INNOVATIVE TECHNOLOGY
Summary Report

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ARROW-PAK Macroencapsulation

Mixed Waste Focus Area

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INNOVATIVE TECHNOLOGY
Summary Report

ARROW-PAK Macroencapsulation

OST/TMS ID 2159

TRU & Mixed Waste Focus Area

Demonstrated at
East Tennessee Technology Park
Oak Ridge, TN

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://www.em.doe.gov/ost under "Publications."

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SECTION 1
SUMMARY

Technology Summary

ARROW-PAK is a macroencapsulation treatment technology. It was tested and qualified, in partnership with the U.S. Department of Energy (DOE) over the past seven years, to be used by DOE and its contractors for the treatment and disposal of low-level and low-level mixed debris. This innovative macroencapsulation treatment technology utilizes high-density polyethylene (HDPE) sleeves mated with HDPE endcaps as a means of encapsulating the waste stream. HDPE enclosures have been used within DOE and commercial industry for years; however, Boh Environmental, LLC (Boh) has the capability of "fusing" the HDPE sleeve and endcaps using a proprietary method of localized heating and high-pressure contact. This capability allows Boh to develop crosslinking between the polyethylene sleeve and the polyethylene endcap. This crosslinking gives the ARROW-PAK its ability to encapsulate waste without allowing seepage through the sealing surface, thereby allowing the ARROW-PAK to be used in a mixed waste processing application.

Macroencapsulation of waste is a technology based treatment under EPA (40 CFR 268.42, Table 1). Waste processing with the Arrow-Pak technology involves super-compaction of the waste in 55-gallon drums, placement of the compacted drums into 85-gallon overpacks, and placement of overpacks into the ARROW-PAK tube, which is then sealed by fusing HDPE endcaps in place. The ARROW-PAK system was developed by Arrow Construction. New Orleans-based Boh Environmental, LLC owns the technology.

Florida International University's Hemispheric Center for Environmental Technology (FIU-HCET) has been evaluating the applicability of the ARROW-PAK macroencapsulation technology for treatment of mixed waste debris from the DOE Oak Ridge Operations (ORO) East Tennessee Technology Park (ETTP). Project funding came through the ORO Environmental Management (EM) Program and through the TRU and Mixed Waste Focus Area (TMFA), created by DOE's Office of Science and Technology (OST) to solve transuranic and mixed-waste technical problems. The ARROW-PAK deployment is one of six Accelerated Site Technology Deployment (ASTD) programs supported by OST in the 1999 to 2001 timeframe.

The advantages of the ARROW-PAK macroencapsulation treatment technology are that it:

- Provides potential for cost savings over current existing baseline technology when deployed in a full-scale production mode
- Provides opportunities for innovative waste management technology to be used for difficult debris waste streams
- Achieves a net volume reduction with respect to existing baseline technologies
- Can be tailored to site-specific conditions and can be readily incorporated into existing treatment trains at DOE legacy and newly generated waste projects
- Can be staged at the generator site or set up at a TSD for regional treatment
- Allows for treatment and disposal of drummed debris wastes without re-packaging, reducing double-handling, costs, and worker exposure
- Produces a tough and flexible waste barrier with excellent chemical and physical resistance: it is durable, leach resistant, compliant with Nuclear Regulatory Commission (NRC) guidelines, and compliant with Resource Conservation and Recovery Act (RCRA) requirements for disposal of mixed waste debris
- Offers a permanent treatment solution for final disposal

Demonstration Summary

The original project scope included the treatment of DOE-ORO legacy waste drums; however, because of permit issues and time constraints, the project team obtained approval to treat newly generated waste from a demolition project at the East Tennessee Technology Park. The demolition waste had to be macroencapsulated within the 90-day-interim-storage timeframe to allow treatment of the waste without additional permitting issues.

