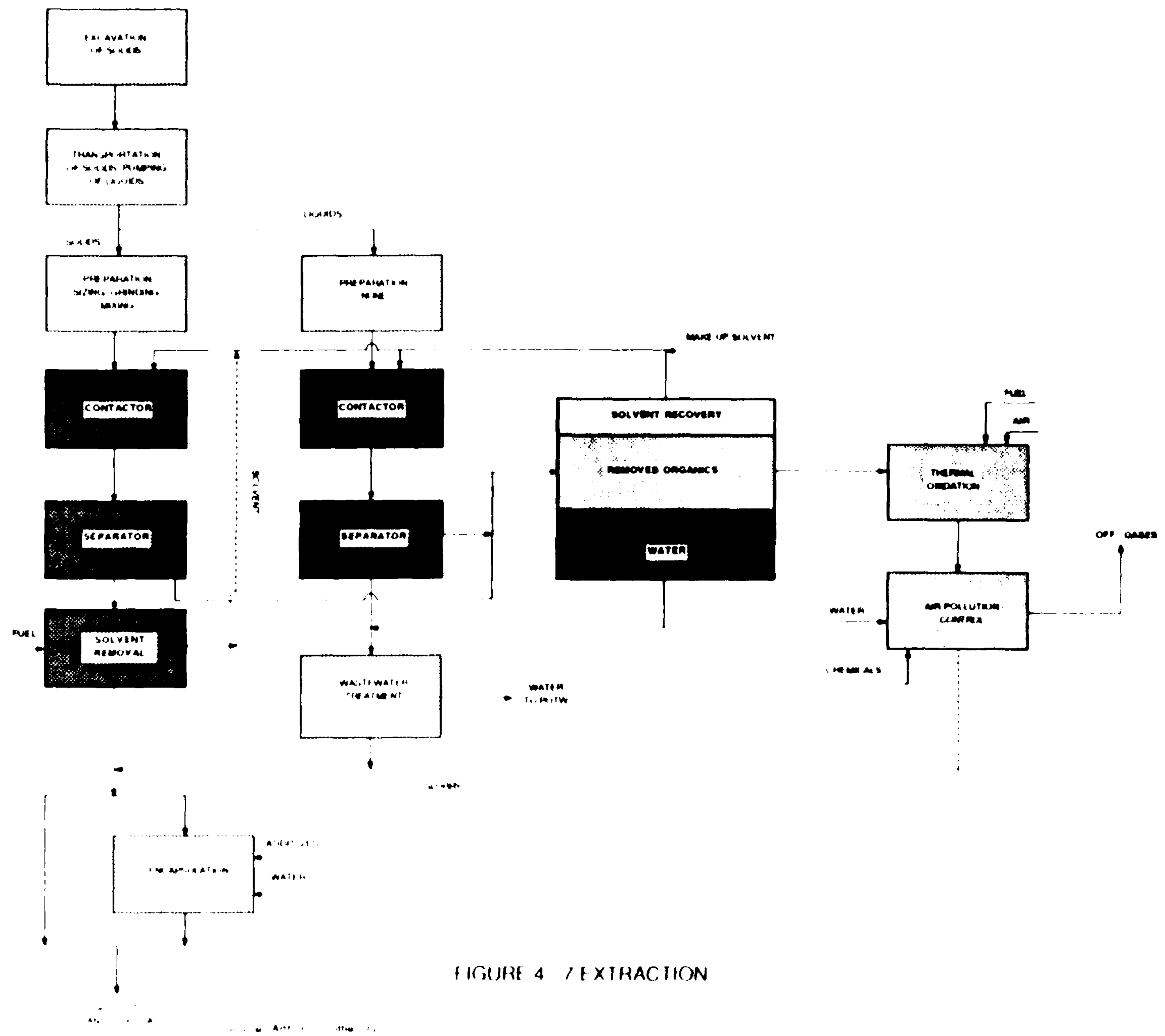

FIGURE 4.7 EXTRACTION

a. <u>Advantages</u>

(1) Low energy use.

b. <u>Disadvantages</u>

(1) Complex multi-stage processing scheme;

(2) No destruction of organics or fixing of metals;

(3) Capital intensive;

(4) Limited operating experience exists for treating hazardous materials; and

(5) Requires wastewater treatment system and organic destruction system.

c. <u>Unknowns</u>

(1) Fate of asphaltic materials;

(2) Effectiveness of solvents for removal of organics.

