Y-12

**OAK RIDGE
Y-12
PLANT**

MARTIN MARIETTA

Y-12 Plant Remedial Action Technology Logic Diagram

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**Volume 3
Technology Evaluation Data Sheets**

**Part A
Remedial Action**

September 1994

Prepared for the Office of
Environmental Restoration

MASTER

Prepared by
Oak Ridge K-25 Site
Oak Ridge, Tennessee 37831
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

**MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
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Volume 3 Data Sheets

Part A Remedial Action

Prepared for the Oak Ridge Y-12 Plant
Environmental Restoration Program

September 1994

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FOREWORD

The *Y-12 Plant Remedial Action Technology Logic Diagram* (TLD) was developed to provide a decision-support tool that relates environmental restoration (ER) problems at the Y-12 Plant to potential technologies that can remediate these problems. The TLD uses information from the *Strategic Roadmap for the Oak Ridge Reservation*, *Oak Ridge K-25 Site Technology Logic Diagram*, *Oak Ridge National Laboratory Technology Logic Diagram*, and a previous Hanford TLD.

The TLD identifies the research, development, demonstration, testing, and evaluation needed for sufficient development of these technologies to allow for technology transfer and application to remedial action (RA) activities. It is essential that follow-on engineering studies be conducted to build on the output of this project. These studies will begin by selecting the most promising technologies identified in the TLD and finding an optimum mix of technologies that will provide a socially acceptable balance between cost and risk.

The TLD consists of three fundamentally separate volumes: Vol. 1 (*Technology Evaluation*), Vol. 2 (*Technology Logic Diagram*), and Vol. 3 (*Technology Evaluation Data Sheets*). Volume 1 contains an overview of the TLD, an explanation of the program-specific responsibilities, a review of identified technologies, and the rankings of remedial technologies. Volume 2 contains the logic linkages among environmental management goals, environmental problems, and the various technologies that have the potential to solve these problems. Volume 3 contains the TLD data sheets.

Volume 1 has been divided into six chapters. The first chapter is an introduction, which defines problems specific to the ER Program for the Y-12 Plant. Chapter 2 provides a general overview of the TLD. Chapters 3 through 5 are organized into necessary subelement categories: characterization, RA, and robotics and automation. The final chapter contains regulatory compliance information concerning RA.

The technology evaluations contained in these volumes are based on the best information available during compilation of the TLD. New or more accurate information is solicited to improve the TLD data base. Please send comments to R. L. Fellows, Editor, *Y-12 Plant Remedial Action Technology Logic Diagram*, Martin Marietta Energy Systems, Inc., P.O. Box 2003, Oak Ridge, TN 37831-7274. FAX (615-576-8558).

REMEDIAL ACTION

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, metals, organics, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelements: Containment/isolation

Alternative: Structural stabilization

Technology: Dynamic compaction. Void volume measurements from several WAG-6 trenches at the Oak Ridge National Laboratory indicate that low-level solid waste occupies up to 30% of the trench volume. From 25% to 50% of the waste volume is encapsulated within containers (e.g., plastic bags, wooden crates, cardboard boxes). The long-term integrity of multilayer caps to intercept surface water is strongly linked to the subsidence characteristics of the waste. Deep dynamic compaction (DDC) is a well-proven technology which can effectively stabilize a wide range of waste forms (e.g., B-25 boxes, plastic bags, cardboard, steel drums). The pounding not only stabilizes the waste but also produces instantaneous data on the effectiveness of the compaction (i.e., quality control is established on a crater-by-crater basis). Dynamic compaction is most effective for low-level waste buried within 30 ft of the surface.

There are environmental risks related to collapse and release of fluid-filled drums. If ground-water transport is present and many fluid filled drums exist, then dynamic compaction is not a good choice. Dynamic compaction is more appropriate for situations where surface water transport is the primary mechanism of waste migration, and closure will eliminate surface water by capping SLBs. If liquid-filled drums are ruptured, leachate collection from shallow wells can be incorporated easily into the dynamic compaction program. If the design life of closure encompasses a time frame that would allow the natural deterioration of drums and other containers, fluids would be released in a haphazard and uncontrolled manner. It may be more acceptable to rupture the drums, release their contents, and actively collect the leachate.

Dynamic compaction is not an effective treatment for biological waste because of long-term subsidence induced by biodegradation.

Status: DDC was successfully used to compact a 58-acre low-level waste site at the Savannah River Plant. Sixteen feet of miscellaneous low-level waste was reduced to a 6-ft

thickness. Internal waste stability was increased five-fold. Worker exposure was minimal, because all work was conducted from the surface, with the nearest worker (crane operator) being about 30 ft from the weight-drop point. Tamper penetration of waste was greatly reduced by placement of surface fill and control of drop height (about 50 ft). Health Physics issues were greatly simplified, because the bottom of the steel plate tamper was the only construction equipment that was likely to ever contact the waste. Tamper replacement cost was low (\$5K). During the year of work at the Savannah River Plant, only one tamper was decommissioned because of contamination issues. Dust control easily accomplished by wetting ground near drop point.

Science/Technology Needs: DDC has been tried at the Oak Ridge National Laboratory to compact waste in the trenches of WAG 6. Because of equipment limitations (60-ton crane, 23-ft lift height for 4.4-ton tamper), inconclusive results were obtained. Additional trial field tests should be performed on WAG-6 trenches and the information, evaluated for applicability to Y-12 sites.

Implementation Needs: DDC is the least costly of all ground/waste stabilization techniques. For the Savannah River Plant trenches, the cost was approximately \$1.50 per ft² of trench stabilized. For the 8-ft diameter tamper and a waste depth of 20 ft, this cost data is equivalent to \$2 per yd³ of waste stabilized.

- Equipment needs:
 - Lampson LDC—350 dynamic compactor
 - 20-ton steel plate tamper
 - Velocity gun
 - Laser surveying level
 - Dozer and pans used to import and spread fill
- Financial needs: \$0.5M to compact 20 WAG-6 trenches

Author: Joe Kauschinger/404-992-3538

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1. Davis, E. C., Spalding, B. P., Lee, S. Y., Hyder, L. K., *Test Area for Remedial Actions (TARA) Site Characterization and Dynamic Compaction of Low-Level Radioactive Waste Trenches FY 1988 Progress Report*, ORNL/RAP/LTR-88, Martin Marietta Energy Systems, Inc., Environmental Restoration Division, Oak Ridge, Tenn., January 1989.
2. Lukas, R. G. and C. Schexnayder, "Dynamic Compaction of Nuclear Waste Deposits," pp. 440-447, *Stabilization and Solidification of Hazardous, Radioactive, and Mixed Wastes, 2nd Volume*, ASTM STP 1123, ed. T. M. Gilliam and C. C. Wiles, American Society for Testing and Materials, Philadelphia, Pa., 1992.
3. Kauschinger, J. L., *Evaluation of Trench Characteristics and Feasibility of Stabilizing Low Level Buried Waste Disposed in Solid Waste Storage Area 6 (SWSA 6)*, prepared for Martin Marietta Energy Systems, Oak Ridge, Tenn., to be published.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals, mixed

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: In situ chemical grouting

Status: Demonstration. A limited amount of information related to chemical grouting of low-level buried waste is available. Polyacrylamide grouting demonstrations performed at ORNL WAG 6 on a limited number of trenches produced a stabile waste (increased penetration resistance) with overall reduction in hydraulic conductivity. However, for 25% of the measured population, hydraulic conductivity could be considered the same as the untreated waste.

Void volume measurements performed on several WAG-6 trenches (TARA I) indicate that from 25% to 50% of the waste has been disposed inside containers which are not water-accessible. Therefore, it would be reasonable to presume that water-based grouts would not penetrate the containers. If containers collapse, over time, open voids would be created in the poorly stabilized waste, thus increasing hydraulic conductivity with time.

There are environmental risks related to drilling through the buried waste, especially if liquid-filled drums are pierced and their contents are spilled. Although grout/waste compatibility studies can be performed using trench leachate, there are no assurances that fluid inside containers contains material detrimental to the grout. Uncured grout would substantially increase the volume of waste that resides within the trench.

Worker exposure to contamination is a moderate risk, because most conventional grouting is performed vertically and requires drilling/grouting to be performed over the waste.

Conventional low-pressure grouting is low-cost and would be approximately \$60-\$80/yd³ of waste stabilized (i.e., 30% void space within waste).

For a large grouting program (500 trenches), waste chemistry can be very variable, with the

degree of waste containerization from none to high. Conventional, low-pressure particulate grout is not robust enough to assure a high degree of success in stabilizing and immobilizing buried waste. Conventional chemical grouting is not recommended as a technology for solving the DOE buried waste problem.

Science/Technology Needs: A major technical issue related to the closure of Oak Ridge Reservation buried waste sites, concerns the stability and hydraulic conductivity of buried wastes. Even if a cap eliminates the surface water as a transport mechanism, the ground-water transport of mobile waste may still be a long-term driving force. Ground-water flow models have met with mixed results in predicting the flow regimes at the trench level. The geohydrology of ORR is extremely complicated, and numerical studies may not produce reliable answers.

Grout/waste compatibility testing must continue to be sponsored to develop a catalogue of grout formulations which are robust enough to cure in an environment of widely varying waste chemistry.

The need exists to develop a grout delivery system which is robust. It would have the ability to rupture a wide variety of containers, to effectively mix the grout with the waste, and to cure to a solid waste with relatively high strength and low hydraulic conductivity. The stabilization method should have multiple lines of defense so that, if the grout did not cure or was not homogeneously mixed, a back-up system would be available.

Implementation Needs: A laboratory study to examine grout waste compatibility issues is needed.

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References:

1. Davis, E. C., et. al., *ORNL Solid Waste Storage Area 6 Trench Photos and Geologic Descriptions: July 1984 Through September 1985*, ORNL/TM-9874, Martin Marietta Energy Systems, Inc., Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tenn., March 1986.
2. Spalding, B. P. and T. A. Fontaine, "Field Demonstration of In Situ Grouting of Radioactive Solid Waste Burial Trenches with Polyacrylamide," pp. 415-425, *Stabilization and Solidification of Hazardous, Radioactive, and Mixed Wastes, 2nd Volume, ASTM STP 1123*, American Society for Testing and Materials, Philadelphia, Pa., 1992.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals, mixed waste

Reference Requirements: Refer to the final chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: In situ particulate grouting

Status: Demonstration. Particulate-based grouting is accomplished using a selection of cementing agents, and bulking agents have been used to chemically fix and solidify a variety of waste streams (including soils). This technology uses inorganic reagents that react among themselves to form chemically and mechanically stable solids based on reactions between the fine-particulate cement, binders, and catalysts and sometimes the waste form itself. Generic processes that have been used in particulate-based grouting include the following: Portland cement, Portland cement/lime, Portland cement/fly ash, lime/fly ash, lime/clay, lime-kiln dust, and gypsum-based processes. Grouting using particulate-based grout can be conducted on an in situ and ex situ basis. However, for true in situ grouting without mechanical mixing processes, microfine cements are preferred, as the fine-grain characteristics of these grouts offer better penetrating capacity and generally fill small void volumes in the soil structure better than conventional Portland cements. The microfine cements have grain-size distributions (50% by weight) or 5 μ m compared to <20 μ m for Portland cements.

Environmental risks related to drilling through the buried waste exist, especially if liquid-filled drums are pierced and their contents are spilled. Although grout/waste compatibility studies can be performed using trench leachate, there are no assurances that the fluid inside the containers contains material detrimental to the grout. Uncured grout would substantially increase the volume of waste that resides within the trench.

Worker exposure to contamination is a moderate risk, because most conventional grouting is performed vertically and requires drilling/grouting to be performed over the waste.

For a large grouting program (500 trenches) where waste chemistry can be very variable (the degree of waste containerization from none to high), conventional low-pressure particulate grout is not robust enough to ensure a high degree of success to stabilize and immobilize buried waste. Conventional particulate grouting is not recommended as a technology for

solving the DOE buried waste problem.

Science/Technology Needs: A major technical issue related to the closure of buried waste trenches involves the stability and hydraulic conductivity of inundated biological waste trenches. Even if a cap eliminates surface water as a transport mechanism, it appears that the ground-water transport of mobile waste still may be a long-term driving force. Ground-water flow models have met with mixed results for predicting the flow regimes at the trench level. The geohydrology of ORR is extremely complicated, and numerical studies may not produce reliable answers.

Grout/waste compatibility testing must continue to be sponsored to develop a catalogue of grout formulations which are robust enough to cure in an environment of widely varying waste chemistry.

The need exists to develop a grout delivery system which is robust. It would have the ability to rupture a wide variety of containers, to effectively mix the grout with the waste, and to cure to a solid waste with relatively high strength and low hydraulic conductivity. The stabilization method should have multiple lines of defense so that, if the grout did not cure or was not homogeneously mixed, a back-up system would be available.

Implementation Needs: Conventional low-pressure grouting is low-cost and would be approximately \$40 to \$60/yd³ of waste stabilized (i.e., 30% void space within waste). A laboratory study to examine grout waste compatibility issues is needed. Samples of biological waste from WAG-6 trenches would be candidates for such a study. Cost for a laboratory study is expected to be \$0.1M.

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1. Davis, E. C., et al, *ORNL Solid Waste Storage Area 6 Trench Photos and Geologic Descriptions: July 1984 Through September 1985*, ORNL/TM-9874, Martin Marietta Energy Systems, Inc., Environmental Sciences Division, March 1986.
2. Tamura, T., et al, *In Situ Grouting of an ORNL Trench Using a Particulate-Type Grout*, ORNL/RAP-23, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1987.
3. Francis, C. W., et al, *In Situ Grouting of Low-Level Burial Trenches with a Cement-Based Grout at Oak Ridge National Laboratory*, ORNL/TM-11839, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1991.
4. Francis, C. W. and B. P. Spalding, *In Situ Grouting of Low-Level Burial Trenches with a Cement-Based Grout*, proceedings of the ER '91 Conference held at Pasco, Wash., September 1991.

BOREHOLE MINING (SUPER SOIL STABILIZATION MANAGEMENT)

REMA-4-OZ

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, metals, organics, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Retrieval

Alternative: Excavation

Technology: Borehole mining (super soil stabilization) (SSS) management. The SSS management process involves drilling a small hole (75 mm) into a zone containing pollutants and surgical removal of the plume by water cutting and air-lifting jets to mine out contaminated soil. A circular hole is stabilized using natural mud or injected slurry (biopolymer or drilling mud). Cavities typically range from 1 to 3 m in diameter. After soil is cut, drill rods are lowered to the bottom of the hole, and the size of the cavity is measured using a sonic transducer. If the size of the cavity fulfills the design requirement, then the hole is filled with cement-based grout. Alternately, washed soil can be reinjected into the open cavities created in the ground during the water-cutting process.

Estimated excavation rates vary from 25 to 50 yd³ of soil per hour. Rates include drilling and jetting activities for a depth of about 25 ft and a soil column of about 10 ft high and 6.5 ft in diameter (i.e., a 6.5-ft-diam cavity created at a depth of 15–25 ft). The estimated cost of removal and reinjection (no soil washing costs are included) is about \$50/yd³ of soil excavated. All excavated soil is beneath the water table.

The major advantage of borehole mining is related to the removal of contamination beneath the structures without compromising foundation support. One disadvantage is the creation of secondary waste and increase of the waste volume needing treatment. Note that this is a process to retrieve waste for treatment.

Status: Demonstration. Water cutting/grouting technology was developed in Japan during the early 1980's. Originally, it was used for stabilization of soil by grouting. More recently in Germany, it has been applied to borehole mining of phenol-contaminated soil from beneath a large warehouse. About one-third of the site had phenol concentrations above 10,000 mg/kg of soil. Borehole mining and soil washing successfully restored the site.

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Science/Technology Needs: Borehole mining technology is based on off-the-shelf equipment. The need exists to perform a full-scale cold test to quantify operational problems such as: techniques to control cuttings brought to the surface and to minimize waste generation and reuse of contaminated drilling/cutting water, reinjection of washed soil, and decontamination of equipment before moving to another borehole. Cold testing also will allow verification of the accuracy of a sonic transducer to measure the cavity. A cold test would involve formation of a bottom seal with vertical sidewalls to create an underground vault.

Implementation Needs: Uncontaminated area in the field is needed to conduct a demonstration. A 10-month demonstration is expected to cost \$0.5M.

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1. *SSS Management Process*, Kodan International Publication (in Japanese), 1990.
2. Grisham, G.R., Sondermann, W., "Extraction and Washing Contaminated Soils Using High Pressure Jet Grouting Techniques," HMCRI 11th Annual National Conference and Exhibition, SUPERFUND '90, November 26-28, 1990, Washington D.C.
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EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, metals, organics, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Structural stabilization

Technology: In situ solidification

Status: Demonstration. The first in situ soil solidification test program was conducted in April 1988 under the U.S. Environmental Protection Agency's (EPA's) SITE Program. The test site was a General Electric Corporation service shop in Hialeah, Florida, which was contaminated with polychlorinated biphenyls (PCBs). Maximum concentration of PCBs in soil was 950 mg/kg (Aroclor 1260 PCB) within the top 18 ft of soil. The soil solidification process was to evaluate the effectiveness of International Waste Technologies (IWT) proprietary grout formulation (HWT-20, cement—organic clay-based grout) and deep soil mixing as a delivery system. Two test sections, each about 10 × 20 × 18 deep were used for the evaluation. Toxicity Characteristic Leaching Procedure analyses indicated that the grout had immobilized PCBs in solidified soil down to the detection limit of the analytical equipment used (1 µg/L PCB). Cost of grout material was \$350/ton (bulk delivery).

Full-scale production work at the General Electric site indicated hard, solidified, grouted waste in the zones where the deep soil mixing augers could penetrate and inject grout. The HWT-20 grout is an effective chemical for solidification and immobilization of PBCs. However, in the deep sections of the site (50-ft maximum), problems arose with the mixing augers penetrating below 35 ft. The general soil profile at the General Electric site is a medium-compact sand with near-surface ground water. The inability to drill the augers below 35 ft is related to the output horsepower of the hydraulic power pack which drives the 4 3-ft-diam augers. Maximum output is 50,000 ft-lb. A possible remedy to this situation would be to use a single- or double- auger system to drill and inject grout to the 50-ft depth.

Estimated cost of treatment for the PCB soil was approximately \$150/yd³ of soil treated.

Other drawbacks related to the deep soil mixing process are related to: the large-size

equipment needed for the four-auger system (Manitowac 250-ton crane); the inability to drill through obstructions, timbers, and boulders; and the ability to perform only vertical injection.

DOE presently is conducting in situ solidification tests at the X-231B site at the Portsmouth Gaseous Diffusion Plant (PORTS) in southern Ohio. Data from the test site are still being processed and evaluated.

Science/Technology Needs: Current studies indicate that the soil mixing process is an effective method for injection of stabilizing chemicals. However, the four-auger deep soil mixing process is questionable for depths below 35 ft in medium-compact sands.

Implementation Needs: Current research is being conducted. Support should be provided for current research to finish the evaluation and publication of results. Additional field studies may not be appropriate until PORTS data are available for peer review.

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EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical/chemical separation

Technology: Soil washing

Status: Accepted. Soil washing is available and has been used as a remedial action for contaminated soils. It is often used as a size segregation technique with washing of fines from coarse soil. Predemonstration, for buried wastes. Conceptually, it is the same as soil washing, but buried waste is more heterogeneous.

The existing data base and prior development have been for soil washing rather than for buried waste. Conceptually, some buried waste and contaminants would be amenable to this approach. If the contaminant is soluble and the contaminated surfaces are accessible (removed from bags and containers), it may be possible to decontaminate the bulk of such buried waste by washing/leaching/extraction. This concept may be proven effective for a given scenario, but not necessarily in general. Once the concept has been accepted as effective, then details such as emptying bags and containers need to be developed. The most difficult part to develop may be proving that the treated waste is clean. The whole point of this treatment is to cleanse the bulk of the waste of contamination. A technique must be developed to assure that the treated waste is truly free of contamination. Without such assurance, the treated waste will be disposed as if it were still contaminated, even if it is not. Finally, the wash water/leachate/extract is a secondary waste. Cleaning and recycling of this secondary waste stream must also be developed if the concept proves to have merit.

Science/Technology Needs: The need exists to prove first that buried waste can really be cleaned by such an approach in the laboratory. The technique has proven effective in soil washing, but the chemical and physical characteristics of buried waste may be too different from contaminated soil for this approach also to work on buried waste. Of course, the technique should be quite acceptable, as already developed, for treating contaminated backfill and soil surrounding buried waste. After proving that the concept is useful, then details such as removing waste from bags and containers need to be developed before field testing. To

claim any benefits from this treatment, a positive test for the cleaned waste must be developed. In addition, a treatment cycle must be developed for the secondary waste stream to recycle the wash water/leachant/extractant and concentrate and to dispose the removed contaminants.

Rawe¹ included the following insights on soil washing:

- "Soil washing is basically a volume reduction technology that uses wash water to separate contaminated soil into two fractions: a large fraction of relatively clean, coarse soil and a smaller fraction of fine soil/sludge containing the concentrated contaminants."
- "Hydrophobic contaminants can be difficult to separate from soil particles into the aqueous washing fluid."
- "Complex mixtures of contaminants in the soil, such as a mixture of metals, nonvolatile organics, semivolatile organics, etc., make it difficult to formulate a single suitable washing fluid that will remove all the different types of contaminants from the soil."
- "A high percentage of clay and silt (e.g., >30–50%) in the soil usually indicates that soil washing will be unfavorable due to the amount of time and money required to treat this volume of contaminated soil."
- "Chelating agents, surfactants, solvents, and other additives are often difficult and expensive to recover from the spent washing fluid and then recycle in the soils washing process."
- Identification of the contaminants is important. Volatile organics may require removal in a pretreatment step or treatment of air emissions. Solubilities of contaminants is important in deciding whether wash solution additives are needed. Metal speciation is important in metal solubility.
- Particle size distribution of the soil and chemical analysis of the contaminants are important characterization data for soil washing.
- The treatment and disposal of contaminated residuals can be a major expense.
- "As a rough estimate, remedy design field tests could be expected to range from as low as \$100,000 up to \$500,000 (1989 costs) or more."
- "There are no full-scale washing operations identified in use at Superfund sites at the present time." (1991 report)
- Costs for a German (Harbauer GmbH) full-scale soil washing facility follow: capital cost—\$6,000,000 (1986 dollars) for a 15 to 20 ton/h facility; O&M costs—\$150/ton soil including water treatment; sludge disposal costs—about \$50/ton soil.
- Processing costs for other European soil washing operations less complex than Harbauer: \$73 to \$110/ ton soil.

Implementation Needs: Soil washing equipment already exists that can be brought on site. Doubtless, modifications will have to be made to handle buried waste and the secondary waste stream. A policy needs to be established about disposition of the cleaned buried waste (i.e., the treated waste must no longer be handled and disposed as contaminated for any benefits for this treatment to exist), and a positive characterization technique needs to be developed

to assess the cleanliness of the treated buried waste (i.e., quality assurance/quality control for the treatment).

Trnovsky, et al.² estimated the present worth from the estimated capital and operating and management costs for several remedial action alternatives at the Petroleum Products Corporation Superfund Site in Pembroke Park, Broward County, Florida. They estimated the unit cost of soil washing to be \$50 to \$65/ton of soil and the unit cost for solidification/stabilization (S/S) to be \$100 to \$120/yd³. For this article, soil washing was being used as a pretreatment to S/S and resulted in significant cost savings by decreasing the volume of soil that needed to be stabilized. The suitability of using S/S for organic contamination was not addressed in this article. The cost estimate for S/S was based on an industry quotation for processing similar wastes. S/S has been used for remediation of Superfund sites containing organic contamination, despite the controversy surrounding its suitability for Resource Conservation and Recovery Act wastes contaminated with organics. Despite the suitability of S/S, the article makes a valid point that soil washing can be used as a pretreatment to reduce the costs of final treatment, but it is not generally a final treatment by itself.

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EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Organics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Low-temperature ashing

Status: Predemonstration for the U.S. Air Force (USAF), who is developing the technology to treat plastic media blasting waste. Low-temperature ashing reduces the volume of waste before final treatment with another technology, such as solidification/stabilization (S/S), by heating the waste to relatively low temperatures (400–600°C). This is a much lower temperature than that required for Resource Conservation and Recovery Act (RCRA) or Toxic Substances Control Act (TSCA) incineration or for vitrification, providing for potentially better control of semivolatile contaminants. Organic materials, such as plastic or paper, either pyrolyze or combust (depending on oxygen conditions) at these temperatures. Contaminants such as RCRA metals or uranium will be left in the ash (bottom or fly) residue. These contaminants then can be recovered from the ash and recycled or treated for disposal, for example, by S/S. The contaminants in the off-gas must be trapped and combined with bottom ash before final treatment. It may be possible to treat volatiles, such as mercury or iodine, by including the proper off-gas treatment steps.

This technique was conceived and developed at Oak Ridge National Laboratory (ORNL) for the USAF to reduce the volume of plastic media blasting waste requiring RCRA disposal. Soft plastic media used by the USAF for paint stripping did not damage the metal skin of their aircraft as a more abrasive blasting media would. The plastic media is recycled about ten times before it is reduced to an unusable powder that must be separated from the useable plastic media and disposed. This plastic waste also contains the pulverized paint. The RCRA metals in some of the paint pigments lead to this waste being characteristically hazardous, currently requiring that the plastic waste be disposed as RCRA waste. Low-temperature ashing leads to a >90% volume reduction of this waste. The resulting ash then can be disposed as a RCRA waste or treated by S/S to be noncharacteristically hazardous. A simple thermogravimetric analysis of this plastic waste demonstrated the large mass reduction

possible at low temperatures and proved the feasibility of this concept. Details, such as recovery of contaminants from the off-gas, are still being developed, but the USAF is proceeding with a pilot-scale operation using this technology.