FIU-HCET was assigned project management responsibility by DOE-ORO for deployment of ARROW-PAK. Task 1, under the Statement of Work, included an evaluation of the applicability of the ARROW-PAK macroencapsulation technology for treatment of Oak Ridge Reservation mixed wastes, with a comparison to baseline technologies, and the identification of any unresolved issues that impede operational deployment of this technology and subsequent disposal of the macroencapsulated mixed waste. Impediments that were identified and resolved before and during the deployment of ARROW-PAK:

- Issues with the disposal facility (Envirocare of Utah) and their regulators (State of Utah)
  - Approval was required and obtained from the State of Utah for disposal at Envirocare of Utah, Inc.
  - Envirocare of Utah's permit was modified to allow for disposal of ARROW-PAKs
  - Qualitative testing was required to provide structural stability data under landfill loading conditions to ensure that the ARROW-PAK could support the burden of standard landfilling, including other ARROW-PAKs and grout.
  - Approval was obtained from Envirocare and the State of Utah for remote approval/verification of treated incoming waste since the waste would not be accessible for inspection/verification upon receipt at Envirocare for disposal.
- DOT 7A certification was required and obtained for the configuration used on this project.

Key Results

ARROW-PAK macroencapsulation provides a viable technology for treatment of appropriate types of mixed waste debris.

- ARROW-PAK technology allows for volume reduction of waste, especially as compared to the volume increase that is experienced in current baseline technologies (macroencapsulation with LDPE). Treatment can achieve waste minimization sufficient for comparable costs to baseline technologies with room for improvement through operational controls.
- The ARROW-PAK container configuration deployed is certified as a Department of Transportation (DOT) shipping container, easing shipping and handling.
- Class 1 modification to the treatment permit is in-place for acceptance at Envirocare.
- Offsite verification program for Envirocare is in-place with regulator approval.
- 80 ARROW-PAK tubes have been disposed in the Envirocare of Utah landfill, processing 10,660 cubic feet of waste reduced to a final volume of 9040 cubic feet. Visual inspections of "in place" ARROW-PAKs in the disposal cell by the State of Utah have consistently shown no problems with the ARROW-PAK structure.

Contacts

Technical
Steve Tujague
Boh Environmental LLC
20 Berg Court
Mandeville, LA 70471
504-525-0952

J. Carpenter
Hemispheric Center for Environmental Technology
Florida International University
Oak Ridge, TN 37830
(865) 220-8844 ext 106
E-MAIL: jcarpent@hcet.fiu.edu

W. J. Krummen
Hemispheric Center for Environmental Technology
Florida International University
Oak Ridge, TN 37830
(865) 220-8844 ext 102
E-MAIL: krummen@hcet.fiu.edu

Principal Investigator
M. A. Ebadian
Hemispheric Center for Environmental Technology
Florida International University
Miami, Florida
(305) 348-4238
E-MAIL: ebadian@hcet.fiu.edu

Management

DOE-ORO Program Manager
D. Hutchins
U.S. Department of Energy – Oak Ridge Operations
Environmental Technology Group, EM-93
P.O. Box 2001, Oak Ridge, TN 37831
(865) 241-6420
E-MAIL: hutchinsda@oro.doe.gov

TMFA Product Line Manager
Vince Maio
Idaho National Engineering and Environmental Laboratory
P.O. Box 1625
Idaho Falls, ID 83415-3875
(208) 526-3696
E-MAIL: vmaio@inel.gov
Greg Hulet
Idaho National Engineering and Environmental Laboratory
P.O. Box 1625
Idaho Falls, ID 83415-3875
(208) 526-0283
E-MAIL: hag@inel.gov

Licensing
All equipment and materials are commercially available.

Permitting
Future deployments will need to baseline time for permitting. Alternatively, consider shipping waste to a facility permitted to use HDPE macroencapsulation for cost savings. If the waste stream is large enough in size to warrant permitting cost or the waste is newly generated, allowing for treatment in the 90 day storage area, treatment on site may be more cost effective.

Other
All published Innovative Technology Summary Reports are available on the OST Web site at www.em.doe.gov/ost under “Publications.” The Technology Management System (TMS), also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST/TMS ID for ARROW-PAK Macroencapsulation is 2159.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

The ARROW-PAK macroencapsulation process involves super-compaction of the debris waste in 55-gallon drums, placement of the compacted drums into 85-gallon overpacks, and insertion of the overpacks into the ARROW-PAK tube, which is then sealed by fusing on HDPE endcaps.

