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"MAWS" -- A DEVELOPMENT PROGRAM AND DEMONSTRATION TO REDUCE VITRIFICATION REMEDIATION TREATMENT COSTS

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ABSTRACT

Low-level radioactive and mixed waste remediation is a major concern at U. S. Department of Energy (DOE) sites across the country. Vitrification (making glass of the waste) has not been extensively used in the DOE complex largely because of the belief that vitrification lends itself to treating mainly low-volume, high-level radioactive wastes. The Minimum Additive Waste Stabilization (MAWS) program will demonstrate that vitrification is an economical treatment alternative for some types of low-level radioactive and mixed waste. This paper will summarize how millions of dollars in savings are possible for the remediation efforts at the Fernald Environmental Management Project (FEMP) located near Cincinnati, Ohio.

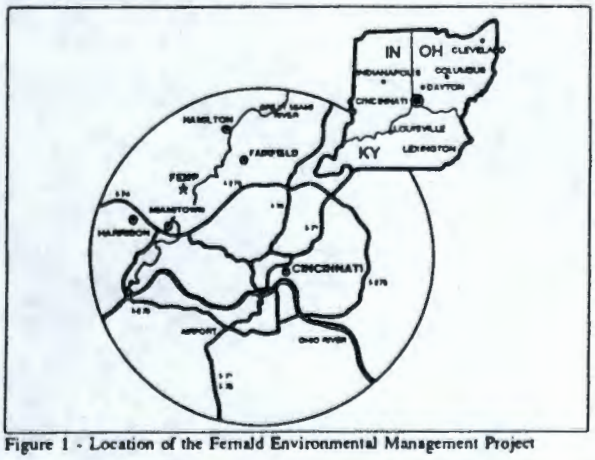

Figure 1 - Location of the Fernald Environmental Management Project

DESCRIPTION AND BACKGROUND

Fernald produced high-purity uranium metal from the early 1950s until 1989. The metal, which was predominantly fabricated into fuel cores and target elements, was used in nuclear reactors at other DOE sites. Many chemical and manufacturing processes were used in the production of uranium metal. Process waste and sludge containing low concentrations of uranium and thorium were stored in large on-site waste pits. Nonhazardous commercial waste was deposited in lime sludge ponds, fly ash piles, and sanitary landfills.

In 1985, the U.S. EPA and Ohio EPA began enforcement proceedings to bring the FEMP into compliance with all existing environmental regulations. In November of 1989, Fernald was placed on the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priority List. Although financing of remediation will not come from the Superfund, the Fernald site will be remediated according to CERCLA using DOE funds.

Operable Unit 1	Waste Pit Area: Waste Pits 1-6, clearwell, burnpit, berms, liners and soil within the operable unit boundary as approved in the RI/FS work plan addendum
Operable Unit 2	Other Waste Units: Flyash piles, other south field disposal areas, lime sludge ponds, solid waste landfill, berms, liners, and soil within the operable unit boundary as approved in the RI/FS work plan addendum.
Operable Unit 3	Production Area: Production area and production - associated facilities and equipment (include all above and below-grade improvements) including, but not limited to, all structures, equipment, utilities, drums, tanks, solid waste, waste, product, thorium, effluent lines, K-65 transfer line, wastewater treatment facilities, fire training facilities, scrap metals piles, feedstocks, and coal pile.
Operable Unit 4	Silos 1-4: Silos 1, 2, 3, and 4 berms, decant tank system, and soil within the operable unit boundary as approved in the RI/FS work plan addendum.
Operable Unit 5	Environmental Media: Groundwater, surface water, and soil not included in the definitions of Operable Units #1-4, sediments, flora, and fauna.

Table 1 - Fernald Operable Units

After preliminary characterization studies in 1986, uranium contamination was found in the surrounding soils and water supply. Further tests revealed uranium-contaminated groundwater (perched water) under four plants. A plume of contaminated groundwater extends approximately one kilometer south of the FEMP. During 1991, the FEMP

officially ceased production of uranium metals and the site's mission was changed to remediation only.