Much buried waste is paper, plastic, and similar combustibles. Such buried waste is amenable to this volume-reducing technology. Even nonvolatile contaminants will unavoidably end up in the off-gas on the fly ash, so off-gas treatment must be developed for expected contaminants. Particulate collection devices will capture the fly ash and most of the contaminants, but volatiles such as mercury or iodine will present a special challenge. This technology is not final treatment, as the ash and off-gas must be treated, but it can significantly reduce the volume and cost of treatment, if combustibles comprise a significant fraction of the buried waste.

Science/Technology Needs: The need exists to develop adequate removal of contaminants from the off-gas and recombination with the bottom ash for final treatment. The need exists to demonstrate that the volume of buried waste can be reduced by low-temperature heating, just as it was for the PMB waste. So far, this approach is a concept only tested in the laboratory, but without off-gas treatment. The USAF is proceeding with a pilot-scale process.

Implementation Needs: Equipment for handling and heating reasonably-sized buried waste can be readily acquired and installed. Waste will have to be removed from metal containers; but, conceptually, plastic bags can be loaded onto the waste handler (conveyor belt, etc.) as is. A final treatment must be developed for the bottom ash and the residue from cleaning the off-gas.

Author: Roger D. Spence/615-574-6782

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EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical separation

Technology: Gravity sorting. The goal of this concept is to achieve physical separation of solid waste and debris to segregate items of similar contamination or which are suitable for similar follow-up processing (such as repackaging or treatment). Conceptually, paper, plastic shoe covers, and other, similar, light items can be segregated from metal objects, construction debris, and other, similar, heavy objects by agitation or flotation (i.e., use of air bubbles) in a liquid, presumably aqueous. Size segregation and density separation are possible. Many such industrial applications could be cited, but applications for the present topic could not be cited. The recovered buried waste would have to be separable and free of containers. In other words, plastic bags, drums, and boxes would be emptied and their contents segregated in this process. For example, such a process may segregate materials suitable for combustion or incineration from incombustibles. One obvious problem is that the liquid will become contaminated and require treatment. This can be especially troublesome for soluble contaminants. The process may act as a washing/leaching/extraction process in addition to density separation. In some cases, such a combination may be desirable.

Status: Demonstration. The technology is commonly used in industry and mining, but not necessarily used or accepted as a waste remedial action.

Science/Technology Needs: Modification of technology for handling low-level waste is needed.

Implementation Needs: Demonstration at field level.

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References: Freeman, Harry, *Standard Handbook of Hazardous Waste Treatment and Disposal*, McGraw Hill, New York, 1988.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: Cementitious solidification

Status: Accepted for Resource Conservation and Recovery Act metals, Comprehensive Environmental Response, Compensation, and Liability Act remediation, and low-level radioactive waste. S/S is one of the most widely used techniques for the treatment and ultimate disposal of hazardous wastes and low-level radioactive wastes. Cementitious materials are the predominant materials of choice because of their low associated processing costs, compatibility with a wide variety of disposal scenarios, and ability to meet stringent processing and performance requirements. Cementitious materials include cement, ground granulated blast furnace slag, fly ash, lime, and silica fume. Various clays and additives are used to help immobilize contaminants or otherwise enhance the waste form properties. Soluble constituents in the waste chemically interact with the cementitious materials to form low-solubility products at the high pH and the Eh prevailing in the waste form. These interactions usually affect the cementitious hardening and properties to some degree. Testing with a specific waste or waste stream is required to tailor the formulation to the desired properties. Sufficient attention must be given to characterizing the waste, to developing the formulation to treat the waste, and to implementing this formulation in the field to assure correct mixing of the formulation. Adding these dry ingredients inevitably increases the volume of the waste treated, which can add significantly to lifetime disposal costs. The volume decrease claimed by techniques such as thermoplastic encapsulation, come from evaporation of the water and encapsulation of the solids. The same evaporation pretreatment could be used with cementitious solidification/stabilization (S/S) to obtain a net volume decrease, but some of the simplicity of the cementitious S/S would be lost. Cementitious waste forms are porous, making them more leachable than polymeric or glass waste forms. The key has been controlling this leachability (by pH, Eh, and/or absorbents) within satisfactory limits for a simpler and cheaper treatment.

For relatively inert materials such as rubble or scrap metal, cementitious materials are ideal

for macroencapsulation. Encapsulated ion-exchange resins can lead to breakdown of the solid matrix because of the volume changes that result from wetting and drying of the resin. Proper formulation and pretreatment of the resin has succeeded in overcoming this problem for encapsulated resins.

The costs for cementitious waste forms from Dole and Trauger (1983) and Kessler et al. (1984) are \$0.05–\$0.15/waste gal for materials cost and \$0.10–\$0.50/waste gal total disposal cost (including material, capital, and operating costs). At the other end of the spectrum, Myrick et al. (1992) had a total estimated project cost of \$115/gal concentrated liquid low-level waste for solidifying 47,000 gal of waste. This cost is unusually high for S/S, even for such a small quantity of waste. The cost of an aluminosilicate stabilization was estimated by Bates et al. (1992) at \$190–\$360/yd³ (\$0.90–\$1.78/gal) to treat 15,000 yd³ of a SITE demonstration waste.

In making a case for vitrification of low-level wastes, Gimpel and Diggs have made economic assessments and published several papers together or separately, either claiming that the costs for vitrification are comparable with that of S/S or that the costs for making the glass waste forms is higher, but the total life cycle costs (including disposal costs and monitoring costs for 100 years after disposal) are comparable between the two options because of the higher volumes that must be disposed and monitored from S/S. They estimate the direct costs to be \$90–\$220/m³ (\$0.34–\$0.83/gal) for S/S and \$400/m³ (\$1.51/gal) for vitrification, but total costs (including disposal) at \$1186–\$2090/m³ (\$4.49–\$7.91/gal) and \$922–\$1500/m³ (\$3.49–\$5.52/gal), respectively. The assumptions made regarding S/S appear reasonable but are more questionable regarding vitrification. However, the authors make a valid point that most cost estimates are the direct costs of making the wastes and do not include disposal costs. The cost deficit from increasing the waste volume should be estimated for S/S or the cost benefit should be estimated from the volume decrease for vitrification.

The disposal costs estimated in a progress report to the Savannah River Laboratory (1989) ranged from \$14.10/ft³ to \$47.50/ft³. Estimated total costs depend on the assumptions made for direct costs of making the waste form and the assumptions made for disposal costs, including final waste form volume compared to initial waste volume.

Jacobs et al. (1984) estimated the costs for treatment (including transportation and burial) of 12,700 ft³/y for 30 yd of concentrated BWR waste for the following options:

- Crystallization followed by S/S: \$37.00/ft³; \$4.95/gal
- Drying followed by S/S: \$28.93/ft³; \$3.87/gal
- Evaporation followed by encapsulation in asphalt: \$35.20/ft³; \$4.71/gal
- Drying followed by encapsulation in DOW binder (VES): \$24.60/ft³; \$3.29/gal
- Evaporation followed by S/S: \$89.21/ft³; \$11.93/gal

Science/Technology Needs: Better understanding of the immobilization mechanisms and the chemistry of these waste forms can lead to improved performance and better predictions

about the durability of these waste forms. This technique is currently in wide-scale use.

Implementation Needs: Formulations need to be developed, or at least tested, for the specific wastes intended for treatment. Proper implementation is necessary to ensure that the waste form tested in the laboratory represents what will be produced in the field. This means having the equipment and expertise necessary to properly blend and mix these solid constituents and managing the operation properly so that the right formulation is mixed.

Author: Roger D. Spence/615-574-6782

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EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Retrieval

Alternative: Excavation

Technology: Solidify and mine (freeze and mine). The goal of this concept is to freeze or immobilize buried waste and contaminants in place and then excavate. The benefits might be reduced personnel exposure and better control of mobile species (e.g., volatile organic compounds). It remains to be determined whether the benefits outweigh the extra cost of applying an isolation technology in addition to retrieval. The structural stability provided by freezing the area may allow selective retrieval of buried waste by mining or tunneling. Cryogenic freezing is an established isolation technology, and its status and costs should be the same as in the Technology Logic Diagram overview for Cryogenics under Isolation.

Status: Predemonstration. The technology is patented and is being marketed. A demonstration for buried waste is under way at the Idaho National Engineering Laboratory. Insights by Chatwin (1991) on freeze and mine follow:

- The concept of freezing soil and buried waste and removing them as a unit is a patented technique known as ISOCELL.
- "...the thermal properties of the soil are critical for predicting the freezing of the soil block..."
- "...difference in moisture content is critical because the arid soil at INEL is typically lower in moisture than the Carnation test site."
- "It is necessary to know the expected moisture content of the soil to be frozen in order to apply this technology."
- "The model predicted that it would take 20 days for the initial freeze down. The actual time taken for freezing the soil block was 21 days."
- "If the separation units encounter a metal piece that spans two or more extraction blocks and the metal piece cannot be sheared, the boundary of the block must be modified to enclose or exclude the full metal piece... If the separation units do not encounter the spanning piece of metal, then a more difficult situation is created, where the block is tied to earth and its location unknown."

- Several questions are posed that must be answered before application of the ISOCELL testing program to buried wastes.

Science/Technology Needs: An evaluation of the technical benefits and the added cost to retrieval needs to be assessed. A demonstration needs to be done to illustrate, first, that cryogenics can be used for such a purpose, and then, the benefits and costs need to be quantified.

Implementation Needs: In situ cryogenic freezing technology exists and can be brought to a surrogate buried waste site or actual buried waste site for a demonstration or actual buried waste retrieval. The benefits of this approach must be demonstrated by retrieving a possible airborne contaminant or a troublesome mobile contaminant under controlled conditions. Comparison to a standard retrieval operation is preferred.

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EM Problem: Remedial action

Y-12 Plant Problem: Soil/sediments

Problem Area/Constituents: Volatile organic compounds (VOCs) in soil

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical separation

Technology: Vapor extraction with radio frequency heating. This technology involves remediation of soils contaminated with VOCs using radio-frequency-enhanced soil vapor extraction.

Status: Predemonstration. Extraction of VOCs from soil can be improved using radio waves to heat the soil in situ. This is an enhancement to vapor extraction. Using a grid of drilled holes into which radio transmitters are placed, soil can be heated using radio waves in the same frequencies as those approved for hospitals. The VOCs, which volatilize as a result of the warmer soil, then can be collected and treated or recycled. A pilot test was performed at Volk Field Air National Guard Base, Camp Douglas, Wisconsin^{1,2} This test was effective in removing VOCs and some semi-VOCs. Hardware for this method already exists commercially. Limitations to radio frequency heating in high-clay soils exist, because the waves do not penetrate deeply into the soil. This means that the radio frequency heat is difficult to apply to deep formations (deeper than 1-2 m) without using "down-hole" transmitters. Even then, heating will not occur far from the transmitting hole. Costs now are only conjectural, but they could be low (<\$100/ton). Development and demonstration costs could be several million dollars. Wastes will result principally from the off-gas treatment system and could consist of spent carbon beds.

Science/Technology Needs: Substantial testing is required, particularly on ORR sites. Currently, only one research team appears to be working on this approach. Characterization of the soils at Y-12 must determine the frequency needed for optimum recovery. The testing needs to include recovery of the toxic materials from the off-gas. Vapor flow paths in complex soils like those at the Y-12 Plant can be difficult to predict or even measure.

Additional large-scale testing and demonstrations are needed to substantiate the results of

the Volk Field pilot study. This technology may likely be assimilated into other in situ soil treatment technologies, especially where radiation and/or worker exposure are acute problems.

Implementation Needs: Acceptable treatment levels are needed. Soil and underground structure should be determined to be suitable for release and transport of volatile contaminants from the soil. Extensive testing of existing hardware in this application needs to be demonstrated. Low costs have been reported (\$45/ton), but the costs probably depend on the degree of organic contamination, moisture content, and off-gas cleanup required.

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EM Problem: Remedial action

Y-12 Plant Problem: Soil/sediments

Problem Area/Constituents: Polychlorinated biphenyls (PCBs), organic compounds

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Incineration

Status: Demonstration. Testing was performed at the EPA's Incineration Research Facility to establish the feasibility of incinerating wastes contaminated with hazardous materials. The contaminants were PCBs, cadmium, chromium, copper, and lead.¹ The PCB concentration was greater than 200,000 mg/kg and the rest were several hundred mg/kg. Tests were run at a kiln exit temperature from 824°C to 984°C. Greater than 99.9999% destruction and removal efficiency was achieved, but the treated wastes still contained PCBs. A major portion of the toxic metals were found in the kiln ash. A few commercial firms now offer PCB incineration services.^{2,3} The existing incinerator at the K-25 Site should be able to meet the conditions, but the incinerator is currently committed to burning liquids. The capacity available for treating soils in the future is unknown.

Costs for incineration can be high. Reported costs range from \$100/ton to \$800/ton. With potential traces of radioactivity in the soil (and ash), costs could be higher. Potential wastes are the treated soil and solids collected in the off-gas system. If these have no residual toxic or radioactive materials, the hazardous waste volume could be small. Several million dollars will be needed for development and testing of any new incinerator before approval.

Science/Technology Needs: These results need to be considered with respect to the soil chemistry at Y-12. These test incinerations were performed on marine sediment in New Bedford Harbor. The test results suggest that incineration could be an effective form of PCB remediation. Sediment dewatering before incineration and increased kiln residence time may be required. Separations of soil fractions (such as removal of larger particles) may reduce the volume of soil to be processed.

A few large-scale tests have been conducted, and more need to be completed to calculate the optimum operation parameters with respect to Y-12 soil. Reliability of operations to maintain

temperature, residence time, and exhaust cleanup must be proven.

Implementation Needs: An incineration facility with Toxic Substances Control Act and Resource Conservation and Recovery Act licensing is needed. Removal efficiencies reported for incinerators and achieved in tests must be approved by regulators. Costs have been reported from \$100/ton to \$800/ton.² Agreement also should be reached on disposition of the residual soils which may contain traces of toxic metals. After incineration, the soil is not expected to be agriculturally useful.

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EM Problem: Remedial action

Y-12 Plant Problem: Soil/sediments

Problem Area/Constituents: Polychlorinated biphenyls (PCBs)

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical separation

Technology: Low-temperature thermal treatment

Status: Demonstrated. PCBs are not normally viewed as volatile compounds. However, when they are heated 300°F to 600°F, their vapor pressure will be sufficient for effective removal. One system demonstrated by Roy F. Weston, Inc.,¹ used semivolatile organic compounds (SVOCs) as well as other compounds, but it is unclear whether any of the SVOCs were PCBs. The concentration of SVOCs was decreased, but it was unclear whether the removal levels were as low as those needed for PCBs. Dioxins were formed in the process but were not formed in the treated sludge. Stack emissions were controlled with filters, condensers, and carbon beds. Costs are likely to be moderately high (i.e., a few hundred dollars per ton). The waste will consist of the treated soil (if it cannot be returned to the ground because of other contaminants) and the materials recovered in the off-gas. If a condenser is used, much of the PCBs may be recovered as liquid in oils. In any case, carbon beds (later wastes) are likely to be used for the final off-gas cleanup. Development is under way in industry. Additional costs may be a few million dollars, perhaps even <\$1M. The Development, Demonstration, and Evaluation Program for the Federal Facilities Consent Agreement (FFCA) is currently conducting treatability tests on PCB contaminated DARA soils at the Y-12 Plant.

Science/Technology Needs: The ability of the technology to handle large concentrations of PCBs needs to be determined. The requirements of residence time and temperature for different levels of removal needs to be determined. Soils that significantly adsorb PCBs also could affect removal rates.

Much better understanding of the science and technology will be needed. Little large-scale testing has been done to evaluate this process.

Implementation Needs: Treatment levels need to be evaluated. The degree of PCB degradation and the toxicity of the degradation products need to be determined. The role of

Y-12 soil properties on PCB removal will have to be determined. Off-gas treatment will have to be demonstrated. Costs are likely to be high, near those of incineration. One advantage will be conduction of the residual soil after low-temperature (below combustion temperature) treatment; the soil would not be sintered and could sustain organisms. Deposition of the treated soil will be an important consideration. If this remains a waste, the waste volume will be large. Implementation needs will be identified after the Y-12 treatability testing is completed.

Author: Jim Wilson/615-576-4413

References:

1. *Low Temperature Thermal Treatment (LT3) System*, demonstration bulletin EPA/590/Mr-92/019, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1992.

EM Problem: Remedial action

Y-12 Plant Problem: Soil/sediments

Problem Area/Constituents: Fuel-based hydrocarbons

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Incineration, cement kiln

Status: Demonstrated technology for liquids. This technology is much like incineration except the incineration occurs in an existing unit. Soil throughput is limited by the capacity of existing cement kilns. Cement kilns have been used more often for incinerating liquids which can be introduced with the fuel. It is more difficult to introduce solid soils to these units.¹ The costs for adding soils to a cement kiln is low. The principal costs are likely to be excavation and transportation, probably only several dollars per ton. If the soil is incorporated into the cement, essentially no waste will be produced.

Science/Technology Needs: Handling methods for introducing solids into a kiln and reliable estimates of the amounts of solids from soils that can be incorporated into the cement product are needed. (Incineration of liquids in a cement kiln may introduce few solids to the cement product, but introducing soils probably would introduce significant solids.)

Implementation Needs: Little capacity is likely to exist for treating solid wastes such as soils in a cement kiln.² The location of the kiln and the limited capacity for handling solids will limit application of this technology to no more than a few specific cases. The potential for introducing radioactivity into the cement (although some natural uranium will be present in all cement) is likely to eliminate treatment of many DOE wastes in this manner.

Author: J. Watson/615-574-6795

References:

1. *Technologies and Options for UST Corrective Actions: Overview of Current Practices*, EPA/542/R-92/010, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1992.
2. E.R. Hansen "New Way to Burn Hazardous Waste," *Rock Products*, April 1990.

EM Problem: Remedial action

Y-12 Plant Problem: Soil/sediments

Problem Area/Constituents: Solid and liquid organics, nitrate-bearing chemicals, PCB-contaminated liquids and solids

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Molten glass combustor. This device adds glass-forming constituents to waste feed to produce a pool of molten glass at the bottom of a reactor in which solid wastes react. Gases produced during combustion are released from the surface of the glass pool. Ash remains in the pool and is periodically removed with the carrier glass matrix. The removed glass is collected in storage containers and solidifies upon cooling.

The glass pool is melted and brought to operating temperature by passing a current between electrodes immersed in the glass at the sides of the combustor. The resistance of the glass to the flow of electrical current creates the needed rise in temperature in the molten-glass pool. Typical materials used to form a base glass are oxides of silicon, boron, and phosphorus. Sodium and potassium oxides are added to adjust glass melting temperature and viscosity. Aluminum oxide is added as required to decrease leachability of the glass.

Volatile constituents of solid and liquid waste feed streams are combusted in the volume of the combustor above the molten-glass pool. Combustion air typically is supplied through ports in the sides of this section of the combustor. Auxiliary fuel burners are used to ensure that the volume above the molten-glass pool is maintained at proper temperature for combustion of the volatiles.

The thermal vitrification process involves heating the materials by electricity or fossil fuels to temperatures beyond 1000°C. At these temperatures, any free liquid or organic material is evaporated, pyrolyzed, or oxidized, and residual inorganics are vitrified to form a molten glass. Thermally formed glasses are produced by fusing or melting crystalline materials and/or amorphous materials at elevated temperatures to produce liquids. Subsequently, these liquids are cooled to a rigid condition without crystallization.

Normally, glass waste forms are obtained by mixing one or more waste streams containing

radioactive and hazardous inorganic chemical compounds with other glass-forming materials and melting these materials during a vitrification process. The glass-forming materials may be commercially melted glass frit, select chemicals, or in some cases, materials present in the waste streams. Generally, silicon oxide (SiO_2) is the major component and provides the three-dimensional network which strongly influences the glass-waste-form character and properties.

The glass waste form discussed in the vast majority of references is borosilicate glass ($\text{B}_2\text{O}_3\text{SiO}$), as employed in the high-level radioactive waste program. The waste form usually contains less than 30 wt% of waste solids; however, the vitrification process generally reduces the volume significantly. Specific waste streams can be added at higher levels and, under conditions where the waste contains sufficient glass formers, a glass containing only waste can be produced. A wide variety of glass compositions may be suitable as glass waste forms and may provide advantages for the vitrification of a particular waste stream.

Because glass can accept a wide variety and amount of radioactive or hazardous materials and because its physical properties normally are consistent with time, glass has been selected to stabilize a variety of waste streams. It should be noted that the U.S. Environmental Protection Agency has determined that vitrification is the "best demonstrated available technology" for chemically hazardous constituents in high-level nuclear waste.

Status: Molten glass combustors are accepted by industry, and units are in use. Removal efficiencies of greater than 99% can be obtained for most waste types. Cost is not well established, but is expected to exceed \$200 per ton. The vitrification process has proven effective, but the costs of operation are not well known. A Cooperative Research and Development Agreement (CRADA) has recently been signed with Scientific Ecology Group.

Science/Technology Needs: The following may cause problems during operation:

- Monitoring the need for changes in additives can be difficult.
- The presence of certain organics and/or metals can result in problems caused by changes in the valence of the glass. This may result in precipitates forming in the glass matrix.
- Certain elements (eg., chromium, ruthenium, and noble metals) have limited solubilities in specific glass structures.

Implementation Needs:

- Process equipment (e.g., indirect or direct-fired rotary kiln, heated screw kiln, etc.)
- Minimum 2000 ft² equipment battery limit
- All utilities, including electricity, cooling water, natural gas, steam, air, nitrogen, etc.
- Drum and material handling equipment
- Trained chemical operators
- EPA-certified laboratory support

Author: Chet Francis/615-574-7257

References:

1. H. M. Freeman, ed., *Standard Handbook of Hazardous Waste Treatment and Disposal*, pp. 8.91-8.104, McGraw-Hill, New York, N.Y., 1989.
2. J. B. Berry, P. W. Lurk, and G. J. Coyle, Jr., *Mixed-Waste Treatment Research*.

EM Problem: Remedial action

Y-12 Plant Problem: Soil/sediments

Problem Area/Constituents: Volatile organic compounds (VOCs) in soil, contaminated concrete rubble, and PCBs in soil

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Thermal treatment

Alternative: Physical separation

Technology: Thermal desorption. Thermal treatment of wastes contaminated with organic compounds can be performed with many different treatment systems. However, the four main types of treatment systems are rotary dryer systems, indirect-fired systems, heated screw-type systems, and asphalt plant aggregate dryers. Each treatment system uses the same basic principle of operation. Each system consists of a furnace in which the organic compounds are desorbed from the waste feed. Desorbed organics are removed from the furnace by a purge gas and are destroyed in an afterburner or are collected by a physical/chemical treatment system. The systems are operated between 300°F and 800°F and are fed with 5-100 tons of contaminated waste per hour. The desorbed organic compounds are removed from the furnace by a purge gas stream, which may flow concurrently or countercurrently to the waste feed. A typical system consists of a feed pretreatment system, feed hoppers and conveyors, a cocurrent or countercurrent furnace (directly- or indirectly-fired), a treated soil cooling system, cyclones, an afterburner, a bag house, an induced draft (ID) fan, and a stack.

Status: Accepted by industry. The technology is more than 99% efficient in removing VOCs from soil. Costs range from \$35/ton (for low contamination—low moisture content soils) to \$120/ton. Thermal desorption of contaminated solids is in use at various remediation sites around the U.S. (some cleanups have been completed). A full scale (5000 cy) application of this technology for roasting gasoline and petroleum contaminated soils at the Y-12 Rust Fuel facility is currently under design for implementation in 1995.

Science/Technology Needs: The following concerns may cause problems during operation:

- Limitations exist on the types of waste and contaminants that can be treated.
- The presence of some contaminants may cause permitting problems.

Implementation Needs: These include the following:

- Process equipment (e.g., indirect- or direct-fired rotary kiln, heated screw kiln, etc.)
- Minimum 2000 ft² equipment battery limit
- All utilities, including reliable electricity, cooling water, natural gas, steam, air, nitrogen, etc.
- Drum and material handling equipment
- Trained chemical operators
- U.S. Environmental Protection Agency-certified laboratory support

Author: Chet Francis/615-574-7257

References:

1. J. J. Cudahy, et.al., "Petroleum Contaminated Soils and Sludges-Markets, Permitting and Thermal Desorption Technologies," *Proceedings of the 1992 Incineration Conference*, Albuquerque, N.M., May 1992.
2. R. K. Nielson and M. G. Cosmos, *Low Temperature Thermal Treatment (LT[®]) of Volatile Organic Compounds from Soil: A Technology Demonstration*, paper presented at the 1988 Summer National Meeting of the AIChE, Denver, Colo., August 1988.

EM Problem: Remedial action

Y-12 Plant Problem: Soil/sediments

Problem Area/Constituents: PCBs, organic compounds

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Thermal treatment

Alternative: Destruction

Technology: Plasma arc furnace. This technology builds on plasma hearth melting developments.¹ The plasma arc furnace is a new and promising technology that uses an electrically heated plasma gas to destroy organic contaminants and bind radionuclides and heavy metals in a glassy slag. The plasma arc furnace (PAF) represents an alternative to cementation and incineration that may be more acceptable to the public.

