IN SITU VITRIFICATION (ISV) BURIED WASTE PROCESSING COSTS COMPARISONS TO EX SITU PROCESSING OPTIONS*

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ABSTRACT

In situ vitrification (ISV) has been demonstrated in laboratory and field tests to be a potentially viable treatment technology for buried radioactive waste. The technology produces a high-integrity glass/crystalline waste form which has been demonstrated to have very low leaching characteristics. This paper compares the estimated life cycle costs of using ISV technology to remediate the Subsurface Disposal Area (SDA) of the Idaho National Engineering Laboratory (INEL) versus an alternative concept of waste retrieval, treatment, and disposal. Cost estimates include development, design and construction, operation and, for the ex situ option, transportation, disposal, and decommissioning.

INTRODUCTION

In situ vitrification (ISV) is a promising technology under development at Hanford site, Idaho National Engineering Laboratory (INEL), and Oak Ridge National Laboratory (ORNL) for the treatment of contaminated soils, buried wastes, and underground structures. However, very little is known about its cost as compared to other processing options. This paper presents the results of studies conducted at the INEL to compare the expected ISV life cycle costs with other system concepts when applied to treating transuranic (TRU)-contaminated waste buried at the Subsurface Disposal Area (SDA) at the Radioactive Waste Management Complex (RWMC) at the INEL. An excellent description of the issues associated with TRU-contaminated buried waste in the Department of Energy (DOE) complex has been provided by the Office of Technology Assessment (1). Specific details on the composition of buried waste at the INEL are presented in a recent review for the INEL Buried Waste Integrated Demonstration Program (2). The ISV process uses electrical energy to melt soil, pyrolyze combustibles, and (upon cooling of the molten soil) creates a solid solution which includes the inorganic contaminants, the non-volatile products of pyrolysis, and the soil (3). The resultant waste form has been shown to meet existing regulatory requirements [toxicity characterization leaching procedure (TCLP)] for Resource Conservation and Recovery Act (RCRA) characteristic hazardous materials, to be 4 to 10 times more durable than similar waste forms developed for high-level nuclear waste, and to be comparable to natural analogs, such as obsidian and granite, which have existed for millions of years with little degradation (4,5). Thus, the process appears to be technically suitable for treatment of buried waste containing small quantities of radionuclides including transuranics such as plutonium and americium.

Two major questions with regard to ISV use in an environmental restoration program are, "Is it cost effective and cost competitive with other options?" and "How effective is it in treating all of the waste and immobilizing the residual contaminants?" This paper addresses the ISV processing strategy and rough order of magnitude (ROM) processing costs for remediation of the TRU waste buried at the SDA.

The answer to the second question has been partially addressed in two field tests conducted on simulated buried waste conducted in July 1990 (5) as well as small-scale laboratory tests (6-10). Additional work including demonstrations on buried waste is needed to better quantify the answer to the second question.

SYSTEM DESIGN STUDY

Various options for remediation of the SDA were explored in a Systems Design Study (SDS) (11) which was performed for the Office of Technology Development (OTD) as part of the Buried Waste Integrated Demonstration (BWID). The SDS had two primary purposes:

1. To identify and evaluate a series of options for processing the soils and buried waste in the SDA at the INEL. The evaluation was to be from a technical risk, environmental acceptance (Comprehensive Environmental Response, Compensation, and Liability Act [CERCLA] criteria), and cost perspective.
2. To identify any technology gaps associated with the most promising options needing further applied

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* Work supported by the U.S. Department of Energy, Office of Environmental Restoration and Waste Management, under DOE Idaho Field Office, Contract DE-AC07-76ID01570.

research demonstration, testing, and evaluation prior *to full-scale* implementation.

The SDS was performed by a team of engineers from Bechtel National, Inc., Ebasco Environmental, IT Corporation, and EG&G Idaho, Inc. The study was initiated in a brainstorming process that led to 73 initial concepts for buried waste processing. After comparison, combination, and elimination, 12 systems were selected for further detailed evaluation. The process selection is described in Ref. 11.

TREATMENT OPTIONS AND FINAL WASTE FORMS

As no specific guidance existed for a final waste form for TRU-contaminated buried waste, the final 12 systems were selected, in part, to span a range of final conditions or waste forms. The 12 selected system concepts were divided into two possible treatment options, in situ treatment and ex situ treatment.

Two in situ concepts were selected for detailed development and assessment. These concepts, which are referred to as "process in-place, leave in-place" systems, are:

- Barrier (1-BE-1)
- In Situ Vitrification (ISV) (1-EB-2).

