INNOVATIVE TECHNOLOGY
Summary Report

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Nochar Petrobond® Absorbent Polymer Tritiated Oil Solidification

Deactivation and Decommissioning Focus Area

Prepared for
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Summary Report

Nochar Petrobond® Absorbent Polymer Tritiated Oil Solidification

OST/TMS ID 2313

Deactivation and Decommissioning Focus Area

Demonstrated at
Mound Site
Miamisburg Environmental Management Project
Miamisburg, Ohio

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.

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SECTION 1
SUMMARY

EXECUTIVE SUMMARY

This report provides an analysis of the cost and performance of the Nochar PetroBond® absorbent polymer technology. The Nochar PetroBond® technology was demonstrated at the Mound Large-Scale Demonstration and Deployment Project, in Miamisburg, Ohio, to determine whether it can be used as an absorbent and solidification agent for high-activity tritium vacuum pump oils, thus replacing current baseline methods and technologies at Mound. The Nochar PetroBond® absorbent is a polymer solidifying agent offered by the Nochar, Incorporated. The purpose of this absorbing agent is to perform safe, efficient solidification of radioactive or mixed-waste oils and provide an acceptable means of transportation and disposal. Nochar PetroBond® polymer crystals have been found to be nontoxic, non-biodegradable, and incinerable to less than 0.02% ash with an absorbent capacity of up to 15:1 (oil–to–solidification agent ratio by weight).

In all phases of the demonstration, the Nochar PetroBond® agent formed an acceptable solidified matrix with waste oils. The toxicity characteristics leaching procedure values were found to be below burial-site limits on specific metals. The product proved very easy to use and required no agitation or mixing, thus mitigating concerns about safety and maintaining toxins at levels that are as low as reasonably achievable. Nochar PetroBond® absorbent polymers were used to solidify 9 gallons of tritiated mixed-waste oil with a mixing oil–to–Nochar PetroBond® ratio of 0.6:1, obtaining an average production rate of 0.23 gallons per minute at a unit cost of $800 per gallon of waste oil.

Introduction

The U.S. Department of Energy (DOE) continually seeks safer and more cost-effective technologies for use in decontamination and decommissioning (D&D) of nuclear facilities. To this end, the Deactivation and Decommissioning Focus Area of the DOE Office of Science and Technology (OST) sponsors Large-Scale Demonstration and Deployment Projects (LSDDPs). The DOE National Energy Technology Laboratory manages the LSDDPs, where developers and vendors of improved or innovative technologies showcase products that are potentially beneficial to the DOE projects and others in the D&D community. Benefits sought include decreased health and safety risks to personnel and the environment, increased productivity, and decreased cost of operation.

The Mound facility, in Miamisburg, Ohio, is an ideal candidate for the LSDDP because its closure requires the D&D of a large number of radioactively contaminated facilities. The tritium operations areas in the T building and the SW/R building complex are on the critical path for this closure project.

As safe shutdown operations continue at the Mound facility, innovative technologies are needed to increase the effectiveness of D&D operations and to decrease overall costs and personnel exposure at the Miamisburg Environmental Management Project (MEMP). Significant inventories of tritiated oil from the operation of hundreds of glove boxes and associated pumps, along with the large quantities of tritium that were inventoried at Mound, present a major challenge in meeting the MEMP goals. The challenge in handling and disposal of tritiated oil has evolved as a two-part task:

- The first is a short-term task dealing with the backlog of tritiated waste oil. This oil backlog is restricting the required change from vacuum and vane pump oil in the Main Hill tritium safe shutdown areas. When the pump oil is not changed, it accumulates even higher levels of tritium and hazardous materials.
- The second task involves the long-term disposition or disposal of the oil as mixed waste, including high-activity tritium (HAT) oils.

Vacuum and vane pumps, which were critical to the handling of tritium gas at Mound, required the use of oil in their operation. While in use, the oil becomes contaminated with tritium, which replaces the hydrogen in the oil hydrocarbons. Hazardous chemicals and metals are introduced to the oil through normal operations and include lead, chromium, barium, mercury, and other metals. In some instances cyclohexane was added to the oil during the pump cleaning process to inhibit coagulation. When an oil contains quantities of heavy metal that meet or exceed activity levels established by the Resource Conservation and Recovery Act (RCRA), it is considered mixed waste and must be handled according to RCRA regulations.

This report provides an analysis of the cost and performance of the Nochar PetroBond® absorbent polymer technology. The Nochar PetroBond® technology was demonstrated to determine whether it can be used cost effectively as an absorbent and solidification agent for tritiated vacuum pump oils, thus replacing current baseline methods and technologies at Mound.

Technology Summary

Baseline Technology

As the safe shutdown at the Mound facility continues, one of the main concerns during the process is to protect personnel, the environment, and surrounding communities from the possible spread of radiological and chemical hazards. Baseline approaches such as long-term storage for decay, incineration, and use of organic solidification agents have been considered as options over the past several years to handle tritiated oil.

- Long-term storage for decay

  Long-term storage has been considered over the past decade. Currently at Mound, this option has little feasibility because the site is being converted to a technology park, and businesses are already being sited there. The DOE-approved radioactive thermal generator production facility is the only government-controlled plant that will remain at Mound. Long-term storage for at least 50 years is now a much less attractive option.

- Incineration

  Even though the site currently has a contract with a vendor to burn low-level tritiated oil, incineration becomes a less likely baseline or option due to the extreme cost involved in this service. In addition, oil still has to be transported to an out-of-state facility and thus presents the same shipping hazards and concerns as do contaminants transported to a burial site at a fraction of the cost. Nevertheless, incineration is the only viable baseline technology that can currently be found at Mound. Although an active contract exists for using this service for mixed-waste, low-radioactivity oil, its costs for use with medium- or high-activity oils become prohibitive immediately. This factor is one of the main incentives for identifying an innovative technology.

- Commercially available organic solidification agents

  Clay products for use as solidification agents have been commercially available for almost two decades. They have been used successfully on solidification projects worldwide. However, in almost every instance they have been used in less restrictive or hazardous environments because they require the addition of flammable liquids during the solidification process and the use of heavy-duty mixers. This type of product does not always self-absorb and requires extensive processing and mixing. Research has also shown that very little solidification of tritiated waste has been conducted with this agent. The logistics of using this technology in a highly hazardous tritium environment are very demanding and in most cases are not cost effective. Specialty liners and packages usually used for shipping tritiated waste are not compatible with this product. This type of product is usually mixed in an open 55-gallon drum and requires a four-blade impeller shaft with an industrial mixer, not an item likely to be used in a glove box or tritium environment. The product has a history of leaving pockets, or “islands,” of unabsorbed oil even when it is mixed with the proper equipment. Such results are not acceptable in a mixed-waste, high-profile hazardous environment.

Innovative Technology

The Nochar PetroBond® absorbent product is a proven oil spill and cleanup technology used by major corporations and many governments. The Nochar PetroBond® polymer crystals have been found to be nontoxic, non-biodegradable, and incinerable to less than 0.02% ash with an absorbent capacity of up to 15:1 (oil–to–solidification agent ratio by weight). Nochar PetroBond ® bonds petroleum-based liquids into a carpet-like mass, resulting in waste minimization. The product initiates a mechanical process in which the oily waste or lubricant undergoes polymerization, locking the waste material in a matrix of crystals. Nochar PetroBond® comes in various formulations. Those used during this demonstration were the A610, A650, and A660 formulations (Figure 1) and the newly formulated N990. Table 1 provides a quick overview of these bonding agents.