The ARROW-PAK deployed at ETTP is a HDPE tube of nominal 1-inch wall thickness, 22 feet long, and 30 inches in diameter. Each ARROW-PAK holds 7 overpacks, representing an average of 21 55-gallon drums of mixed waste debris, depending on the physical nature of the waste and the efficiency of the supercompactor.

Each ARROW-PAK consists of a HDPE cylindrical pipe with two endcaps. During manufacturing, the pipe is extruded and the end caps are cast. Both the pipe and the end caps are made from Marlex M-8000 resin. Fusing of the endcaps to the pipe first requires resurfacing the ends of the pipe with a cutter head to ensure a good seal. Next, the ends of the pipe and caps are fused by heating to 425°F with an electrical platen, followed by hydraulically pressing the softened surfaces together at pressures of 440 psi.

The fusion process, proprietary to Boh Environmental, thermally melts the HDPE's semi-crystalline molecular structure so that upon cooling and resolidifying, the polymer chains in both the pipe and endcap physically co-mingle/co-entangle. The result is a homogeneous and monolithic unit that is completely leak-tight.

The welds are critical and must be done by qualified operators and inspected before any transportation of the tube. When verification is complete, the waste package (with an overall reduced volume due to the supercompaction operation) is ready for shipment to the final disposal site.

When deployed at the generator's site, because of the impenetrable nature of the final ARROW-PAK package, the waste is unavailable for verification against the waste profile at the disposal facility. Envirocare and the State of Utah required 100% verification and sampling of the waste against the waste profile prior to processing.

Figure 1. Arrow-Pak loading operation.

System Operation

A description of the major steps required to deploy the Arrow-Pak technology are listed below:

- The initial population of debris to be disposed needs to be identified, characterized, and profiled for disposal. The proper permit modifications and acceptance procedures must be in place to utilize the ARROW-PAK regardless of location.

- Arrangements must be made with the host state for the disposal site (i.e., Utah for Envirocare) to qualify the process and to allow waste processed offsite to be disposed without additional intrusive inspection once received at the disposal facility.

- At the onset of operations, the waste must be in packaging appropriate for loading into the ARROW-PAK tube. Optimally, this means sizing or compaction should be complete prior to mobilizing Boh onto the site. The bulk density of the waste must meet the waste acceptance criteria of the disposal site (70 lbs/ft^3 at Envirocare). The final sealed tube must be heavy enough to prevent it from “floating up” through a disposal cell.

- The site operators and equipment need to be onsite and ready when Boh is mobilized. Boh will bring the required number of tubes, the loading sled, the sealing unit, and all the endcaps. The site operators will work with Boh to get the tubes into the loading sled, and load the waste into the tubes. This will be done in accordance with the waste management plan and all appropriate permits and licenses.

- After the waste is loaded into the tube, the operators lift the tube onto the sealing unit. When the sealing unit is heated and ready to seal, Boh’s technicians resurface of the ends of the tube for consistent heating. The operators heat the resurfaced tube and end cap and pressure seal the end cap onto the tube, which is then allowed to return to ambient temperature. The entire process can take 1 to 2 hours per tube, depending upon the ambient temperature.

- After the sealing is complete, and the required quality assurance tests have been performed, the tubes are ready for loading onto the trucks for transport. Site waste management personnel are then responsible for proper shipping protocol and interface with the disposal site for shipping clearance.

SECTION 3
PERFORMANCE

Demonstration Plan

The ARROW-PAK phase I deployment was completed onsite at ETTP in conjunction with remedial activities in support of the DOE Reindustrialization effort. The major objectives of the first deployment were to develop acceptance of the new technology at the disposal facility, to overcome transportation issues, and to actually deploy the technology on site at ETTP. Initial plans to treat legacy waste in the deployment were changed to address debris coming from demolition and decontamination activities at ETTP, as the timeframe of the project did not allow for the issuance of a RCRA treatment permit necessary to treat legacy waste. Thus, the option to treat a newly generated waste stream within the 90-day storage limit was chosen. The selected waste stream was newly generated MLLW debris from the reindustrialization at ETTP.

For macroencapsulation to be an acceptable treatment method for the subject waste, the rate of gas generation for the waste had to be low enough to prevent pressurization of the sealed cylinder. Waste Management Federal Services, Inc. Northwest was contracted to study the gas production rate for the expected waste stream to ensure that excessive pressure buildup within the ARROW-PAK did not occur. They determined that the gas generation rate for the debris was acceptable.