Systems considered for the ex situ treatment were divided between three categories according to system output: (a) those producing a leach resistant, high integrity (i.e., glass or crystalline) waste form, (b) those producing waste forms that meet land disposal restriction (LDR) requirements and limit the hydrogen generation potential from metals, and (c) those producing waste forms that meet the current Waste Isolation Pilot Plant (WIPP) and TRAMPAC (transportation package) waste acceptance requirements for TRU wastes. The following is a listing of ex situ systems that were considered:

- High Integrity/Leach Resistant Waste Form
  - Melting/Incineration System with LLW Presort (2-EG-1)
  - Melting/Incineration System with LLW Postsort (2-EG-4)
  - ISV and Retrieval Processing System (2-EB-3)
- LDR Compliance, Hydrogen Generation Restricted Waste Form
  - Thermal Treatment/Solidification with LLW Presort (3-IT-1)
  - Thermal Treatment/Solidification with LLW Postsort (3-IT-3)
  - Pyrolysis/Acid Leach with Plutonium Extraction (3-EB-6)
  - Molten Salt Oxidation (3-BE-7)
  - Chemical Oxidation/Solidification (3-IT-8)
- WIPP and TRAMPAC Compliance Waste Form
  - Sort, Treat, Repackage (4-BE-2)
  - Volume Reduction and Repackage (4-BE-4).

In addition, four subsystems were chosen to be used as options within the systems. The subsystems examined were:

- Retrieval (S-BE-4)
- Metal Decontamination/Sizing (S-BE-1)
- Soils Processing (S-EB-2)
- Low-Level Waste (S-IT-3).

Subsequent to completing the SDS, a follow-on study was conducted by Bechtel for EG&G Idaho to assess the costs of the backend of the cycle, namely transportation, disposal, and facility decommissioning (12). With the addition of these other costs, a more complete picture of the total life cycle cost of a waste processing option is presented.

DISCUSSION

The primary purpose of this paper is to compare the merits and costs of three of the systems evaluated in these studies. The three systems are: (a) ISV (1-EB-2), (b) ISV and Retrieval Processing System (2-EB-3), and (c) Melting/Incineration System with LLW Postsort (2-EG-4). The three systems selected all produce a glass or crystalline product which has been shown in laboratory studies to produce a high integrity, leach-resistant final waste form capable of immobilizing the RCRA hazardous elements (not already destroyed in the thermal processing) and the radioactive contaminants, particularly the transuranic materials (3,13,14,15).

The other systems are not discussed further in this paper because of space limitations. If interested, the reader can review those results from the cited references. However, it is worth noting that the system ROM life cycle costs for all ten ex situ systems evaluated were comparable at the level of design detail available for these studies (11). When disposal costs are added, some processes with larger volume waste streams become more expensive (12). In general the studies show that the systems producing vitreous or crystalline wastes (the end result depends on cooling rates) were comparable to the costs of systems producing a lower quality waste form (cement stabilized). This observation, in part, relates to the final volume of the wastes and, since the vitrification processes produce the highest density waste forms, they generally produce the lowest volume of wastes. There are many other factors affecting the cost comparisons as described in the referenced reports.

SYSTEM DESCRIPTIONS

ISV - Treat in Place - Leave in Place

ISV has been developed over the last ten years at the Pacific Northwest Laboratory (PNL) of Battelle (16). The work at PNL has focussed primarily on the treatment of soils and underground structures. EG&G Idaho, in cooperation with PNL, has been looking at the application of ISV technology to buried wastes since 1989. A series of laboratory-scale tests (6-10) and two pilot-scale field tests (5) have been conducted to demonstrate the applicability of ISV to buried wastes. Although considerable engineering development needs to be completed prior to the wide-scale application to buried wastes, sufficient experience has been attained to provide confidence that the process and fundamental physics are sound and the remaining development needs should be focused on process control, engineering for safety, and demonstration of production scale hardware.

The process flow diagram for ISV is shown in Fig. 1. In the ISV process, electrical currents pass between the electrodes placed into the waste and heat the material to about 3600°F. Metals, soils, and other wastes fuse into a molten magma of the oxides present while organics are destroyed by pyrolysis. Gases move upward through the melt and escape at the surface where air is added and the pyrolysis gases combust. All of the gaseous effluents are collected and treated by an off-gas hood and treatment system. The off-gas treatment