Table 1.
Overview of Nochar PetroBond® Agents Tested

	A610	A650	A660	N990
Description	Granulated polymer that solidifies petroleum-based liquids into large bonded pieces, resulting in waste minimization	Granulated polymer that bonds hydrocarbon-based liquids such as oil, fuels, and solvents	Granular polymer that stabilizes acid spills by bonding them into a solid waste, providing waste minimization	Granulated polymer that solidifies petroleum-based liquids into large bonded pieces, resulting in waste minimization
Problem	Petroleum or hydrocarbon-based spills	Petroleum or hydrocarbon-based spills	Acid-based spills	Petroleum or hydrocarbon-based spills
Action	Solidifies spill on land or water	Solidifies spill on land or water	Gels or solidifies spill	Solidifies spill on land or water
Result	Large, solid pieces	Solid, carpet-like mass	Gelled or solid pieces, depending on acid	Solid, carpet-like mass
Pick-up ratios*	1:15 by weight	1:10 by weight	Varies with acid	Varies with type of hydrocarbon (1:1 to 5:1 by weight)
Reaction time*	Good	Good	Varies with acid	Good
Fire retarded	No	No	No	No
Packaging	3-lb (1.4-kg) shaker 40-lb (18.2-kg) drum 800-lb (363-kg) bulk box	4-lb (1.8-kg) shaker 40-lb (18.2-kg) drum 900-lb (408-kg) bulk box	4-lb (1.8-kg) shaker 40-lb (18.2-kg) drum 400-lb (181-kg) bulk box	40-lb (18.2-kg) drum 1000-lb (454-kg) bulk box

*Varies with chemical properties, viscosity, concentration, temperature, and desired degree of solidification of the liquid being bonded.

Figure 1. Nochar PetroBond® 600 Series

Demonstration Summary

The Nochar PetroBond® absorbent polymer was demonstrated in July 1999, at the Mound facilities as part of the Mound Tritium D&D LSDDP. The demonstration was performed in three phases:

- Phase I included a bench-scale test of non-radioactive RCRA-defined contaminated oil
- Phase II included a full-scale solidification of clean oil in a U.S. Department of Transportation (DOT)–certified shipping package
- Phase III demonstrated the solidification of tritiated mixed-waste oil in a 22-gallon DOT shipping container

In all phases, the specific formula developed for the Mound waste oil was used. Extensive data were collected in the areas of cost, time and motion study, materials and equipment, man-hours, and other pertinent issues. A toxicity characteristics leaching procedure (TCLP) and durability tests of vibration, rotation, and elevated temperature were performed on all solidified media, with results found to be within Nevada Test Site guidelines. These results initiated limited deployment of this technology at Mound and many other DOE sites. Site administrators are discussing possible deployment at this time.

Key Results

- The agent absorbs oils and lubricating substances with no mixing and does not require mixing equipment. The absorbent capacity is up to 15:1 (oil–to–solidification agent ratio by weight), depending on the material.

- The product is highly dependent on a volatile ingredient to act as a catalyst or primer in the activation of the polymer and its solidification process of the oil.

- Tritiated mixed-waste oil solidification results showed an average production rate of 0.23 gallons per minute and a contamination level of 0.32 curies, based on a 0.6:1.0 oil–to–Nochar PetroBond® mixing ratio.

- Results of TCLP tests on tritiated mixed-waste oil (Phase III) were all under land disposal restriction (LDR) limits. For example, mercury registered 0.00092 mg/l, which is below the LDR limit of 0.025 mg/l.

- The unit cost for solidification of activated oil using Nochar PetroBond® is $800.71 per gallon of waste oil.
- The Nochar PetroBond® product can be effectively used for free-liquid control in storage, transport, and disposal of radioactive and RCRA-defined waste oils.
- Nochar PetroBond® polymer crystals are nontoxic, non-biodegradable, and incinerable to less than 0.02% ash.

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Licensing

There are no issues related to licensing patent, and commercialization is pending

Permitting

A radiological work permit is required for the demonstration.

Other

All published Innovative Technology Summary Reports are available on the OST website at www.em.doe.gov/ost under "Publications." The Technology Management System, also available through the OST website, provides information about DOE Office of Science and Technology (OST) programs, technologies, and problems. The OST reference number for Nochar PetroBond® polymer is 2313.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

Demonstration Goals and Objectives

The overall goal of this demonstration was to assess the benefits that may be derived from using the Nochar PetroBond® polymer to effectively solidify tritiated mixed-waste oils and to enable them to be shipped to the Nevada Test Site under its waste acceptance criteria. The primary goal of the demonstration was to collect valid operational and cost data to make a legitimate assessment of the Nochar PetroBond® polymer. The objectives of this demonstration project were as follows:

- Identify a viable technology option that will adequately solidify tritiated oil for safe and economical shipment and burial site disposal (compared with other baseline technologies) while adequately meeting all governing regulations and requirements.
- Provide overall cost savings for treatment and disposal of tritiated oil.
- Provide improved productivity and ease of deployment.
- Reduce worker exposure by maintaining toxin levels as low as is reasonably achievable.
- Minimize processing times by reducing handling and having minimal setup times.

Technology Description

The Nochar PetroBond® polymer is a polymer solidifying agent marketed by the Nochar, Incorporated of Indianapolis, Indiana, which has extensive experience in oil handling and spill operations. Its products are accepted in many countries around the world and are used extensively throughout the United States. Nochar PetroBond® polymer crystals have been found to be nontoxic, non-biodegradable, and incinerable to less than 0.02% ash and have an absorbent capacity of up to 15:1 (oil–to–solidification agent ratio by weight). The product initiates a mechanical process by which the oily waste or lubricant undergoes polymerization, locking up the waste material in the matrix of the crystals. The TCLP analysis of treated material to date has shown it to be effective at producing acceptable results in meeting burial site waste acceptance criteria. Nochar PetroBond® products are normally shipped and marketed in 4-pound shaker containers and 40-pound fiber drums. For large commercial jobs, the product could potentially be shipped in 1000-pound containers or larger. On small quantities, the purchase price is calculated by the pound and can range as high as $18.65 per pound and as low as $4.53 per pound for more generic products. The company also has the capability of loading designated shipping containers, drums, or liners at the factory for a specific cost-per-container handling charge, thus eliminating costly handling and loading of disposal containers at the site. A view of the crystals, both unabsorbed and absorbed are shown in Figures 2 and 3.

Figure 2. Nochar PetroBond® Crystals, Unabsorbed.

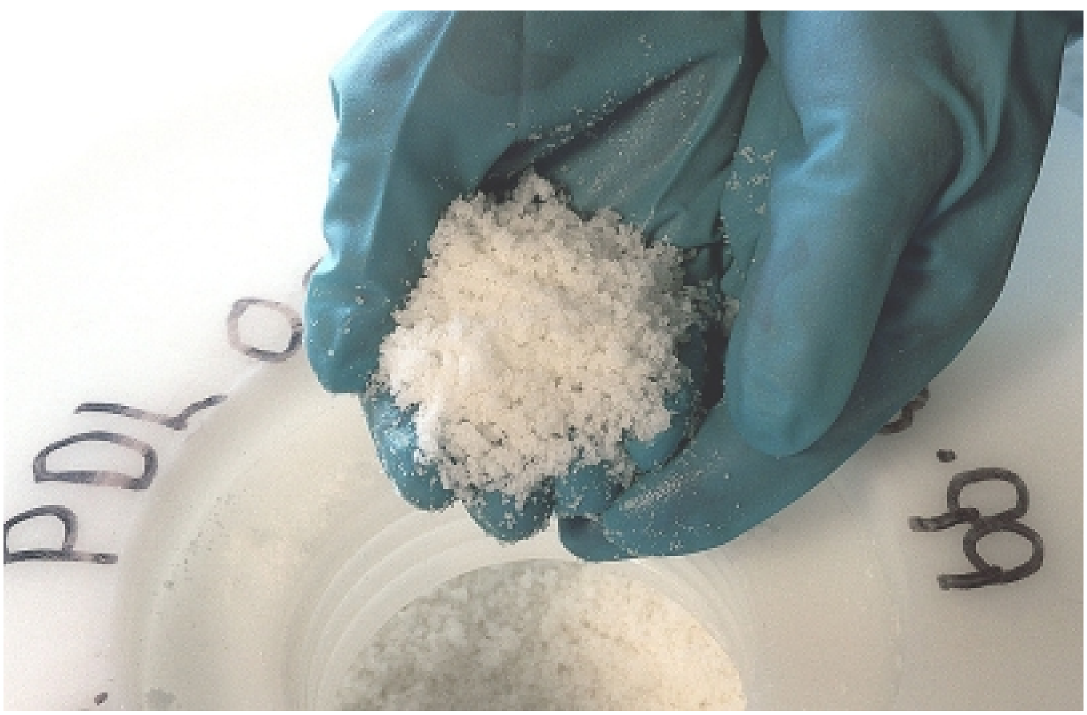

Figure 3. Nochar PetroBond® Absorbed Oil.