The plasma technology typically includes a continuous plasma torch operated in transfer mode (one end of the torch arc impinges on the material being heated) or nontransferred mode. The system includes an enclosed feeder, an afterburner, a slag removal system, a waste-gas chiller, a waste-gas scrubber, a continuous emissions monitoring system, stack samplers, and various controls and diagnostic equipment. The PAF can be operated under reducing or oxidizing conditions.

The term "plasma" refers to a highly ionized gas. Plasmas can be generated by a variety of techniques and occur over a wide range of pressures and energy levels. Typically, a torch uses a flowing gas to stabilize an electrical discharge (arc) between two electrodes. One or both of these electrodes is contained within the torch. For treatment of solid materials, the second electrode is usually the material being processed (using arc welding terminology, this is called the "workpiece"). Energy is dissipated as heat and light as the electrical current flows through the gas. Through resistance heating (Joule heating), this process creates a high-temperature gas as well as directly heating the workpiece.² Plasma torches have high energy densities with local temperatures up to 15,000°K.¹ Qualitative benefits of this technology are high-integrity final waste form, portability, and low off-gas and contamination control. Potential disadvantages are that plasma processes are very energy intensive, and power costs could limit applications to small-scale.⁶

Status: Demonstration. The following pilot-scale systems are installed:

- Centrifugal Retech Furnace—Switzerland
- Centrifugal Retech Furnace, DOE/EPA Site Program—Butte, Montana⁵
- Fixed Hearth Retech Furnace—Ukiah, Calif.
- Plasma Facility—Charleston, S.C.³
- Westinghouse Pilot Facility—Pittsburgh, Pa.³

Some operating and emissions data exist for these facilities, but additional data are needed for process design and scale-up to meet DOE mixed waste management objectives for treatment of Y-12 waste streams.

Science/Technology Needs: Research and development is required to assess metals carry-over from the primary chamber (not zone) and to optimize slag chemistry regarding metals stabilization, variations in waste input streams, reintroduction of condensed volatile metals into the slag phase, and radionuclide partitioning⁴ in the effluent streams, including metal specification studies in the entrained particulates in the off-gas as a function of particle size. Additional development is required to determine and improve electrode life, materials of construction in general, destruction and removal efficiency of hazardous/toxic organics, power efficiency, mass/energy balances to effect minimum secondary waste generation, and optimal safe operating methods as a function of heterogeneous waste processing.

Implementation Needs: The cost of demonstrating this technology to treat a wide range of low-to-high ash inorganic/organic waste feed streams to produce a low leachable slag is estimated to be \$10M. Estimated time to complete full-scale demonstration to treat specific Y-12 waste streams at 1-2 tons/hour capacity is 3 years (funding requests: FY 93: \$2M; FY 94: \$4M; FY 95: \$4M).

Author: Jim Wilson/615-576-4413

References:

1. W. Hoffelner, et al., "Plasma Technology for Rapid Oxidation, Melting and Vitrification of Low/Medium Radioactive Waste," *Nuclear Engineering International*, Need Business Publishers, Sutton, England, October 1992.
2. M. I. Morris, *The Plasma Hearth Process: The Fixed Hearth Arc Plasma Treatment Process for Mixed Waste Treatment Applications*, draft TIP, December 10, 1992.
3. W. H. McCulla, personal communication with M. I. Morris, December 1, 1992.
4. J. B. Berry, et al., *Mixed Waste Treatment Research, Development, Demonstration, Testing and Evaluation*, draft report, DOE Office of Technology Development, December 1992.
5. Retech, Inc., *Plasma Centrifugal Furnace Applications Analysis Report*, EPA/540/A5-91/007, U.S. EPA Risk Reduction Engineering Laboratory, Cincinnati, Ohio, June 1992.
6. L. C. Borduin, et al., *Thermal and Photochemical Processes Applicable to Environmental Restoration and Waste Management Operations*, 1989.

7. C. G. Whitworth, et al., *Slag Chemistry and Metals Volatilization in the Plasma Arc Furnace Experiment*.
8. W. H. Hermes, background file containing personal notes of discussions with SAIC regarding emissions from centrifugal furnace in Switzerland, Retech Lab-Scale System, and Fixed Hearth Plasma System at Ukiah, Calif.

EM Problem: Remedial action

Y-12 Plant Problem: Soil/sediments

Problem Area/Constituents: Soils contaminated with radionuclides, toxic heavy metals, and hazardous organic compounds

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: In situ vitrification

Status: In situ vitrification (ISV) for radioactively contaminated soils and sediments has been demonstrated at the pilot scale and on a large scale for application to contaminated soils.¹ ISV produces an excellent waste form for most radionuclides of interest, including all transuranic isotopes: ⁹⁰Sr, ¹³⁷Cs, ⁶⁰Co. The ambient earthen materials and backfills within the ORR have been shown to pose no impediment for ISV. ISV currently applies to soil depths to 19 ft and areas where ground-water recharge is not too fast (i.e., <E- 03 cm/s). ISV would apply to contaminated soils and sediments which, because of their high radiation field, would present a hazard for direct contact or handling by personnel or which would have no realistic disposal scenario if exhumed. ISV also would destroy all organic contaminants if these also were present in radioactive soils or sediments. Inorganic contaminants, including Hg, Cd, and Pb (as well as any tritium), would volatilize significantly during ISV; however, these would be removed by the off-gas scrubbing system but would thus generate a secondary waste stream. Production costs for ISV have been projected at about \$390/ton of product.¹ Regulatory agency personnel have approved demonstrations and remain enthusiastic that ISV will be implemented at the ORR.

Science/Technology Needs: Minor but significant volatilization of ¹³⁷Cs can occur during ISV, particularly in the presence of materials containing chloride. The only technological challenge for ISV is to carry out an actual field-scale implementation to establish that necessary target depths can be attained, adjoining melts can be overlapped, and site characterization and post-ISV verification techniques can be developed to establish effectiveness and actual field waste form quality. No significant research and development efforts (non-field-scale tests) would be required for application to contaminated soils and sediments.

Implementation Needs: The implementation needs for ISV for ORR contaminated soils and sediments center only on establishing field-scale implementation. An Environmental Restoration-funded project to perform ISV on part or all of ORNL WAG 7 Pit 1 in FY 1995 is being planned. Using Pit 1 will establish ISV at a field scale at ORR with a minimal amount of product produced and a minimal risk for radiological problems during its ISV. Pit 1 is actually quite representative of ORR contaminated soils and sediments and results from its vitrification will be directly applicable to the problem of contaminated soils and sediments with lower levels of radioactivity.

Author: Brian Spalding/615-574-7265

References:

1. *Vitrification Technologies for Treatment of Hazardous and Radioactive Waste*, EPA Handbook EPA/625/R-92/002, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1992.

EM Problem: Remedial action

Y-12 Plant Problem: Soil/sediments

Problem Area/Constituents: Radionuclides, toxic heavy metals, and hazardous polar organic compounds

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Chemical separation

Technology: Electrokinetic removal. Electrokinetic remediation of soils involves application of direct current between two electrodes inserted in the soil. Passing of direct current through the soil produces three general electrokinetic effects. These are (1) electroosmosis, (2) an electroosmotic transport of contaminants, and (3) reactions at the electrodes. Electroosmosis involves the movement of pore water through the soil by virtue of the applied electrical field. The influence of electroosmosis is greatest in heavy, textured soils (soils with high concentrations of silts and clays and low permeabilities). Thus, electrokinetics offers a method to enhance movement of water in low-permeable soils. Electroosmotic transport of contaminants result as charged anions and cations move in an electrical field. Cations move with the water toward the cathode, and anions generally move toward the anode by electrical conduction. Some anions may be transported to the cathode because of convective transport of water by the electroosmosis effect. Gaseous hydrogen and OH⁻ anions are generated at the cathode while protons (H⁺) are generated at the anode, creating a significant pH gradient between the two electrodes.

Status: Exploratory studies have moved toxic metals through soil under electrostatic potential.¹ A DOE-sponsored workshop was held recently in Atlanta to evaluate the potential of this concept. Much remains to be understood about the concept before it can be applied to uranium contamination. For instance, does the uranium have to be oxidized to the more soluble VI state before it becomes mobile? If uranium IV can form complexes with chloride, carbonate, or sulfate to form anions and neutral specie as well as cations, which way(s) will the uranium go under an electric field? How will the uranium be recovered from the electrodes as the migration is completed? How far apart can the electrodes be spaced? This appears to be a concept, not a proven technology. Costs are very uncertain now, because the concept is not sufficiently defined. Costs are not expected to be even once the entire removal scheme is defined. Costs could still exceed \$100/t. Development and demonstration costs probably will be moderate, perhaps \$1M to \$10M.

Science/Technology Needs: As previously mentioned, much remains to be learned about this concept before its applicability can be evaluated. The need exists for studying uranium solution chemistry in soils and soils with humus and other organic materials (such as those found near the soil surface). The previously mentioned questions should be addressed. The technology, if operated in situ in shallow soils (near the surface) as expected, would have to operate under conditions ranging from drought to heavy rainfall. The role of acid formation from electrolyte electromigration on uranium movement needs to be understood. Although the technique could also be considered an ex situ method, excavation and placement in treatment bins will increase the cost and the need for more rapid treatment rates. Concepts need to be developed and tested for recovering uranium from the electrodes (of the electrode region).

Implementation Needs: Much needs to be learned about this technology before all implementation needs can be assessed. It is too early to assess costs, but one would expect in situ costs to be moderate if the uranium can be removed from the electrode regions at moderately high concentrations and be easily concentrated for disposal. Ex situ costs might be excessive if the rates are low and treatment facilities are not sufficiently inexpensive. Treatment levels are also not yet established.

Author: Chet Francis/615-574-7257

References:

1. Y. Acar, R. Gale, et al., *Electrokinetic Soil Processing: Project EKSITE*, EK-BR-008-079, 1991.

EM Problem: Remedial action

Y-12 Plant Problem: Soil/sediments

Problem Area/Constituents: Refractory organohalides; heavy metals along with refractory organic materials; organic sludges with radionuclides; spent, radioactive, ion-exchange resins and contaminated soils

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Thermal treatment

Alternative: Destruction

Technology: Chem char process. This process destroys hazardous wastes by reverse-burn (where flame and oxidant move in opposite direction) gasification. The wastes to be treated are mixed with char, and the mixture is mechanically pushed upward through a gasifier. The char, prepared by reverse-burn gasification of subbituminous coal, has a macroporous structure and a surface area of approximately 200 m²/g, which can effectively sorb and immobilize waste liquids and sludges and provide an ideal physical matrix for treatment. Limited oxygen is supplied from the bottom of the gasifier so that a thin layer of flame travelling upward is created in the middle of the gasifier. Flame zone temperature is about 1500°C. The flame supplies the energy needed to gasify the wastes. The gaseous products then flow upward to pass through a heated char bed, which is claimed to provide a strong reducing atmosphere that will effectively destroy the refractory organic compounds without producing undesirable by-products.

This gasification process is claimed to be a significant breakthrough for thermal treatment of environmental wastes. No inorganic particulates are present in the gas effluent, and metal emissions are minimal, probably because of capture of the volatilized metal vapors by the char bed, either through condensation or chemisorption. Char residue is a dry, inert, carbonaceous solid which is either nonhazardous or can be mixed readily with cement to prevent leaching of radioactive, toxic, or heavy metal constituents which are retained in the char residue or ash. Char residue can be gasified further in a forward-burn mode to produce a highly stable, low-volume, glassy slag.

Status: Predemonstration

Science/Technology Needs: Development work will be initiated with a thorough review of the chem char process in collaboration with researchers of Chem Char Research, Inc., (CRI)

holder of a patent on this process. Experimental studies on treating various liquid and solid wastes then will be conducted. Work will occur in conjunction with CRI (or independently at the Oak Ridge National Laboratory) and will involve design and installation of a pilot gasifier system. Experiments will be planned to collect data, such as gasifier temperature profile, product gas composition, particle size, mixture flow rate and residence time, and treatment quality. Potential operational problems also will be investigated (e.g., channeling of oxygen and product gases, controllability of a stable and uniform flame front in the gasifier, incomplete combustion, and nonuniformity of treatment quality). Subsequently, an assessment of this process will be made regarding its technical and economic viability, and the result of this assessment will determine whether a larger facility (and its capacity) can be justified.

Implementation Needs: Development work is estimated to cost \$0.75M-1.5M.

Author: Chet Francis/615-574-7257

References:

1. *The Chem Char Process for Hazardous Waste Treatment*, technical bulletin, Chem Char Research, Inc.
2. C. D. Reach, personal communication with W. D. Altman, Martin Marietta Energy Systems, Inc., March 2, 1992.

EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water/surface water—inorganics and radionuclides

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Chemical separation

Technology: Precipitation. Precipitation is a chemical treatment process by which soluble contaminants are removed from water by converting them into insoluble compounds. Soluble contaminants may include metals, alkaline earth ions (hardness), or other inorganic anions. An example of chemical precipitation is metals precipitation using hydroxide, sulfide, phosphate, or carbonate ions as the precipitating agent. Metal hydroxide precipitation is a pH adjustment process used to treat aqueous wastes containing metals. Base (usually lime or caustic) is added to adjust the pH to the point where the constituents to be removed have the lowest solubility. This treatment results in a metal sludge and a treated effluent that has an elevated pH.

Sometimes, metal sulfide precipitation is used to remove metals to lower effluent concentrations than can be achieved using hydroxide precipitation. Sodium or ferrous sulfide is added as a precipitating agent. After precipitation, excess sulfide ions must be removed by oxidation. Effluent metal concentrations of less than 1 mg/L (and sometimes lower) are achievable. Chromium can be precipitated to less than 0.1 mg/L if reduction is used as a pretreatment step to convert hexavalent chromium to trivalent chromium.

Contaminated wastewater is fed continuously or batch-wise into the rapid mix tank. Treatment chemicals may include acids or bases for pH adjustment and other coagulants such as alum or ferric chloride and polymers. As an option, polymers can be fed in-line downstream of the rapid mix tank. Polymers may be organic polymers which promote flocculation through hydrogen bonding and electrostatic forces or synthetic polyelectrolytes with anionic or cationic functional groups which promote agglomeration.

Status: Accepted for heavy metals and radionuclides. Specific wastewater streams would need to be tested to determine the treatment levels that could be achieved. Treatment of Co-60 and Tc-99 normally will require additional treatment steps, such as chemical reduction, along with precipitation. Lab-scale tests have shown that aluminum powder will

break Co-60 complexes and will reduce Tc-99 from a +7 to a +4 oxidation state so that they will precipitate. Specific wastewater streams would need to be tested to determine the treatment levels that could be achieved.

Science/Technology Needs: The flow rate needs to be estimated to properly size unit processes. Characterization of the waste stream allows the technology to be selected and the effectiveness to be estimated. Characterization parameters include metals, other cations, anions, and complexing and chelating agents. Total suspended solids and total dissolved solids are used to predict the solids generation rate and to properly size the sedimentation process. The alkalinity and acidity of the stream are used to predict the chemical requirements for pH adjustments.

Implementation Needs: The addition of coagulants such as aluminum or iron salts and polymers sometimes are used to help form precipitates. Precipitation also can result in lower effluent concentrations through coprecipitation. Often, iron is added to enhance the coprecipitation effects.

Sludge recovered from precipitation requires dewatering and disposal. Treated effluent from metal hydroxide precipitation may require pH adjustment before discharge. Treated effluent from metal sulfide precipitation may require sulfide removal before discharge.

Author: P. A. Taylor/615-574-1965

References:

1. Taylor, P. A., and Robinson, S., *Oak Ridge National Laboratory Nonradiological Wastewater Treatment Plant Optimization Report*, ORNL/TM-11877, Oak Ridge National Laboratory, Oak Ridge, Tenn., June 1991.

EM Problem: Remedial action

Y-12 Plant Problem: Impoundments/Quarries

Problem Area/Constituents: Impoundments in contact with ground water, plutonium, uranium, organics, inorganics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Barriers

Technology: Slurry walls. Slurry walls are narrow, vertical excavations which are backfilled with a slurry while excavation is in progress. The slurry prevents collapse of the sidewalls during excavation and produces a barrier to ground-water flow. The slurry is generally a bentonite, bentonite/clay, or bentonite/Portland cement mixture.

Status: Accepted. This technology is commercially available. Slurry walls have been used on environmental projects at the Portsmouth Gaseous Diffusion Plant. For slurry walls to be effective, a confining layer must be present in which to key the wall. At ORR, the fractured and solution-featured bedrock lacks a confining layer or aquiclude and thus, is not suited for slurry-wall use.

Science/Technology Needs: Developments are needed which would allow the use of slurry walls in fractured or solution-featured bedrock. The technology could be combined with other technologies in new or unique applications which would not depend on confining layers to be effective.

Implementation Needs: Detailed characterization of subsurface conditions and materials is needed.

Author: Bill Barton/615-576-0519

Reference:

1. *Underground Storage Tank Corrective Action Technologies*, EPA/625/6-87-015, PEI Associates, Inc., Cincinnati, Ohio, 1987.
2. Corbitt, Robert A., *Standard Handbook of Environmental Engineering*, McGraw Hill, New York, 1988.

3. Freeman, Harry M., *Standard Handbook of Hazardous Waste Treatment and Disposal*, McGraw Hill, New York, 1988.

EM Problem: Remedial action

Y-12 Plant Problem: Impoundments/Quarries

Problem Area/Constituents: Plutonium, uranium, organics, inorganics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Barriers

Technology: Sheet pile walls. Sheet pile walls are walls constructed in the ground of interlocking sections of steel. The corrugated steel panels are driven to refusal/top or rock. Sheet pile walls do not provide a complete barrier against ground-water flow, as water can move through the sheet pile joints, and thus, are usually only used for temporary dewatering.

Status: Accepted. This technology is commercially available for use in shallow applications (30–40 ft maximum depth). Sheet piling is applicable to the soil depth above bedrock, as sheet piling will refuse on hard rock. Sheet piling will not provide a complete barrier against ground-water migration. It will leak at the sheet pile joints and, if no confining layer exists, ground water will migrate under it.

Science/Technology Needs: None.

Implementation Needs: Detailed characterization of soil conditions and subsurface geology is needed.

Author: Bill Barton/615-576-0519

Reference:

1. *Underground Storage Tank Corrective Action Technologies*, EPA/625/6-87-015, PEI Associates, Inc., Cincinnati, Ohio, 1987.
2. Corbitt, Robert A., *Standard Handbook of Environmental Engineering*, McGraw Hill, New York, 1988.
3. Freeman, Harry M., *Standard Handbook of Hazardous Waste Treatment and Disposal*, McGraw Hill, New York, 1989.

EM Problem: Remedial action

Y-12 Plant Problem: Impoundments/Quarries

Problem Area/Constituents: Plutonium, uranium, organics, inorganics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Barriers

Technology: Grout curtains. Grout curtains are narrow, vertical walls installed in the ground to divert laterally flowing ground water. A grout curtain may be used up-gradient of a contaminated area, to prevent clean water from migrating through wastes, or down-gradient, to limit migration of contaminants.

Status: Accepted. This technology is commercially available for use in shallow applications (30–40 ft maximum depth). The effectiveness of this technology largely depends on the presence of a confining layer of clay or rock into which the grout curtain is keyed. Without a confining layer, the grout curtain will not form an effective barrier (ground water will find pathways under the grout curtain).

Science/Technology Needs: This technology needs to be demonstrated (to be either effective or ineffective) in the fractured geology of the Oak Ridge Reservation.

Implementation Needs: Detailed characterization of soil conditions and subsurface geology is needed.

Author: Bill Barton/615-576-0519

Reference:

1. *Underground Storage Tank Corrective Action Technologies*, EPA/625/687-015, PEI Associates, Inc., Cincinnati, Ohio, 1987.
2. Corbitt, Robert A., *Standard Handbook of Environmental Engineering*, McGraw Hill, New York, 1988.
3. Freeman, Harry M., *Standard Handbook of Hazardous Waste Treatment and Disposal*, McGraw Hill, New York, 1989.

EM Problem: Remedial action

Y-12 Plant Problem: Impoundments/Quarries

Problem Area/Constituents: Plutonium, uranium, organics, inorganics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Drains

Technology: French drains. French drains are narrow, vertical trenches filled with porous backfill. Ground water intercepted by the trench is either pumped from sumps located at low points in the drain or is gravity drained, if the terrain allows.

Status: Accepted. This technology is commercially available. Deep French drains have been constructed successfully in SWSA 6 and along Lagoon Road at the Oak Ridge National Laboratory (ORNL). Cost-effective construction of French drains is limited to rippable materials—soil and rock which can be excavated without blasting, jack-hammering, etc.

Science/Technology Needs: Cost-effective techniques are needed for French drain installation in hard rock.

Implementation Needs: Characterization of soil conditions and subsurface geology.

Author: Bill Barton/615-576-0519

Reference:

1. *Underground Storage Tank Corrective Action Technologies*, EPA/625/6-87-015, PEI Associates, Inc., Cincinnati, Ohio, 1987.
2. Corbitt, Robert A., *Standard Handbook of Environmental Engineering*, McGraw Hill, New York, 1988.
3. Freeman, Harry M., *Standard Handbook of Hazardous Waste Treatment and Disposal*, McGraw Hill, New York, 1989.

EM Problem: Remedial action

Y-12 Plant Problem: Impoundments/Quarries

Problem Area/Constituents: Plutonium, uranium, organics, inorganics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Drains

Technology: Biopolymer drains. Biopolymer drains are French drains which are installed using a biodegradable slurry for sidewall support. Use of the biopolymer installation method enables a narrow, vertical trench to be excavated without shoring, to be backfilled with a porous stone fill, and to be converted into a high-transmissivity interceptor trench. The technique is especially useful in locations of unstable or saturated soils which are likely to collapse if excavated vertically. The major advantage is related to ability to maintain excavation stability (similar to bentonite slurry), yet disposal is greatly simplified since biopolymer naturally decays. Biopolymer is popular in Europe to create drainage trenches. Polymer used as drilling fluid maintains slurry trench open so that freely draining material (sand or gravel) can be placed into slot. Biopolymer can be destroyed by injection of Chlorox or allowed to naturally decay.

Drawback of biopolymer is related to time in which drilling fluid is stable. After 300 hours most polymers have decayed and lost their ability to stabilize an excavation. Chemistry to control biopolymer properties are more complex than conventional bentonite drilling fluids.

Status: Accepted. This technology is commercially available for use in soils or loose-rock materials which can be excavated with conventional excavation equipment. Geo-Con, Inc., (of Pittsburgh, PA) has installed biopolymer trench drains at the Portsmouth Gaseous Diffusion Plant as part of two site remediation projects.

Science/Technology Needs: Though this is a mature technology, opportunities may exist to apply it in new applications or with different construction equipment.

Implementation Needs: Characterization of soil and subsurface geology.

Author: Bill Barton/615-576-0519

References:

1. Bachy Process, Deep Drainage Trench, company literature, Bachy, Cattenom, France, 1993.
2. Polymer Drilling Systems, company literature, El Durado, Ark., 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Impoundments/Quarries

Problem Area/Constituents: Plutonium, uranium, organics, inorganics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Drains

Technology: Horizontal wells. Horizontal wells are cased wells installed horizontally or with directional drilling techniques for isolating a site from ground water infiltration. Whereas a vertical well has only a small cross-section of well at a given elevation, a horizontal well can have hundreds of feet of cased length at a key elevation. One horizontal well would be a much more effective ground-water interceptor than a series of vertical wells. In the early 1990s, directional drilling applications were expanded so that gravel-packed wells could be installed. The well installation employs real-time directional drilling to place wellscreens of various types (PVC, HDPE, or stainless steel). The filter packing is achieved by pulling back a casing while pneumatically stowing graded sand around the wellscreen, which is centrally located within the casing. Drains up to 12 in. in diameter, and from 10–500 ft deep can be installed over a 1000-ft length.

Some of the major advantages of horizontal drains are related to:

- Small-diameter boreholes (3–12 in.) produce small volume of waste generation during drain installation. Vacuum preventer at wellhead with closed loop drilling and recirculation of biopolymer mud also greatly reduces waste generation and minimizes worker exposure.
- Directionally drilled drains can be strategically drilled into the soil horizon for maximum hydraulic efficiency. In contrast, drainage trench must remove large volumes of soil above the ground-water table. Large volumes of slurry requires disposal after trench backfilled with granular soil.
- Single header pipe at wellhead can service multiple drains.
- Directionally drilled drains can be installed in areas which are inaccessible for crane and/or backhoe installation of drainage trench.

Status: Demonstration. Horizontal drilling technology is commercially available and has been used extensively in river-crossing applications. Directional drilling is also widely used in oil-field applications. However, horizontal or directional drilling for installation of

ground-water interceptor wells around hazardous waste sites is a new application for this technology. The most promising application may be use an array of horizontal wells under waste trenches to suppress ground water in areas where waste was placed below the water table.

Science/Technology Needs: Demonstrations need to focus on the technical feasibility of drilling long distances horizontally in bedded shales and interbedded shales and limestone. The effective distance between wells for ground-water interception should be investigated. Use of horizontal drilling as an alternative to French drain construction should be considered. The problem of handling contaminated cuttings needs to be addressed. Little seepage analysis has been presented in the literature which allows comparison between the efficiency of vertical and horizontal wells versus drainage trenches. The hydrologic equivalency would be required to perform an economic feasibility study of each drain type. Computer modeling would be conducted using site-specific scenarios for the Y-12 reservation. Preliminary calculations for an isotropic, homogeneous deposit indicate that a single horizontal well is hydraulically equivalent to five vertical wells (for sandy soil) or ten vertical wells (for clay soil). Cost evaluation would consider permitting required for single versus multiple wells.