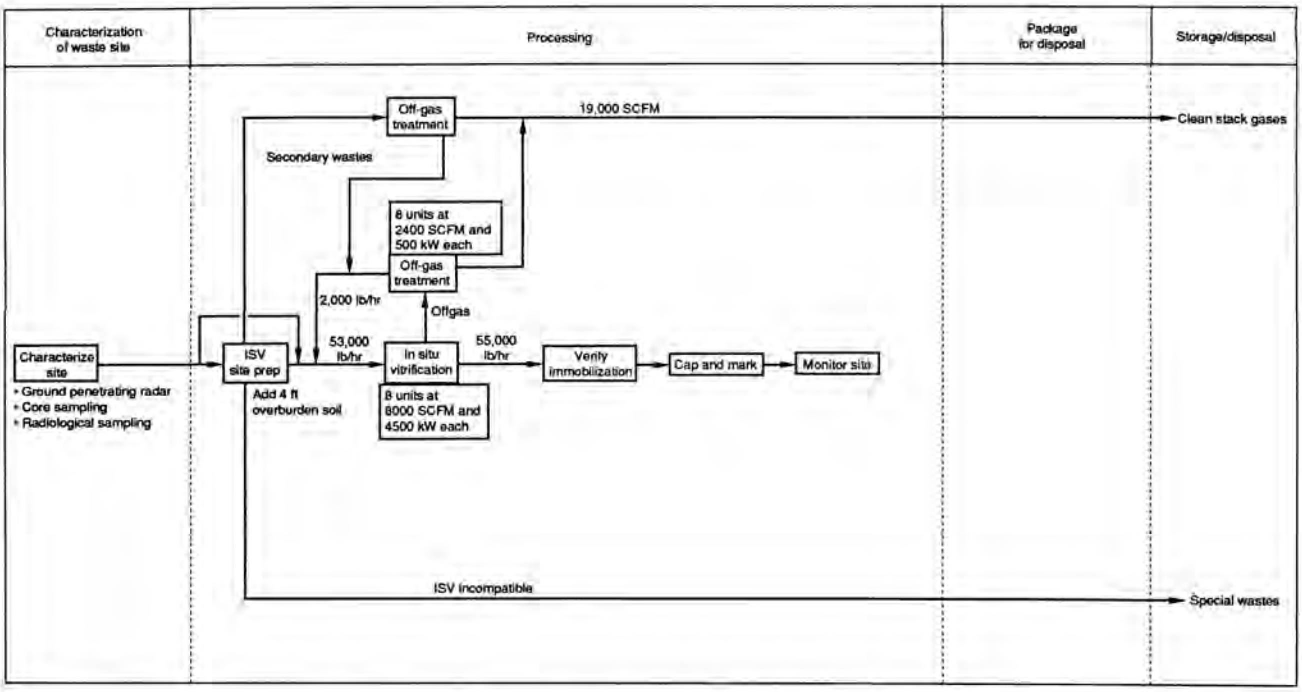


Fig. 1. Process functional diagram for the ISV system (1-EB-2).

system cools, scrubs, sorbs organics, and filters the gases collected before releasing clean gases to the atmosphere. System components typically include a gas cooler, wet scrubber, off-gas to glycol-water heat exchanger, process solutions scrub tank, scrub solution pump, condenser, mist eliminators (vane separators), heater and charcoal filter, blower, and high-efficiency particulate air (HEPA) filter bank.

The convection currents created by the escaping gases and the thermal gradients mix the molten mass, which effectively dissolves and immobilizes radioactive elements into the glass-like product. The molten magma cools and hardens to a high integrity material with very low leachability, is very resistant to weather degradation, and is comparable to the naturally occurring volcanic glass (obsidian). The volume of the waste is reduced as the interstitial voids are eliminated and the soil is densified. To complete the process, clean fill is added to cover the area treated.

Additional process details and assumptions related to processing requirements are described in Volume III of the SDS. In summary, the "facility" basically consists of a portable secondary gas containment or structure enclosing eight ISV sites (30 x 30 ft). Any gases escaping the gas treatment system are captured in the secondary containment and filtered prior to release. Inside this containment, eight ISV systems are operating simultaneously, as shown in Fig. 2.

After the melts are complete, the ISV electrodes and hoods are moved one cell pitch within the secondary containment and the treatment is continued. Movement of the equipment and secondary containment structure continues until all areas are treated.

ISV Followed by Retrieval (2-EB-3)

This design concept uses the ISV process previously described but is followed with a mining operation to fracture the waste form and remove the material for disposal elsewhere (location to be determined). The process flow diagram for this system is shown in Fig. 3. Assuming that the mining and retrieval process leaves a substantial fraction of fines, a melter furnace has been assumed to be necessary to remelt the fines. This furnace would also be potentially suitable for processing small amounts of any untreated waste (if present) discovered after removal of the frozen rock.