System Operation

Table 2 summarizes the operational parameters and conditions of the Nochar PetroBond® polymer demonstration.

Table 2.
Specification and Operational Parameters of Nochar PetroBond®

Working Conditions	
Problem set	Large quantities of HAT-contaminated vacuum pump oil
Problem set locations	T and SW/R buildings
Test performed	Phase I: Bench-scale test of non-radioactive RCRA-defined contaminated oil Phase II: Large-scale test of clean oil as adapted to a DOT-certified shipping package (translucent poly material liner) Phase III: Tritium-contaminated RCRA-defined contaminated oil solidified in a 22.5-gallon poly liner and 30-gallon drum overpack (DOT shipping container)
Action	Solidifies mixed-waste production oils
Appearance and odor	Solid, generally granular, slight hydrocarbon odor in N990
Result matrix	Spongy absorbed material
Waste Management	
Primary waste generated	Solidified waste matrix
Secondary waste generated	Disposable PPE
Waste containment and disposal	All waste generated by the demonstration was handled and disposed of according to the Mound waste management plan
Materials Used	
Work area preparation	Waste oil handling and staging; solidification operations site setup (RWP dress-out)
PPE	PPE dress-out was consistent during solidification operations and consisted of 1 pair of disposable coveralls, cotton glove liners, rubber gloves (reusable), plastic shoe covers or booties, and tape on all openings. No respiratory equipment was required during demonstration operations. In case of fire, an insulating breathing apparatus must be worn because of fumes and dangerous gases.
Health Hazard Data	
Volatility	Varies with the flammability of the liquid being bonded
Reactivity	Avoid strong oxidizing agents
Toxicity	Appendix G of the Mound Detailed Technical Report

DOT, U.S. Department of Transportation; HAT, high-activity tritium; poly, polyethylene; PPE, personal protective equipment; RCRA, Resource Conservation and Recovery Act; RWP radiological work permit.

SECTION 3
PERFORMANCE

Demonstration Plan

The technology assessment was conducted in three phases. Phase I was conducted with two separate bench tests, with each providing acceptable solidified waste TCLP results for hazardous waste burial sites. A total of 30 samples using different types of oils and various ratios of polymers was prepared and analyzed for RCRA TCLP. A summary of the results is presented in Table 3; additional bench-scale test information is presented in Appendix B. Phase II involved physical inspection and paint filter testing of a large quantity (>20 gallons) of solidified material and its performance. Nevada Test Site (NTS)-accepted 22-gallon high-integrity burial liners were used in phase II. During this phase, the container was subjected to hole drilling at the base, and core samples were taken of solidified material, with paint filter tests run on sampled material. No visible standing liquid was observed or found in any of these tests. Table 4 presents a summary of the results obtained during phase II. Phase III involved the actual solidification of tritiated RCRA-defined mixed waste in a hazardous work environment. TCLP and core samples taken again revealed very acceptable results, as observed in the other phases of the demonstration. The tritiated oil demonstration was limited to a maximum of three shipping containers or polyethylene (poly) liners, and a total of 9 gallons of tritiated mixed-waste oil was used. Table 5 presents a summary of the results obtained during this phase of the demonstration. Additional information can be found in Appendix B.

Technology Performance

Table 3.
Performance of Nochar PetroBond® Phase I: Non-Radioactive Oil Solidification

Technology Performance	
Tests performed	Phase I: bench-scale test of non-radioactive RCRA-defined contaminated oil
Problem set locations	Phase I: bench-scale demonstration conducted in R-166, a non-radioactive section of laboratory
Type of evaluation performed	Pass/fail evaluation performed by putting absorbed material in paper filter and performing standard paint filter test TCLP tests performed by Quanterra Environmental Services (St. Louis, MO)
Nochar PetroBond® formula tested	Bench-scale test 1: A610, A650, and A660 Bench-scale test 2: Specifically designed formula, 610V and 650V
Results	Bench-scale test 1: 30 samples tested; 19 passes, 9 fails, 2 N/A 125-ml and 250-ml containers used 50 ml of oil used in oil-to-Nochar ratios of 1:1 and 6:1 Bench-scale test 2: 9 samples tested; 8 passes, 1 N/A 50-ml, 125-ml, and 250-ml containers used in oil-to-Nochar ratios of 1:1, 2:1, and 3:1 TCLP test, bench-scale 1: 0.19 mg/l and 0.040 mg/l (mercury) TCLP test, bench-scale 2: 0.0058 mg/l (mercury)

Table 3. (cont.)
Performance of Nochar PetroBond® Phase I: Non-Radioactive Oil Solidification

Technology Performance	
Comments	Nochar formula was added to container based on predetermined ratios as established during bench test 1. All measurements were made by "weight" using weight scales staged in work area. Confirmation of complete absorption and bonding with agent was performed by visual inspection and probing with laboratory tools. All TCLP analysis was found to be below regulatory limits, but in many cases slightly below. Second bench-scale testing illustrated a dramatic increase in the effectiveness of Nochar to sequester heavy metals (i.e., mercury) when specifically designed formulas (610V and 650V) were used.

N/A, not applicable; RCRA, Resource Conservation and Recovery Act; TCLP, toxicity characteristics leaching procedure; V, virgin product.

Table 4.
Performance of Nochar PetroBond® Phase II: Quality Test

Technology Performance	
Tests performed	Phase II: large-scale (large quantities) test of clean oil as adapted to a DOT-certified shipping package (translucent, high-density poly liner)
Problem set locations	Building 19, a "clean area" building
Type of evaluation performed	Material expansion: observations recorded Moisture check: visual inspection by drilling 4 equally spaced ¼-inch-diameter holes around base of drum Core samples: section of pipe inserted down middle of solidified mixture, with upper end sealed to form a vacuum; core samples examined for liquid and non-absorbed oil EPA standard paint filter test Overall solidification form: visual inspection through translucent poly material of liner
Nochar formula tested	N990 formula
Results	All oil adequately stabilized, with no visible free liquids
Comments	No free liquid observed coming through the paint filter

DOT, U.S. Department of Transportation; EPA, U.S. Environmental Protection Agency; poly, polyethylene.

Table 5.
Performance of Nochar PetroBond® Phase III: Tritiated Mixed-Waste Oil

Technology Performance	
Tests performed	Phase III: tritium mixed-waste oil solidified in three 22.5-gallon poly liner and 30-gallon drum overpack (DOT shipping container)
Problem set locations	Building 23, waste facility
Type of evaluation performed	Time studies: time for complete solidification Core samples: section of pipe inserted down middle of solidified mixture with upper end sealed to form a vacuum; core samples examined for liquid and non-absorbed oil Pass/fail evaluation: EPA standard paint filter test Overall solidification form: visual inspection through translucent poly material of liner
Nochar formula tested	Specially designed Mound formula N990, with catalyst and water stabilization ingredients
Results	Three tests were conducted during this phase; 23 lb of oil versus 40 lb of Nochar formula was used; i.e., an oil-to-formula ratio of 0.6:1 in each container. Solidification occurred in approximately 70 minutes for container 1, with a final volume of 20.4 gallons, which translates to a production rate of 0.28 gal/min. Solidification occurred in approximately 80 minutes for container 2, with a final volume of 20.4 gallons, which translates to a production rate of 0.25 gal/min. Solidification occurred in approximately 120 minutes for container 3, with a final volume of 20.4 gallons, which translates to a production rate of 0.17 gal/min. All three containers passed the EPA standard paint filter test and core sample tests. TCLP test: 0.00092 mg/l (mercury) Amount of radioactivity for all three tests: 0.32 curies per container
Comments	The type of tritiated oils used during phase III included vacuum pump mineral oils, glycol waste lubricants, and polyphenyl ether.