The Fernald site remediation involves a variety of material (process and pit waste, soil, fly ash, drummed waste) with a variety of contaminants such as heavy metals, organics, and radioactive elements. The task of remediating Fernald is divided into subtasks called Operable Units (OUs). Presently, there are five Operable Units. Each is responsible for remediating a specific medium or site location. Table 1 describes the different responsibilities for the Operable Units at the FEMP, and Figure 2 shows the physical layout of OU 1. Because the bulk of Fernald's process wastes come from OU 1, which contains several waste pits, this paper will focus on it as a vitrification site.

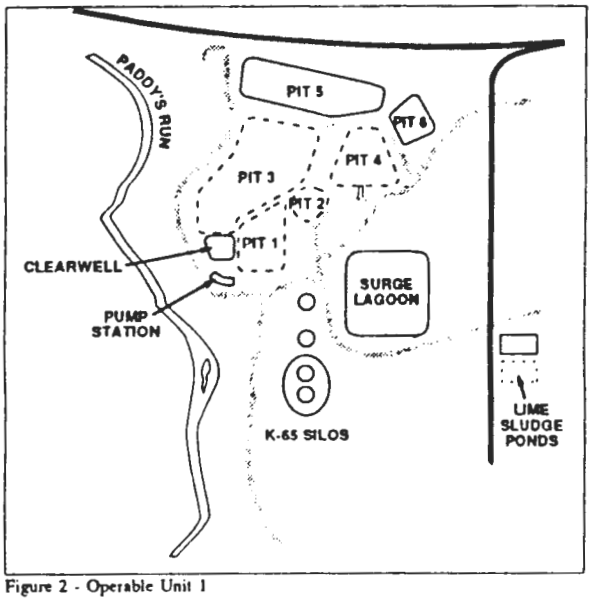

Figure 2 - Operable Unit 1

Operable Unit 1 contains approximately 350 000 m^3 of pit wastes and up to 540 000 m^3 of soil under the pits, in the caps, and in the berms needing treatment. However, present estimates assume that only a portion of the soil surrounding the pits is contaminated to the extent that it requires treatment. Table 2 shows the quantities of contaminated material expected in OU 1. The major cost driver at Fernald is not the fact that the materials are radioactive, but rather, the large quantities of materials needing remediation.

MAWS TECHNOLOGIES

The object of MAWS is to reduce waste volume through a vitrification process that exploits the chemical nature of the Fernald waste streams. By blending them in optimum proportions, this process increases the overall volume reduction of the final treated waste, and it eliminates the additives that would otherwise be necessary for making vitrified waste. Soil washing, ion exchange, and vitrification technologies can each individually result in volume reductions. The net volume can

	Depth M	Waste M^3	Soil M^3
Pit 1	4.3	25,749	75,192
Pit 2	4.2	14,128	41,614
Pit 3	8.2	163,049	25,398
Pit 4	7.3	41,064	100,742
Pit 5	9.1	75,573	184,028
Pit 6	7.3	8,836	60,770
Clear Well	8.2	7,310	28,326
Burnpit	6.1	6,938	12,180
Totals		342,647	528,250

Table 2 - OU 1 Waste Quantities

be further reduced by integrating the process to form a synergistic effect. MAWS centers on stabilization by vitrification, with soil washing and ion exchange, to obtain synergism. Figure 3 is a process flow diagram showing the integration of the various technologies into the MAWS system. Descriptions of the technologies follow:

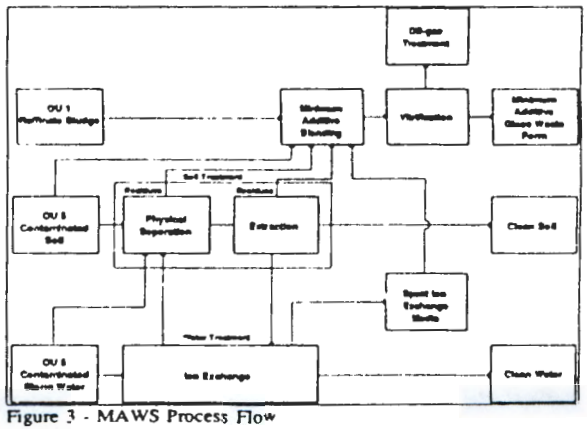

Figure 3 - MAWS Process Flow

Vitrification

Glassware was made by the Romans several hundreds of years before Christ, and some of this glassware has been discovered in ancient shipwrecks. The glassware has eroded less than ½ millimeter over 2,500 years. The erosion rate of the crude Roman glass in corrosive salt water implies that low-level radioactive wastes dissolved in molten glass should remain entombed in the glass for extremely long periods of time (10,000 years or more). The extremely low leach rate for such a glass should keep concentrations in the environment below regulatory limits and thereby provide protection of the environment indefinitely.

Wastes placed in a vitrifier are treated by physically making the wastes part of the glass. At elevated temperatures,

glass becomes electrically conductive. Current passing between the electrodes in the vitrifier causes the conductive glass to heat and maintain the glass in the molten state. This is known as joule heating. Joule-heated vitrifiers normally need to be brought up to temperature by another heat source such as gas heating. Organics dropped into the molten glass between 1100 °C and 1600 °C burn and oxidize to gasses (mostly CO_2 and H_2O) that are collected and treated in the off-gas. Most inorganics will oxidize and dissolve in the molten glass. Molten glass at 1300 °C behaves as a solvent that has a viscosity similar to 10-weight motor oil. Most oxides are soluble in glass.

The vitrifier (glass melter system) for the MAWS will process between 300 kg/day - 1 metric ton/day. The system will be a versatile, robust vitrification system, tailored to address Fernald and DOE low-level radioactive waste remediation problems. The system will be designed to handle waste pit sludge, residues, and site soils. Site fly ash will be tried as a source of silica. The system will also be capable of vitrifying asbestos (transite) with little or no modification. This capability is necessary for potential future DOE Decontaminating and Decommissioning programs (D&D). The off-gas scrubbing system will have HEPA filtration and meet regulatory requirements for release. Monitoring equipment will be provided.

The system will be capable of dispensing the glass product into drums in the form of frit; glass marbles are preferred. The marbles will be of two different sizes to increase packing and volume reduction.

Soil Washing

Soil washing will separate the contaminated soil into clean and contaminated streams. The soil washing unit will be sized to supply the silica needs for the vitrifier.

The soil from all three streams (input stream, clean and contaminated output stream) will be analyzed for contaminants to determine the success of the soil washing. Mass balances will show that the majority of the contaminants go to the contaminated stream before the process can be declared successful.

Water Treatment

The water treatment system will handle all contaminated waste water from the vitrification and soil wash systems. All water leaving the MAWS will meet the water quality standards for discharge to the Great Miami River near Fernald.

The uranium and thorium contaminates will be stripped off by a traditional organic ion-exchange resin and redeposited onto a glass resin that can be fed to the vitrifier. This should allow conventional disposal of the spent organic resin. The success and economics of this process will be evaluated and documented at the end of the demonstration.

MAWS CONCEPT, APPLICATION, AND SYNERGISM

Presently, separate waste treatment processes are being developed at Fernald and other DOE sites. Operable Unit 1, for example, is developing solidification and vitrification while OU 5 is investigating soil washing. This can lead to duplication and unnecessary expense because synergism is not achieved. The MAWS program will show that significant savings are possible by demonstrating the following concepts:

- Blending Site Wastes will Eliminate or Minimize Costly Additives: All the constituents for making glass can be found by blending the various site wastestreams in correct proportions. By doing this, the need for buying expensive additives can be eliminated. For example, reduction of sodium fluxes in FEMP's wastes can result in a savings of $14 million for each percentage of sodium reduced (typical glass formulas use 10% sodium flux).

- Integrating Site Waste Streams will Result in Net Volume Reductions: Treating site wastes by other methods will not result in a significant reduction in waste volumes. Since the individual wastes on-site do not contain all the components to make a good glass, the necessary additives would need to be brought on-site at extra expense.