Melting and Incineration with LLW Postsort (2-EG-4)

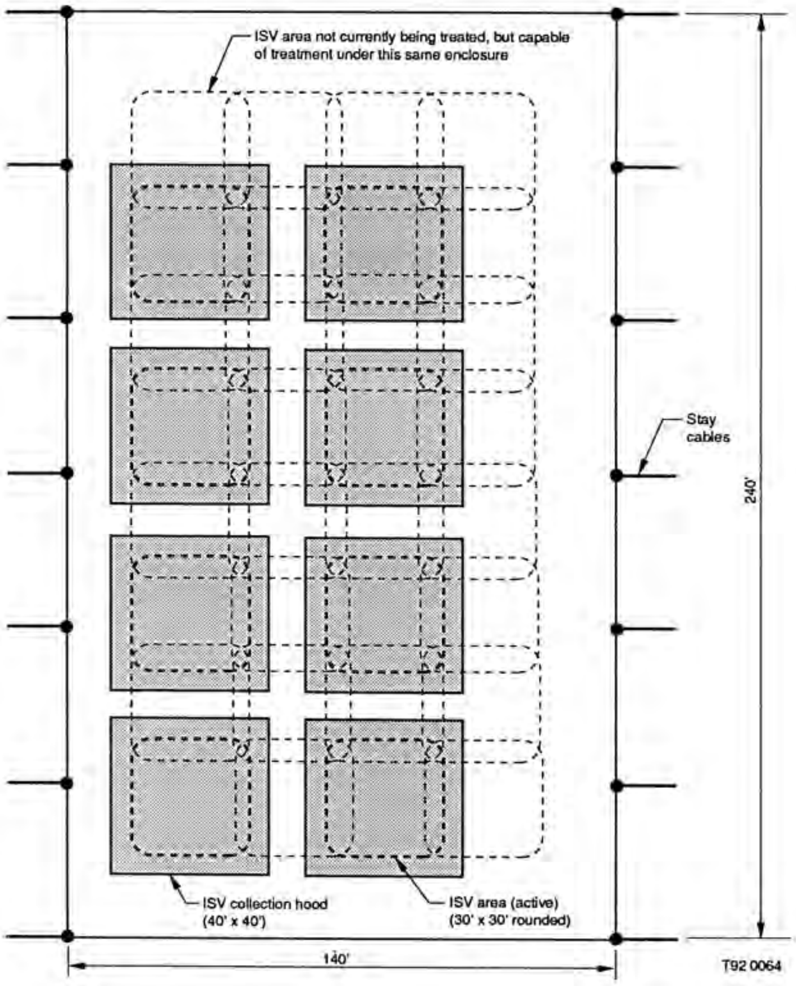
This system, as shown in Fig. 4, is comprised of two thermal processes: incineration and melting. These technologies are combined to minimize overall waste volume and produce a leach resistant, high-integrity final waste form (glass/crystalline).

The waste is comprised of soil, metals, and combustible and noncombustible waste. The soil and bulk metals are sorted out during the retrieval process and transported to the Soil Processing and Metals Decontamination Subsystems for processing. Other metals commingled with the waste and soil are sorted out at the processing facility and transported to the Metals Decontamination/Sizing Subsystem for decontamination. After the metals are removed, the waste is sorted into noncombustible and combustible waste. The noncombustible waste is processed in the melter along with the TRU waste from the exit streams of the Soil and Metal Subsystem facilities. The combustible waste is incinerated and the resulting ash is processed in the melter with the other waste. As in the previous concept, contaminated or clean soil is added to the melter to bring the slag chemistry to a suitable blend to form a high integrity waste form. The process off-gas streams are blended together and processed through an off-gas treatment system.

SYSTEM COST ESTIMATES

Demonstration, Design and Construction, and Operation

The level of system design in the SDS is what might be termed preconceptual design. Thus, cost estimates in this



Notes:
1. Trailers not shown in plan view. Estimated trailer size is 8' x 45' x 12' H.
2. The ISV enclosure allows for treating an area of 120' x 200' (24,000 sq ft), and a volume of 600,000 cu ft (includes 2 ft of basalt).
3. The plan view shows eight ISV cells with off-gas collection hoods, indicating the eight sites being treated at one time. The inactive ISV sites are treated next, inside the same enclosure, by relocating the collection hoods.

Fig. 2. Secondary containment for the eight operating ISV off-gas collection hoods.

paper can be considered as a ROM. Nevertheless, the costs are considered representative of facilities constructed under the requirements of the DOE orders (especially DOE Order 6430.1a) for a Solid Radioactive Waste Facility with a moderate hazard classification (UCRL 15910). Operating assumptions were 24 hours/day, 5 days/week and 240 days per year for 10 years for all of the ex situ systems; the processing time for ISV was 5 years.