DOT, U.S. Department of Transportation; EPS, U.S. Environmental Protection Agency; gal/min, gallons per minute; lb, pound; poly, polyethylene; RCRA, Resource Conversion and Recovery Act; TCLP, toxicity characteristics leaching procedure.

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

Baseline Technology

The Nochar PetroBond® polymer competes with baseline approaches considered as options at Mound. These baseline approaches include long-term storage for decay, incineration, and commercially available organic solidification agents. Since there is no existing baseline at Mound for treatment or disposal of large quantities of tritiated oils, Nochar Petrobond® is considered an enabling technology.

Competing Technologies

The only competing technologies are manufactured by the Microset Corporation and by Petroset. The Microset Corporation has no interest or experience in the nuclear industry.

Technology Applicability

The Nochar PetroBond® polymer is a fully developed technology that is commercially available for solidification of radioactive and hazardous waste. As a proven oil spill and cleanup technology, the Nochar PetroBond® polymer is used by industry and governments worldwide. At Mound, significant quantities of HAT-contaminated vacuum pump oil contained in over 100 small reservoirs were generated during weapons production activities. The Nochar product holds great promise in providing a solidification agent that may outperform baseline options. Its superior performance during this demonstration makes it a prime candidate for deployment throughout the DOE complex. In addition, the product was found to perform quite effectively on non-hydrocarbon lubricants such as glycol and thus provided a solution to this “problem” waste. The product has good availability and is actively being marketed with an impressive amount of data to support its performance.

Patents, Commercialization, and Sponsorship

The Nochar, Incorporated markets the Nochar PetroBond® polymer. No issues related to patents, commercialization, or sponsorship is pending.

SECTION 5
COST

Methodology

The cost analysis for performing solidification of tritiated mixed-waste oil using the Nochar PetroBond® polymer is based on the assumption that the D&D facility requires a method of disposing of radioactive mixed-waste oil. The Mound facility has a specific need to dispose of HAT-contaminated vacuum pump oil. This analysis uses data presented to the cost engineer to determine the unit cost for the solidification and disposal of the waste. The effects of various cost drivers on unit cost are analyzed to determine the impact of various applications (U.S. Army Corps of Engineers 2000).

Significant assumptions are as follows:

- The amount of waste is limited and would not support significant economies of scale.
- The solidification process will move to the location of the waste (i.e., waste will not be centralized).
- D&D project life is 6 years (based on the present schedule at Mound).
- These testing data are representative of actual use.

The lead test engineer Polymer at the Mound facility gathered the data for this cost analysis from field-testing of the Nochar PetroBond® polymer. The field tests consisted of several activities, which can be summarized as start-up, mobilization, solidification, and demobilization. The tests involved preparation, solidification, and disposal of 9 gallons of radioactive petroleum waste. The waste material was pumped from the in-place oil reservoirs into an engineered container in which the solidification agent had been previously placed. Time and cost data were collected for all activities during all test phases.

The raw test data are included in Appendix C. This cost analysis uses the following operations data:

- Item 24–26: start-up costs
- Item 36–38: mobilization costs
- Item 39–42: task execution and operations costs
- Item 43–45: demobilization costs

Cost Analysis

There was no baseline cost analysis for the Nochar PetroBond® polymer because it is an enabling technology. Thus, a unit cost was determined and used to evaluate the potential cost savings for various alternatives. The unit cost was developed for solidifying a gallon of waste oil. Total unit cost is defined as the sum of the following costs:

- Labor: based on the specific operators for each system
- Materials: items expended during the operation
- Equipment: defined as ownership costs per unit operation
- Disposal: inclusive of transportation and fees
- Personnel protective equipment

Equipment costs are calculated using the U.S. Army Corps of Engineers guide EP 1110-1-8. The equipment cost for this activity is the cost of a transfer pump. It is assumed that the pump will be used for transferring 60 gallons of material. The actual life of the pump is much longer, but because of the operating conditions found in working in a radiologically contaminated area and the associated decontamination requirements, along with the inability to use the pump in a lower-activity area after use in a higher-activity area, this life limitation was judged reasonable.

Disposal costs for a full truckload of waste were provided in the raw data for this operation. These costs were used to estimate the cost of disposal of 1 gallon, assuming a full load of waste was being shipped.

The personal protective equipment costs were defined in the raw data (Appendix C).

The unit price calculation is exclusive of the cost described earlier as start-up. These costs are considered to be one-time expenditures unique to each site. As such the unit cost is defined to include only those costs that each site implementing this operation would be expected to incur. Start-up costs and unit cost are discussed separately.

Start-up costs are calculated to be a total of 142.8 man-hours, or $8,244.60 (it should be noted that start-up involves labor cost only). This cost varies based on the specific facility requirements for the preparation of the work and safety plan and the level of review required by each facility. Start-up costs are representative of the following work tasks, which are assumed to be required by each facility where use of this technology would be attempted. The following work tasks are related to start-up:

- Acquire supplies and materials.
- Conduct walk-through inspection of facilities.
- Notify facility managers.
- Place project on “plan of day” schedule.
- Obtain sign-on for safety and health plan.
- Complete “hot” work package.

Discussions with the project engineer lead to the assumption that these tasks represented 40% of the total time for activity 24 and 25 through 26, as shown in the raw data work sheets (Appendix C, Table C.1). This start-up cost element is presented as a separate cost because the applicability of its elements to other sites is not as consistent as the applicability of the unit cost. However, the cost is presented here as a reasonable estimating tool. The remaining 60% of the time shown in item 24 is deemed to be test specific and should not need to be duplicated at an implementation site.

Two cost estimates have been prepared using the Micro Computer-Aided Cost Engineering System cost system (Appendix C, Tables C1 and C2). The basic unit cost analysis is the development of the unit cost based on the raw data and the corrections discussed above. Table 6 is a summary of the estimate costs.

Table 6.
Summary of Costs from Basic Unit Cost Analysis Estimate

Operation Title	Man-hours	Labor Cost, $	Equipment Cost, $	Material Cost, $	Unit Cost D/T, $	Total Cost, $
Set up or construct temporary facility	5	249	0	2499	0	2748
Dismantling activities	34	2251	85	60	0	2396
Disposal (commercial)	18	799	0	0	578	1377
Final decontamination	10	553	0	0	0	553
Personal protective equipment	0	0	0	132	0	132
Totals	67	3852	85	2691	578	7206

D/T, disposal and transportation.

For the total listed in Table 6, the amount of product solidified was 9 gallons of waste oil. Thus, the unit price is $800.71 per gallon. This unit cost is inclusive of all costs associated with the activity except the start-up as discussed earlier. The base production rate for that unit cost is 7.4 man-hours per gallon.

The second estimate is based on a large increase in the volume of waste oil to be solidified (Appendix C, Table C2). The total volume of HAT vacuum pump oil at Mound is about 100 gallons, and this estimate is based on solidifying that total. The summary of the cost estimate is presented in Table 7.

Table 7.
Summary of Costs from Ramped-Up Unit Cost Analysis Estimate

Operation Title	Man-hours	Labor Cost, $	Equipment Cost, $	Material Cost, $	Unit Cost D/T, $	Total Cost, $
Set up or construct temporary facility	56	2766	0	27,765	0	30,531
Dismantling activities	311	21,135	946	669	0	22,750
Disposal (commercial)	117	6,116	0	0	6,428	12,544
Final decontamination	111	6,149	0	0	0	6,149
Personal protective equipment	0	0	0	1,449	0	1,449
Totals	594	36,166	946	29,884	6428	73,423

D/T, disposal and transportation.

The total amount of product solidified for the total in Table 7 is 100 gallons of waste oil. Thus, the unit price is $734.23 per gallon. This unit cost is inclusive of all costs associated with the activity except the start-up, as discussed earlier. As shown, the unit cost for this operation is rather static.

Cost Conclusions

The unit cost for solidification of tritiated mixed-waste oil using the Nochar PetroBond® polymer is estimated (see Table 6) to be $800.71 per gallon of oil. At first glance, this cost appears high. However, extensive research conducted by the Mound test engineer indicates that other possible alternatives would cost much more. Rough estimates for incineration suggest that the cost would be in the range of $50,000 per gallon of oil, based on previous incineration contracts. Thus, the unit cost for the Nochar PetroBond® polymer appears more than reasonable.