- An Optimally Integrated System May Not Need Optimal Processes: Soil washing can be used as an example. Development activities are striving to obtain an optimal separation ratios of 95:5 to 97:3. However, for the MAWS concept, this is not required. Because soil is needed to make glass, the soil washing process can work at a lower efficiency ratio (80:20 to 90:10) to optimize the integrated system. Also, since the individual systems do not need to work at optimum, clean water is not necessary for all steps; contaminated water and recycled water can be used.

PROCESS NEED AND DEVELOPMENT

Two divisions of DOE are actively involved with the MAWS program: The Office of Environmental Restoration (EM-40) and The Office of Technology Development (EM-50). EM-40 has the responsibility for remediating the various DOE sites; EM-50 has the responsibility for developing and demonstrating promising remediation technologies for the entire DOE complex. EM-40 has great interest in the MAWS through OU 1 and its development program. EM-50 is interested in the MAWS from a more global perspective and seeks to support the development needs of all the DOE sites. For example, the MAWS concept may be applicable to Weldon Springs' (near St. Louis) pit wastes and Rocky Flats' (near Denver) plutonium-contaminated asbestos wastes.

Even though vitrification does not appear as expensive as originally thought, neither vitrification nor solidification has been demonstrated at the production rates required at Fernald.

As indicated earlier, a 272 metric ton/24-hour day treatment facility such as that planned at Fernald will take ten years and 20% of the surrounding soils to remediate the pit wastes. Attempting design of such a process with little development is unwise and can lead to failure. Scale-up factors between five and twenty are reasonable. For OU 1, the following development schedule is proposed:

Characterization and Laboratory Studies: Small-scale laboratory studies to determine the feasibility of vitrification. The wastes will be analyzed, and crucible melts will be done to determine how well they produce glass. Characterization and laboratory development will also provide information about any "bad actors" in the waste that may hinder treatment and, thus, determine what pretreatment of the waste is necessary. To date, Laboratory melts show that the waste can be made into good glass with the site soils.

Bench-Scale Demonstration -- ½ to 1 metric tons/day treated waste: Studies to develop the formulas and provide design parameters for scale-up to a pilot unit. The MAWS program will provide the bench-scale melter capability along with soil washing and water treatment integration.

Pilot-Scale Demonstration -- 18 to 23 metric tons/day treated waste: A pilot study will determine large-scale operations and economics, in addition to providing parameters for designing full-scale vitrification facilities.

Full Scale -- 272 metric ton/day. Four 90-metric ton/day melters (one is an operating spare).

Development activities for vitrification and solidification will be pursued at Fernald until technical data is developed to show one more practical and economical than the other. Both vitrification and solidification will progress through laboratory and bench-scale phases, but because of the cost involved, probably only one will progress through the pilot-scale phase. The development program is estimated to cost approximately $40 million to $50 million. Schedules for these phases will be discussed later.

COST ANALYSIS STUDY

Solidification was first recommended as the treatment process for OU 1. However, the U.S. EPA recommended that vitrification be given further consideration as a treatment process option. Even though vitrification can produce an excellent treated waste form, the initial reaction was that it was too expensive to warrant further investigation. Past studies cited excessive electrical power cost and technology concerns as reasons to exclude vitrification for application at the FEMP. When researchers estimated life-cycle costs, however, the results were surprising. The study did not eliminate vitrification, but rather showed that vitrification should be retained as a treatment method.

Just comparing the cost of making concrete to the cost of making glass is inaccurate. To objectively compare vitrification and solidification expenses, it is more reasonable to evaluate the life-cycle costs for each method. The models devised for the life-cycle cost estimates contained all "cradle-to-grave" activities and costs: RI/FS, design, construction, treatment and disposal of the waste, and one hundred years of monitoring. The schedule used for the life-cycle models is shown in Table 3.