Costs were estimated in the SDS (11) for three categories:

- Demonstration, Testing and Evaluation - this category was for pilot-scale demonstration of systems whose industrial use was not routine.
- Design and Construction - this category included all title design costs and construction.
- Operation - this estimate included all operating costs including materials, labor, and facility maintenance.

Transportation, Disposal, and Facility Decommissioning

In the follow-on effort (12), three additional cost categories were included for each ex situ waste processing system:

- Transportation to the disposal sites.
- Disposal costs for the LLW and TRU wastes. The LLW disposal cost used was \$150/ft^3 based on estimates from the California LLW Compact. For TRU waste disposal costs, an estimate was derived based on the capital cost of WIPP plus the 25-year operating cost divided by the available storage volume. This represents a cost of \$740/ft^3.
- Facility decommissioning. Decommissioning costs were assigned on the basis of Bechtel experience on a nuclear hot cell and fuel fabrication facility. The cost assigned was \$450/ft^2.

The resulting cost estimates for the three systems discussed in this paper are presented in Table I and shown graphically in Fig. 5.

The sensitivity of costs for waste (LLW and TRU) transportation, disposal, and facility decontamination and decommissioning (D&D) are evaluated to determine the impact on the system concept life cycle cost ranking (12). The transportation and D&D are small in comparison to those of

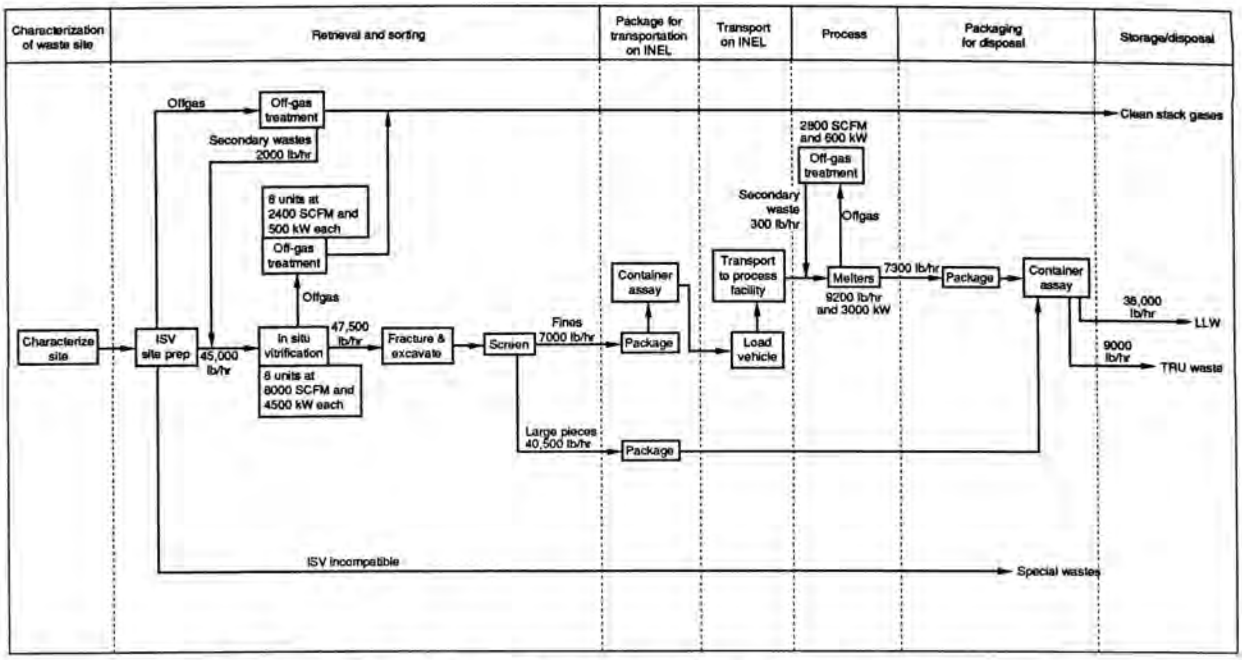


Fig. 3. Process functional diagram for the ISV followed by retrieval system (2-EB-3).