SECTION 6
REGULATORY AND POLICY ISSUES

Regulatory Considerations

In accordance with Ohio Environmental Protection Agency regulations and requirements in Sections 3745-51-04 (E) and (F), "Treatability Studies," all oils used in the demonstration were accounted for, so as to not exceed amounts authorized at Mound for treatability studies only. The waste acceptance criteria specified for burial at the Nevada Test Site have been met. TCLP values (see Table 5) are acceptable by several magnitudes at this participating burial site for Mound mixed waste (Brunkow 2000).

No other special regulatory considerations were required to demonstrate or implement this technology. However, prior to the initiation of the demonstration, job-specific radiological work permits were required for work within the tritium contamination area. All waste materials involved in the demonstration were disposed of in proper waste stream containers, as required by Mound waste management procedures. Also, all personal protective equipment was deposited and disposed of in the proper waste receptacles, as required. All personnel involved in the project met site regulatory and procedural requirements for work in the radiological and Occupational Safety and Health Administration–defined areas, including all medical, training, qualifications, and experience criteria.

Safety, Risks, Benefits, and Community Reaction

During the course of this demonstration, all personnel working in a controlled area were required to wear the appropriate personal protective equipment to perform work and did so. While radiological control technicians collected swipes in the contamination area to support ongoing work, they wore the appropriate personal protective equipment as required by the radiological work permit. Procedurally required tritium monitoring equipment was in service and properly calibrated while all tritiated oil waste was solidified. In one instance, a work stoppage was ordered because of tritium activity levels recorded by the continuous air monitor. Levels subsided and work continued shortly afterward. Properly inspected laboratory hoods were used for all bench tests performed in the R-166 laboratory. When handling lab samples, the radiological control technicians and other workers wore surgical gloves, face shields, and lab coats. All solidified waste was handled and stored in accordance with site safety procedures. All waste generated from the demonstration was properly disposed of, controlled, and handled in accordance with Mound waste management policies.

Further evaluation of this technology has not revealed any community safety issues or environmental impact. If the demonstrated technology does prove to be a viable alternative or supplement to the existing technology, it is anticipated that the data from this demonstration would be sufficient to solicit regulatory acceptance and industry-wide deployment of the demonstrated technology.

SECTION 7
LESSONS LEARNED

Implementation Considerations

The innovative technology demonstrated was found to be a viable solution to the Mound mixed-waste problem. By reviewing the performance of this technology, it is apparent that it is the best alternative, from an economic and technological standpoint, to be used for this critical path task in the D&D of the Mound facility. The reasons for this determination are presented throughout this report.

Technology Limitations and Needs for Future Development

Few negative issues were identified in evaluating this innovative technology and comparing it to any baseline technologies that show some promise of feasibility. Some limitations that were identified included the following:

- Familiarization training of the various Nochar formulas (i.e., mixtures of polymers) is required. Due to complex oil-liquid “mixtures” usually found in waste reservoirs, use of the product requires oversight and control by a knowledgeable technician.
- This technology could entail some concerns regarding non-radioactive airborne material in the handling of the dry product in large quantities, as given on the material safety data sheets (Brunkow 2000) for the products.
- The product requires a primer or catalyst composed of a flammable volatile liquid.
- The technology will not solidify oils with detergent additives.
- The technology will not produce a hard or concrete-like solid consistency, if that is what is needed as the final product or to meet burial site waste acceptance criteria.
- Using high levels (i.e., >50 ppm mercury) of heavy metals may result in a final solidified product that exceeds TCLP requirements.

Technology Selection Considerations

The positive results realized from this technology and identified throughout this report can be summarized as follows:

- Ability of the product to solidify in a slurry-type mixture that allows repackaging if needed and safe transfer to incineration facilities if implemented with non–mixed waste, low-activity oil.
- Ability to burn the solidified product with a very low level of residue and/or ash.
- Availability of the product immediately and in large quantities, including 1000-pound containers and truckload shipments for up to a 20% discount off small-quantity prices.
- One of the few “streamlined” task-oriented oil solidification or stabilization agents being marketed today.
- Minimal increase in solidified waste volume.
- Premixed formulas requiring little, if any, mixing of ingredients and allowing quick and efficient solidification, thus resulting in contaminant levels that are as low as reasonably achievable in a hazardous and/or radiologically controlled environment.
- Ability of the Nochar, Inc., with its technical expertise, to custom-design a formula for most situations and most liquid-waste scenarios.
- Ability of the Nochar, Inc., to preload waste disposal containers with the product and ship containers back to the waste site (loaded at the factory) with the agent for even more streamlined solidification operations.

Recommendations

The Nochar PetroBond® technology proved to be safe, clean, and highly effective in reducing material handling and resultant exposures. It was found that the product is highly dependent on a volatile ingredient to act as a catalyst or primer in the activation of the polymer and its solidification process on the oil. This requirement, along with the combination of ingredients that may be required for solidification of specific oil-and-water combinations and other additives or substances that can be found in waste oils, necessitates technical expertise from company representatives on the use and deployment of this product. Another important issue requiring this expertise is the speed at which the product solidifies some materials. If solidification is too fast, the mixture may “crust over” and not allow the non-solidified liquid to filter down into the agent and complete the process. Analysis and recommendations from a technical specialist are needed to identify the proper formula or combination of agents required, based on the characterization and analysis of the waste oil to be disposed of.

APPENDIX A
REFERENCES

Brunkow, W. G. April 30, 2000. *Detailed technology report for the Nochar PetroBond® absorbent polymer tritiated oil solidification demonstration at Mound.* Morgantown, W. Va.: U.S. Department of Energy, National Energy Technology Laboratory.

U.S. Army Corps of Engineers. Louisville District. March 14, 2000. *Nochar Cost Analysis.*