Activity	Date or Duration
Record of Decision (ROD)	Spring 1995
Remedial Construction Start	Mid-1996
RI/FS, CERCLA Permits	1998-1995
Development	1991-1995
Design	1991-1996
Site Preparation:	
For Development	1993-1994
For Final Remedial Action	1996-1997
Construct Facilities	1997-1998
Remediation (Operation)	1999-2008
Demolition & Decommission	2009
Long-term Monitoring	2010-2109

Table 3 - OU 1 Proposed Schedule

Results of the study showed that solidification and vitrification life-cycle costs appear to be comparable at Fernald. The potential savings are associated with the promise of integrating innovative technologies with vitrification in a synergistic fashion to achieve highly durable, long-lasting, treated waste forms with smaller volumes than are currently possible. Vitrification appears more economical if disposal costs are high. The higher installation and processing costs of vitrification are offset by the lower disposal costs due to volume reduction, whereas solidification appears more economical if disposal costs are low. Figure 4 illustrates this concept in a simplified manner for the treatment and disposal of one cubic meter of waste.

The total estimated life-cycle cost for OU 1 is $1.07 billion for vitrification and $1.26 billion for solidification ($766 million and $667 million in present worth dollars respectively). These feasibility estimates were based on 460 000 m^3 of wastes being processed. This includes all the pit wastes and 115 000 m^3 of surrounding soils, which supplies the amount of silica needed to form a good glass from the wastes. The following are the base parameters for the feasibility estimates:

- 5.5% escalation
- Two year construction of facilities
- 270 metric ton/24-hr day process
- 10 years remedial operation
- On-site, tumulus type storage facility.
- Treated waste physical form:
  - Large concrete blocks for solidification
  - Glass frit or marbles for vitrification
- Waste to treated waste volume change:
  - Plus 50% for solidification
  - Minus 15% for vitrification

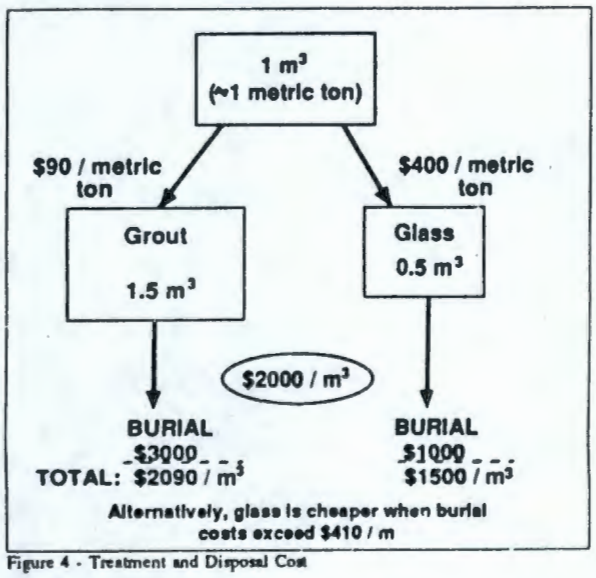

Figure 4 - Treatment and Disposal Cost

MAWS PROGRAM IMPLEMENTATION STRATEGY

The MAWS program involves participants from many different organizations and locations. The need for timely and effective execution of program activities dictates that sufficient resources and attention be dedicated to maintaining the rate of progress required to attain program objectives. The responsibilities and coordination interfaces are described below.

Two DOE sites are involved in implementation of the MAWS program; as such, two contracting organizations will be involved in the procurement of equipment and services. Argonne National Laboratory handles contracts for DOE EM-50. Argonne is procuring the services of GTS Duratek with the Vitreous State Laboratory (VSL) at The Catholic University of America to supply the vitrification equipment, soil washing equipment, water treatment system, technical services for system operation, and analytical support. The VSL is one of the foremost authorities on vitrification.

WEMCO is charged with providing the site facilities and services to run the MAWS demonstration. FEMP site support programs and activities will be planned and implemented with FEMP site DOE OU 1 oversight. WEMCO will act as the program integrator with OU 1, providing the programmatic coordination. R.M. Parsons Co. will provide design engineering services for site and facility modifications through its current contract, while Rust Engineering, the site construction manager, will provide construction management services.

Because of the complexity of environmental regulatory and DOE departmental policy compliance issues involved in the MAWS program, all parties involved must plan wisely in order to expedite the reviews of technical and programmatic document development. Federal and state agencies will need a clear understanding of all the technical and regulatory aspects that apply to the program. The regulatory review process could be enhanced through informational briefings, which will introduce regulators to the document content. To reduce the time required to obtain concurrence on program documents, workshops where review comments and responses can be discussed and issues resolved without the need for interactive reviews or correspondence will be proposed to the regulators.