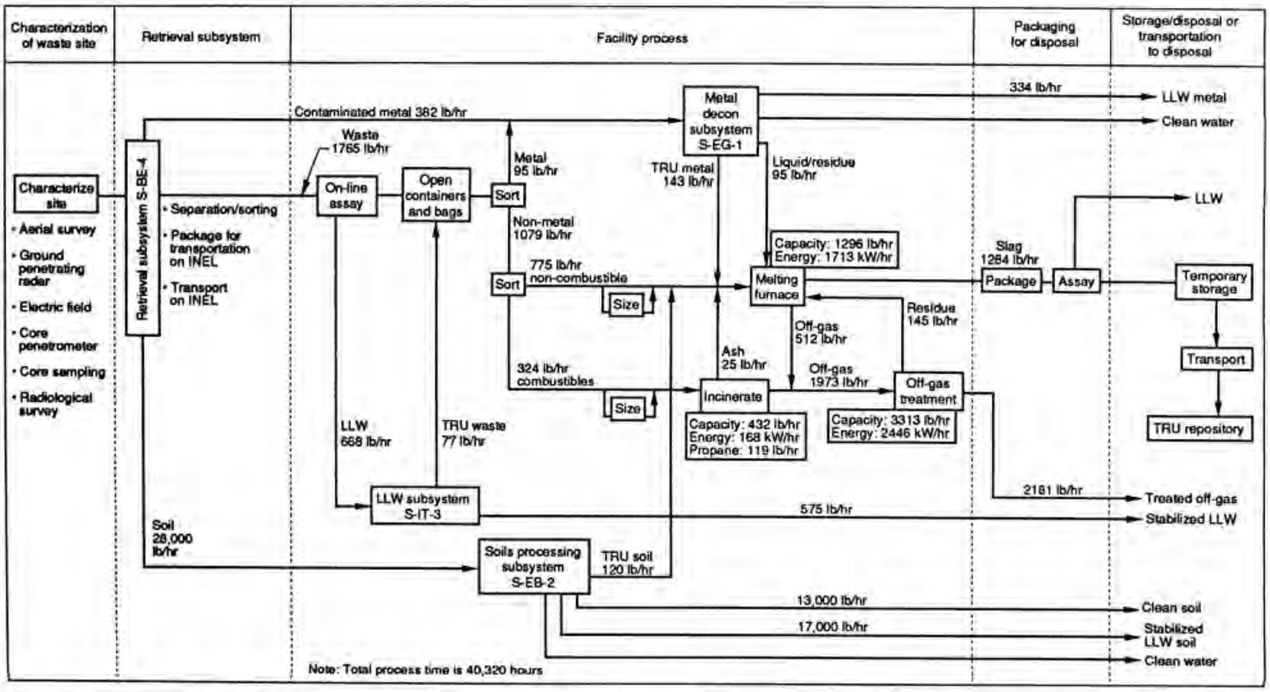


Fig. 4. Process functional diagram for the incineration and melting system with LLW postsort (2-EB-4).

waste processing and disposal and variation in these costs would have little impact on life cycle costs. Of significance are the costs for waste disposal, an important component of life cycle costs. The magnitude of system concept life cycle costs are significantly affected by disposal costs. For example, the cost of ISV and retrieval becomes comparable to the incineration/melting life cycle costs for the high cost of TRU waste form disposal. Fig. 6 demonstrates the system life cost sensitivity for three different TRU waste disposal costs.

CONCLUSIONS

This study demonstrates the importance of complete life cycle cost estimates as part of an overall basis for waste processing technology selection. The study also demonstrates that the ROM cost of an ISV system for treating the SDA buried waste, when used as a final treatment, is about 10% of incineration/melter system costs. This same conclusion applies to the other systems considered in the SDS. The key factors for this dramatic cost difference are the simplicity of the ISV facility, minimized handling of the waste, and no reliance on an external disposal facility. The ISV cost includes an estimated \$37 million that still will be needed to develop the ISV process parameters and optimize the equipment design prior to large-scale implementation. Even if this figure is underestimated by several hundred percent, the final cost comparison will not be significantly affected.

In a system concept where ISV is followed by vitreous waste retrieval, packaging, and off-site disposal, the cost is about 50% to 75% of the incineration/melter system (depending on the TRU waste disposal costs). The cost difference is largely due to a substantially less complicated retrievalsubsystem, as well as a smaller waste packaging facility in the ISV and retrieval option. This comparison shows that for treatment of buried wastes, the ISV option can be used as an interim action followed by retrieval in the future, if required, and still be more cost effective than an incinerator/melter system.

TABLE I

A ROM Cost Comparison of In Situ and Ex Situ Treatment Options

Cost Element	Treatment Process		
	ISV and Leave in Place (1-EB-2)[a]	ISV and Retrieval of Waste Form (2-EB03)[a]	Retrieval and Treatment LLW Post-Sort (2-EG-4)[a]
Remaining Development Testing and Evaluation (\$ x 10^6)	37	59	258
Construction (\$ x 10^6)	124	210	667
Operation and Maintenance (\$ x 10^6)	130[b]	180[b]	900[c]
Transportation (\$ x 10^6)	N/A	27	12
Disposal (\$ x 10^6)	N/A	1613	900
Facility Decommissioning (\$ x 10^6)	N/A	43	68
Total Life Cycle Costs (10 years) (\$ x 10^6)(d)	291	2132	2805
Life Cycle Costs/yd^3 (e)	650	4800	6300

a. Numbers refer to original system reference designations (11).
b. Based on five years operation.
c. Based on ten years operation.
d. These numbers do not consider time value of money. This is discussed in Ref. 12.
e. Based on 2.325 x 106 ft^3 waste and 9.734 x 10^6 ft^3 soil input to processing. Final numbers are rounded.