FIU-HCET worked with the State of Utah regulators and Envirocare of Utah to address all concerns regarding the use of HDPE sleeves for macroencapsulation so the macroencapsulated waste could go to Envirocare for disposal. The viability of the HDPE itself, from structural stability under landfill operations to leach resistance in the presence of chemical contaminants in the waste, was reviewed. Normal waste acceptance procedures for Envirocare of Utah require that incoming waste be sampled to ensure that the waste falls within its profile and meets Envirocare's waste acceptance criteria, a procedure not possible with a sealed ARROW-PAK. The inspection issue was resolved; the state of Utah has given agreement to 100% offsite inspection and sampling to allow for acceptance at the disposal facility. The permit at Envirocare of Utah has been amended to allow for treatment and disposal of macroencapsulated waste in HDPE, in addition to their previously permitted macroencapsulation treatment using LDPE.

The configuration of the ARROW-PAK used in this treatment had not been previously certified by DOT for transporting waste. Project personnel were able to achieve DOT certification for the ARROW-PAK configuration as a Type 7/ 7A container, allowing shipment to the final disposal site without need for additional packaging.

The generator of the waste stream provided logistical support for the sizing and compaction of the waste and material handling support to Boh Environmental, LLC. The compaction was subcontracted to GTS Duratek, using their mobile 1000-ton compactor. The generator performed all drum loading, movement, and tracking, including the initial loading of the waste into the 55-gallon drums. These drums were then compacted into pucks and loaded into the 85-gallon overpacks. At that time the overpacks were weighed and divided into groups of seven for loading into the ARROW-PAKs. Each group of seven was adjusted to normalize the weight distribution of the overpacks, for compliance with both the DOT weight restrictions and the Envirocare of Utah density requirements.

The families of overpacks were loaded into the ARROW-PAKs with the use of one 30-ton crane, one forklift with drum manipulator, and a second forklift to power the loading plunger supplied by Boh. The crane was required for moving the empty tube into the rack for stabilization during loading, for moving the loaded tube onto the sealing equipment, and for moving the tube onto the trucks for shipment. Riggers and operators were required for support of these operations. Boh supplied their own operators for sealing the tubes and for the quality assurance activities required for waste acceptance by the disposal site.

Results

The major results of the ARROW-PAK deployment at Oak Ridge are summarized in the following:

- An intermediate volume reduction of the initial waste stream was 41% and final volume reduction of 15% was achieved (see table below). However, given that competing treatment technologies often double the initial waste volume, this technology offers a net burial volume reduction of 58% (see second table below).

- DOT certification was obtained for the configuration of ARROW-PAK used at ETTP (22 feet length, 30 inches diameter, maximum gross weight of 9500 pounds)

- State of Utah approval was obtained for disposal of the ARROW-PAK at Envirocare of Utah

- Phase I treated over 10,000 ft^3 of mixed waste debris from ETTP

Stage	Container	Volume per Container (ft^3)	Number of Containers	Total Volume Per Container Type (ft^3)	Total Volume (ft^3)
Starting Volume	Drums (55-gallon)	7.4	1284	9441	**10668**
	Overpack (85-gallon) Filled directly with uncompacted waste	11.4	108	1227	
Intermediate Volume	Overpack (85-gallon) Filled with compacted drums	11.4	449	5102	**6330**
	Overpack (85-gallon) Filled directly with uncompacted waste	11.4	108	1227	
Final Volume for Disposal	ARROW-PAK	113	80	9040	**9040**

Starting Volume of Waste (ft^3)	Final Volume as Treated by ARROW-PAK Macroencapsulation (ft^3)	Final Volume as Treated by Baseline (LDPE) Technology (ft^3)
10668	9040	21336

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

The Debris Rule (57 FR 37194, August 18, 1992) identifies extraction or destruction technologies as alternatives to macroencapsulation of debris wastes. The materials sent to Envirocare could not be decontaminated because of volumetric contamination.

The advantages of ARROW-PAK polymer encapsulation over other methods of macroencapsulation are greater impact resistance and durability, enhanced resistance to environmental degradation after disposal (lower leachability/permeability), and net volume reduction at approximately equivalent or lesser cost.