During installation of horizontal drains the drilling process will produce smear zones in the saprolitic soils, which dominate ORR. The smear zone will create an impedance layer adjacent to the filter pack which surrounds the drain. If the pneumatic stowing of the filter pack does not produce a pervious filter (1K-10K times more pervious than adjacent saprolite), then horizontal wells will only be partially effective. Analytical techniques can evaluate the degree of filter pack perviousness required for a perfect drain. Installation techniques may require using water jetting tools to cutaway the smear zone along the borehole prior to wellscreen installation. Vacuum cleaning of cuttings or fines in the borehole may also be required due to the clayey nature of the saprolite.

Implementation Needs: Computer studies—computer software for transient and steady state seepage of water for unconfined flow, incompressible soil, anisotropic conductivities. Numerical analysis would form the basis for determining equivalency between vertical and horizontal wells and drainage trenches. Cost effectiveness of each drainage method would be determined. Studies published by Los Alamos indicate that horizontal air stripping system is approximately 40% less for volatile organic compound (VOC) extraction when compared to conventional soil vapor extraction. A major cost reduction factor is related to the higher efficiency of a horizontal well to remove VOCs. Estimated cost—\$0.15M.

Field demonstration—perform test field to evaluate the operational problems of installing a filter-packed horizontal well. Demonstration should also include comparative measurements between vertical and horizontal wells and drainage trenches. Estimated cost—\$0.35M.

Author: Bill Barton/615-576-0519; Joe Kauschinger/404-421-3400

References:

1. Freeman, Harry M., *Standard Handbook of Hazardous Waste Treatment and Disposal*, McGraw Hill, New York, 1989.
2. EVI Cherrington, "WELLPAC System."
3. Schroeder, J.D., Rosenberg, N.D., Barnes-Smith, E.P., Booth, S.R., "In Situ Air Stripping: Cost Effectiveness of a Remediation Technology Field Tested at the Savannah River Integrated Demonstration Site," Report No. LA-UR-92-1927, 1992.

EM Problem: Remedial action

Y-12 Plant Problem: Impoundments/Quarries

Problem Area/Constituents: Sludge with radionuclides, organics, inorganics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Capping

Technology: Capping. Capping of waste areas consists of placing a barrier over a site to prevent infiltration of water into the waste from above. Many different barrier systems fall under the broad heading of caps. Caps may be as simple as sheet plastic held down by sand bags or as complex as multilayered systems which include low-permeability layers, drainage layers, vegetative layers, intruder protection layers, etc.

Status: Accepted. Some capping systems have become fairly common, with numerous installations occurring nationwide. Other systems are only in the developmental stages. Though caps are being designed and constructed, many aspects of the technology are still in demonstration or predemonstration stages.

The U.S. Environmental Protection Agency (EPA) published "Minimum Technology Guidance" documents for caps which outline performance standards and give recommended cross-sections of caps for hazardous waste closures. Many sites have been capped in accordance with the EPA guidance. Some of these caps have failed, and EPA and the technical community currently are rethinking the technology in an effort to produce more dependable caps.

Science/Technology Needs: For caps with soil layers, additional work needs to be performed in the area of desiccation of clays and the effect of desiccation on cap permeability. For geomembrane caps, extensive materials testing and longevity testing is needed. A "water balance" cap approach is being developed for the arid west. Elements of the water balance approach may apply to humid areas, but more study is required.

Implementation Needs: Characterization to define site to be capped. Removal of existing water and construction of barriers to limit lateral movement of ground water may also be required.

Author: Bill Barton/615-576-0519

Reference: Freeman, H.M., *Standard Handbook of Hazardous Waste Treatment and Disposal*, McGraw Hill, New York, 1989.

EM Problem: Remedial action

Y-12 Plant Problem: Impoundments/Quarries

Problem Area/Constituents: Sludge with radionuclides, organics, inorganics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical separation

Technology: In situ soil flushing. Water or an aqueous solution is injected into, or sprayed onto, the area of contamination, and the contaminated elutriate is collected and pumped to the surface for removal, recirculation, or on-site treatment and reinjection. During elutriation, the flushing solution mobilizes the sorbed contaminants by dissolution or emulsification. Handling and treatment of the elutriate are required.

Status: Demonstrated.

Science/Technology Needs: The achievable level of treatment depends on contaminant and soil characteristics. This technology is most applicable to highly permeable soils. Medium-solubility organics and soluble salts are the most likely contaminants to be treated by this technology. Further development is required to determine applicability to Y-12 Plant site conditions. Delivery and recovery systems are needed.

Implementation Needs: Characterization of site and subsurface geology.

Author: Bill Barton/615-576-0519

References:

1. *Underground Storage Tank Corrective Action Techniques*, EPA/625/6-87-015, PEI Associates, Inc., Cincinnati, Ohio, 1987.

EM Problem: Remedial action

Y-12 Plant Problem: Impoundments/Quarries

Problem Area/Constituents: Sludge/sediments with radionuclides, organics, inorganics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Retrieval

Alternative: Excavation

Technology: Dredging. Dredging is the removal of sediment/soils from a pond, lagoon, or other waterway. Saturated sediment becomes fluid-like when agitated and typically is excavated as a slurry (2%-10% solids by weight). Dredging equipment is almost always floating or operated from shore and is used to move material either mechanically or hydraulically. Mechanical dredges, such as draglines or clamshells, dislodge and excavate the bottom sediment material at nearly in situ densities. Hydraulic dredges pump contaminated sediment in slurry form through floating or pontoon-supported pipelines to a hopper or a treatment/storage area.

Status: Accepted. Most dredging equipment has not been specifically designed to operate in contaminated sediment, and modifications have been necessary to control resuspension and to handle slurries with high solids content. Removal of contaminated sediment by hydraulic dredging is a relatively new field with few major projects completed.

Science/Technology Needs: Development may be required for application to Y-12 Plant site conditions.

Implementation Needs: Field screening and material handling will be required in conjunction with sediment removal. Further treatment will be required following removal.

Author: Bill Barton/615-576-0519

Reference:

1. Remedial Action Assessment System prepared for DOE by Battelle Memorial Institute, Pacific Northwest Laboratory, December 1992.

EM Problem: Remedial action

Y-12 Plant Problem: Impoundments/Quarries

Problem Area/Constituents: Sludge/sediments with radionuclides, organics, inorganics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Retrieval

Alternative: Excavation

Technology: Vacuum loaders. Vacuum loaders are large (up to tanker-truck size) vacuum systems used to pneumatically load bulk materials, sludges, granular materials, slurries, or liquids. Operating at around 5000 cfm, a vacuum loader can quickly load a 5000-gal tanker, then haul the material in a tanker which meets U.S. Department of Transportation standards for transportation of hazardous waste. Vacuum loaders are used extensively in asbestos removal projects because of their built-in high-efficiency particulate air filtration and complete containment.

Status: Accepted. Vacuum loader technology is commercially available and is used extensively in industrial cleanup of solid, semisolid, sludge and liquid materials. The advantage of vacuum loaders is their ability to load a variety of materials, wet or dry—anything that will pass through an 8-in. suction hose. With a vacuum loader, accidental spread of contaminants is greatly reduced.

Science/Technology Needs: Development may be required for application to Y-12 Plant site conditions.

Implementation Needs: Field screening and material handling will be required in conjunction with sediment removal. Further treatment will be required following removal. Remotely controlled equipment may be needed for some sites.

Author: Bill Barton/615-576-0519

References: Personal experience, discussions with Oak Ridge Y-12 Plant Engineering, and vendor information.

EM Problem: Remedial action

Y-12 Plant Problem: Impoundments/Quarries

Problem Area/Constituents: Sludge/sediments with radionuclides, organics, inorganics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Retrieval

Alternative: Excavation

Technology: Mechanical excavation. Excavation is the mechanical removal of soils and sediments. Examples of excavation equipment include clamshells and backhoes.

Status: Accepted. Excavating equipment is commercially available and has been used extensively at Oak Ridge Reservation sites.

Science/Technology Needs: Development of remotely controlled equipment and controls to limit airborne emissions are needed. A remotely controlled excavation/retrieval demonstration is planned for WAG 6 at ORNL in FY-94.

Implementation Needs: Field screening and material handling will be required in conjunction with sediment removal. Further treatment will be required following removal. Remotely controlled equipment and controls for airborne emissions may be required.

Author: Bill Barton/615-576-0519

References: Personal experience and discussion with Y-12 Plant Engineering staff.

EM Problem: Remedial action

Y-12 Plant Problem: Impoundments/Quarries

Problem Area/Constituents: Sludge with radionuclides, organics, inorganics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical/chemical separation

Technology: Soil washing (impoundments). Soil washing is the extraction of contaminants from excavated soil by mixing the soil with water, solvents, surfactants, or chelating agents. The contaminated water or solution is then treated for removal of contaminants. Heavily contaminated soils are commonly treated several times in a multistage countercurrent system. All soil washing systems are mobile.

Status: Demonstrated. Soil washing has been demonstrated by the Environmental Protection Agency at Superfund sites.

Science/Technology Needs: Further development will be required for the specific contamination found at each impoundment site. This technology has not been used for removal of radioisotopes, and its effectiveness in the predominately clay ORR soils remains to be determined.

Implementation Needs: Field screening and material handling will be required in conjunction with the sediment removal. Further treatment will be required following removal.

Author: Bill Barton/615-576-0519

References:

1. *Underground Storage and Corrective Action Technologies*, EPA/625/6-87-015, PEI Associates, Inc., Cincinnati, Ohio, 1987.

EM Problem: Remedial action

Y-12 Plant Problem: Pipelines

Problem Area/Constituents: Nitrates, uranium, and mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Fixation

Technology: In situ grouting (pipelines). Buried or aboveground pipelines that have carried or presently carry process waste have been known or suspected to leak, causing contamination of the soil around the pipe. In the case of buried pipelines, the pipe backfill, which in some cases is more porous than the surrounding soil, may then serve as a conduit for transport of contaminants away from the original leak area.

Status: Accepted. Grouting of pipelines has been used to seal off abandoned pipes and leave them in place.

Science/Technology Needs: Special engineering design will be required for grouting of pipelines that are located beneath permanent structures, but probably no scientific development is needed.

Implementation Needs: Types of contaminants present, location of the pipeline, and areal extent of contamination all will affect the types of equipment used. In most cases, the costs involved are those of conventional excavation.

Author: Jill Greene/615-574-1462

References: Personal experience and discussion with Oak Ridge National Laboratory Environmental Restoration staff.

EM Problem: Remedial action

Y-12 Plant Problem: Pipelines

Problem Area/Constituents: Nitrates, uranium, and mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Retrieval

Alternative: Excavation. Buried pipelines that have carried, or that presently carry, process waste have been known or suspected to leak, causing contamination of the soil around the pipe. The pipe backfill, which in some cases is more porous than the surrounding soil, may then serve as a conduit for transport of contaminants away from the original leak area.

Technology: Pipeline excavation

Status: Excavation is currently the most commonly used method for remediating pipelines and the surrounding contaminated soil.

Science/Technology Needs: Pipelines in easy-to-access locations can be excavated using normal methods and equipment. Special engineering design will be required for excavation of pipelines that are located beneath permanent structures, but probably no scientific development is needed. The final disposition of excavated soil and pipe material would require another step in the logic diagram (i.e., chemical or physical treatment and either reuse as fill material or disposal as contaminated or uncontaminated waste). Final disposition of the pipe itself also would require another step in the logic diagram (i.e., either disposal or decontamination and reuse/disposal).

Implementation Needs: Types of contaminants present, location of the pipeline, and areal extent of contamination all will affect the types of equipment used and final disposition of the excavated material. In most cases, the costs involved are those of conventional excavation with added costs created by the presence of contamination. Where pipelines lie beneath permanent structures, grouting of the pipe and surrounding soils may be most cost-effective.

Author: Jill Greene/615-574-1462

References: Personal experience and discussion with Oak Ridge National Laboratory Environmental Restoration staff.

EM Problem: Remedial action

Y-12 Plant Problem: Soil/sediments

Problem Area/Constituents: Radionuclides, toxic heavy metals, and hazardous organic compounds

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Fixation

Technology: Stabilization/fixation by grouting. Stabilization/fixation of contaminated soils can be conducted using two basic grouting techniques: grouting using particulate-based formulations and grouting using chemical-based formulations.

Particulate-based grouting is accomplished using a selection of cementing agents, and bulking agents have been used to chemically fix and solidify a variety of waste streams (including soils). This technology uses inorganic reagents that react among themselves to form chemically and mechanically stable solids based on reactions between the fine-particulate cement, binders, and catalysts and sometimes the waste form itself. Generic processes that have been used in particulate-based grouting include the following: Portland cement, Portland cement/lime, Portland cement/fly ash, lime/fly ash, lime/clay, lime-kiln dust, and gypsum-based processes. Grouting using particulate-based grout can be conducted on an in situ and ex situ basis. However, for true in situ grouting without mechanical mixing processes, microfine cements are preferred, as the fine-grain characteristics of these grouts offer better penetrating capacity and generally fill small void volumes in the soil structure better than conventional Portland cements. The microfine cements have grain-size distributions (50% by weight) of 5 μ m compared to <20 μ m for Portland cements.

Chemical-based grouting techniques were developed much later than particulate-based grouting. The greatest advantage of chemical-based grouting techniques are their application in in situ treatment of contaminated soils. For example, chemical grouts often have viscosities <10 cpoise which allows them to be injected directly into soils. The most common chemical grouting materials are made from sodium silicate or acrylamide.^{9,10} Acrylamide-based grouts can be made exhibiting viscosities <2 cpoise and are excellent for penetrating fine-textured soils (permeabilities <10⁻⁴ cm/s). Most sodium silicate grouts generally exhibit higher viscosities (5–10 cpoise) and thus, are only useful for direct injection into silt and sandy-textured soils (soil permeabilities generally between 10⁻² and 10⁻³ cm/s). Sodium silica

grouts also generally tend to shrink faster (and irreversibly) than acrylamide grouts when exposed to drying conditions. When dried, acrylamide grouts will shrink to approximately 10% of their original volume, but swell to their original volume with the addition of water. The acrylamide monomers are highly neurotoxic, but when polymerized (using ammonium persulfate combined with triethanolamine as an activator and potassium ferricyanide as an inhibitor to control set time) is nontoxic. Because of the inability to ascertain complete containment of the monomer, the U.S. Environmental Protection Agency (EPA) has prohibited its use for in situ grouting of soils, and landfills.

Status: Grouting soils using particulate-based grouts for the fixation or reduction in the leachability of radionuclides or heavy metals is an acceptable practice, depending on the characteristics of the radionuclide or heavy metal. The technology has been demonstrated in several EPA SITE tests. One of the major concerns is the additional volume of waste generated. For radionuclides or metals that form soluble anions or complexes, use of such a grouting technology should be thoroughly tested. The best results are obtained with radionuclides and metals that form insoluble reaction products with the cementitious particulate or are rendered insoluble at the alkaline pH regime often encountered in the formulation of pozzolanic reactions of Portland cement and fly ash. For anionic species of metals or radionuclides (i.e., those containing chromates or pertechnetates), specific actions must be taken, such as addition of reducing agents, to form reduced forms which are less mobile in grouted forms.^{1,3,5} Grouting with particulate-based grouts is not generally considered applicable for the containment of organic compounds; however, recent formulations containing additives of activated carbon to sorb organic contaminants or the use of organoclays for adsorption and catalytic destruction of specific contaminants have been proposed.^{2,11} The effectiveness of these formulations, however, has not been validated. In his review and evaluation of chemical fixation and solidification of hazardous wastes, Conner⁴ best summarized the existing data of fixation of organic constituents in waste: "In the last few years, several chemical fixation/stabilization processes, mostly proprietary, have been offered that claim to fix, destroy, or immobilize organic priority pollutants and other organics of environmental concern. Unfortunately, virtually no credible data are available. Low leaching levels are claimed without any indication of the initial levels in the waste, or the effects of dilution or volatilization of the constituents."

Relatively little data are available on the use of chemical-based grouts to stabilize and fix contaminated soils. In fact, in his recent book on chemical fixation and solidification, Conner does not refer to any work using acrylamide grouts. Sodium silicates are referenced extensively (the basis of the Chemfix® process developed by the author); however, only in conjunction with Portland cement grouting technology. The most comprehensive stabilization/fixation work dealing with chemical grouting materials is that conducted by Spalding.¹⁴⁻¹⁸ This work was directed at determining the most suitable grouting materials and methods of deployment for the stabilization of low-level waste burial trenches at the Oak Ridge National Laboratory (ORNL). Most of the data relate to trench stability and hydraulic conductivity before and after treatment of the trenches. For example, hydraulic conductivity measurements in monitoring wells within trenches grouted with polyacrylamide revealed conductivities ($10^{-6.1}$ cm/s) considerably less than those in the surrounding soil formations

($10^{-3.4}$ cm/s). In addition, a large data base was developed on the effect of the concentrations of various constituents measured in trench leachate on grout set-time and the degree of polymerization of acrylamide. Only benzene and toluene showed a detectable effect on the degree of polymerization: 98.8% and 99.3%, respectively, vs 99.9% for neat grout. None of the chemicals had a significant effect on grout set-time.

Science/Technology Needs: The use of particulate-based grouts to fix and stabilize contaminated soils depends on the speciation of the contaminants in soils and the reaction products formed on solidification. The major problem, other than increased volume of waste produced, is making certain that enough mixing occurs between the soil and grouting materials. In ex situ applications, mixing can be controlled to a greater extent than in in situ applications. Also, in ex situ applications, validation of fixation and solidification can be determined more easily than in in situ applications. In situ operations using Portland Type-I-based cements require mixing of soil using deep soil mixing processes, as penetration of soil voids by these formulations will not occur in the heavy textured soils that dominate the ORNL site (i.e., hydraulic conductivities of most soil are $<4.0 \times 10^{-4}$ cm/s, Spalding et al. 1989). Use of microfine cements, most often made from finely ground blast-furnace slag, mixed with high-energy mixers (those that generate sufficient shear to fully disperse the microfine cement) have been documented to reach permeabilities on the order of 10^{-5} and 10^{-9} cm/s.¹⁹ However, data from field-scale validation studies are unavailable. Using a clay-based microfine cement formulation to grout low-level radwaste burial trenches, Francis et al.⁸ measured hydraulic conductivities on the order of 10^{-3} cm/s in grouted trenches compared to estimates of 10^{-1} cm/s in ungrouted trenches; however, these levels were significantly higher than hydraulic conductivity in soils surrounding the trenches (10^{-5} cm/s), indicating that grouting the trenches with these formulations would have little effect in isolating the waste from ground water or surface water moving into the trench area.

Deep soil mixing was used recently for in situ injections of a particulate grout containing activated carbon at the Portsmouth Gaseous Diffusion Plant to test its feasibility to contain tetraethylene chloride (TEC) in soil.¹² The quantity of reject soil (that augured to the surface following grout inject) was higher than expected, and tests are being developed to validate the degree of containment post-treatment.¹³ Thus, like the EPA SITE demonstrations, the most important scientific need is to provide adequate follow-up studies to clearly define or validate the effectiveness of remediation. In many cases, the apparent benefits are not easy to verify.

Implementation Needs: The greatest need is development of methods to inject grout in an in situ mode. Injection of particulate-based grouts largely depends on soil mixing processes. Several demonstrations have been conducted using auguring-type mixers in soil. Also, some demonstrations have used jet grouting techniques. Both of these operations require expensive, large-scale equipment, making them capital-intensive. More research should be directed toward development of acceptable chemical-based grouts, as delivery of these grout forms in an in situ mode would be less capital-intensive than delivery of particulate-based grouts.

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EM Problem: Remedial action

Y-12 Plant Problem: Soil/sediments

Problem Area/Constituents: Radionuclides, toxic heavy metals, and hazardous organic compounds

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical/chemical separation

Technology: Soil washing (contaminated soil/sediments). Soil washing is a combination of physical and chemical treatments performed on soil in an aqueous solution. Early development and implementation of soil washing technology was based primarily on the use of water as the extracting solvent.¹¹ This process only applies in the remediation of soils containing highly water-soluble constituents or soils containing very low concentrations of silt and/or clay particles (usually <15% smaller than 50 μm). As a consequence, soil washing using only water as an extraction media has very limited application to ORR contaminated soils. The U.S. Environmental Protection Agency (EPA) SITE Program now includes soil washing processes using extraction media ranging from alkaline mixtures of ionic and nonionic surfactants and bioremediating agents which act as biosurfactants¹ to acid extractions for removing heavy metals from contaminated soils and solids.¹⁰ Both of these processes represent a significant extension of existing soil washing techniques presently being used on a wide scale in Germany and the Netherlands.

Status: Several full-scale soil washing plants with capacities of 6.5 to 30 tons/h are in operation in the Netherlands and Germany.⁵ Soils (165 tons) from the United States have been shipped to the full-scale facility at Moerdijk, The Netherlands, for testing.⁸ This plant has a annual treatment capacity of 80,000 tons. However, emphasis in Europe is on removal of semivolatile organic compounds, polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides; none of the plants is presently removing radionuclides or heavy metals from soils. Also, most of the soils and sediments being remediated are sandy-textured (>85% being >50 μm diam.). Bench-scale studies have been conducted evaluating the effectiveness of various extraction media on the removal of Pu and Am.^{13,12,9,7} Extraction media included (1) pH 12.5 NaOH solution, (2) a 2% HNO_3 , 0.2% HF, 2% pine oil, and 5% Calgon, and (3) 2N HCl. Soils from 5 different DOE sites were extracted (at a 1:1 soil-to-solution ratio in a rotary extractor for 6 min. at 70 rpm). The extractions appeared to reduce concentrations of Pu and Am in the fractions >105 μm and concentrated the

radionuclides in the <105 μm size fractions. Based on wide variations in the results, the authors concluded that the selection of extraction media will have to be tailored for each soil. Grant⁶ used physical segregation and chemical extraction techniques to remove uranium, mercury, and PCBs from land soils and storm sediment from the Oak Ridge Y-12 Plant. The results indicated that the uranium was difficult to extract from the size fractions <250 μm . The best extraction procedure for uranium appeared to be attrition scrubbing using sodium carbonate solutions containing hypochlorite. Research funded under the Uranium in Soils Integrated Demonstration at Fernald, Ohio, is indicating that soils containing 400 to 500 mg/kg of uranium (soils sampled from within the Fernald production area and around a low-level waste incinerator) can be lowered to concentrations <50 mg/kg using extraction media which are selective for uranium leaching. The best results have been obtained using an extraction medium that includes a strong reducing agent and strong complexing agents for uranium.^{2,3} The reducing agent lowers the redox potential of the system to the point that uranium (VI) and ferric compounds are reduced to lower valence states, resulting in enhanced dissolution of the solid-phase mineral. The presence of complexing agents for uranium in the extraction media (Tiron and citrate) selectively removes uranium and maintains a soluble complex for uranium removal. Carbonate leaching in combination with attrition scrubbing also appears to be a possible method for removing uranium to levels <50 mg/kg for the soil sampled within the production area.⁴ Uranium from soils surrounding the incinerator area appear to be more characteristic of a low-fired uranium oxide and were more difficult to leach uranium from than the uranium in soil sampled from within the production area.

Science/Technology Needs: Recent bench-scale studies on the selective leaching of uranium from uranium-contaminated soils have indicated that specific extraction media can be tailored to remove uranium to levels that appear to be acceptable to state and federal regulatory agencies. A major need in development of soil decontamination technology is a clear understanding of what levels are acceptable for cleanup. Knowing these levels, similar bench-scale studies need to be conducted for other radionuclides and heavy metals observed in ORR soils. The nature of the extraction media depends on characteristics of the radionuclide and/or heavy metal (or organic pollutant) in the soil and the physicochemical characteristics of the soil; thus, each contaminant and soil needs to be investigated to properly assess the probability of decontamination. Simple soil washing, using water as the extraction medium, will not suffice in cleanup of the heavy-textured ORR soils containing a variety of radionuclides, heavy metals, and organic contaminants.

Economic viability of drainage wells are a strong function of deep rock drilling costs. The need exists to examine the range of drilling techniques applicable for drilling through contaminated rock: directional drilling with down-the-hole motors (DTH) and reverse circulation system air drilling with DTH hammers/tricones and other drill bits.

Implementation Needs: Bench-scale studies identify the basic mechanisms by which radionuclide, heavy metal, or organic contaminants can be removed from soil. However, bench-scale studies do not provide engineering process information as to the best ways to make liquid/solid separations or to handle a variety of soil components (rocks, clays, plant roots, etc.). Before full-scale soil decontamination plants are designed, pilot-scale studies

need to be conducted addressing a variety of process engineering variables so that the full-scale facility can be designed to operate safely, effectively, and under the most economical conditions. Thus, to conduct these pilot-scale studies, a Martin Marietta Energy Systems pilot-scale soil decontamination facility needs to be constructed.

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EM Problem: Remedial action

Y-12 Plant Problem: Impoundments/Quarries

Problem Area/Constituents: Radionuclides (uranium, plutonium), Resource Conservation and Recovery Act constituents (inorganics, possibly some organics), impoundments in contact with ground water, proximity of impoundments to Laboratory population.