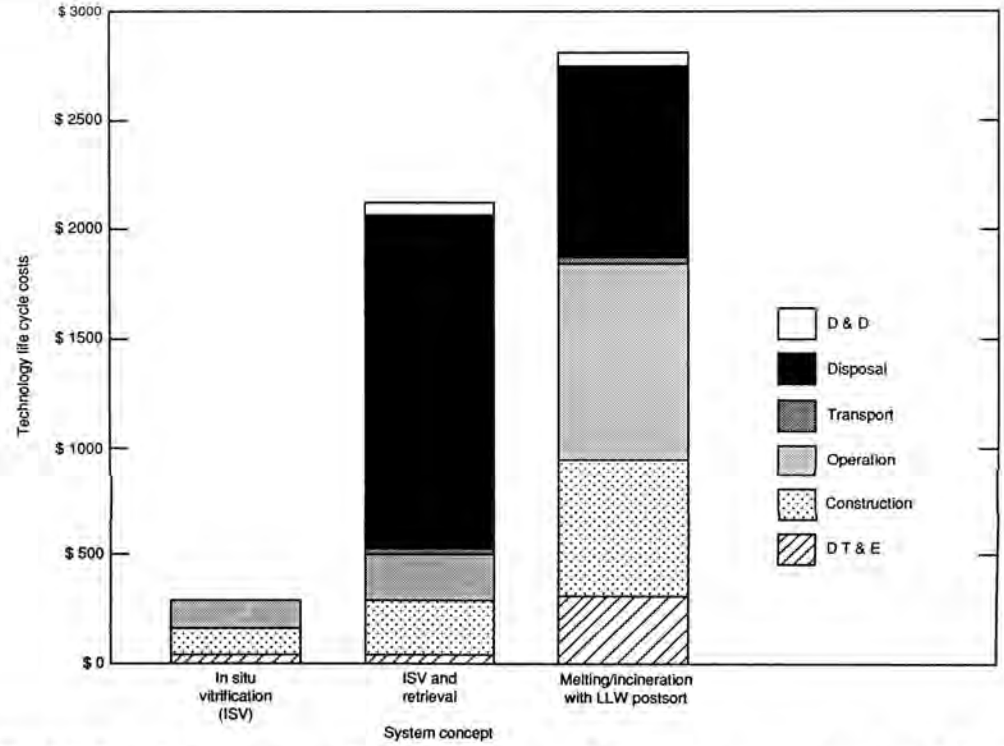


Fig. 5. Life cycle cost segments for leach resistant, high-integrity structure (nominal dollars).

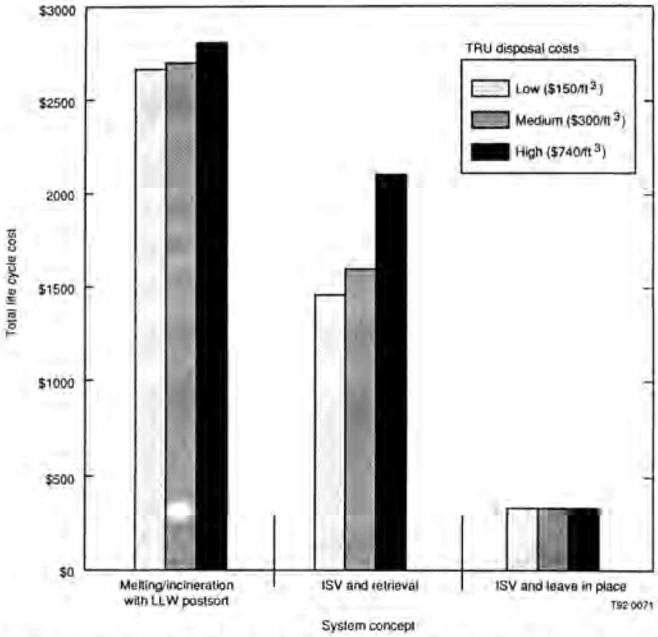


Fig. 6. System concept TRU disposal cost sensitivity (nominal dollars).