Other polymer macroencapsulation technologies are available:

- Low-density polyethylene extrusion macroencapsulation process uses commercially available single-screw extruders to melt, convey, and extrude molten polyethylene into a waste containers in which mixed waste debris is suspended or supported. After cooling to room temperature, the polyethylene forms a low-permeability barrier between the waste and the leaching media. Waste volume is increased approximately two-fold.

- Thermoset polymer encapsulation technologies are also available. These technologies are attractive for their flexibility and high mobility, but base resin costs are significantly higher than those of polyethylene. Polyester resins, as well as epoxies, are classified as thermosetting.

Technology Applicability

- ARROW-PAK macroencapsulation can be scaled or tailored to site-specific conditions and can be readily incorporated into existing treatment trains.

- Potential uses of this technology include LLW and MLLW debris treatment at the other DOE sites, for both legacy and newly generated debris.

- Another efficient use of this technology would be to house the operations at one treatment site and ship the waste to that location for treatment under their permit. A cost sharing relationship could be established for DOE to assist in start-up cost, such that a price break on disposal would then be available to DOE.

- EPA regulation 40CFR268.42(b) specifically prohibits the macroencapsulation of lead in containers. In the future, a determination of equivalent treatment (DET) would have to be obtained to use the ARROW-PAK process for radioactively contaminated elemental lead. This DET has been drafted and supporting evidence is currently being gathered.

Patents/Commercialization/Sponsor

The mechanism of closing and sealing each Arrow-Pak is proprietary. Boh was granted a patent for the process by the United State Patent Office in November 1995 (Patent No. 5,471,065).

SECTION 5
COST

Methodology

Actual cost information was collected during Phase I of the project, along with starting volumes, intermediate volumes (after compaction and/or placement into the overpacks), and disposal volumes of the waste being treated. This information is summarized here.

The costs below are cited from the actual cost of all subcontract expenses. The implementation costs are one-time only fees required for mobilization of this technology onsite. In the future, these costs should be minimal for follow-on work at Oak Ridge. They include the gas generation study (which may need to be repeated depending upon the nature of the waste to be treated), the DOT certification, and permitting fees from the disposal facility.

The Operating and Maintenance costs are derived from actual invoice amounts from all support subcontractors on this project, including Boh, DRS, and FIU-HCET. These costs have room for improvement during future deployments, due to poor operational efficiency in this mobilization model, as explained in the cost conclusions. The costs shown are representative of the costs that may be expected for a re-mobilization of the treatment technology. One-time project set-up costs are shown, but qualified as to how applicable they would be to future deployments at Oak Ridge or at other sites.

Cost Analysis

Table 3 contains the results of a preliminary cost analysis performed for the Phase I deployment. Costs are reported for the 10,600 cubic feet of waste processed.

Table 3. Costs for ARROW-PAK deployment at East Tennessee Technology Park

Cost Category	Cost	Explanation
Project Startup Costs		
Envirocare of Utah	$38,400.00	Modification of Envirocare permit to allow disposal of ARROW-PAKs. Cost would not be repeated for disposal at Envirocare.
MHF Logistics	$32,875.00	Certification of ARROW-PAK configuration as a DOT container. Cost would not be repeated if same configuration is deployed elsewhere.
Providence Group	$26,193.40	Waste logistics. Cost should be substantially less for other deployments
WM Northwest	$18,394.13	Measurement of gas generation rates. Similar cost for other deployments.
Boh Environmental	$29,974.00	Project initiation cost. Should not be seen in other deployments.
DRS	$16,150.64	Waste handling. Should be less in future deployments
FIU-HCET	$133,871.37	Project management and coordination. Costs should be considerably less on future deployments because of reduced complexity and lessons learned.
Startup Total	$295,858.54	