APPENDIX B
TESTS DATA

Table B.1.
Phase I: Bench-Scale Test 1 Data Results

Sample No.	Con-tainer Size, ml	Solidifi-cation Agent	Oil Type*	Container Weight, g	Amount of Nochar Required, g	Weight of Container + Nochar, g	Oil Initial Volume, ml	Nochar Initial Volume, ml	Weight of Oil, g	Actual Amount of Nochar Added, g	Weight of Solid Mass, g	Start Time	Stop Time	Final Volume (ml)**	Ratio of - Oil to Nochar Used	Pass / Fail ***	Comments
1	125	A 650	DuoSeal	111	43	154	50	100	43	43	86	0920	[1]	125	1/1	P	Oil only
2	125	A 650	DuoSeal	111	7	118	50	20	43	7	50	0935	[1]	60	6/1	F	Oil only
3	125	A 650	Duo/Cat	111.2	43	154.2	50	100	43	43	86	1116	[1]	125	1/1	P	Oil & Cat.
4	125	A 650	Duo/Cat	112	7	119	50	15	43	7	50	1115	[1]	60	6/1	F	Oil & Cat.
5	250	A610	Inland	182	42	224	50	180	42	42	84	0940	[1]	250	1/1	P	Oil only
6	125	A610	Inland	111	7	118	50	20	42	7	49	0945	[1]	75	6/1	P	Oil only
7	250	A660 / A610	Duo/Wat	181.5	7	188.5	50	15	43	7	50	1030	[1]	60	6/1	F	[2]
8	125	A660 / A610	Duo/W/C	111.2	7	118.2	50	15	43	7	50	1035	[1]	70	6/1	F	[3]
9	125	A660 / A610	Duo/Wat	111.2	7	118.2	50	15	43	7	50	1045	[1]	75	6/1	P	[4]
10	125	A660/A610	Duo/W/C	111.2	7	118.2	50	15	43	7	50	1050	[1]	70	6/1	P	[5]
11	250	A 610	Inld/Cat	183.5	43	226.5	50	180	43	43	86	1125	[1]	240	1/1	P	10% Cat.
12	125	A 610	Inld/Cat	111	7	118	50	20	42	7	49	1230	[1]	75	6/1	P	10% Cat.
13	250	A 610	Inld/Cat	182	42	224	50	180	42	42	84	1240	[1]	240	1/1	P	20% Cat.
14	125	A 610	Inld/Cat	111	7	118	50	20	42	7	49	1250	[1]	60	6/1	P	20% Cat.
15	125	A 650	Duo/Cat	112	43	155	50	100	43	43	86	1305	[1]	125	1/1	P	30% Cat.
16	125	A 650	Duo/Cat	111	7	118	50	15	43	7	50	1310	[1]	60	6/1	F	30% Cat.
17	125	A 650	Duo/Cat	111	43	154	50	100	43	43	86	1315	[1]	125	1/1	P	50% Cat.
18	125	A 650	Duo/Cat	112	7	119	50	15	43	7	50	1320	[1]	60	6/1	P	50% Cat.
19	125	A 650	Ultima	111	48	159	50	105	48	48	96	1330	[1]	125	1/1	F	Ultima
20	250	A 610	Ultima	183	48	231	50	190	48	48	96	1335	[1]	230	1/1	P	Ultima
21	250	A 610	DuoSeal	181	43	224	50	170	43	43	86	1340	[1]	220	1/1	P	10%PreL
22	250	A 610	DuoSeal	184	7	191	50	20	43	7	50	1345	[1]	75	6/1	P	10%PreL
23	250	A 610	DuoSeal	184	43	227	50	170	43	43	86	1350	[1]	230	1/1	P	20%PreL
24	250	A 610	DuoSeal	182	7	189	50	15	43	7	50	1355	[1]	60	6/1	F	20%PreL
25	250	A 610	DuoSeal	184	43	227	50	170	43	43	86	1400	[1]	240	1/1	P	30%PreL
26	125	A 610	DuoSeal	111	7	118	50	15	43	7	50	1405	[1]	65	6/1	F	30%PreL
27	250	A 650	Inland	181	43	224	50	80	43	43	86	1410	[1]	150	1/1	P	10%PreL
28	125	A 650	Inland	111	7	118	50	15	43	7	50	1420	[1]	60	6/1	F	10%PreL
29	125	N/A	Inland	111	N/A	N/A	50	N/A	42	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30	125	N/A	DuoSeal	112	N/A	N/A	50	N/A	43	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Stop time and examination time conducted 4 days after sample start time.
[2] Oil + 10% water mixture, water/oil formula used 1 part A660 to 4 parts A610.
[3] Oil + 10% water + 10% catalyst, water / oil formula used 1 part A660 to 4 parts A650.
[4] Oil + 20% water, water / oil formula used 1 part A660 to 4 parts A610.
*   DuoSeal oil has a density of 43 g/50 ml. Inland 19 oil has a density of 42 g/50 ml.
** Final volumes as reported are rough estimations.
***Pass/fail evaluations are based only on visual observations and how well oil appeared to be absorbed.
C or Cat, catalyst; N/A, not applicable; PreL, Nochar product preloaded with catalyst (paint thinner); W or Wa, water; Duo, DuoSeal oil; Inld, Inland 19 oil; Ultima, scintillation fluid.

Table B.2.
Phase I: Bench-Scale Test 1 TCLP Results

Client: BWXT of Ohio, Inc.
One Mound Rd, Attn: Dr. Eugene Jendrek
Miamisburg, OH 45343
Project: DOE Mound

Sample Date: 03/11/99
Receipt Date: 03/17/99
Report Date: 04/01/99
Quanterra Project No.:145.04

Category: TCLP Metals

Matrix: Solid

Quanterra ID: 20899-001
Client ID: OO1

Analyte	Method	Extraction Date	Prep Date	Analyses Date	Result	Units	Detection Limit	Reg. Limit	Dilution
Mercury	EPA7470	3/22/99	3/25/99	3/25/99	0.19	mg/l	0.0080	0.20	40
Arsenic	EPA6010	3/22/99	3/27/99	3/28/99	0.010	mg/l	0.040	5.0	4
Barium	EPA6010	3/22/99	3/27/99	3/28/99	0.24	mg/l	0.80	100.0	4
Cadmium	EPA6010	3/22/99	3/27/99	3/28/99	0.0042	mg/l	0.020	1.0	4
Chromium	EPA6010	3/22/99	3/27/99	3/28/99	0.085	mg/l	0.040	5.0	4
Copper	EPA6010	3/22/99	3/27/99	3/28/99	0.12	mg/l	0.10		4
Lead	EPA6010	3/22/99	3/27/99	3/28/99	0.14	mg/l	0.012	5.0	4
Selenium	EPA6010	3/22/99	3/27/99	3/28/99	0.013	mg/l	0.020	1.0	4
Silver	EPA6010	3/22/99	3/27/99	3/28/99	0.010	mg/l	0.040	5.0	4
Zinc	EPA6010	3/22/99	3/27/99	3/29/99	0.16	mg/l	0.080		4

Quanterra ID: 20899-017
Client ID: O25

Analyte	Method	Extraction Date	Prep Date	Analyses Date	Result	Units	Detection Limit	Reg. Limit	Dilution
Mercury	EPA7470	3/22/99	3/25/99	3/25/99	0.040	mg/l	0.0080	0.20	4
Arsenic	EPA6010	3/22/99	3/27/99	3/29/99	0.010	mg/l	0.040	5.0	4
Barium	EPA6010	3/22/99	3/27/99	3/29/99	0.061	mg/l	0.80	100.0	4
Cadmium	EPA6010	3/22/99	3/27/99	3/29/99	0.0057	mg/l	0.020	1.0	4
Chromium	EPA6010	3/22/99	3/27/99	3/29/99	0.0072	mg/l	0.040	5.0	4
Copper	EPA6010	3/22/99	3/27/99	3/29/99	0.014	mg/l	0.10		4
Lead	EPA6010	3/22/99	3/27/99	3/29/99	0.052	mg/l	0.012	5.0	4
Selenium	EPA6010	3/22/99	3/27/99	3/29/99	0.012	mg/l	0.020	1.0	4
Silver	EPA6010	3/22/99	3/27/99	3/29/99	0.010	mg/l	0.040	5.0	4
Zinc	EPA6010	3/22/99	3/27/99	3/29/99	0.19	mg/l	0.080		

Quanterra ID: 20899-012
Matrix: Oil (raw, nonsolidified)
Client ID: O30

Analyte	Method	Extraction Date	Prep Date	Analyses Date	Result	Units	Detection Limit	Reg. Limit	Dilution
Mercury	EPA7470	3/18/99	3/30/99	3/30/99	7.60	mg/l	2.0	0.20	10,000
Arsenic	EPA6010	3/18/99	3/27/99	3/29/99	0.25	mg/l	1.0	5.0	100
Barium	EPA6010	3/18/99	3/27/99	3/29/99	0.12	mg/l	20.0	100.0	100
Cadmium	EPA6010	3/18/99	3/27/99	3/29/99	0.16	mg/l	0.50	1.0	100
Chromium	EPA6010	3/18/99	3/27/99	3/29/99	0.18	mg/l	1.0	5.0	100
Copper	EPA6010	3/18/99	3/27/99	3/29/99	0.83	mg/l	2.50		100
Lead	EPA6010	3/18/99	3/27/99	3/29/99	3.60	mg/l	0.30	5.0	100
Selenium	EPA6010	3/18/99	3/27/99	3/29/99	0.29	mg/l	0.50	1.0	100
Silver	EPA6010	3/18/99	3/27/99	3/29/99	0.25	mg/l	1.0	5.0	100
Zinc	EPA6010	3/18/99	3/27/99	3/29/99	3.90	mg/l	2.0		100