(3) Solvent losses;

(4) Effectiveness of solids/solvent separations; and

(5) Type of wastewater treatment required.

5.0 OTHER TECHNOLOGY CONSIDERATIONS

There are innumerable combinations and permutations of various technologies and equipment for which conceptual flowsheets might be developed. We have chosen those discussed previously as representing a spectrum of innovative technologies that might have a reasonable basis for being considered for application to Basin F materials based on the status of their development and our judgment on the likelihood of developing equipment for carrying out the technology or transferring equipment designs from other industries.

For example, we did not consider plasma arc destruction because we expect that development of equipment for handling the large volumes of materials over the required time period would be rather remote. On the other hand, soil washing was chosen because the equipment for carrying out the operation has been well developed. Another innovative technology, thermal stripping, was not considered because of the relatively high boiling or decomposition temperatures of some of the organic constituents; however, investigations of the effectiveness of relatively low temperature vaporization followed by thermal destruction might warrant consideration after evaluation of the laboratory results of thermal removal now underway in a RMA Project Management Office contractors' laboratory. We felt, however, that the evaluation and ranking of the flowsheets previously discussed should be performed because they are representative of those technologies generally considered innovative for hazardous materials management by the technical community.

6.0 EVALUATION AND RANKING OF TECHNOLOGIES

In order to develop a qualitative comparison of the eight technologies for which conceptual flowsheets were developed, we had four senior professional staff members independently rank each for its Relative Importance Value (RIV) and its Performance Value (PV) for each of 20 criteria as shown in the Evaluation Matrix of Table 6-1. These criteria were developed by USATHAMA for the initial screening and appear to account for the significant factors. Obviously, other evaluation matrices might have been chosen, but it is doubtful that another matrix would significantly alter the relative rankings. As noted in Table 6-1, the RIV was multiplied by the PV which was selected on a basis of from 1 to 3. If an evaluator was uncomfortable with a whole number ranking, he/she was instructed to use the average, i.e., 1.5 if between 1 and 2 and 2.5 if between 2 and 3. The results of Arthur D. Little's rating of technologies is shown in Table 6-2. Based on the aforementioned criteria, it appears that encapsulation and high temperature oxidation processes are preferred for future evaluation.

Based on the conceptualized flowsheets and the criteria for performance of the various technologies, it is apparent that encapsulation and high temperature processes are the leading contenders for future evaluation in small-scale and/or pilot plant tests. In post-ranking discussions among the evaluators, however, it was apparent that the somewhat qualitative/subjective ratings shown in Table 6-2 might be altered if certain factors were better defined. Among the most pertinent of those factors were:

(1) Off-site versus on-site treatment.

(2) Off-site versus on-site disposal of treated residuals.

(3) Effectiveness, such as the degree of containment, removal or destruction from the Basin F material and the leach resistance required of the residuals.

(4) The relative difficulties in obtaining operating and environmental permits for the various technologies.

(5) The time period over which Basin F must be cleaned up.

(6) The qualitative nature of the capital and operating [illegible] available, and

(7) The importance, if any, of expanding the [illegible] variety of concepts (non-high temperature [illegible]) that knowledge could be gained for technologies where [illegible] amounts of available information exists [illegible]

Unfortunately, however, many of these factors [illegible] this time.

In subsequent discussions with USATHAMA, however, it was pointed out that we had not, as yet, been given the opportunity to review the [illegible] prior work performed by the U.S. Army Engineer Waterways Experiment [illegible]

TABLE 6 1

EVALUATION MATRIX

TECHNOLOGY NAME ______________________________

Criteria Identification No	Criteria	Relative Importance Value (RIV)	Performance* Value (PV)
1a	Treatment of Metals	2	
1b	Treatment of Organics	3	
1c	Treatment of Inorganics	2	
2a	Handling Operations	1	
2b	Handling Safety	3	
3	Emissions & Monitoring	2	
4	Associated Equipment	1	
5	Throughput Rate	3	
6	Equipment Complexity	1	
7	Testing Time	3	
8	Vendor Test Facilities	3	
9	System Safety	3	
10	Capital Costs	2	
11	Operational Costs	2	
12	Maintenance	1	
13	Ease of Operation	1	
14	Reliability	2	
15	Permitting	3	
16	Barriers	1	
17	Proprietary Status	2	______
		Total	