Cost Category	Cost	Explanation
Project Startup Costs		
Project mobilization/ execution Costs		
Boh Environmental	$772,390.00	ARROW-PAK operational costs including $27000 for additional mobilizations
Decon and Recovery Services of Oak Ridge		
Materials	$126,455.04	All material costs including drums.
Labor	$588,941.70	Sizing, packaging and other support work. These costs could be reduced for project requiring less material handling
Compaction	$149,611.64	Compaction costs should be similar for other deployments
Subcontracts	$86,479.54	These costs should be eliminated for a less complex project
Total	$840,763.52	
FIU-HCET	$299,746.35	Project management and coordination for execution.. Costs should be considerably less on future deployments because of reduced complexity and lessons learned.
Mobilization/execution Total	$1,730,088.59	
Phase I deployment Total	$2,025,947.13	

Cost Conclusions

Because macroencapsulation is an approved treatment technology, waste form qualification testing is not required. This can lead to significant cost savings compared to destruction and separation technologies.

Current LDPE extrusion macroencapsulation costs range from $200-300 per cubic foot of waste treated, depending on waste type and volume. This cost estimate takes into account that the waste volume to be disposed will essentially double during LDPE macroencapsulation treatment. Thus, a quoted cost for treatment by LDPE macroencapsulation and disposal should be doubled to obtain the actual cost per volume of waste treated. FIU-HCET estimated a price for LDPE treatment and disposal of the waste treated under this deployment at $3,140,000. Sites considering deployment must take the ARROW-PAK costs provided and add in costs for disposal to determine overall costs for their sites.

Phase I costs included several additive cost factors/premiums due to the approach used, i.e., that of treating newly generated waste without permit within 90 days of accumulation:

- waste generated for B-25 boxes had to be size-reduced for placement into drums prior to compaction
- overtime rates were paid for subcontractor support for contractual reasons

- due to the requirement to treat the newly generated waste within 90 days of accumulation, Phase I was not able to optimize mobilization costs by staging the whole waste population for compaction before beginning macroencapsulation

Despite these added cost factors, Phase I deployment costs were still competitive with baseline technologies.

SECTION 6
REGULATORY AND POLICY ISSUES

Regulatory Considerations

The waste streams treated in this demonstration were subject to the Resource Conservation and Recovery Act (RCRA) but not the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

- Macroencapsulation, which is the RCRA technology-based treatment standard for mixed waste debris and D008 radioactive lead solids, is defined in 40 CFR 268.42 as "Application of surface-coating materials such as polymeric organics (e.g., resins and plastics), or use of a jacket of inert inorganic materials to substantially reduce surface exposure to potential leaching media." Macroencapsulation for lead solids specifically does not allow for use of any material that would be classified as a tank or container according to 40 CFR 260.10.

- Currently, macroencapsulated debris contaminated with a listed waste must be managed as a RCRA hazardous waste. Proposed regulatory modifications (i.e., DOE's response and recommendations to the U.S. Environmental Protection Agency's proposed Hazardous Waste Identification Rule, 64FR63382) would exclude immobilized mixed debris from RCRA Subtitle C restrictions after treatment. This exclusion would be similar to the one provided for hazardous debris treated by extraction or destruction technologies.

- RCRA permitting depends on site-specific requirements. The ARROW-PAK macroencapsulation technology utilizes collection and preprocessing of the mixed waste debris followed by the macroencapsulation treatment of the debris. This process requires RCRA permitting. However, for this deployment, the waste generator, Decon and Recovery Services of Oak Ridge, LLC (DRS), did not permit the facility but rather treated the hazardous waste in waste storage areas during the period of accumulation. Under this provision, the waste generator is required to follow certain storage requirements such as monitoring the containment, and tracking and documenting the time in storage. As long as the processing occurs in the storage containers and within 90-days of waste generation, the RCRA permit is not required (TDEC 1999). Any waste that is not removed from storage within 90-days will require RCRA permitting for storage and subsequent treatment.

- National Environmental Policy Act (NEPA) review for categorical exclusion. All work on a DOE site requires NEPA assessment. This project qualified for the NEPA Categorical Exclusion under 10 CFR 1021 Subpart D Appendix B. According to this section, projects may be categorically excluded if they meet the requirements of the following citation:

  > "Small-scale, short-term cleanup actions, under RCRA, Atomic Energy Act, or other authorities, less than approximately 5 million dollars in cost and 5 years duration, to reduce risk to human health or the environment from the release or threat of release of a hazardous substance other than high-level radioactive waste and spent nuclear fuel, including treatment (e.g., incineration), recovery, storage, or disposal of wastes at existing facilities currently handling the type of waste involved in the action."