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical separation

Technology: Sludge drying. As an ex situ treatment for the predominantly inorganic sludge, drying would be used basically as an aid in handling and disposal. Some volatilization of organics may occur, depending on the temperature achieved by the type of drying used. However, organics are not the primary constituent of concern. In both microwave heating and radio frequency (RF) heating, electrodes are placed in the sludge to generate the energy. Microwave heating uses microwave energy with wavelengths of 1 to 1000 mm. Radio frequency heating uses electromagnetic energy with wavelengths of 1 to 1000 m. Temperatures typically range from 150°C to 160°C for RF heating.

Status: Developmental. The use of RF heating for sludges has been successfully piloted.

Science/Technology Needs: Potential for generation of toxic off-gases and need for treatment should be evaluated.

Implementation Needs: Determination of the water content of the sludge and detailed chemical and physical characterizations are needed.

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EM Problem: Remedial action

Y-12 Plant Problem: Impoundments/Quarries

Problem Area/Constituents: Radionuclides (uranium, plutonium), RCRA constituents (inorganics, possibly some organics), impoundments in contact with ground water, proximity of impoundments to Laboratory population.

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: In situ fixation. The technology involves mixing additives such as silicates, cements, and/or polymers into the sludge, causing metals and other relatively immobile inorganics to be bound into a chemically and physically stable material. Some additives may immobilize organics. The resulting mixture is nonleachable and structurally stable.

Status: Demonstration. This technology considerably increases the amount of waste produced. Depending on the fixation agent and the degree of solidification achieved, the amount of waste could be doubled. Overall cost is inexpensive. The technology has demonstrated success in binding metals, has produced large amounts of waste, and probably cannot be considered a permanent solution.

Science/Technology Needs: In situ additive mixing and injection equipment and long-term additive/waste compatibility testing.

Implementation Needs: Detailed chemical and physical characterization of sludge.

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EM Problem: Remedial action

Y-12 Plant Problem: Impoundments/Quarries

Problem Area/Constituents: Radionuclides including uranium, plutonium, strontium, cesium; Resource Conservation and Recovery Act constituents.

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternatives: Walls/barriers

Technology: Cryogenic barriers. Cryogenics, or (ground) freezing, is a technology that was first employed in a Welsh coal mine in 1862 for soil stabilization. Since that time, tremendous progress has been made in the technology and its application. Most cases in which cryogenics has been employed has involved geotechnical stabilization, including controlling the movement of ground water at construction sites. The technology is typically applied for interim periods which correspond to construction schedules and needs; however, longer term applications may be justified as capital and operating costs are compared to alternate environmental restoration technologies.

Cryogenic barriers provide containment of subsurface chemical and nuclear wastes using barriers composed of a frozen layer of the native geologic materials. The individual application may require that a perimeter of frozen material be established to isolate the source of contamination, or the entire area could require freezing.

A typical isolation application requires installation of freeze pipes around the circumference of the site at angles that reach below the area of contamination or down to the impermeable layer below the site. A second set of pipes is installed a set distance away from the first array of pipes. Once in place, the piping is connected and supplied with a refrigerant. The layer between the two arrays of piping is frozen and serves as the barrier to prevent movement of contaminants and water into or out of the area that has been isolated. This type of barrier can serve as an effective alternative to using slurry walls, grout curtains, or steel sheet barriers. Conditions that might favor cryogenic barriers are areas that contain high concentrations of buried pipes and utilities (interferences), locations where the generation of soils from excavation to install grout curtains or slurry walls results in a waste that is difficult and expensive to manage (only an interim barrier is required), or where the depth to a layer that could serve as the bottom isolation barrier is costly to reach.

An application that, to the author's knowledge, has not been demonstrated in the field is use

of cryogenics to solidify waste material to aid in removal. This potential application would be useful where the material requires solidification for ease of excavation and packaging; however, the final waste form has not yet been agreed upon. Waste material could be allowed to thaw in its packaging and, when the final waste form has been agreed upon, the material would be in a form that could be easily transferred for treatment. (See REMA-10-OY, Solidify and Mine.) Use of this technology for the impoundment's remediation would allow use of proven mechanical excavation/mining techniques and technologies, while at the same time hydrologically isolating the area to prevent or control movement of ground water into the remediation site.

It is reported that areas up to 100 acres can be contained by this technology. The refrigerant can be aqueous ammonia, propylene glycol, or liquid nitrogen. Selection of the refrigerant is based on schedule requirements for implementation, expected duration required for freezing the area, and capital and operating costs.

Status: Use of cryogenics for geotechnical stabilization is a proven technology that is being used in all regions of the United States. Its use for environmental restoration and remediation has yet to be demonstrated on a large scale.

One of the major advantages of cryogenics is avoidance of producing large volumes of waste by the construction technique.

Another major advantage is the ability to implement the technology in areas where underground utilities are not well defined or where many underground interferences exist.

Costs for implementation of the technology are expected to be equal to or less than the costs for slurry walls, grout curtains, or other mechanical isolation technologies. The technology (i.e., mechanical equipment) would be expected to cost more; however, the costs depend on the site and technology. Operating costs are not expected to be prohibitive.

Science/Technology Needs: Demonstration/predemonstration. The technology is mature for application to geotechnically stabilize construction sites. Application as a remediation technology is not believed to be mature. No major obstacles are known to exist for site stabilization or isolation.

Using cryogenics for converting the supernates, sludges, and sediments into a solid form that would be amenable to removal via mechanical means (compared to slurring and pumping) has not, to the authors knowledge, been demonstrated.

Implementation Needs: Site-specific issues and concerns regarding location of the impoundments at the Y-12 Plant and contaminants of concern warrant further evaluation

of cryogenics. A technology assessment to determine the cost benefits of developing and using cryogenics in remediating select impoundments should be performed. It is anticipated that the technology is mature enough to apply immediately to stabilizing the site and control of ground water during the construction stage.

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1. Vendor literature and contacts.

EM Problem: Remedial action

Y-12 Plant Problem: Impoundments

Problem Area/Constituents: Radionuclides (uranium, plutonium), Resource Conservation and Recovery Act constituents (inorganic, organics).

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: In situ vitrification (impoundments)

Status: In situ vitrification (ISV) has not been demonstrated on impoundment sludge at ORNL; however, in situ vitrification for low-level radioactive seepage pits and trenches has been demonstrated at the pilot scale (approximately half scale for an actual application). The technology has been accepted for this application and is the basis for the baseline cost estimates for WAG 7 at ORNL. ISV produces an excellent waste form for all radionuclides of interest. Ambient earthen materials and backfills used in the seepage pits and trenches and the surrounding soil formation have been shown to pose no impediment to ISV. Regulatory agency personnel have approved demonstrations and remain enthusiastic that ISV will be implemented at the ORR.

Science/Technology Needs: Minor but significant volatilization of ^{137}Cs can occur during ISV, particularly in the presence of materials containing chloride. The only technology challenge for ISV is to carry out actual field-scale implementation to establish that necessary target depths can be attained, that adjoining melts can be overlapped, and that site characterization and post-ISV verification techniques can be developed to establish effectiveness and actual field waste form quality. Off-gas handling techniques will need to be modified to deal with potential volatilization of ^{137}Cs during ISV, so that radiation fields do not build up in the off-gas handling system.

Implementation Needs: Implementation needs for ISV for impoundments only center on establishing field-scale implementation. This need is partially being addressed by an ER-funded project to perform ISV on part or all of ORNL Pit 1 in FY 1995. Pit 1 was selected because it is the smallest of the seven pits and trenches, and because it contains the smallest inventory of activity (about 400 Ci). Therefore, using Pit 1 will establish ISV at a field scale at ORR with a minimal amount of product produced and a minimal risk of radiological problems. Experience with this ISV program on pits and trenches should greatly increase the

knowledge base for implementing ISV on impoundments.

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EM Problem: Remedial action

Y-12 Plant Problem: Impoundments

Problem Area/Constituents: Radionuclides (U, Pu), RCRA constituents (inorganic, organic)

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Walls/barriers

Technology: Clay/bentonite additives. Use of clays, in particular bentonite, as a material to apply to impoundments for controlling outleakage is a technology that has been used throughout the United States and Europe. However, the typical application is made during the construction phase of the project, when bentonite can be applied and worked into the soil to provide the mechanism to lower the soil's permeability, thereby serving to provide a liner for the impoundment. The application being considered for the impoundments at the Oak Ridge National Laboratory (ORNL) is different in that the impoundments were constructed many years earlier, and the addition of the bentonite would be performed to stop or greatly reduce the flow of waste water from the impoundment.

Applying bentonite clays to an existing impoundment which contains liquids would be made by depositing clay, typically in granular or pellet form, from the surface of the impoundment. The clay would have to be spread over the aerial surface with special attention paid to the areas where, through dye tracer testing or operational knowledge, the impoundment is known to have, or is suspected of having, the most significant outleakage. If information regarding the location and physical description of the leak is known (e.g., through rock fissures), an alternate to bentonite pellets or granules might be employed. The alternate method of application would be to lay bentonite mats over the aerial surface of the impoundment and to allow them to sink to the bottom.

Status: Use of bentonite as an additive to the materials for construction of liners for impoundments and disposal cells has been practiced for many years with varying degrees of success. Use of bentonite as an additive to an existing impoundment has been performed in limited cases (e.g., for sealing the containment of fish ponds or for sealing the containment of ponds used in landscaping). The author could not locate any cases where bentonites or other clays have been used to stop outleakage from impoundments that had been used for containing process liquids or wastes.

There are several apparent advantages in using bentonite to control the permeability of the containment of an impoundment.

Material costs are relatively low. Assuming an application rate of 6 lb/ft², material cost would be \$0.55/ft². Other costs for application (materials and labor), procurement, assessment of the impoundment before and after, and design would be additional.

Risks of application are minimal, if the bentonite should fail to attenuate the outleakage. The additional volume of material made by the bentonite could result in an increase of waste generated by final remediation of the site, depending on the alternative selected. Little, if any, excavation would be required for the application. Resources required for application would include off-the-shelf technology operated by existing labor forces.

The bentonite layer could offer a degree of self-healing.

Depending on the specific site conditions, the layer could offer limited isolation of the sediments on the bottom of the impoundment from wildlife.

Judging the effectiveness of the bentonite could be difficult and would certainly not be exact.

The bentonite might not work well on the sloped sides on an impoundment, unless the sides first received a layer of gravel.

Science/Technology Needs: Performance of a controlled field test is needed to allow evaluation of the technology. If the technology holds promise based on the first technology demonstrations, additional testing should be performed to develop design and construction requirements.

Implementation Needs: Characterization is needed to identify the areas of the impoundment that are likely to be leaking.

Author: W.T. Thompson/615-574-6549

References: Personal experience.

EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water, organics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology In situ chemical oxidation. Implementation of in situ chemical treatment generally requires incorporation of the treatment reagent into the contaminated medium. The means by which this is done largely depends on the depth of the contamination. Conventional agricultural techniques can be used in cases where contamination is in the shallow subsurface zone. In cases of deeper contamination, the treatment reagent is typically introduced into the subsurface in an infiltration trench or injection well. The infiltration trench or injection well is often coupled with drains or production wells to induce flow of the reagent through the contamination. This "closed loop" approach can also be used to extract mobile contaminants from the subsurface and provides some degree of control of the migration of both contaminant and treatment reagent.

With chemical oxidation, the oxidation state of a substance is increased through the loss of an electron. In many instances the intermediate products of chemical oxidation can be further oxidized if sufficient oxidizing reagent is applied. When hydrogen peroxide is used as the oxidizing agent, it is uncertain whether contaminant removal is the result of chemical oxidation or free radical destruction. It is well documented in the literature that in the presence of ferrous iron, hydrogen peroxide can undergo catalytic conversion to hydroxy free radicals (Fenton's reagent). These free radical are known to be very strong, nonspecific reactive species, capable of destroying a wide variety of compounds.

Status: Predemonstration. Chemical oxidation of organics with potassium permanganate and ozone has been demonstrated in aqueous matrices and, on a limited basis, with waste sludges. Demonstration. In situ chemical oxidation with hydrogen peroxide has been demonstrated at the field level (Portsmouth X-231B Technology Demonstration) as an effective remediation technique for TCE-contaminated soils and ground water. This approach included delivery of hydrogen peroxide to the contaminated subsurface using deep soil mixing and reagent injection equipment.

Science/Technology Needs: Soil characteristics such as moisture content, porosity, and particle size distribution are used to evaluate the ability to deliver reagents to the matrix. Waste characterization is used to determine the suitability of the material for in situ treatment and to select the appropriate oxidizing agents. Hydrogeological data are used to determine the ability to recover untreated or unreacted material and to determine injection locations. Chemical interactions are assessed to determine reagent dosage and its impact on the contaminants of concern and on other chemicals present.

Implementation Needs: The cost of this technology could vary depending on cost of the oxidants and required reagent delivery systems. The reagent delivery systems requirements vary depending on the depth to contamination and the hydrogeological characteristics of the contaminated site. Both potassium permanganate and hydrogen peroxide are commercially available and can be obtained without much difficulty. Although the application of in situ hydrogen peroxide oxidation only requires weak peroxide solutions, many vendors deliver higher strength solutions to be diluted prior to use. There may be handling, storage, and disposal problems with these higher strength peroxide solutions. Overall, the cost per unit volume of ground water treated would likely be low (a few \$/1000 gal).

Author: Dianne Gates/615-576-0427

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2. D.D. Gates and R.L. Siegrist, *Laboratory Evaluation of Chemical Oxidation Using Hydrogen Peroxide*, ORNL/TM-12259, report from X-231B Project for In Situ Treatment of Clay Soils Contaminated by Volatile Organic Compounds and Radioactive Substances, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1993.
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4. S.W. Leung, R.J. Watts, and G.C. Miller, "Degradation of Perchloroethylene by Fenton's Reagent: Speciation and Pathway," *J. Environ. Qual.*, **21**: 377-81, 1992.
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6. P.A. Vella and B. Veronda, "Oxidation of Trichloroethylene: A Comparison of Potassium Permanganate and Fenton's Reagent," *Proceedings of Third Annual International Symposium on Chemical Oxidation Technology for the Nineties*, Vanderbilt University, Nashville, Tenn., 1993.
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EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water, inorganics, and radionuclides

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Chemical separation

Technology: In situ precipitation. Various chemicals are available that could conceivably precipitate contaminants from ground water in situ, such as lime, iron sulfide, and iron filings. Methods are available for injecting slurries into soil formations.

Implementation of in situ chemical treatment generally requires incorporation of the treatment reagent into the contaminated medium. The means by which this is done largely depends on the depth of the contamination. Conventional agricultural techniques can be used in cases where the contamination is in the shallow subsurface zone. In cases of deeper contamination, treatment reagent is typically introduced into the subsurface in an infiltration trench. The formed material precipitates out in the trench, allowing eventual recovery of the material.

Precipitation of metals occurs when the solubility product of the ions forming the precipitate is exceeded in the solution. Metals may be precipitated as sulfides, carbonates, phosphates, and hydroxides, with sulfide precipitates being the most insoluble for several metals, even at acidic pH levels. The extent of metal sulfide precipitation is a function of pH, type of metal, sulfide content, and interfering ions.

Status: Predemonstration. Because of the innovativeness of the delivery system and the uncertainties of the chemical reaction in the subsurface, the technology needs further development.

Science/Technology Needs: The optimum treatment chemicals for various contaminants needs to be determined. Whether flow paths through the soil would remain open as metals are precipitated in situ needs to be determined. The long-term stability of the precipitated metals needs to be determined. The kinetic aspects of precipitation and dissolution reactions

involving metals in a soil system have not been well-characterized and may limit the effectiveness of this treatment technology. Chelating agents, other competing reactions (formation of soluble metal complexes) and the salt content of the waste may reduce the effectiveness of in situ precipitation.

Implementation Needs: A trench containing the chemical-causing precipitation would need to be located and installed in the down-gradient direction. It would probably be necessary to periodically replace the trench and the materials. The precipitated contaminants would need to be removed and treated further or disposed. Treatment costs would probably be relatively low, assuming that inexpensive treatment chemicals would work.

Author: P.A. Taylor/615-574-1965

References: Personal experience and discussions with Oak Ridge National Laboratory Chemical Technology Division staff.

EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water/surface water, organics, and inorganics

Reference Requirements: Refer to Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Artificial wetlands. Ex situ bioaccumulation technologies include use of constructed or natural wetlands. Wetlands have been used for disposing and treating contaminated water since the 1950s in a wide variety of applications: municipal wastewater, industrial wastewater, storm water runoff, mine discharge and surface mine runoff, agricultural nonpoint source runoff, and ground water. Documented treatment effectiveness varies relative to the parameter in question (e.g., loading rates, detention times, flow-path length, and age of the system). Constructed systems are generally more effective than natural systems, because the hydraulics and detention times can be controlled and optimized. Natural wetlands may also become degraded as a result of contaminant additions and high loadings. Documented wetland treatment efficiencies range from 30% to 95% on an annual, mass-removal basis.

Artificial wetlands provide treatment through physical (sedimentation), chemical (precipitation and adsorption), and biological (adsorption, plant uptake, biodegradation) processes. Plant uptake consists of planting a plant species which concentrates the contaminant in a harvestable portion of the plant. The plant tissue is then removed seasonally and disposed. This is a fairly slow process, depending on the plant species used, the biomass produced, timing of the harvest, and the contaminant. In biodegradation, microorganisms use the contaminants (usually organic compounds and some inorganic compounds such as ammonia) as part of their metabolism.

Status: Predemonstration for inorganics, demonstration for organics. Artificial wetland use for synthetic organics such as toluene and xylene have been tested in laboratory-scale systems.

Science/Technology Needs: The forms of potentially toxic contaminants and degradation products needs to be determined. Flow volumes and average contaminant concentrations in water and soil are used to assess potential loading rates. Climate conditions, such as the length of the growing season, the average winter temperature, the length of period when pipes

and ponds may freeze in winter, the summer evapotranspiration rate, and precipitation, are used to assess the effectiveness of the technology and to determine design parameters. Local surface and ground-water hydrology, such as topographic setting, water budget, depth to average and high ground-water table, ground-water chemistry, and distance to natural water bodies, also includes important variables. Soil conditions and organisms in the soil will determine the success of the technology or what type of additives are needed.

Implementation Needs: The soil may need amendments to support vegetation. Microbial stimulation is accomplished by providing a conducive environment for growth. Properties that can be altered physically or chemically include temperature, moisture, oxygen content, carbon, nutrients, hormones, sunlight, enzymes, pH, availability of substrate compounds, solubility, competing organisms, concentration of organisms, and concentration of contaminants. Year-round vegetation cover needs to be maintained for maximum treatment and to avoid water and wind erosion and resultant contaminant mobilization. Artificial wetlands typically require a surface area of 4 to 12 ha/1000 m³ wastewater/day. Construction costs were about \$100,000/ha in 1990, and operating costs were low.

Author: P.A. Taylor/615-574-1965

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1. D.A. Hammer, *Constructed Wetlands for Wastewater Treatment*, Lewis Publishers, Ann Arbor, Michigan, 1989.

EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water, inorganics, and radionuclides

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Chemical separation

Technology: In situ ion exchange. Ion exchange is based on the use of specifically formulated resins and natural inorganic materials having an "exchangeable" ion bound to the resin with a weak ionic bond. If the electrochemical potential of the ion to be recovered (contaminant) is greater than that of the exchangeable ion, the exchange ion goes into solution, and the ionic contaminant binds to the resin. Chabazite zeolite, which is planned for the ORNL Process Waste Treatment Plant, is specific for ^{90}Sr and ^{137}Cs . Other resins and natural zeolites are specific for other inorganics. These materials can be applied in situ through a trench-and-fill chemical barrier.

Status: Predemonstration. Ion exchange is fully developed, although applications have been very waste-stream-specific. Applications have included removal of radionuclides from power plant waste streams, recovery and removal of metals, and deionization/softening of process water. However, the application of ion exchange in situ has not been demonstrated. Issues of monitoring breakthrough of the resins, contact of the contaminants with the resin, locating the trench, potential for clogging the trench, and removing spent resins and regenerating or disposing of the resins need to be resolved. A field demonstration is currently being implemented at WAG 5 at Oak Ridge National Laboratory.

Science/Technology Needs: Lab-scale treatability tests are used to provide data for resin selection and to provide estimates of contaminant loading. The presence of constituents such as organics, chelating agents, and other significant ionic species that will compete for ion exchange sites also need to be assessed. The acidity and alkalinity of the water will determine the solubility of the metals and the effectiveness of the resin. The presence of potential clogging compounds such as total suspended solids will be used to determine the maintenance frequency. Locating the trench and determining the flow rates through the trench requires an understanding of the hydrogeology of the site.

Implementation Needs: The most appropriate resin needs to be selected. An appropriately located trench needs to be constructed. Methods to limit fouling while allowing flow-through

need to be identified and implemented. Additionally, it may be necessary to optimize flow through the trench bed by modifying the ground-water flow velocity. Continual maintenance to control breakthrough of the contaminants and to remedy clogging will be needed. Monitoring of the ground-water condition, both before and after the trench, will be needed to assess effectiveness of the technology and to identify any needed operation modifications. Once the resin is removed from the trench, it must be either regenerated or disposed. Regeneration will produce a concentrated solution of the contaminant removed that will require either further treatment or disposal. Costs are unknown pending field tests.

Author: Joseph Perona/615-576-9280

References:

1. *Remedial Investigation Plan for Waste Area Grouping 2 at ORNL*, ES/ER-14&D1, Oak Ridge National Laboratory, Oak Ridge, Tenn., December 1990
2. M.D. Loizidou, R.P. Townsend, *Zeolites*, Vol. 7, March 1987.
3. S.M. Robinson et al., *The Development of a Zeolite System for Upgrade of the Process Waste Treatment Plant*, ORNL/TM-12063, Oak Ridge National Laboratory, Oak Ridge, Tenn., July 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water/surface water, inorganics, and radionuclides

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Chemical separation

Technology: Ion exchange. Ion exchange is an ex situ volume and toxicity reduction technology to remove ionic species, principally inorganics, from aqueous waste streams. Ion exchange is based on the use of specifically formulated resins and natural inorganic materials having an "exchangeable" ion bound to the resin with a weak ionic bond. If the electrochemical potential of the ion to be recovered (contaminant) is greater than that of the exchangeable ion, the exchange ion goes into solution and the ionic contaminant binds to the resin.

Typically, four operations are carried out in a complete ion exchange cycle: service, backwash, regeneration, and rinse. In the service step, the ion exchange resin is contacted with solution containing the ion to remove. After a critical relative concentration of contaminant ion to exchange ion in solution is reached, the resin is said to be spent. A backwash step then is operated to expand the resin and to remove fines that may be clogging the bed. The spent resin is regenerated by exposing it to a very concentrated solution of the original exchange ion, so that a reverse exchange process occurs. The rinse step removes excess regeneration solution before the next service step. Chabazite zeolite columns are planned for the ORNL Process Waste Treatment Plant, to replace the Dowex HCR-S strong acid cation resin currently used. Unlike the typical operation, spent zeolite would not be regenerated but stored as solid waste. Zeolites give the smallest volume of secondary waste of any ion exchangers found so far. The zeolite is specific for ^{90}Sr and ^{137}Cs . Calcium competes with strontium for ion exchange sites. Other resins and natural zeolites are specific for other inorganics.

Status: Accepted. The technology is fully developed, although applications have been very waste-stream-specific. Applications have included removal of radionuclides from power plant waste streams, recovery and removal of metals, and deionization/softening of process water. Promising applications include removal of cyanides from mixed waste streams and selective removal of heavy metals without complete deionization.

Science/Technology Needs: Laboratory-scale performance tests provide data for resin selection, estimates of resin loading and regeneration requirements, and other needed parameters for column design. Wastewater characteristics, such as the presence of competing ions or chelating agents, are used in the design of an ion exchange system. The solubility of the metals and, hence, the effectiveness of the system is affected by the acidity/alkalinity of the wastewater. The presence of suspended solids may indicate the need for pretreatment.

Implementation Needs: Resins exhibit different selectivities for specific contaminants. In a mixed contaminant stream, one metal may be effectively removed from solution while another will not. Ion exchange may be difficult without pretreatment to remove organics, to destroy chelating agents, or to destroy the chelant metal bond. Pretreatment may also be needed to remove solids (to prevent blinding of the column), to modify the pH of the influent stream for optimum removal efficiencies, or to remove competing ions.

The process yields a large volume of purified solution, regenerated zeolite, and a concentrated solution of removed ions which can then be further processed for recovery or disposal. The system uses columns containing the resin and various pumps and piping to carry the waste streams and potentially new and spent resin. Cost (capital plus operating) is estimated to be \$5-\$10/1000 gal.

Author: Joseph Perona/615-576-9280

References:

1. *The Development of a Zeolite System for Upgrade of the Process Waste Treatment Plant*, ORNL/TM-12063, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1989.
2. *Remedial Investigation Plan for Waste Area Grouping 2 at ORNL*, ES/ER-14&D1, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1990.
3. Calmon, C. (ed.), *Ion Exchange for Pollution Control*, CRC Press, Boca Raton, Fla., 1979.

EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water/surface water, organics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Chemical separation

Technology: Activated carbon. Liquid-phase adsorption technology encompasses those processes that use a solid material of high surface area or permeability to selectively adsorb organic contaminants from aqueous streams. Liquid-phase adsorption works on the principle that the concentration of certain organics will be higher on the surfaces of certain solids than in the bulk-liquid phase. The principal mechanisms involved in adsorption of organics are physical adsorption and chemisorption. Physical adsorption occurs between the dissolved compound and the surface because of weak atomic and molecular forces such as Van der Waal forces. Chemisorption involves a chemical reaction between the compound and the surface of the solid. Most adsorbents also possess ion exchange sites which involve the exchange of ions. Granular activated carbon is, by far, the most commonly used adsorbent and system used in industrial waste treatment applications. It is invariably used in packed column systems and is often regenerated. Contaminated water is passed through the column until the key contaminant is detected at some predetermined level in the effluent. Usually two or three columns are placed in series, so that the first column can be loaded to its maximum capacity while residual levels of the contaminant are removed in the subsequent columns.

Status: Accepted. Activated carbon is frequently used for the treatment of organic-laden wastewaters. It is used in tertiary treatment for wastewater treatment plants and to treat industrial wastewaters. It also has been used significantly for treatment of hazardous waste streams.

Science/Technology Needs: Flow rate is used to size the system. The contaminant requiring removal determines the feasibility of the technology and the potential adsorbents to use. Final selection of the adsorbent is frequently determined using treatability studies. Column tests are used to design a full-scale system using information on adsorbent usage rates and competitive adsorption effects.

Implementation Needs: Some potential design parameters in a capacity of 15–100 gal/min and hydraulic loadings of 0.25–2.5 gal/min/cf are needed. Linear flow rates may be 0.4 to

3 gal/min/sf cross-sectional area. Typical bed depths vary from 8 to 40 ft, with a height-to-diameter ratio of 2 : 1. An enclosed area is used to protect the carbon columns and ancillary equipment. A regeneration facility or disposal means for the used carbon is needed. A means of conveying ground water or surface water to the treatment facility is needed.

The suspended solids content should be reduced to less than 50 mg/l which may require pretreatment. Oil and grease concentrations above 10 mg/l are generally undesirable because of fouling characteristics. Calcium or magnesium concentrations above 500 mg/l can precipitate out and foul or plug granular-activated-carbon columns. Cost (capital plus operating cost) is \$1.20/1000 gal. Disposal costs could be significantly greater, \$5-\$10/1000 gal.

Author: Joseph Perona/615-576-9280

References:

1. *Control of Organic Substances in Water and Wastewaters*, EPA-600/8-83-022, SRI International, Menlo Park, Calif., June 1983.
2. *Removal of Volatile Organic Chemicals from Potable Water*, Noyes Data Corporation, Park Ridge, N.J., 1986.
3. *Removal Investigation Plan for Waste Area Grouping 2 at ORNL*, ES/ER-14&D1, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1990.
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6. *Treatment Technologies for Solvent Containing Wastes*, Noyes Data Corporation, Park Ridge, N. J., 1988.

EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water/organics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Chemical separation

Technology: In situ activated carbon. Liquid-phase adsorption technology encompasses those processes that use a solid material of high surface area or permeability to selectively adsorb organic contaminants from aqueous streams. Liquid-phase adsorption works on the principle that the concentration of certain organics will be higher on the surfaces of certain solids than in the bulk-liquid phase. The principal mechanisms involved in adsorption of organics are physical absorption and chemisorption. Physical adsorption occurs between the dissolved compound and the surface because of weak atomic and molecular forces such as Van der Waal forces. Chemisorption involves a chemical reaction between the compound and the surface of the solid. Most adsorbents also possess ion exchange sites which involve the exchange of ions. Granular activated carbon is, by far, the most commonly used adsorbent and system used in industrial waste treatment applications.

In situ carbon adsorption occurs by ground water passing through a subsurface bed of carbon, usually placed in a permeable trench. Spent carbon will have to be removed from the trench and replaced with new or regenerated carbon. The spent carbon will need to be regenerated or disposed.

Status: Predemonstration. While carbon adsorption is an accepted technology, its in situ application is predemonstration. The uncertainties associated with controlling flow through the bed, controlling fouling of the bed, competing contaminants or ground-water constituents, and monitoring the condition and effectiveness of the carbon result in the need for further development of the technology.

Science/Technology Needs: Information about the local hydrogeology is used to locate and size the trench(es). Flow control may be used to optimize treatment. The contaminant requiring removal determines the feasibility of the technology and the potential adsorbents to use. Final selection of the adsorbent is frequently determined using treatability studies.

Implementation Needs: Costs unknown pending field tests.

Author: Joseph Perona/615-576-9280

References:

1. *Control of Organic Substances in Water and Wastewaters*, EPA-600/8-83-022, SRI International, Menlo Park, Calif., June 1983.
2. *Removal of Volatile Organic Chemicals from Potable Water*, Noyes Data Corporation, Park Ridge, N.J., 1986.
3. *Removal Investigation Plan for Waste Area Grouping 2 at ORNL*, ES/ER-14&D1, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1990.

EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water/surface water, organics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Biological oxidation. Aerobic biological wastewater treatment processes employ microorganisms, principally bacteria, that can use wastewater contaminants as part of their metabolism. The contaminants are thereby removed from the wastewater or transformed into a benign form. The primary mechanism of removal is oxidation with molecular oxygen serving as the oxidant or electron acceptor. The contaminant compounds serve as the electron donor and are typically referred to as substrates. The microorganisms obtain energy from mediating these redox reactions and use this energy to maintain cells and synthesize new cells or biomass.

In addition to an energy source, the microorganisms need a source of carbon, nitrogen, phosphorus, and a wide variety of other trace nutrients in order to synthesize new cells. These nutrients must be either be present in the wastewater or added in sufficient quantity so that the limiting factor in the growth of the microorganisms is the concentration of contaminant compounds. For a biological treatment process to effectively remove a given compound from a wastewater, an organism capable of using the compound as a substrate must exist and be able to proliferate in competition with the other microorganisms in the system. The culture of biomass that develops in the system will depend on the relative concentration of all the substrates in the wastewater and on the characteristics of the seed material used to provide the initial biomass during startup. Some compounds may be metabolized by many different organisms, while some require a specialized organism. These considerations make it difficult to predict removals of specific compounds without performing bench-scale or pilot-scale studies.

The main physical component of an aerobic biological treatment system is a reactor in which the wastewater and biomass are mixed together while maintaining favorable environmental conditions. Environmental conditions that affect the growth rate of microorganisms include the following: temperature, pH, nutrient availability, presence or absence of toxicants, and dissolved oxygen concentration. Two major categories of aerobic biological treatment systems for wastewater are suspended growth and attached growth. In suspended growth systems,

the microorganisms and the incoming wastewater are mixed in a tank called the aeration basin. Maintenance of high concentrations of biological solids in the aeration basin is accomplished by separating and recycling suspended solids from the aeration basin effluent. The separation of solids and wastewater is usually accomplished by gravity in a separate tank called a clarifier. In attached growth systems, most of the biomass is attached to a stationary medium that is submerged in the wastewater. This attachment serves to retain high concentrations of biomass and allows for long solids retention times. Attached growth systems usually require an external clarifier to remove excess solids from the effluent.

Status: Accepted. The Oak Ridge National Laboratory (ORNL) Sewage Treatment Plant (STP) treats wastewater by biological oxidation. Biological oxidation is routinely used to degrade water-soluble organics, but more refractory contaminants, such as chlorinated solvents, may require specially designed treatment systems.

Science/Technology Needs: Characterization of the wastewater to be treated is desirable when evaluating wastewaters for which there is little treatment experience. Characterization will help evaluate potential problems with toxicity. The chemical oxygen demand to ultimate biological oxygen demand (COD/BOD_u) ratio indicates the degradability of organics in wastewater. Treatability testing may be useful to accurately size aeration basins. However, most of this information is collected for design. Additional research is needed to assess the effectiveness of biological oxidation in the treatment of refractory organic compounds.

Implementation Needs: If the existing plant is used, methods for collecting wastewater from the site and for transporting it to the STP are needed. The permit for the STP may need to be modified if large volumes of contaminated ground water are to be treated. The concentration of organics in the wastewater must be high enough to support biological growth. Treatment costs at the ORNL STP are about \$0.01/gal.

If a new treatment plant is built, the room to build the plant, the equipment and tanks, the chemicals, the solids handling facilities are all needed.

Author: Paul Taylor/615-574-1965

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1. W. W. Eckenfelder, Jr., *Industrial Water Pollution Control*, 2 ed., McGraw-Hill Book Company, New York, 1989.
2. Grady, Jr., C. P., and Lim, H. C., "Biological Wastewater Treatment," Marcel Dekker, Inc., New York, New York, 1980.
3. Metcalf and Eddy, Inc., "Wastewater Engineering: Treatment, Disposal, Reuse, McGraw-Hill Book Company, 1979.

EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water/surface water—polychlorinated biphenyls

Reference Requirements: Refer to the 'Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Anaerobic dechlorination. Anaerobic bacteria are capable of partially dechlorinating PCBs. Dechlorination involves breaking the chlorine-carbon bond. Organic chemical dechlorination uses chemical reagents or catalysts to remove chlorine atoms from a chlorinated hydrocarbon. Organic chemical dechlorination may reduce the toxicity of a chlorinated hydrocarbon and/or make it amenable to other forms of treatment. Several reagents for dechlorinating dioxins and PCBs have been developed. These reagents include alkali metal polyethylene glycolate salts (APEGs), including potassium polyethylene glycol (KPEG). The KPEG process is generally useful on ex situ soils. Heat and excess reagent are required for soils containing more than seven percent moisture. Research work on other polychlorinated compounds, including DDTs and several other commercial pesticides, has shown that a catalyst can be used at room temperature to cause a rapid reduction reaction where chlorines on the organic compound are replaced with hydrogen atoms. This is a different reaction mechanism than the APEG mechanism. However, the process does not completely dechlorinate most organic chemicals. The applicability of these technologies to wastewater is not known.

Status: Predemonstration. Laboratory-scale tests have shown that higher-chlorination PCBs can be dechlorinated anaerobically.

Science/Technology Needs: Better fundamental understanding of the biological and chemical processes involved in dechlorination is needed. The water characteristics (pH, temperature, conductivity, etc.) need to be assessed.

Implementation Needs: Improvements in degradation rates are needed before feasible treatment systems can be designed. Based on current experimental results, treatment costs will be very high because of the very low degradation rates.

Author: P.A. Taylor/615-574-1965

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1. D. A. Abramowicz, *Critical Reviews in Biotechnology*, 3-241-51, CRC Press, Boca Raton, Fla., 1990.
2. Kornel, A., and Rogers, C., "PCB Destruction: A Novel Dehalogenation Reagent," *Journal of Hazardous Materials*, 1985.

EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water, organics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: In situ biological oxidation. Bioreclamation of the saturated zone uses water to deliver the electron acceptor, usually oxygen. Water amended with an electron acceptor, nutrients, and optional microorganisms is introduced into the contaminated ground-water zone via one or more injection wells to stimulate biodegradation. Extraction wells are normally used to pull amended water horizontally through the contaminated zone. The extracted water may require further treatment. A variety of methods are available for delivering oxygen to the subsurface via recharge water. Air or oxygen can be transferred to water using an aboveground or in-well sparging system. The disadvantage of these techniques is the limited amount of oxygen that can be transferred to water. Use of hydrogen peroxide can greatly increase the oxygen-carrying capacity of injected water since molecular oxygen is liberated during the natural decomposition of hydrogen peroxide. Hydrogen peroxide is toxic to bacteria at high concentrations, but microbial activity is not inhibited at dilute concentrations. Hydrogen peroxide at 40 mg/l of ground water is reported to release sufficient oxygen to sustain in situ biodegradation.

Status: Demonstration. In situ bioremediation is being tested extensively at superfund sites for destroying organics in ground water. Fluids-cycling bioreclamation has been used most frequently to treat soil/water systems contaminated with gasoline, diesel, jet fuel, and BTEX such as at the Kaispel Construction Site in Horseheads, New York. Cometabolic biodegradation of chlorinated aliphatic solvents has been demonstrated using this process.

Science/Technology Needs: To implement in situ aerobic biodegradation, the dissolved oxygen concentration must be greater than 1 mg/l and the minimum air-filled pore space should be about 10 percent. The redox potential should be greater than 50 mV, the pH between 4.5 and 8.5, and the carbon to nitrogen to phosphorus ration about 120:10:1. Microbial toxicity and inhibition is also determined as is bacterial characterization. If native organisms are not present, cultured biomass must be added. Another issue is the particle size distribution. Variable waste composition and nonuniform particle size lead to inconsistent bioreclamation of contaminated media.

More control over the in situ addition/removal process needs to be obtained. Studies to improve the contact between contamination, bacteria, and oxygen are needed.

Implementation Needs: Development work would be needed to evaluate in situ treatment of Y-12 contaminated ground water. In situ biological processes are usually considered to be relatively inexpensive.

A means for injecting oxygen-laden water is needed along with a means of controlling the water movement through hydraulic controls, if appropriate. Nutrients and bacteria may be needed to supplement subsurface conditions. Nitrogen and phosphorus are most frequently the rate-limiting nutrients.

Author: P.A. Taylor/615-574-1965

References:

1. E. Riser-Roberts, *Bioremediation of Petroleum Contaminated Sites*, C. K. Smoley and Sons, Chelsea, Mich., 1992.

EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water, polychlorinated biphenyls

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: In situ anaerobic dechlorination. PCBs could be dechlorinated biologically or chemically. Anaerobic bacteria are capable of partially dechlorinating PCBs. Dechlorination involves breaking the chlorine-carbon bond. Organic chemical dechlorination uses chemical reagents or catalysts to remove chlorine atoms from a chlorinated hydrocarbon. Organic chemical dechlorination may reduce the toxicity of a chlorinated hydrocarbon and/or make it amenable to other forms of treatment. Several reagents for dechlorinating dioxins and PCBs have been developed. These reagents include alkali metal polyethylene glycolate salts (APEGs), including potassium polyethylene glycol (KPEG). Most of these reagents are used on ex situ soils; potentially, they could be introduced into the contaminated ground water via injection with water. As with any in situ ground-water treatment technology, control of the reagents and the ground-water flow affect the overall effectiveness.

Status: Predemonstration. Laboratory-scale tests have shown that higher-chlorination PCBs can be dechlorinated anaerobically. Evidence from several sites suggests that these reactions have occurred naturally in PCB-contaminated sediments.

Science/Technology Needs: Better fundamental understanding of the biological and chemical processes involved in dechlorination is needed. The aquifer soil physical conditions (permeability, density, particle size, etc.) need to be assessed to determine the potential for mixing reagents with the contaminated ground water. Also the ground-water characteristics such as pH, temperature, other organics, and conductivity will also assist in determining the effectiveness of the technology. However, first more information about the technology, especially if applied in situ, needs to be gathered through treatability studies. Its cost and effectiveness are not well understood.

Implementation Needs: Methods must be developed to control the process and to greatly increase degradation rates. Better water characterization is needed. A means for injecting reagent-laden water is needed along with a means of controlling the water movement through hydraulic controls, if appropriate.

Author: P.A. Taylor/615-574-1965

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1. D. A. Abramowicz, *Critical Reviews in Biotechnology*, 3-241-51, CRC Press, Boca Raton, Fla., 1990.
2. Kornel, A., and Rogers, C., "PCB Destruction: A Novel Dehalogenation Reagent," *Journal of Hazardous Materials*, 1985.

EM Problem: Remedial action

Site Problem: Groundwater and surface water

Problem Area/Constituents: Groundwater and surface water contaminated with organics

Reference Requirements: Refer to "Regulatory Compliance," Volume 1, (Pt. A, B, or C as appropriate) for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Chemical oxidation. Chemical oxidation is used to remove a variety of wastewater constituents by converting the constituents to an insoluble form, a form that can be removed by further treatment, or a form that can be removed by complete degradation through oxidation. The cost-effective treatable concentration range is typically not more than 5,000 ppm. Treatment chemicals need to be added in excess of the stoichiometric requirements. There are many oxidizing agents, but only a few are convenient to use. Common ones include chlorine-containing agents, ozone, permanganate, and peroxide. Ultraviolet radiation, in combination with the oxidant, can improve effectiveness. In particular, ultraviolet radiation has been found to increase the oxidizing power of peroxide and ozone.

Chlorine and chlorine-containing compounds such as hypochlorite are the most widely used disinfectants. Chlorine oxidizes a variety of compounds such as ammonia, cyanide, sulfide, and mercaptans. Ozone is one of the most powerful oxidation agents available. It can oxidize a variety of organic compounds such as phenols, cyanides, organometallic complexes, and organic nitrogen compounds. Ozone is fed as a gas and must be generated on-site immediately before use because of its instability. Ozone is unstable and breaks down to molecular oxygen with a half life of 20 min. Ozone is also nonselective and is uneconomical for wastes with high chemical or biological oxygen demands. Hydrogen peroxide is used to remove sulfides, mercaptans, amines, cyanide, and lead. It is particularly effective for the oxidation of phenols.

Status: In Use. Perox-Pure Advanced Oxidation Technology, developed by Peroxidation Systems, Inc., is an example of a successfully designed system that uses UV radiation along with hydrogen peroxide. It has been applied at over 80 sites in the United States to treat contaminated groundwater, industrial wastewater, landfill leachates, potable water, and industrial reuse streams. Contaminants include chlorinated solvents, pesticides, polychlorinated biphenyls, phenolics, fuel hydrocarbons, and other organics ranging in concentrations between a few thousand mg/L to 1 µg/L. This technology was demonstrated

in the EPA SITE program at the Lawrence Livermore National Laboratory Site 300 Superfund Site.

Ultrox International has also produced a successful system that uses UV radiation, ozone, and hydrogen peroxide. The process oxidizes compounds that are toxic or refractory, resistant to biological oxidation, in concentrations of ppm or ppb. A system is fully commercial, with over 25 systems installed at various site cleanup activities. It was tested at a U.S. Department of Energy (DOE) site in Kansas City, Missouri, in which groundwater was treated for VOC and PCB contamination.

Efficacy: The Perox-Pure system was demonstrated for the removal of trichloroethene (TCE) and tetrachloroethene (PCE) at concentrations of 1,000 and 100 $\mu\text{g/L}$, respectively, from 40,000 gal of groundwater. Results showed removal efficiencies of about 99.9 and 99.7%, respectively, corresponding to effluent concentrations below 1 $\mu\text{g/L}$.

Weaknesses: Oxidation may introduce additional pollutants into an effluent. Products of incomplete oxidation, such as chlorinated hydrocarbons, may be hazardous. Chlorine is not recommended for treating streams with high organic content as toxic chlorinated organics can be produced. Chlorine gas is toxic as an irritant and by inhalation. Human tolerance is 1 ppm in air. The effluent produced during the SITE demonstration of the Perox-Pure system was acutely toxic in bioassay tests, even though the influent was not. Comparison of the effluent toxicity data to that of hydrogen peroxide residual in the effluent (10.5 mg/L) indicated that the toxicity may be a result of the hydrogen peroxide residual rather than treatment by-products.

Wastes: No wastes are generated in ozone, chlorine, hydrogen peroxide, or UV treatment of water. Treatment with potassium permanganate leaves manganese salts, which can be hazardous.

Science/Technology Needs: Degradation rates for specific organics in wastewater will need to be determined. Flow rates are identified to size treatment processes. Waste characterization is conducted to determine suitability of oxidation. The chemical oxygen demand (COD) predicts chemical requirements. The COD generally must be less than 5,000 mg/L for oxidation to be cost-effective. Oxidants are nonselective, so easily oxidizable nonhazardous material in the waste stream will increase the COD and possibly limit the use of oxidation on a given hazardous constituent.

Implementation Needs: Treatment costs for dilute wastewater should be relatively low (<\$0.10/gal). Ozone generation has relatively high capital and operating costs compared to other oxidizing agents. UV-enhanced oxidation also results in relatively high capital and operating costs depending on the amount of wastes treated. The UV lamps are susceptible to coating, which decreases efficiency. The number of bulbs required is proportional to the waste stream flow.

In general, more information to optimize the oxidizing agent used on site-specific wastewaters is needed. It is anticipated that treatment costs for dilute wastewater should be less than \$0.10/gal, except for ozone and UV. Standard equipment and piping would be needed along with space for the treatment facility.

Cost estimates for the treatment at the SITE demonstration of the Perox-Pure system at Lawrence Livermore National Laboratory, assuming only the two contaminants (TCE and PCE) were present, produced capital costs of \$776,000 of which the Perox-Pure system's direct capital cost is \$55,000. Estimated annual operation and maintenance (O&M) costs were \$111,000 of which the system's direct O&M costs are \$61,000. Total groundwater remediation costs were estimated at \$11 per 1,000 gal of which Perox-Pure system direct treatment costs were \$3 per 1,000 gal.

Author: P.A. Taylor/615-574-1965; Todd DiNoia, R. L. Fellows/615-576-5632

References:

1. P.W. Lankford and W.W. Eckenfelder, Jr., ed., *Toxicity Reduction in Industrial Effluents*, Van Nostrand Reinhold, New York, 1990.
2. SITE Program Demonstration of the Ultrox International Ultraviolet Radiation/Oxidation Technology.
3. "Treatment of Acid Mine Drainage by Ozone Oxidation," Brookhaven National Laboratory, Department of Applied Science.
4. U.S. Environmental Protection Agency, SITE Program, *Technology Profiles, Sixth Edition*, EPA/540/R-93/526, Office of Research and Development, Washington, D.C., 20460, November, 1993.
5. U.S. Environmental Protection Agency, *Applications Analysis Report - perox-pure Chemical Oxidation Technology Peroxidation Systems, Inc.*, EPA/540/AR-93/501, Office of Research and Development, Washington, D.C., 20460, July, 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water, inorganics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Chemical separation

Technology: In situ biomedial adsorption. In situ biomedial adsorption operates on the same principals as ex situ adsorption. However, the resins loaded with microorganisms are placed in a trench below the water table. The contaminated ground water flows through the media and contaminants bioaccumulate on the media. Issues that currently limit this technologies application include controlling the flow of ground water so there is sufficient contact time to allow bioaccumulation and keeping the microbes alive buried in the subsurface. This technique is especially difficult in fractured flow zones and is not useful for remediation of deep ground water.

Status: Predemonstration. Bioadsorption is an accepted technology but the use of resins to accumulate microbes and the trench and fill method of content are both predemonstration.

Science/Technology Needs: Characterization of contaminant concentrations and variations with season and rainfall along with uptake experiments are required to provide data for field tests. Application of this technology requires better characterization of hydrology.

Implementation Needs: Costs are unknown pending engineering development and field tests. A means of replacing microbes frequently is needed and is a way to minimize or prevent clogging at the subsurface drains.

Author: Joseph Perona/615-576-9280

References:

1. B. Volesky, ed., *Biosorbents and Biosorption Recovery of Heavy Metals*, CRC Press, Boca Raton, Fla., 1990.
2. *Remedial Investigation Plan for Waste Area Grouping 2 at ORNL*, ES/ER-14&D1, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1990.

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EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water/surface water—nitrates

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Biological denitrification. Suspended-growth denitrification is usually carried out in a plug-flow type of activated sludge system. It can follow a process (nitrification) that converts organic nitrogen and ammonia to nitrates. The bacteria oxidize an organic carbon source, which must normally be added, and simultaneously reduce nitrates to nitrogen gas. Nitrified effluents are usually low in carbonaceous matter and so methanol is commonly used as a carbon source. Because the nitrogen gas formed in the denitrification reaction hinders the settling of the solids, a nitrogen-gas stripping reactor may have to precede the denitrification clarifier.

Fixed-film denitrification is carried out in a column reactor containing stone or one of several synthetic media upon which the bacteria grow. Depending on the size of the medium, this process may or may not need to be followed by a clarifier. Periodic backwashing is necessary to prevent solids buildup in the column that can cause excessive head loss. As in the suspended-growth denitrification process, an external carbon source is usually necessary.

Status: Accepted. The Oak Ridge Y-12 Plant has operated a full-scale treatment system to biologically denitrify high-concentration nitrate wastewater. Denitrification of low-concentration nitrate wastewater is commonly done at larger sewage treatment plants.

Science/Technology Needs: Treatment rates would need to be determined for specific wastewater streams.

Implementation Needs: None, technology in use. If additional streams are added depending on the other contaminants, it may not be desirable and/or possible to transfer wastewater to the Y-12 denitrification system. Experimental tests to determine treatment rates on specific wastewater streams would then be needed to modify or build another treatment system. Treatment costs for low-nitrate-concentration wastewater have been <\$0.20/gal.

Author: P.A. Taylor/615-574-1965

References:

1. *Denitrification of Acid Wastes From Uranium Purification Processes*, Y-1990, Oak Ridge Y-12 Plant, Oak Ridge, Tenn., November, 1975.
2. Metcalf and Eddy, "Waste Water Engineering: Treatment, Disposal, Reuse," McGraw Hill Book Company, 1979.

EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water/surface water, volatile organic compounds

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical separation

Technology: Air stripping. Air stripping for water remediation normally uses packed towers. Extensive literature exists on the stripping of organics from ground water; also, the stripping of a solute from a liquid phase is a standard industrial process. Air stripping phenomena involves the transfer of a solute from a liquid phase to a gas or vapor phase. Treatment of the effluent air from an air stripping process is frequently necessary. Air stripping of water is typically accomplished by countercurrent extraction in a packed tower equipped with an air blower. Variations include the cross-flow tower, air pulled by fan across a downward flow of liquid; the coke-tray aerator, liquid flowing through layers of coke trays; and aeration basins, liquid sprayed through the air. The purpose of the packed tower is to increase the contact surface between air and water; the cleanest air contacts the cleanest water at the bottom of the tower, allowing the treated water flowing downward to reach very low levels of contamination.