*From 1 to 3

Note Rating equals RIV x PV

Source USATHAMA

TABLE 6-2

ADL PRELIMINARY RATING OF TECHNOLOGIES

Technology	EVALUATOR (1)	EVALUATOR (2)	EVALUATOR (3)	EVALUATOR (4)	Technology Avg.
Encapsulation	92.0	97.0	93.5	92.0	94
Rotary Kiln Incineration	95.0	92.5	90.0	88.0	91
Classification	92.0	81.0	87.5	100.0	90
Circulating Bed Combustion	87.0	79.5	88.5	96.0	88
In-Situ Vitrification	90.0	72.0	91.5	86.0	85
Soil Washing	84.0	70.0	75.5	86.0	79
Wet Air Oxidation	84.0	72.0	72.0	81.0	77
Extraction	79.0	62.5	70.0	81.0	73
Evaluator's Avg.	88.0	78.0	84.0	89.0	

Total Points Possible for a Technology - 123

Source: Arthur D. Little, Inc.

contained in a July 1983 Draft Report (3), "Laboratory-Scale Solidification of Basin F Concentrate--Rocky Mountain Arsenal." Evaluation of that report indicated that none of the encapsulating agents tried prevented significant leaching of organic components when subjected to the U.S. EPA Extraction Procedure (EP) Toxicity Test and the Battelle Solid Waste Leaching Procedure (SWLP). Based on the measurement of Total Organic Carbon (TOC) in the leachate, it was the investigators' conclusion that the EP and SWLP leachates indicated that the leachates from solidified Basin F liquid concentrate could pose a serious problem. Consequently, at the direction of USATHAMA and RMA Program Management Office personnel, encapsulation was eliminated from further consideration. Furthermore, discussions on the difficulties of verifying low leaching rates from in-situ vitrification coupled with consideration of schedules and funds available resulted in the selection of the following three technologies for laboratory/pilot-scale tests. These were:

- Glassification;
- Fluidized/circulating bed combustion; and
- Soil washing.

In actuality, these three technologies offer one the opportunity to evaluate a spectrum of processes, each offering potentially distinct advantages. Glassification destroys organics and fixes metals under controlled conditions whereby further treatment of residuals may be eliminated; circulating bed combustion destroys organics and offers in-situ acid gas removal, thereby possibly eliminating wet scrubbing; and soil washing offers the possibility of removing organics from soil without having to heat considerable quantities of soil to very high temperatures.

During the evaluations as well as subsequent to the decision to focus on small-scale/pilot testing of the above three technologies, we contacted and received proposals from the following organizations:

- Battelle Pacific Northwest Laboratories - Glassification and In-Situ Vitrification;
- G.A. Technologies, Inc. (presently Ogden Environmental Services, Inc.) - Circulating Bed Combustion;
- MTA Remedial Resources, Inc. - Soil Washing;
- Penberthy Electromelt International, Inc. - Glassification;
- Waste-Tech Services, Inc. - Fluidized Bed Combustion; and
- Westinghouse Electric Corp. (Waste Technology Services Division) - Electric Pyrolyzer.

Based on our assessment of these proposals which included taking into consideration elements such as schedule, costs, quantities of Basin F materials requiring shipment, sampling conditions and process controls, we executed contracts with the following organizations to perform small-scale/pilot plant tests:

- Battelle Pacific Northwest Laboratories - Glassification;
- Ogden Environmental Services, Inc. - Circulating Bed Combuster; and
- MTA Remedial Resources, Inc. - Soil Washing.

The Test Plan for these technologies (which will outline the test conditions to be operated under, process streams to be sampled and analyses to be performed) will be the subject of another report.

7.0 REFERENCES

(1) EBASCO Services, Inc., "Task No. 17 Incineration/Fixation and Building 1611 Pilot Study for Basin F Wastes," Report to Program Manager's Office for Rocky Mountain Arsenal Cleanup under Contract No. DAAK11-84-D-0017, April 1986.

(2) Environmental Science and Engineering, Inc., "An Accelerated Cleanup Plan for the Contamination at RMA," Report to Program Manager's Office for Rocky Mountain Arsenal, June 1986.

(3) U.S. Army Engineer Waterways Experiment Station (Environmental Laboratory), "Laboratory-Scale Solidification of Basin F Concentrate-Rocky Mountain Arsenal," Report to USATHAMA, July 1983.

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