  The scope of work fell within the requirements of 10 CFR 1021, Subpart D, Appendix B and work was performed under a Categorical Exclusion received for D&D activities at ETTP on July 12, 1996.

- For work occurring at facilities under NRC license, radioactive materials license requirements need to be reviewed on a project specific basis.

- Air permits were not required for this deployment and are unlikely to be required elsewhere.

- Because macroencapsulation is a technology-based treatment standard, the process used must be approved by local regulatory agencies as meeting the definition of MACRO, as provided in 40 CFR 268.42, prior to disposal in a RCRA Subtitle C landfill.

- Radiological exposures to personnel must be kept "as low as reasonably achievable" (ALARA) pursuant to DOE regulations.

- The ARROW-PAK macroencapsulation system was permitted for disposal at Envirocare in January 2000. Future deployments must have disposal facility cooperation from the start to ensure compliance with the profile and verification/acceptance criteria at the disposal site.

- A version of the ARROW-PAK macroencapsulation unit had been demonstrated to meet the requirements for DOT 7A Type A certification. However, the version deployed at ETTP was significantly larger and a separate DOT 7A Type A certification evaluation was required. This certification was received on 11/30/99. Future deployments would not require additional certification work unless the configuration of the ARROW-PAK cylinder is modified.

Safety, Risks, Benefits, and Community Reaction

Worker Safety Issues

As in all waste handling operations involving radioactive and hazardous waste and operating equipment, hazards are inherent in the ARROW-PAK process that must be mitigated to operate safely. The main ARROW-PAK process hazards are:

- The localized heating used to fuse the endcaps onto the ARROW-PAK tube can cause severe burns, so precautions for worker safety are necessary.

- Physical safety is an issue as at any construction site due to the heavy equipment used (overhead crane, forklifts with drum handlers). In addition, the overpacks weigh approximately 1,000 pounds, the empty ARROW-PAK approximately 950 pounds, and the loaded ARROW-PAK in excess of 7,900 pounds. Care during loading and unloading activities is essential.

- Level B or C personnel protection is required during compaction and packing the drum pucks into the overpack, depending on waste characteristics and process ventilation. Once the overpack is closed, the packages can be handled with minimal PPE, if allowed by facility permit requirements.

Community Safety, Potential Environmental Impacts and Exposures

The risk to the community of deploying the ARROW-PAK process is very low. Macroencapsulation waste meet LDR requirements, and the physical process used to encapsulate waste has very low accident and release potential. Transportation risk was determined to be acceptable through the DOT certification process. The ARROW-PAK was required to pass “drop tests” in order to be certified a DOT Type 7/7A container, allowing for some assurances in stability of the waste package during transport.

Benefits

The predominant benefits associated with the ARROW-PAK process are:

- Provides opportunities for innovative waste management technology to be used for difficult and costly waste streams

- Can achieve a net waste volume reduction over the conventional macroencapsulation approach

- Can be tailored to site-specific conditions and can be readily incorporated into existing treatment trains at DOE legacy and newly generated waste projects

- Eases handling and shipment of final waste package
- Produces a tough and flexible waste barrier with excellent chemical and physical resistance: durable, leach resistant, compliant with Nuclear Regulatory Commission (NRC) guidelines, and compliant with Resource Conservation and Recovery Act (RCRA) requirements for disposal of mixed waste debris
- Provides potential for cost savings over current site baseline when deployed in a full-scale production mode
- Offers a permanent treatment and disposal solution

Potential Socioeconomic Impacts and Community Perceptions

- ARROW-PAK macroencapsulation has minimal economic or labor force impact.
- No adverse public input regarding ARROW-PAK macroencapsulation technology was received.

SECTION 7
LESSONS LEARNED

Implementation Considerations

Many of the issues that had to be resolved to deploy the ARROW-PAK system at Oak Ridge can be more easily resolved at other sites if the lessons learned at Oak Ridge can be applied effectively. Some of the more prominent lessons learned at Oak Ridge are:

- Each deployment of the ARROW-PAK technology must evaluate the maximum gas generation rate for the target waste stream over the life of the ARROW-PAK to avoid possible concerns for potential pressurization and subsequent containment breach. Chemical compatibility should also be verified for the selected waste stream.