Status: Accepted. Air stripping is a proven treatment technique for VOC removal and is used extensively in pilot- and large-scale water remediation systems.^{1,2} Air stripping is considered by EPA to be a best available technology.³

Science/Technology Needs: A thorough characterization of the contaminated water, including identification of the chemical species present, is necessary for the successful design of air stripping systems. Iron and carbonates can foul the air stripping unit.

Emission controls may be required for the effluent air stream, depending on the nature of the contaminate and the applicable environmental regulation and administrative policies. The effluent water is usually treated, so that regulations concerning its discharged to surface waters are maintained.

Implementation Needs: Design of an air stripping system with and without emission controls is available from several private firms. Emission control by activated carbon adsorption is typical. Fouling of the air stripping tower is a well-known phenomena, and

procedures for cleaning the tower packing and internals should be part of the operational plan; an alternative to this periodic cleaning is pretreatment of the influent water to prevent iron oxidation and precipitation, the prime cause of air stripper fouling.

Operating cost for air stripping greatly depends on the flow rate of the water to be treated and the contaminant concentration. For a water flow rate of 100 gpm contaminated with 0.1 ppm benzene, the estimated cost per 1000 gal for 99% removal is \$4.10 (with emission control) and \$3.20 (without emission control); at a flow rate of 1000 GPM with similar contaminate concentration and removal efficiency, the estimated cost per 1000 gal is \$2.20 (with emission control) and \$0.60 (no emission control).²

Author: R.M. Counce/615-574-6857

References:

1. S.P. Singh and R.M. Counce, *Removal of Volatile Organic Compounds from Ground Water; Survey of the Technologies*, ORNL/TM-10724, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1989.
2. J.H. Wilson, R.M. Counce, A.J. Lucero, H.L. Jennings and S.P. Singh, *Air Stripping and Emissions Control Technologies: Field Testing of Countercurrent Packings, Rotary Air Stripping, Catalytic Oxidation, and Adsorption Materials*, U.S. Air Force report, Tyndall Air Force Base, Fla., to be published.
3. *Air Stripping of Contaminated Water Sources-Air Emissions and Controls*, EPA/459/3-87/017, U.S. Environmental Protection Agency, 1987.
4. W.D. Byers, "Air Stripping Technology," *Physical and Chemical Processes, Innovative Hazardous Waste Treatment Technologies Series*, ed. H. M. Freeman, Technomic Publishing Company, 1990.

EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water/surface water, volatile organic compounds

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical separation

Technology: Steam stripping. Steam strippers are usually operated at elevated temperatures (100°C) and atmospheric pressure. At this temperature, the vapor-liquid equilibrium ratio of the organic solute (m) is increased, thus enhancing its transfer from the liquid phase to the vapor phase. The vapor-liquid equilibrium ratio is the ratio of the vapor/gas phase composition of a solute to its composition in the liquid phase. At 100°C, many organic compounds may be stripped effectively that cannot be effectively stripped at ambient conditions. Based on the vapor-liquid equilibrium ratio of an individual solute, some guidelines for stripping effectiveness may be established:

$\log(m) < 1$	ineffective
$1 < \log(m) < 2$	strippable
$2 < \log(m)$	effective

The vapor-liquid equilibrium ratios for several organic pollutants are presented by Hwang et al.³ If the condensed vapor-phase separates into separate organic and aqueous phases (low solubility of organic in the aqueous phase), then a very attractive removal system for organics is available; otherwise, the stripping will, at best, only concentrate the organic in yet another aqueous phase.

Status: Accepted. Steam strippers have been used in industry for many years.^{1,2}

Science/Technology Needs: A pilot-scale demonstration to confirm design objectives is necessary for treating Y-12 Plant ground water and surface water contaminated with VOCs. A thorough characterization of the contaminated water, with identification of the chemical species present, is necessary for successful design of the steam stripping system. It is also necessary that the vapor-liquid equilibrium ratio for each organic contaminant be available or be estimated for the design process to proceed on a sound basis.

Provision for on-site accumulation and disposal of the condensed organic phase will be necessary. The aqueous-phase condensate is normally recycled to the stripper. Demonstration activities should provide for chemical analysis of individual species identified in the original ground-water survey as well as total carbon analysis; this analysis should be performed on all streams entering and leaving the stripper/condenser system, so that individual and total carbon mass balances may be determined. Proper disposal of the condensate phase(s) should be demonstrated.

Implementation Needs: Design of a steam stripping system is available from several private firms. Operating cost information for steam stripping system treating 100 gpm was estimated by Parmele and Allen⁴ to be \$8/1000 gal.

Author: R.M. Counce/615-574-6857.

References:

1. Y.L. Hwang, G.E. Keller, and J.D. Olson, "Steam Stripping of Organic Pollutants from Water. 1. Stripping Effectiveness and Stripper Design," *Ind. Eng. Chem. Res.*, **31**, p. 1753, 1992.
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EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediments

Problem Area/Constituents: Volatile organic compounds

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical separation

Technology: Soil vapor extraction (SVE). This technology, also called in situ air stripping or enhanced volatilization, is a proven in situ method for removing volatile organic compounds from a soil matrix. It uses vacuum wells to induce a flow of air through the soil to remove volatile compounds. The system consists of a network of wells with perforated well screens potentially extending into the ground water. These wells are packed with gravel and sealed at the top with bentonite to prevent short-circuiting. The extraction wells are connected to the suction side of a vacuum extraction unit through a surface collection manifold. The vacuum extraction unit induces a flow of air from the subsurface into the extraction wells. As air is pulled through the soil, contaminants are volatilized from both the soil and the water in pore spaces. The vacuum not only draws vapors from the unsaturated zone, but is also decreases the pressure in soil voids, thereby causing the release of additional VOCs. The extracted vapor flows through the surface collection manifold and is either vented to the atmosphere, connected to a vapor-phase carbon absorption system, or flared, depending on the nature and extent of VOC contamination.

Experience has shown that 50 percent of the VOCs are typically removed in the first 10 percent of operating time. Up to 98 percent removals has been reported; however, total removal is not possible with this method. The time for completion is variable depending on the contaminant volatility, contaminated zone geology, and the soil permeability. Ten days to 3 years to achieve maximum removal have been reported. Soil vapor extraction is typically applied using extraction wells but has been demonstrated at the DOE PORTS site using a combination of deep soil mixing and vapor extraction to a surface shroud.

Status: Demonstration. This technology is commercially available and has been demonstrated at several contaminated sites.

Science/Technology Needs: The improvement of soil vapor extraction by introducing hydrofractures to the subsurface warrants evaluation and further study.

Information about contaminant volatility, vapor pressure, and Henry's Law constants K_d (adsorption coefficient) are all required to determine the mass transfer rate between the liquid and vapor phase contained in the soil. The total mass of contaminants will be used to estimate the required air flow rate and treatment time (amount of air treatment) required; the contaminant concentrations will be used to determine the rate of removal and off-gas treatment needs. The porosity and permeability, or hydraulic conductivity, of the soil affect the rate of removal. Additionally, high natural-organic-carbon soil may retard SVE. The lateral and vertical extent of contamination is needed in order to site the placement of the wells.

The development needs for SVE application to ground water are high. So far, the effectiveness of SVE decreases with increasing soil moisture. It can be used after the water table is lowered. A means for introducing air into the subsurface water in sufficient quantities to promote stripping of VOCs is needed before this technology is applicable to ground-water remediation. For those applications, sites need to be open enough to allow well placement at distances of 15-100 ft. Capping may be required to direct air flow through the extraction wells. On-site storage and/or treatment of extracted water-organic mixtures may be needed. Some type of gaseous treatment will also be needed.

Soil vapor extraction is most efficient in high conductivity soils. The need exists to improve an implementation at sites having fine-textured soil.

Implementation Needs: Commercial vendors are available who can design and operate soil vapor extraction systems for soil remediation.

Author: Olivia West/615-576-0427

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2. G.P. Treweek and J. Wogec, "Soil Remediation by Air/Steam Stripping," *Proceeding of the Fifth National Conference of Hazardous Wastes and Hazardous Materials*, pp. 147-153, 1988.
3. O.R. West, R.L. Siegrist, H.L. Jennings, A.J. Lucero, S.W. Schmunck, D.W. Greene, "Laboratory Evaluation of In Situ Vapor Stripping," Report from the X-231B Project for *In Situ Treatment of Clay Soils Contaminated by Volatile Organic Compounds and Radioactive Substances*, ORNL/TM-12260, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water, radionuclides, and organic compounds

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: Cryogenic immobilization. This technology is used to freeze radionuclide-contaminated water and soil. A series of interconnected double pipes are placed in the region where immobilization is desired. As coolant is circulated through the piping network, free water in the soil is frozen resulting in the formation of a frozen block. Contaminants in the frozen "free water" are effectively immobilized using this technology. The presence of the subsurface frozen barrier can also impend the infiltration or migration of contaminants.

Status: Demonstration. Ground freezing has been employed in Civil Engineering practice for many years. Most applications have been for short periods for structural (mine/tunnel shaft) support. With cryogenic immobilization of radionuclide-contaminated ground water, much longer durations of ground freezing are desired. This technology will be of most benefit for containment of short lived radionuclides such as tritium. Its application at the Y-12 Plant may be limited to temporary containment.

Science/Technology Needs: The applicability of ground freezing over long periods and the impact of soil integrity need to be evaluated. Also, the range of soil conditions in which this technology applies and possible amendments to soils outside this range need to be investigated. The soil moisture regime may require prewetting of soil to increase soil water content to acceptable levels for freezing. Time domain reflectometry (TDR) has excellent application for measuring in real time moisture front migration. Furthermore, Smith (1982) has reported use of TDR to determine ice/water content of frozen soil during active freezing. TDR possibly used to determine closure of ice wall. A demonstration of this technology for containment of tritium contaminated ground water is planned at WAG5, ORNL.

Geotechnical investigation must closely focus on the ground-water conditions; how much water and where the water is flowing; ground-water chemistry. Seepage velocities above 1-2 m/day can present problems.

Implementation Needs: The materials required for ground freezing are commercially available and easily obtained. The selected site would need to be serviced with sufficient electrical power to operate refrigeration units. With cryogenic immobilization initial cost can be high. Over 80% of the initial cost associated with this technology is due to the cost of drilling for freeze pipe installation. The energy required for this technology decreases significantly once the initial freezing is accomplished. The technology was found to be economically feasible when compared with in situ slurry wall formation.^{1,2}

To date, ground-freezing technology has usually been applied over the short term. A cryogenic barrier must function for long periods of time. Maintenance of the freezer pipe system to prevent long-term leaks and brine pockets must be considered. The cost evaluation should examine purchase and amortization of entire cryogenic hardware (refrigeration unit, freeze pipes, headers, instrumentation).

Need to develop automated temperature profile scanning of freezer pipes and soil to evaluate possible long-term water (heat) erosion of ice wall.

Should consider horizontal directional drilling for installation of instrumentation using SEAMIST technology, thermocouples or thermistors, sonic wave profiling, deploy wave guides for TDR.

Author: Dianne D. Gates/615-576-0427; Joe Kauschinger/404-992-3538

References:

1. Iskandar, I. K., *Effect of Freezing on the Level of Contaminants in Uncontrolled Hazardous Waste Sites*. U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Special Report No. 86-19, 1986.
2. Sullivan, J. M., Lynch, D. R., Iskandar, I. K., "The Economics of Ground Freezing for Management of Uncontrolled Hazardous Waste Sites," *Proceedings, 5th National Conference on Management of Uncontrolled Hazardous Waste Sites, November 7-9, 1984, Washington, D.C.*
3. Sopko, J. A., personal communication.
4. Smith, M. S., Patterson, D. E., Lewis, C. H., "Determination of Ice/Water Contents of Frozen Soils by Time Domain Reflectometry," *Proceedings of Third International Symposium on Ground Freezing*, USAE CRREL, Hanover, N.H.

EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediments

Problem Area/Constituents: Volatile organic compounds

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical separation

Technology: Thermally enhanced soil vapor extraction. This technology is a variation on soil vapor extraction. It uses the co-injection of steam or hot air to provide local heat to enhance the removal rates over SVE. Otherwise, it is similar to SVE (see REMA-78-OZ).

Status: Demonstration. This technology is commercially available and has been demonstrated at several contaminated sites. With this technology, hot air or steam is injected into contaminated subsurface regions, and a vacuum is applied to create air flow through the vadose zone, so that air containing volatile organic contaminants can be removed from sites with contaminated ground water. This technology is typically applied using extraction wells but has been demonstrated at the Portsmouth Gaseous Diffusion Plant using a combination of deep soil mixing, hot air injection and vapor extraction to a surface shroud.

Science/Technology Needs: The improvement of soil vapor extraction by introducing hydrofractures to the subsurface warrants evaluation and further study.

Information about contaminant volatility, vapor pressure, and Henry's Law constant are all required to determine the mass transfer rate between the liquid and vapor phase contained in the soil. The total mass of contaminants will be used to estimate the amount of air treatment required; the contaminant concentrations will be used to determine the rate of removal and off-gas treatment needs. The porosity and permeability, or hydraulic conductivity, of the soil effect the rate of removal and may affect the amount of heat added to the system. Additionally, high soil carbon may retard SVE. The lateral and vertical extent of contamination is needed in order to site the placement of the wells.

The development needs for thermally enhanced SVE application to ground water are high. So far, the effectiveness of SVE decreases with increasing soil moisture. It can be used after the water table is lowered. A means for introducing heat and air into the subsurface water in sufficient quantities to promote stripping of VOCs is needed before this technology is applicable to ground-water remediation. For those applications, sites need to be open enough

to allow well placement at distance of 15–100 ft. Capping may be required to direct air flow through the extraction wells. On-site storage and/or treatment of extracted water-organic mixtures may be needed. Some type of gaseous treatment will also be needed. A means of heating the air or creating steam is required.

Implementation Needs: Commercial vendors are available who can design and operate soil vapor extraction systems.

Author: Dianne D. Gates/615-576-0427

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1. G.R. Allen and D.L. Anderson, "Case Study: Vacuum Extraction to Remediate Contaminated Soil—Selection of Optimum Extraction and Emission Control Equipment," *Proceedings of the 1992 U.S. EPA/A&WMA International Symposium on In Situ Treatment of Contaminated Soil and Water*, pp. 278–290, Dublin, Ohio, 1992.
2. G.P. Treweek and J. Wogec, "Soil remediation by air/steam stripping," *Proceeding of the Fifth National Conference of Hazardous Wastes and Hazardous Materials*, pp. 147–153, 1988.
3. O.R. West, R.L. Siegrist, H.L. Jennings, A.J. Lucero, S.W. Schmunck, D.W. Greene, "Laboratory Evaluation of In Situ Vapor Stripping," *Report from the X-231B Project for In Situ Treatment of Clay Soils Contaminated by Volatile Organic Compounds and Radioactive Substances*, ORNL/TM-12260, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, metals, organics, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Structural stabilization

Technology: Horizontal mixed in-place

Status: The horizontal mixed in-place (HMIP) method is a relatively new technology based on well-established techniques of directional drilling and jet cutting. The process would involve directional drilling from the surface away from the buried waste area. Once the horizontal borehole is formed, a plastic pipe (polyvinylchloride, SEAMIST plastic membrane) can be inserted into the hole to maintain stability. Then the jet cutting/mixing phase would commence.

The jet cutting phase can be used to inject a variety of grouts, chemical agents, and biomass. For instance, inundated biological waste can be stabilized in situ using chemical grout. This will solidify the biological waste in situ and render the pollutant immobilized. Alternatively, the jet cutting can be used to inject steam and/or peroxides to chemically burn biological material.

Because directional drilling and water cutting equipment are located off the buried waste area, issues related to tractability of the site are of little concern. Also, jet cutting technology can easily rupture plastic bags and cardboard boxes to assure intimate mixing of the chemicals (grout, peroxide) with the waste. Obstructions, such as construction debris and steel drums, can be penetrated using a variety of in-hole drill bits.

Techniques such as deep soil mixing (mechanical mixing) suffer for need of a large crane, which requires a relatively level site with excellent tractability characteristics. Furthermore, containerization of the waste is problematic for the mixing augers, because steel drums and plastic bags can become entangled within the augers. Worker risk is much higher, because all activities must be conducted over the buried waste.

Science/Technology Needs: Buried waste represents a significant challenge for environmental restoration at the Y-12 Plant. It may be proposed that an integrated

demonstration be conducted of horizontal directional drilling for both site characterization (see SEAMIST technology under site characterization) and permanent in situ stabilization of buried waste. The cold trench would be impregnated with surrogate tracers and used to evaluate site characterization instrumentation package and the stabilization method.

Concurrent with the site characterization stage is a laboratory study to identify tracer components contained in leachate and smear samples retrieved from SEAMIST instrumentation. Leachate will be used in grout/waste compatibility studies to identify candidate grout formulations which can be used as stabilizing agents. Grout characteristics will be: high strength in the presence of organics and chemical species found in leachate, fluid that permits grouted waste to be uniform, and dense grout that sets rapidly to prevent ejecting cuttings from the borehole.

The most compatible grout (from lab study) will be injected using high velocity (1000 fps) jet cutting technology. A grouting lance will be placed inside the SEAMIST membrane. A high velocity grout will cut away the membrane and mix the cold trench waste with a stabilizing agent. Several jet cutting techniques will be examined for effective grouting of biological waste. Once grouted material has cured, cold trench will be excavated to expose stabilized waste. Complete segments of stabilized material will be removed from the trench and brought to the laboratory for testing.

Implementation Needs: At present, control of cuttings ejected during directional drilling is somewhat problematic. Complete control of surface spoil is impossible. Development and manufacture of a reverse circulation, down-the-hole motor for directional drilling would be a significant enhancement to the drilling phase for excellent control of ejected spoil. The combined affect of working away from the buried waste area and complete control of the ejected spoil would assure minimal worker exposure and greatly reduce environmental risk.

Author: Joe Kauschinger/404-992-3538

References:

1. Mallon, B., Martins, S. A., et al., "SEAMIST Soil Sampling for Tritiated Water, First Years' Results," Sixth National Outdoor Conference, Las Vegas, Nev., May 9-13, 1992.
2. Science and Engineering Associates, SEAMST application literature, Santa Fe, N. Mex., 1991.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, metals, organics, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Structural stabilization

Technology: Surcharge. The technique involves use of a mandrel to push into place disposable geotextile drains, which increase the rate at which water is removed from low-permeability material. The surcharge (soil fill) is placed incrementally at the surface and is used to create pore fluid gradients within the subsurface material. As the water drains, a decrease in the volume of the subsurface material occurs. The decrease in volume results in an increased stability and a decrease in hydraulic conductivity. No air pollution problems result.

Surcharge with geotextile drains is a support technology for placement of multilayered caps. Increased waste stability will reduce to tolerable levels the shear distortions in the compacted clay portion of a multilayer cap.

This technique does not decrease the solids volume of waste, nor does it decrease waste conductivity to deem the waste immobilized. Another drawback is related to the creation of hydraulic gradients within the waste, which would tend to cause soluble components of waste to migrate as water moves out of the waste.

Status: Demonstrated. Surcharge with geotextile drains has been used for the past 15 years in civil engineering as a means to increase the strength and decrease the compressibility of very soft clay soils, even soils that are highly organic. The main use of surcharge with drains is to accelerate the consolidation of the waste which decreases waste compressibility.

Science/Technology Needs: Technology is widely used commercially, and off-the-shelf equipment is readily available.

The need exists to develop different installation techniques for soft and shallow buried waste. A possible need exists to redesign geotextile drain, so that a drain can be placed on the outside of an installation mandrel. Thereby, the geotextile drain acts as a protective cover over the mandrel.

Implementation Needs: A demonstration project is needed. Operational worker hazards are related to the mandrel which must pierce the waste and then be removed to the surface after being exposed to the waste. Field demonstration and monitoring: \$0.40M.

Author: Joe Kauschinger/404-992-3538

References:

1. R. M. Koerner, *Designing With Geosynthetics* 2 ed., Prentice Hall Inc., New York, 1990.

SLURRY WALL WITH HIGH-DENSITY POLYETHYLENE INSERT

REMA-83-OZ

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, metals, organics, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Walls

Technology: Slurry wall with high-density polyethylene insert. A hydraulic barrier, based on slurry trench technology, involves installation of an interlocked high-density polyethylene (HDPE) screen within a panel-type slurry wall. The HDPE screen consists of a double-liner membrane sandwich with a core of geonet which acts as a leachate collection/leak detection system. Panel construction is adaptable to any plane geometry and can be installed easily to depths of 100 ft. A panel-type wall prevents system-wide failure of the entire cutoff wall. Single panels are isolated wall segments that can be sealed in the event of leakage by injecting grouts into the geonet core. Alternately, the geonet can be used to collect leachate. The integrity of the liner can be determined over time by surcharging geonet with water and measuring leakage rates. A water-filled geonet can also be used as a hydro-barrier, wherein seepage out of the wall prevents contaminant migration through the wall.

Status: Demonstration. The technology has been used on a few test projects in Europe. The insert wall has never been constructed in the United States. The estimated cost for construction is \$30-\$50/ft² of cutoff wall.

Science/Technology Needs: A demonstration project is needed to document operational problems with the insert wall and to monitor performance as a hydrologic barrier.

Implementation Needs: Implementation needs include a test demonstration wall consisting of an enclosed area measuring about 100 ft on each side. The wall should terminate in an impervious layer to prevent under-seepage and should assure that boundary affects are eliminated from the evaluation of cutoff wall efficiency. Piezometers should be installed inside and outside the wall to evaluate the hydraulic efficiency of the cutoff. Pump tests need to be performed on the cutoff wall by lowering the water level contained by the wall perimeter.

During the demonstration, the need exists to examine excavation procedures which minimize waste generation and surface contamination. Common grab excavation is unacceptable

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because of slurry spillage at the surface. The need exists to consider using biopolymer drilling fluids (biodegradable) or a cement-bentonite drilling system (self-hardening). Reverse circulation drilling systems should be examined for possible use in forming the secant pile wall. Reverse circulation drilling will help to minimize worker exposure and to reduce environmental risks.

Before field work, laboratory study is needed to select the proper backfill mixture (soil bentonite, cement bentonite, etc.).

The buried waste facility will require installation of seepage cutoff as part of the Record of Decision. The need exists to perform site characterization studies to locate uncontaminated soil which has the same stratigraphy as the buried waste site. A soil testing lab is needed to screen candidate backfill material. Cost is expected to be \$2M-\$3M over a 1-year evaluation period.

Author: Joe Kauschinger/404-992-3538

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1. Cavalli, Nicholas, *Environmental Cut-off and Drain*, U.S. Patents No. 4,741,644, May 3, 1988.
2. Cavalli, Nicholas, *Environmental Cut-off for Deep Excavations*, U.S. Patent No. 4,601,615.
3. *GEOLOCK Technology: HDPE-lined Slurry Trench*, corporate brochure, Bachy, Inc., 1989.
4. Rodio-SLT, *Diaphragm Wall for Pollution Prevention in Waste Disposal*, Rodio Impresa Costruzioni Speciali S.p.a., Internal Report 20,972, Casalmiocco (Milano), Italy, June 16, 1989.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, metals, organics, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Wall

Technology: Hydromill. This is an excavation tool developed in France by Soletanche Enterprises in the late 1970s. A unique feature of the machine is related to continuous excavation of soil/rock while creating a slurry trench panel. The spoil removed at the cutter head is transported via hydraulic pumps to desanding equipment at the surface. The closed-loop circulation of slurry and its reuse for continuous excavation makes the technique an excellent choice for an excavation method in highly contaminated ground. The recent introduction of hydromill by Rodio, Inc., makes available a totally electronic excavation tool which can be remotely controlled. The lower cost of the Rodio cutter head (\$1M vs \$7M for conventional hydrofraise) may make the capital cost for purchasing equipment more reasonable if the cutter head cannot be decontaminated.

Hydromill can continuously excavate soil (gravel, sand, silt, clay) and soft rock (weathered shale/limestone) at rates of up to 2000 ft²/10-h shift. The depth does not enter into production rate estimates because spoil removal is continuous, and no need exists for removing the excavation tool from the trench, as is the case for conventional grabs. The cutter head can excavate hard rock up to about 30,000 psi. The excavation rate is reduced to about 100 ft²/10-h shift. This rock excavation rate is still ten times faster than using conventional grabs with chisel for rock excavation.

Status: Demonstration

Science/Technology Needs: Hydromill is in an advanced state of design and is used commonly in Europe for slurry wall excavation. The greatest concern is related to decontamination procedures required for green tagging of equipment after use in contaminated soil/rock. The need exists to examine operational procedures and health physics issues related to common maintenance of equipment during production work. Cutter teeth change/replacement is the greatest maintenance need.

Implementation Needs: The need exists to coordinate with the decontamination committee to examine the hydromill process and to develop decontamination and Health Physics control procedures when maintenance of equipment is required.