Table B.3.
Phase I: Bench-Scale Test 2 Data Results

Sample No.	Container Size, ml	Solidification Agent	Oil Type	Container Weight, g	Amount of Nochar Required, g	Weight of Container + Nochar	Oil Initial Volume, ml	Nochar Initial Volume, ml	Weight of Oil, g	Actual Amount of Nochar Added, g	Weight of Solid Mass, g	Start Time	Stop Time	Final Volume, ml	Ratio of - Oil to Nochar Used	Pass/ Fail	Comments
5/12/99																	
1	125	Formula	Duo/ Wat	121	24	145	N/A	100	24	24	48	1445	1630	105	1/1	P	
2	125	Formula	Duo/ Wat	120	17	137	N/A	60	34	17	51	1452	1630	105	2/1	P	
3	125	Formula	Duo/ Wat	121	18	139	N/A	60	54	18	72	1501	1630	105	3/1	P	
4	250	610-V	Duo/ Wat	193	44	237	N/A	190	44	44	88	1522	1630	240	1/1	P	
5	250	610-V	Duo/ Wat	193	36	229	N/A	130	72	36	108	1536	1630	240	2/1	P	
6	125	N/A	Duoseal	N/A	N/A	N/A	125	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Baseline oil sample
5/19/99																	
7	50	Formula	Synth	87	14	101	N/A	50	28	14	42	1331	1700	50	2/1	P	
8	50	610-V	Synth	87	13	100	N/A	50	13	13	26	1345	1700	50	1/1	P	
9	50	650-V	Synth	86	22	108	N/A	50	22	22	44	1402	1700	50	1/1	P	

Duo, DuoSeal oil; N/A, not applicable; Synth, synthetic oil; V, virgin product; Wat, water.

Table B.4.
Phase I: Bench-Scale Test 2 TCLP Results

Sample Id	Hg	As	Ba	Cd	Cr	Cu	Pb	Sn	Ag	Zn	Dilution
Reg Limit mg/L	0.2	5.0	100	1.0	5.0		5.0	1.0	5.0		
Inst Det Limit	0.0001	0.0018	0.0042	0.0002	0.0016	0.0010	0.0012	0.0024	0.0009	0.0005	
B2 SAMPLE 01	0.0058	<0.0072	0.0200	0.0030	<0.0064	0.0420	0.0160	0.0130	0.0110	0.16	4X
B2 SAMPLE 02											
B2 SAMPLE 03											
B2 SAMPLE 04	0.0063	<0.0072	0.0500	0.0017	<0.0064	0.0260	0.0210	0.0096	0.0077	0.19	4X
B2 SAMPLE 05											
B2 SAMPLE 06	3.40	<0.18	<0.42	0.07	<0.16	1.00	1.20	<0.24	<0.09	3.00	100X
	Sample 06 was diluted X1,000 for Hg										

Note: Samples 02, 03, and 05 were sacrificed because of laboratory problems that developed, as advised by Quanterra Environmental Services.

TCLP, toxicity characteristics leaching procedure; Inst Det Limit, Instrumentation Detection Limit.

Table B.5.
Phase III: Tritiated Mixed-Waste Oil Solidification Data Results

Sample No.	Container Size, gal	Solidification Agent	Oil Type*	Container Weight, lb	Amount of Nochar Required, lb	Weight of Container + Nochar, lb	Oil Initial Volume, gal	Nochar Initial Volume, gal	Weight of Oil, lb	Actual Amount of Nochar Added, lbs	Weight of Solid Mass, lb	Start Time	Stop Time	Final Volume, gal	Ratio of Oil to Agent Used	Pass/Fail	Contamination, Level (curie)
1	22.5	Formula	1, 2, 3	25.5	40	65.5	3	15.5	23	40	63	1333	1443	20.4	0.6:1	P	0.32
2	22.5	Formula	1, 2, 3	25.5	40	65.5	3	15.5	23	40	63	1348	1513	20.4	0.6:1	P	0.32
3	22.5	Formula	1, 2, 3	25.5	40	65.5	3	15.5	23	40	63	1405	1602	20.4	0.6:1	P	0.31

Note: Testing was conducted in Building 23, a waste facility, on August 29, 1999. One gallon of each oil waste was used per liner.

*1 = 1 gal vacuum pump mineral oils; 2 = 1 gal glycol waste lubricant; 3 = 1 gal polyphenol ether (Mixture = 3 gallons total)

Table B.6.
Phase III: Tritiated Mixed-Waste Oil Solidification TCLP Results

Sample No.	Lab No.	Date Sampled	Prep Date	Analy-sis Date	Phs	Analyze	Result	Units	RL, mg/l	Fg	Detect-ion Limits	Dilu-tion	Blank*	Method	SW-486**
NC830	22033-001	8/30/99	9/9/99	9/9/99	Solid	Mercury	.00092	mg/l	0.2		.0008	4	QCBLK206777-1	TCLP Metals	EPA 7470
NC830	22033-001	8/30/99	9/8/99	9/8/99	Solid	Arsenic	ND	mg/l	5	U	1.2	4	QCBLK206552-1	TCLP Metals	EPA 6010
NC830	22033-001	8/30/99	9/8/99	9/8/99	Solid	Barium	ND	mg/l	100	U	0.8	4	QCBLK206552-1	TCLP Metals	EPA 6010
NC830	22033-001	8/30/99	9/8/99	9/8/99	Solid	Cad-mium	0.014	mg/l	1	B	0.02	4	QCBLK206552-1	TCLP Metals	EPA 6010
NC830	22033-001	8/30/99	9/8/99	9/8/99	Solid	Chrom-ium	0.0047	mg/l	5	B	0.04	4	QCBLK206552-1	TCLP Metals	EPA 6010
NC830	22033-001	8/30/99	9/8/99	9/8/99	Solid	Copper	0.12	mg/l			0.1	4	QCBLK206552-1	TCLP Metals	EPA 6010
NC830	22033-001	8/30/99	9/8/99	9/8/99	Solid	Lead	0.29	mg/l	5	B	0.4	4	QCBLK206552-1	TCLP Metals	EPA 6010
NC830	22033-001	8/30/99	9/8/99	9/8/99	Solid	Selen-ium	ND	mg/l	1	U	1	4	QCBLK206552-1	TCLP Metals	EPA 6010
NC830	22033-001	8/30/99	9/8/99	9/8/99	Solid	Silver	ND	mg/l	5	U	0.04	4	QCBLK206552-1	TCLP Metals	EPA 6010
NC830	22033-001	8/30/99	9/8/99	9/8/99	Solid	Zinc	0.071	mg/l		B	0.08	4	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	EXTBLK20 6439-1	9/7/99	9/9/99	9/9/99	Solid	Mercury	ND	mg/l	0.2	U	.0008	4	QCBLK206777-1	TCLP Metals	EPA 7470
N/A	EXTBLK20 6439-1	9/7/99	9/8/99	9/8/99	Solid	Arsenic	ND	mg/l	5	U	1.2	4	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	EXTBLK20 6439-1	9/7/99	9/8/99	9/8/99	Solid	Barium	ND	mg/l	100	U	0.8	4	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	EXTBLK20 6439-1	9/7/99	9/8/99	9/8/99	Solid	Cad-mium	ND	mg/l	1	U	0.02	4	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	EXTBLK20 6439-1	9/7/99	9/8/99	9/8/99	Solid	Chrom-ium	ND	mg/l	5	U	0.04	4	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	EXTBLK20 6439-1	9/7/99	9/8/99	9/8/99	Solid	Copper	ND	mg/l		U	0.1	4	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	EXTBLK20 6439-1	9/7/99	9/8/99	9/8/99	Solid	Lead	ND	mg/l	5	U	0.4	4	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	EXTBLK20 6439-1	9/7/99	9/8/99	9/8/99	Solid	Selen-ium	ND	mg/l	1	U	1	4	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	EXTBLK20 6439-1	9/7/99	9/8/99	9/8/99	Solid	Silver	ND	mg/l	5	U	0.04	4	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	EXTBLK20 6439-1	9/7/99	9/8/99	9/8/99	Solid	Zinc	0.012	mg/l		B	0.08	4	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	QCLCS206 552-1	9/8/99	9/8/99	9/8/99	Solid	Arsenic	102	%rec	5			1	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	QCLCS206 552-1	9/8/99	9/8/99	9/8/99	Solid	Barium	102	%rec	100			1	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	QCLCS206 552-1	9/8/99	9/8/99	9/8/99	Solid	Cad-mium	100	%rec	1			1	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	QCLCS206 552-1	9/8/99	9/8/99	9/8/99	Solid	Chrom-ium	98	%rec	5			1	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	QCLCS206 552-1	9/8/99	9/8/99	9/8/99	Solid	Copper	99	%rec				1	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	QCLCS206 552-1	9/8/99	9/8/99	9/8/99	Solid	Lead	96	%rec	5			1	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	QCLCS206 552-1	9/8/99	9/8/99	9/8/99	Solid	Selen-ium	99	%rec	1			1	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	QCLCS206 552-1	9/8/99	9/8/99	9/8/99	Solid	Silver	99	%rec	5			1	QCBLK206552-1	TCLP Metals	EPA 6010
N/A	QCLCS206 552-1	9/8/99	9/8/99	9/8/99	Solid	Zinc	97	%rec				1	QCBLK206552-1	TCLP Metals	EPA 6010