MAWS SCHEDULE

The program schedule for MAWS is based on the pressing need to develop technical information and process parameters for the design of a pilot-scale system. The primary schedule driver is the requirement to have sustained remediation activity underway 15 months after approval of the OU 1 Record of Decision. Current thinking is that the pilot system can be used to establish this capability.

Even though permits technically are not required for the MAWS because the program is being implemented under CERCLA guidelines, there is concern about the ability to obtain regulatory concurrence to operate the MAWS in a timely fashion. An approach taken to help speed this process is to build two melters. A smaller, identical 100 kg/day melter would be installed early at the VSL in Washington, D.C. Catholic University already has permits for operating melters. Operational data from this melter would be used in the developing the technical information summaries for the 300 kg/day melter at the Fernald site. Data from the 100 kg/day melter should demonstrate that the 300 kg/day melter will operate as designed and allow faster approval for operation.

MAWS activities have been sequenced to allow results of laboratory investigations to guide the design of the demonstration-scale system for each of the integrated technologies . Other activities such as regulatory and program document development, system safety analysis, and facility modifications have been integrated to prepare for system operation at the FEMP by April 1993.

The schedule details are displayed in Table 4.

Activity	Date or Duration
Laboratory Studies	1/92 - 9/92
MAWS - Bench Scale	
Approve MAWS	2/92
Install 100 kg/day melter VSL	5/92 - 11/92
Operate 100 kg/day melter VSL	12/92 - 9/94
Design Facility to house MAWS	3/92 - 8/92
Modify Facility to house MAWS	9/92 - 12/92
Procure & Deliver 300 kg/day	1/92 - 12/92
Install Soil Washing and Water Treatment	10/92 - 11/92
Operate MAWS Cold	3/93 - 4/93
Operate MAWS Hot	5/93 - 9/94
MAWS - Pilot Scale	
Install Pilot Unit	10/93 - 1/95
Operate Pilot Hot	2/95 -

Table 4 - MAWS Schedule

LONG-TERM PROTECTION OF THE ENVIRONMENT

Even if the MAWS concept is proven technically feasible and economical, assurance must be provided that the vitrified treated wastes' performance will protect the environment and endure with time. The MAWS program will include extensive testing and provide a database of quality, consistency, homogeneity, leachability, and durability of the product glass. Expected long-term performance of the glass will be determined and documented. As vitrified wastes leach very slowly, studies will be done to determine if traditional, expensive disposal facility requirements are necessary. It may be possible to place the treated waste in less expensive disposal facilities, thus, further reducing site remedial costs.

MAWS PERFORMANCE CRITERIA

The MAWS demonstration will be considered successful when it meets the following criteria:

- MAWS technologies are installed and operating according to the demonstration work plan.
- The integration of the water treatment, soil washing, and vitrification cycle has demonstrated how blending of waste streams can reduce additives needed for vitrification and decrease the final volume of waste to be disposed.
- Technical evaluations and determinations are made that show how the vitrified wastes will effectively protect the environment.
- The following qualities of the MAWS process are quantified:

  A. Versatility
  B. Effectiveness
  C. Economics
  D. Potential for waste reduction
  E. Process safety

- Demonstration and data are verified in accordance with U.S. EPA Document No. EPA/540/2-89/058, "Guide for Conducting Treatability Studies Under CERCLA," Interim Final dated 1989.
- The necessary parameters are obtained to provide scale-up to a pilot unit.

SUMMARY

Information and expertise gained from the MAWS demonstration will be beneficial and applicable to all other DOE sites considering vitrification as a waste treatment alternative. A better understanding of vitrification as a treatment for low-level radioactive wastes and mixed wastes and how it may be integrated with other treatment technologies is needed before it can be recommended as a treatment method for multimillion dollar remediation projects. Successful completion of the MAWS program will generate the confidence necessary to further adapt this technology for use in the DOE complex.