Another significant outcome of the cost study is the difference in the number of cost uncertainties in the ISV system as compared to other ex situ treatment options. The ISV system concept has less uncertainties because it is a relatively much simpler process. The key uncertainties of ISV system could be the design of the environmental enclosure and the level of fail-safe features that must be added to mitigate a potential accident. In an incinerator/melter system, there are numerous cost uncertainties because very little is known about the design of a practical and acceptable retrieval subsystem, incinerator/melter process, its ancillary equipment and systems, and the final disposal facility.

Clearly, the ISV process will require a substantial development effort to reach the technical maturity necessary for a firm decision to use it for the SDA buried waste remediation. The SDS studies, however, point out that the simplicity and the resultant significant cost benefit inherent in an ISV process may justify continued examination of this option.

REFERENCES

1. U.S. Congress, Office of Technology Assessment, Long-Lived Legacy - Managing High-Level and Transuranic Waste at the DOE Nuclear Weapons Complex: Background Paper, OTA-BP-0-83, May 1991.
2. D. A. ARRENHOLZ and J. L. KNIGHT, A Brief Analysis and Description of Transuranic Wastes in the Subsurface Disposal Area of the Radioactive Waste Management Complex at INEL, EGG-WTD-9438, Rev. 1, August 1991.
3. R. A. CALLOW and L. E. THOMPSON, "In Situ Vitrification - Application to Buried Waste," Waste Management '91 - Waste Processing, Transportation, Storage and Disposal, Technical Programs and Public Education: Vol. I -Programmatic, Communications and Environmental Restoration, Proceedings of the Symposium on Waste Management, Tucson, Arizona, February 24-28, 1991.
4. B. P. MCGRAIL and S. O. BATES, "An Evaluation of In Situ Vitrification for Remediation of a Buried Waste Site," VII International Conference on the Physics of Non-Crystalline Solids, Proceedings to be published, Churchill College, Cambridge, England, August 4-9, 1991.
5. R. A. CALLOW, L. E. THOMPSON, J. R. WEIDNER, C. A. LOEHR, B. P. MCGRAIL and S. O. BATES, In Situ Vitrification Application to Buried Waste: Final Report of Intermediate Field Tests at Idaho National Engineering Laboratory, EGG-WTD-9807, August 1991.
6. K. H. OMA, M. A. H. REIMUS and C. L. TIMMERMAN, Support for the In Situ Vitrification Treatability Study at the Idaho National Engineering Laboratory: FY 1988 Summary, PNL-6787, February 1989.
7. R. K. FARNSWORTH, K. H. OMA and M. A. H. REIMUS, Crucible Melts and Bench-Scale ISV Tests on Simulated Wastes in INEL Soils, PNL-7344, May 1990.
8. R. K. FARNSWORTH, K. H. OMA and C. E. BIGELOW, Initial Test on In Situ Vitrification Using Electrode Feeding Techniques, PNL-7355, May 1990.
9. C. A. LOEHR, J. R. WEIDNER and S. O. BATES, Product Evaluation of In Situ Vitrification Engineering Test 4, EGG-WTD-9868, September 1991.
10. C. A. LOEHR and J. R. WEIDNER, Physical and Chemical Properties of the Products of In Situ Vitrification Engineering Tests 5, 6, and 7, EGG-TD-901, December 1991.
11. J. L. MAYBERRY, W. J. QUAPP, F. FEIZOLLAHI and J. C. DEL SIGNORE, Preliminary Systems Design Study Assessment Report, Vols. I through VIII, EGG-WTD-9594, July 1991.
12. R. O. SCHLUETER, F. FEIZOLLAHI, and W. J. QUAPP, Low Level and Transuranic Waste Transportation, Disposal and Facility Decommissioning Cost Sensitivity Analysis, EGG-WTD-10092, May 1992.
13. J. G. CONLEY, P. V. KELSEY and D. V. MILEY, *Advances in Ceramics, Vol. 8*, Columbus, OH: American Ceramics Society, Inc., 1984, pp. 302-309.

14. S. O. BATES, "In Situ Vitrification of Buried Waste," Waste Management '92, Tucson, Arizona, August 23-27, 1992 (to be published).

15. G. A. REIMANN, J. D. GRANDY, T. L. EDDY, G. L. ANDERSON, Summary of INEL Research on the Iron-Enriched Basalt Waste Form, Thermal Processing Technologies Buried Waste Program, EGG-WTD-10056, January 1992.

16. J. L. BUELT, C. L. TIMMERMAN, K. H. OMA, V. F. FITZPATRICK, J. G. CARTER, In Situ Vitrification of Transuranic Waste: An Updated Systems Evaluation and Applications Assessment, PNL-4800 Suppl. 1, March 1987.