* Form documenting results of water run-through analysis.
** Quality control document number for solid waste.
B, between regulatory report and instrumentation limit; EPS, U.S. Environmental Protection Agency; Fg, flag; N/A, not applicable; ND, no data; Phs, phase; rec, recovery; RL, regulatory limit; TCLP, toxicity characteristics leaching procedure; U, undetected.

APPENDIX C
TECHNOLOGY COST ANALYSIS

Table C.1.
Demonstration Raw Data

Task No.	Description	Man-hours	Worker Type	Materials
24	Task or demonstration preparation: write procedures and get site-required approvals, review and implement all safety documents, set up and initiate chain of custody, acquire all supplies and materials, conduct walk-through inspection and reserve facilities, complete work package, notify building managers, schedule placed on "plan of the day," HASP sign on and review, complete "hot" work package, miscellaneous site-specific requirements. (Note: work was conducted in a radiologically contaminated area.)	200 80 32	Engineer 1 Engineer 2 Engineer 3	
25	Pre-job briefing preparation, schedule, and notification	8	Engineer	
26	Conduct pre-job briefing with question-and-answer period	1 1 1 1 1 1 1 1 1 1	Engineer 1 Engineer 2 Operator Demo technician Demo technician Waste specialist Safety specialist Project manager RCT RCT	
36	Disposal liner acquisition (22.5-gal, medium density)	1.75	Engineer	3 poly liners @ $88.95
37	Nochar loaded in liner @ 40 lb per liner	1.5	Demo technician	$744 per 40 lb of Mound formula
38	Receiving and movement of preloaded liners to work site	1.75	Demo technician	
39	Waste oil handling and staging at work site	1 1	Demo technician Engineer	+RWP dress-out +RWP dress-out

		1	RCT	+RWP dress-out
40	Solidification operations site setup	8 4 2 2 4	Demo technician Engineer Operator RCT RCT	+RWP dress-out +RWP dress-out +RWP dress-out +RWP Dress out Spill pads, 6 @ $2.00 Peristaltic transfer pump @ $375.00 Tygon® tube, 8 feet @ $1.50 per foot Oil cleanup treated wipes, 3 packages, @ $3.75 Decontamination materials, $25.00 *Waste disposal bags

Table C.1. (cont.)
Demonstration Raw Data

Task No.	Description	Man-hours	Worker Type	Materials
41	Solidification operations: with everything staged, oil is pumped into a liner of Nochar. No mixing or other mechanical movement is necessary; oil only needs to be transferred and observed. (Note: data are supplied for a total of 3 drums solidified.)	3 4 4 2 3	Engineer RCT RCT Operator Demo technician	+RWP dress-out +RWP dress-out No dress +RWP dress-out Tech + RWP dress-out 50% of time
42	Phase III solidification results: observation, inspection, and recording	3	Engineer	+ RWP dress-out 50% of time
43	Solidification package (liner) top-off and seal	0.75 0.75 1	Demo technician Engineer RCT	+RWP dress-out
44	Recovery and cleanup	2 4 4	Engineer Demo technician RCT	
45	Overpack loading and package preparation for burial	10 3 2	Waste technologist Ship engineer RCT	+RWP dress-out, 50% of time
46	DOT shipment by truck to burial site (NTS)			Truck preparation cost, $2500 Shipping cost, $3500
47	Burial cost at NTS per drum, disposal			$12.50 per cubic foot 3 drums @ $50

Note: Personal protective equipment dress-out was consistent during solidification operations and consisted of 1 pair of disposal coveralls, cotton glove liners (reusable), rubber gloves, and plastic shoe covers or booties in addition to tape on all openings. No respiratory equipment was required during demonstration operations.
*Cost insignificant.
Demo, demonstration; DOT, U.S. Department of Transportation; gal, gallon; HASP, health and safety plan; lb, pound; NTS, Nevada Test Site; poly, polyethylene; RCT, radiological control technician; RWP, radiological work permit.

Table C.2.
Mound Radiation Protection Services and Supplies

Protective Item	Unit	Cost, $
Coveralls	Each	6.00
Surgical gloves	Pair	0.212
Shoe covers	Pair	2.345
Smears	Each	0.026
Coin envelopes	Each	0.0418
7-ml vials	Each	0.0685
Scintillation cocktail	ml	0.0165
Kaydry® wipes	Each	0.0335
Duct tape	Roll	3.15
30-gallon plastic bags	Each	0.0722
Masking tape	Roll	4.67
Glass cleaner	Bottle	4.96

Table C.3.
Waste Disposal Costs

Description	Unit	Cost, $
Nevada Test Site projected burial of radioactive and/or mixed waste (meeting acceptance criteria)	Cubic foot	12.50
Radioactive truck shipment preparation costs	Per full truckload	2500.00
Radioactive shipment truck transportation costs for semi-trailer load	Per full truckload	3500.00

Table C.4.
Labor summary*

Labor Type	Total Hours	Hourly Rate, $	Labor Total, $
Project manager	1	70.82	70.82
Engineer (less start-up)	150.3 (25.5)	58.12 (58.12)	8,735.44 (1,482.06)
Operator	5	26.98	134.90
Demonstration technician	22	45.30	996.60
RCT (inside CA)	11	64.00	704.00
RCT (outside CA)	13	64.00	832.00
Waste disposal technician	11	35.50	390.50
Safety engineer	1	58.12	58.12
Shipping engineer	3	58.12	174.36
Totals	217.3		12,096.74

CA, contaminated area; RCT, radiological control technician.
* Excludes “Test” specific labor items, i.e., 60% of Item 24 of Table C.1

Table C.5.
Materials Cost Summary

Materials Item	Quantity	Unit	Unit Cost, $	Total Cost, $
22.5-gallon poly liner	3	Each	88.95	266.85
Nochar PetroBond®	120	Pound	18.60	2232.00
Total				2498.85

poly, polyethylene.

Table C.6.
Supplies Cost Summary

Supply Item	Quantity	Unit	Unit Cost, $	Total Cost, $
Spill pads	6	Each	2.00	12.00
Tygon® tube	8	Linear feet	1.50	12.00
Clean wipes	3	Package	3.75	11.25
Decontamination materials	1	Lump sum	25.00	25.00
Total				60.25

Table C.7.
Personal Protective Equipment Summary

Task No.*	RWP Dress-out**	Total Cost***
39	3 sets	26.31
40	4 sets	35.08
41	4 sets	35.08
42	1 set	8.77
43	1 set	8.77
45	2 sets	17.54
Total		131.55

* See Table C.1.
** One pair coveralls, 2 pairs surgical gloves, and 1 pair shoe covers.
***Dress-out = $8.77 each.
RWP, radiological work permit.

APPENDIX D
ACRONYMS AND ABBREVIATIONS

D&D	Decontamination and Decommissioning
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
ft	Feet
HAT	high-activity tritium
hr	Hour
in.	Inch
ITSR	Innovative Technology Summary Report
lb	Pound
LDR	land disposal restriction
LSDDP	Large-Scale Demonstration and Deployment Project
MEMP	Miamisburg Environment Management Project
ppm	parts per million
RCRA	Resource Conservation and Recovery Act
TCLP	toxicity characteristics leaching procedure