- The ARROW-PAK may require re-certification to meet DOT requirements if modifications are made to the technical specifications (e.g., if a different size of ARROW-PAK is deployed).

- Mobilizations by the compaction subcontractor and by Boh can be optimized by:

  - obtaining a RCRA permit to allow for the staging of waste beyond 90-days and for the subsequent treatment

  - completing the waste compacting prior to mobilizing Boh, allowing the resolution of problems inherent in compacting operations without impacting ARROW-PAK loading schedule

- Loading operations of the ARROW-PAK can be optimized by providing Boh enough lead time to fuse one endcap to the tube prior to mobilization. This reduces the time required to load the ARROW-PAK as only the final endcap must be fused onsite.

- Upfront planning should develop a candidate waste stream, considering the following factors:

  - the ease of profiling newly generated waste versus legacy waste

  - time and cost considerations of re-sizing waste for placement into 55-gallons drums; future projects can incur significant costs to size large-scale D&D waste; thus, contracts will either have to be written to take sizing of waste into account or to add costs for shredding of the waste for loading into 55-gallon drums

  - packing of the waste into drums to optimize packing density

  - components in the waste stream that may evolve liquid under compaction

  - components in the waste stream that may adversely impact the compaction operations

    - asphaltic materials that can seize up the compactor and require that it be shut down and cleaned repeatedly. Each shut down can lose one to two days.

    - asbestos containing material that could become airborne during compaction

- Compaction contract can be optimized by pricing per drum or per stroke costs instead of an hourly cost, improving efficiency and reducing costs

Technology Limitations and Needs for Future Development

The ARROW-PAK endcap “welding” is a critical step in ensuring that the ARROW-PAK enclosure meets all Federal and State waste handling regulations. Therefore, the procedure for this critical step must be reviewed carefully and Boh personnel must be trained and experienced in performing the weld. Additionally, the “weld” monitoring instrumentation must be calibrated and checked routinely. Finally, a trained inspector must inspect the completed “weld”. Boh performed the welding and inspections during deployment at ETTP. The macroencapsulation procedure, training plans, operator training and experience documentation and inspection criteria must be reviewed prior to implementing a site-specific ARROW-PAK encapsulation process. However, this review is expected to identify only minor changes (i.e., ARROW-PAK handling heights, procedures for ensuring specific materials are not encapsulated, etc.) required for the site-specific implementation rather than significant modifications that will delay project implementation and increase project cost.

Technology Selection Considerations

- ARROW-PAK macroencapsulation is a viable treatment option for debris wastes contaminated with low levels of radioactivity and or RCRA contamination.

- ARROW-PAK macroencapsulation has been demonstrated to be effective in the treatment of radioactively contaminated debris wastes.

- Polymers are highly resistant to microbial attack. Ecological concerns over the ability of plastics to resist microbial degradation have precipitated numerous studies on the biodegradability of plastics and potential techniques for enhancing it. All of these studies concluded that, under normal conditions, biodegradation rates for polyethylene are negligible.

- Low levels of ionizing radiation will not adversely impact the structural integrity of the final waste form.

- Polyethylene's resistance to chemical attack is one of the main reasons for its widespread use in many diverse applications. At ambient temperatures, polyethylene is insoluble in virtually all organic solvents and is resistant to many acids and caustic solutions.

APPENDIX A
REFERENCES

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APPENDIX B
ACRONYMS AND ABBREVIATIONS

ALARA	as low as reasonably achievable
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DRS	Decon and Recovery Services of Oak Ridge, LLC
ETTP	East Tennessee Technology Park
FIU	Florida International University
HCET	Hemispheric Center for Environmental Technology
HDPE	high-density polyethylene
INEEL	Idaho National Engineering and Environmental Laboratory
LDPE	low-density polyethylene
LDR	land disposal restriction
MLLW	mixed low-level waste
NEPA	National Environmental Policy Act
NRC	Nuclear Regulatory Commission
OST	Office of Science and Technology
PPE	Personal protection equipment
RCRA	Resource Conservation and Recovery Act
TMFA	TRU and Mixed Waste Focus Area