Author: Joe Kauschinger/404-992-3538

References:

1. *Use of Hydromill in Urban Sites*, Rodio Impresa Construzioni Speciali S.p.a., internal report, September 19, 1991.
2. Soletanche Enterprises, *Hydrofraise: Principle of Operation*, corporate brochure, 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, metals, organics, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Barriers

Technology: Jet grouting. Grout injection involves high pressure pumps (6000 psi) to impart cutting energy to the grout jet stream (velocity = 1000 fps). Vertical drilling/jet grouting has been used to form the bottom seal at the White Oak Creek Embayment (WOCE) at the Oak Ridge National Laboratory (ORNL). WOCE was the first time (worldwide) that jet grouting was used in production work to form a bottom seal beneath radioactive mixed waste. Work was conducted at a shallow depth (15 ft). Radiologic and other environmental monitoring indicated that jet grouting could be successfully performed over water (i.e., no release of grout or contamination downstream during construction activities and no Clean Water Act violations). The grout injected was very-high-density cement grout without additives. Grout formulation was a key element which minimized waste generation. However, dense grout caused bottom heaving of White Oak Creek. Grout formulation is not recommended for use where a bottom seal is required beneath a structure, buried tank, etc.

Status: Demonstration. Jet grouting to form a bottom seal is well established in Europe as a technique to control water inflow into the bottom of an excavation. The technology was successfully used full-scale to form a bottom seal beneath radioactive waste at WOCE at ORNL.

Science/Technology Needs: Grout formulation needs to be developed which would allow larger percent mixing of injected grout with in situ material. Improved grout formulation would help minimize surface heaving while simultaneously improving the volume of grout mixed in-place. The grout formulation would minimize waste generated during injection which must be handled at the surface. Grout formulation would enhance the soil saw demonstration which is currently being conducted at the Savannah River Plant under a Program Research and Development Announcement administered by Morgantown, West Virginia.

Implementation Needs: Combined laboratory/field studies are needed to test candidate grout formulations to form the soil/cement bottom seal.

Bench-scale tests are needed to examine the rheologic properties of various grouts. Development of a field test (from lab experiments) is needed for identifying the percent solids (waste, cement), water, and air contained within solidified waste which is ejected from borehole and remains in the ground. A grout formulation that solidifies waste and keeps a large percentage of waste in the ground would be a candidate for soil saw experiments at the Savannah River Plant.

A cold test area impregnated with "safe" surrogates is needed to examine grout performance (from the lab study) under field conditions. The cold test area could be at the Savannah River Plant.

Estimated costs are: lab study—grout: \$150K. Field study—cold test: \$500K (or coordinate with Savannah River soil saw experiments); lab support: \$150K

Author: Joe Kauschinger/404-992-3538

References:

1. *Jet Grout Bottom Seal at White Oak Creek Embayment*, Ground Engineering Services Report to U.S. Army Corp of Engineers, Nashville District, 1992.

MICROTUNNELED HIGH-DENSITY POLYETHYLENE LINER

REMA-86-OZ

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, metals, organics, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Barriers

Technology: Microtunneled high-density polyethylene liner

Status: Demonstration. This is an evolving technology which is in the demonstration phase. HDPE installed via microtunnels is conceptual. The microtunneling procedure is a well-established construction method in Europe and in Asia. Tunnel drives can be performed to lengths of several thousand feet using intermediate jacking stations. No severe limitation is placed on the depth of the bottom seal. The requirement to install jacking and reception pits to 100-ft depths is easily achieved. The possibility exists of eliminating the reception pit because of machine development which will allow extraction of machine-out microtunnels used during jacking.

Techniques to install a continuous layer of high-density polyethylene (HDPE) appear sound (see Zublin reference).

The main advantage of the technique is related to continuous bottom sealing using plastic liners designed for particular waste leachates. The microtunnel/liner system can be installed in widely varying ground conditions (i.e., soil to soft rock).

Science/Technology Needs: The individual components of the bottom seal (HDPE, microtunneling) are well-proven technologies. Integration of each to form a bottom seal is not well-proven. A shallow demonstration (easily excavated) is needed to evaluate operational problems associated with installing HDPE liners.

A major drawback of microtunneling is related to the need for jacking/reception pits down to elevation of the bottom seal. This limitation is related to the laser guidance system used to steer the machine. The laser system cannot easily be used to turn sharp curves. A possible

need exists for a gyroscopic guidance system like that used in horizontal directional drilling. Research and development are needed to improve the guidance system so that microtunneling can be conducted from the surface or from shallower shafts.

A 2-year test program is needed. Estimated cost is \$2M-\$3M.

Implementation Needs: A cold test facility is needed for a full-scale demonstration.

Author: Joe Kauschinger/404-992-3538

References:

1. Ed Zublin, AG literature, *Arbeitsgemeinschaft Altlast—Basisabdichtung*, 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, metals, organics, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Barriers

Technology: Vibrated plastic tube bottom seal. The technique involves installation of a bottom seal via vibrating a drive pipe into the ground. The drive pipe is covered with a thin (ID = 14 mm) polyethylene tube. Once the depth of the bottom seal is attained, the drive pipe is removed. Major advantages for environmental grouting are related to the drive pipe being protected from contamination by the plastic tube. The disposable portion of the grouting system is very inexpensive (a plastic tube with a grout valve).

Status: This is a well-proven technology (in Germany) for creating a bottom seal at the invert of pit excavations. The drawback is related to the depth limitation to which the drive pipe can be accurately driven (i.e., 50 ft).

Science/Technology Needs: The continuity of the bottom seal is related to control of drilling deviations and the size of grouted bodies. If buried waste contains a large portion of large debris (lab equipment, construction refuse), then the drill pipe will deviate as the pipe deflects off obstructions. Then, grout injection will be performed in the wrong location, leaving untreated soil and creating a window in the bottom seal. Although a borehole camera can be used to measure drilling deviations, the drilling technique (vibrated pipe) is not robust enough to penetrate obstructions.

Vibrated plastic pipe applies where buried waste is loosely placed and contains few major obstructions (possibly biological waste).

Implementation Needs: A vibrated plastic tube grouted slab has not been used (as of 1993) in the U.S. as a bottom sealing method. A test program would involve forming a cold trench containing various waste with sandy soil in the invert which would allow leachate to migrate out of the buried waste. The need exists to perform the grouted slab method and to excavate waste to examine the continuity of the bottom seal.

Author: Joe Kauschinger/404-992-3538

References:

1. Norbert Tausch, *Recent European Developments in Constructing Grouted Slabs*, American Society of Civil Engineers, Geotechnical Special Publication No. 30, Vol. 2, pp. 301-312, New Orleans, La., February 1992.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, metals, organics, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Walls

Technology: Soil saw. This technology uses jet grouting technology to form a vertical barrier wall. A steel casing is drilled into the ground down to the bottom elevation of the cutoff wall. The casing contains a large array of jet cutting nozzles. Grout nozzles create high-velocity jet streams which are used to cut (monodirectional) the soil while the casing is pulled back and forth in a sawing action. As soil is cut away, a hydraulic excavator is used to pull the casing forward, so that a continuous cutoff wall is created.

A major advantage of the technique is related to formation of a continuous grout curtain wall. Quality control/quality assurance is based on the ability to drag casing through the ground to assure continuity. The efficiency of the grout curtain still depends on grout curing and not being eroded away by flowing water.

Status: Predemonstration. This is an evolving technology which is in the predemonstration phase. A program research and development award (PRDA) has been given to Haliburton—NUS for a demonstration at the Savannah River Plant. The award is administered by Morgantown, West Virginia. The technology has applicability for forming grout curtain walls for tank sites at Oak Ridge National Laboratory Waste Area Group (WAG) 1, pits and trenches at WAG 7, WAG 4, and at the Y-12 Plant Bear Creek Operable Units to provide a barrier between waste sites and the nearby stream.

Science/Technology Needs: The major drawback is related to obstructions (cobbles, boulders, utilities, buildings) being in the path of the soil saw. This technology has been demonstrated to depths of about 25 ft. Spoil generated during jet grouting can be excessive and can create waste handling problems. Estimates for volume of spoil range from 40%–100% of grout volume injected.

Implementation Needs: The technology is currently undergoing testing under the PRDA at the Savannah River Plant.

Author: Joe Kauschinger/404-992-3538

References:

1. "Haliburton-NUS Environmental Soil Saw Demonstration Workplan," Martin Marietta Energy Systems, Inc., internal correspondence, A.P. Malinauskas, January 21, 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Organics/DNAPLS

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical separation

Technology: Fracted air stripping

Status: Demonstration. An integrated demonstration is ongoing at the Savannah River Plant. Results from the study indicate the following:

- The horizontal directional drilling technique had difficulties with aligning the lower sparging well and upper vacuum extraction well. If the intent of the demonstration was to have both wells contained in the same vertical plane, then drilling deviations corresponded to about 50% (i.e., for each foot of drilling horizontal bore, it was 0.5 ft off target).
- The sparging well was partially effective in stimulating formation and release of trichloroethylene (TCE). Vacuum extraction accounted for about 50 kg TCE/day, while injection of air increased the extraction rate by 9 kg solvent/day (only an 18% increase). Helium gas tracer experiments were conducted to evaluate the possible cause of the small increase in extraction rate as air was injected through the sparging well. Helium tracer experiments indicated that communication occurred between sparging and vacuum wells. Forty-five percent of injected helium was extracted from the vacuum well. However, long lag times were observed between the injection of helium and its detection in the vacuum well. The majority of helium tracer was accounted for. It is postulated that the tracer was trapped beneath clay layers (dome affect) in the soil stratigraphy and/or escaped outside the zone of influence of the vacuum extraction well.

Science/Technology Needs: The air stripping system described in U.S. Government patent 4,832,122 is limited by normal sedimentary geologic processes which tend to deposit soils in horizontal layers. Usually, the major hydraulic conductivities are in the lateral direction. Another drawback of the described air stripping system is related to the lack of confinement of the volatile organic compound (VOC) flow path between the sparging and vacuum wells.

Technology improvement is needed in the area of stimulating the soil to develop a primary conductivity in the vertical direction. Simultaneously, a technique should exist for establishing well-defined boundaries at the edges of the well, so that VOC migration is controlled within well established boundaries.

The proposed research would develop a combined air stripping/drainage well system which would overcome the limitations of the technology previously described. The new in situ remediation technique would still be based on horizontal directional drilling. Both wells would have the integrated capability of forming a cutoff wall at the end of each well. This would establish well defined boundary conditions which would allow little migration of VOCs away from the influence zone of well pairs (sparging/vacuum well pair). Stimulation of the soil formation would be accomplished using water cutting technology, enhanced by simultaneous injection of high velocity air or methane gas. Water cutting technology would create a fluidized bed of soil which would release trapped VOCs toward the vacuum extraction well. The major hydraulic conductivity would be oriented in the vertical direction, because the water jets would totally destroy the original soil anisotropy. If dense nonaqueous-phase liquids (DNAPLs) are present, then the chemicals would sink through the fluidized bed under controlled conditions. Lateral spreading of DNAPLs would be prevented because of destruction of soil layering and structure. The jet stream velocities would be varied, so that the DNAPLs would preferentially settle as chemical density overcomes the seepage forces created by the jet streams. The heavy contaminants (DNAPLs) would be collected by converting the sparging well into a drain.

Worker exposure and environmental risk would be greatly reduced by development of a reverse circulation, down-the-hole motor to install the sparging and vacuum extraction wells.

Implementation Needs: A manufacturing facility capable of designing and manufacturing a reverse circulation, down-the-hole motor is needed. A drill string will have the capabilities of performing directional water cutting to create a cutoff wall structure at the end of the drill string and of directionally cutting the soil to destroy the soil's original fabric. The following also are needed:

- A drilling test facility for evaluating the proposed system,
- A manufacturer specializing in directional drilling equipment,
- A contractor with directional drilling capabilities,
- A high-pressure pumping manufacturer to design a water cutting system,
- Civil engineers during field trials,
- Analytical chemists to evaluate the efficiency of a sparged-vacuum system,
- Manufacturing design, development, prototype manufacturing (6 months), and
- A demonstration facility: deployment and 12 months of testing = \$750K. Estimated budget = \$1.25M.

Author: Joe Kauschinger/404-992-3538

References:

1. J.C. Corey, B.B Looney, and D.S. Kaback, *In-situ Remediation System and Method for Contaminated Ground Water*, United States Patent 4,832,122, (assignee: U.S. Department of Energy).
2. B.B. Looney, D.S. Kaback, and J.C. Corey, *Field Demonstration of Environmental Restoration Using Horizontal Wells*, Third Forum on Innovative Hazardous Waste Treatment Technologies: Domestic and International, Dallas, Tex., June 11-13, 1991.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Retrieval

Alternative: Excavation

Technology: Precision excavation. Excavation is a method of removing contaminated surface and subsurface materials from hazardous waste sites by scraping, cutting, digging, scooping, or vacuuming. Decisions about what equipment to use and how the excavation should be done are best left to the contracting firm, which can then use its own judgement to determine the most economical use of resources for the work. For more precise excavation, where the area or volume of material to be removed is small, a clamshell can be useful and can give trench-like excavations. Excavation of areas containing drums, buried tanks, or similar obstructions may require significant amounts of hand and small-machine excavating.

Equipment with which drums may be excavated and staged include: drum grappler, forklift, horizontal drum-grab attached to forklift, vertical drum-grab attached to backhoe, forklift or crane, sling attached to a backhoe, manual loading into the bucket or a front-end loader, or drum hand-truck. Where hazardous drums require excavation, a drum grappler offers personnel safety. This remote handling device can lift drums in several orientations. Preliminary sampling of drums as they are excavated is critical to provide an indication of the degree of hazard to workers.

Status: Accepted by industry. Precision excavation by robots is still in the demonstration phase.

Science/Technology Needs: The content of the buried material (large pieces vs contaminated soil), the volume and area of material to be excavated, the soil type and strength, the site topography, the location of the ground-water table, the proximity to existing structures, and the activity of radionuclides will all be factored into the selection of excavation equipment.

Implementation Needs: These include the following:

- Excavation equipment—clamshells, robots, shovels, small bulldozers, and front-end loaders;
- Access to buried material;
- Drum and material handling equipment;
- Transportation means;
- Trained health and safety personnel; and
- Dust and vapor suppression, if needed.

Author: Julie Pfeffer/615-482-5045

References:

1. *Radioactive Waste Spill and Cleanup on Storage Tank at the Savannah River Plant*, Du Pont De Nemours & Co., Savannah River Laboratory, Aiken, S. C., 1986.
2. R. L. Peurifoy, *Construction Planning, Equipment, and Methods*, 2 ed., McGraw-Hill, New York, 1970.
3. *Foundation and Earth Structures*, Design Manual 7.02, U. S. Department of the Navy, Naval Facilities Engineering Command, Alexandria, Va., September 1986.
4. Wagner, et.al., *Drum Handling Practices at Hazardous Waste Sites*, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1986.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical separation

Technology: Freeze purification. Freeze purification processes are used to remove dissolved solids from low-viscosity aqueous liquids, slurries, and sludges. The process involves five steps: heat exchange, freezing, washing, melting, and refrigerant or energy recovery. When an aqueous solution containing dissolved contaminants is slowly frozen, pure water ice crystals form on the surface, and the contaminants are concentrated in the remaining solution (called "mother liquor"). The ice crystals can be separated from the mother liquor by mechanical means, washed, and melted to yield nearly pure water. The technique can be used on liquid waste streams containing potentially hazardous materials, typically in the range of 1%-10% total dissolved solids. Removal efficiencies of 99.9% have been achieved on aqueous waste streams with as little as 30 ppm total dissolved solids. The process is not effective on streams containing only organic contaminants.

Two basic forms of freeze purification techniques used in industry include the vacuum flash/vapor compression (VFVC) process and the secondary refrigerant freezing (SRF) system. The VFVC process operates so that some water is evaporated and ice is formed simultaneously. The water vapor is condensed and combined with the ice after the ice is freed of the mother liquor. Mother liquor generated during the process must be disposed appropriately. Exhaust heat generated in the compressors (used for refrigeration) is used to melt the ice crystals.

The SRF system produces an ice-liquor slurry by direct contact of the contaminated stream and an evaporating refrigerant. The slurry is washed in a column by a counter-current flow of the freshwater product, thus yielding contaminant-free ice. Ice is melted to water by waste heat generated in the refrigeration loop.

Status: Predemonstration. For almost any application, pilot-scale studies are needed to determine the best operating conditions. Composite wastes exhibit complex solubility curves. Technology has been used in the juice industry. Limited application probably exists to buried wastes, possibly to collected leachate.

Science/Technology Needs: These include the following:

- High total suspended solids wastes may require an upstream filtration unit to remove suspended solids.
- Total dissolved solids are needed to determine the type of crystallization technology to be used and to size the unit.
- Flow rate is used to size the unit.
- Influent and effluent freezing points are required for sizing the refrigeration and crystallizer unit.
- Influent and desired effluent concentrations are used to size the unit.
- Physical and chemical characteristics are used to determine the applicability of the technology and to determine unit construction materials. Crystallizer performance may be sensitive to variations in feed rate, concentrations, pH, and temperature. Excessive scaling of heat exchange surfaces can result in frequent shutdown.
- The compatibility of the contaminated material with the refrigerant is assessed to ensure safe operation in the secondary freeze drying process.
- Variations in feed quantity and quality can affect the crystallizer design and performance.

Implementation Needs: These include the following:

- The leachate needs to be collected.
- Process equipment including crystallizers, refrigeration units, wash columns, strippers, heat exchangers, separators, and pumps.
- If the facility is in a hot climate, excess heat is sent to the atmosphere via a cooling tower.
- Electricity consumption is estimated to be more than 359 kW/1000 gal melted water recovered.

Author: Julie Pfeffer/615-482-5045

References:

1. Heist Engineering Corporation, *Use of Freezing for Liquid Hazardous Waste Concentration*, prepared for the State of California Department of Health and Safety, Sacramento, Calif., 1987.
2. J. A. Heist, et.al., *Remediation and Treatment of RCRA Hazardous Wastes by Freeze Crystallization*, presented at Forum on Innovative Technologies: Domestic and International, June 1989.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Organics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical separation

Technology: Thermal desorption. The desorption of volatile material from excavated buried waste is a method of separating contaminants. Compared to thermal destruction, thermal desorption is a relatively low-temperature, 300°F-800°F thermal separation process. The fraction remaining on the buried material may require further treatment or controlled disposal. The volatilized fraction is collected and, if appropriate, treated further. Typically, thermal desorption is performed for removal of organic compounds, although certain metals and radionuclides are also volatile and may be released from the material during treatment.

Thermal desorption of waste contaminated with organic compounds can be performed with many different treatment systems. However, the four major types of treatment systems are rotary dryer systems, indirect-fired systems, screw-type systems, and asphalt plant aggregate dryers. Each treatment system uses the same basic principal of operation. Each system consists of a furnace in which the organic compounds are desorbed from the waste feed. Desorbed organics are removed from the furnace by a purge gas and are destroyed in an afterburner or are collected by a physical/chemical treatment system. The systems are operated between 300°F and 800°F and are fed with 5-100 tons of contaminated waste per hour. The desorbed organic compounds are removed from the furnace by a purge gas stream, which may flow cocurrent or countercurrent to the waste feed. A typical system consists of a feed pretreatment system, feed hoppers and conveyors, a cocurrent or countercurrent furnace (directly or indirectly fired), a treated soil cooling system, cyclones, an afterburner, a bag house, an induced draft (ID) fan, and a stack.

Most existing thermal desorption units are designed for consistent size feed such as soil. Some materials handling, such as size reduction or coarse separation, may be needed before treatment of excavated buried materials.

Status: Demonstrated. This technology is accepted by industry for certain applications. The technology is more than 99% efficient in removing volatile organic compounds from soil. Costs range from \$35/ton (for low-contamination/low-moisture-content soils) to \$120/ton

(also for soils). Thermal desorption of contaminated solids is in use at various remediation sites around the U.S. (some cleanups have been completed). However, use on buried material is limited.

Science/Technology Needs: The following concerns may cause problems during operation. Information about these conditions is needed before use of the technology is considered.

- Limitations exist on the types of waste and contaminants that can be treated. Large pieces of material, more than 3 in. in diameter, are likely to be untreatable. The technology is not very effective for decontaminating heavily impregnated materials. Materials need to have a large surface area-to-volume ratio for effective removal.
- The presence of other semivolatile materials (tritium, ^{137}Cs , mercury) may cause problems with permitting or treating the off-gases.
- Over 60% moisture may render the process uneconomical.
- The process generates dust and vapor which has to be appropriately suppressed. The residual soil and aqueous or organic phases have to be appropriately stored or disposed.

Implementation Needs: These include the following:

- Process equipment (e.g., indirect- or direct-fired rotary kiln, heated screw kiln, etc.);
- Minimum 2000 sf equipment battery limit;
- All utilities, including reliable electricity, cooling water, natural gas, steam, air, nitrogen, etc.;
- Heating requirements depend on throughput, organic content, and moisture content, but may be about 1M–7.5M Btu/hr;
- Drum and material handling equipment;
- Trained operators; and
- EPA-certified laboratory support.

Author: Julie Pfeffer/615-482-5045

References:

1. J.J. Cudahy, et.al., "Petroleum Contaminated Soils and Sludges-Markets, Permitting and Thermal Desorption Technologies," *Proceedings of the 1992 Incineration Conference*, Albuquerque, N.M., May 1992.
2. R.K. Nielson and M.G. Cosmos, "Low-Temperature Thermal Treatment of Volatile Organic Compounds from Soil: A Technology Demonstration," paper presented at the 1988 Summer National Meeting of the American Institute of Chemical Engineers, Denver, Colo., August 1988.
3. Canonie Environmental Services Corporation, *Soil Remediation and Site Closure, McKin Superfund Site, Gray, Maine*, prepared for the U.S. Environmental Protection Agency, Washington, D.C., July 1987.
4. *Forum on Innovative Hazardous Waste Treatment Technologies: Domestic and International*, EPA/540/2-89/056, U.S. Environmental Protection Agency, Atlanta, Ga.,

June 19-21, 1989.

5. Roy F. Weston, Inc., *Pilot Investigation of Low Temperature Stripping of Volatile Organic Compounds, VOCs, From Soil*, technical report prepared for U.S. Army Toxic and Hazardous Materials Agency, Aberdeen, Md., June 1986.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical separation

Technology: Shredding and magnetic separation. Magnetic separation consists of sorting one solid from another using a magnetic field. Many natural minerals have measurable magnetic susceptibilities, but fewer than 20 are amenable to magnetic separation. Magnetic separation can be performed wet or dry, or with either low- or high-density magnets. Separation is often promoted by shredding or screening waste to 2 in. or less mean diameter. If contaminated material is magnetic, it is removed from uncontaminated material. If contaminant is nonmagnetic, removal of magnetic material may reduce the volume of waste to be treated or disposed. If contamination exists in both a magnetic and nonmagnetic form, the separation of the two may allow different treatment or disposal technologies to be implemented. Magnetic separation typically will recover 70%–99% of magnetic material from a waste stream, depending on the specific configuration of the material and the system. A multiple magnet system is required for high efficiency.

Status: Demonstration. The technology is available; however, it has not been applied under the conditions present at the Y-12 Plant.

Science/Technology Needs: These include the following:

- Identification of the magnetic portion of the waste, size distribution, and magnetic properties of contaminants is needed to assess the applicability of the technology and to determine the type of system required. The applicability of magnetic separation is limited to solid wastes or mixed debris containing magnetic wastes (i.e., iron and steel).
- Shredding or some type of material size reduction may be needed before magnetic separation.

Implementation Needs: Development costs could range from \$0.5M–\$1M. Estimated capital costs for a developed system are \$75K–\$150K/system. Operating costs may be about \$200K/system/year.

Author: Julie Pfeffer/615-482-5045

References:

1. Martin Marietta Energy Systems, Inc., staff members.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Capping

Technology: Intruder barriers. Caps are used to control access to waste and to reduce infiltration into the waste. Intruder barriers are designed to achieve the first objective (although the second objective may be achieved through appropriate design) without reliance on institutional controls. Typical caps require institutional controls to prevent humans from disturbing the material and annual maintenance to prevent plant and animal disturbances. An intruder barrier uses a deep and sometimes impenetrable material to prevent access to the buried waste.

An intruder barrier is defined in 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste" as follows: "Intruder barrier means sufficient depth of cover over the waste that inhibits contact with waste and helps to ensure radiation exposures to an inadvertent intruder will meet the performance objectives set forth in this part, or engineered structures that provide equivalent protection to the inadvertent intruder." The effective life of the barriers is 500 years. To achieve protection of an inadvertent intruder, the depth of capping material is at least 5 m or a barrier layer such as cobbles or concrete is placed to alert the potential intruder to the presence of buried material.

Status: Accepted. Nuclear Regulatory Commission regulations and 10 CFR 61 specify the use of intruder barriers under certain circumstances for radioactive waste. Although many of the circumstances do not directly apply to the Y-12 Plant, intruder barriers have been implemented in similar situations.

Science/Technology Needs: These include the following:

- A description of the materials to be covered. The potential for subsidence and gas production needs to be assessed. It is also important to identify any potential for explosions. It may be necessary to stabilize the material before installing a cap.

- The need exists for general configuration information such as side-slopes and under-drain requirements. Also, the potential for penetration of the cap, such as by-gas or ground water, is identified.
- The need exists to assess the potential for freeze/thaw cycles and the impact on the cap material. Also, the anticipated rainfall could affect the design of the drainage layer.

Implementation Needs: These include the following:

- Area for construction equipment;
- Capping materials such as clay, soils, cobbles;
- Nearby utilities, especially water; and
- Dust control.

Author: Julie Pfeffer/615-482-5045

References:

1. 10 CFR 61, *Licensing Requirements for Land Disposal of Radioactive Waste*, 1992.
2. *Technological Approaches to the Cleanup of Radiologically Contaminated Superfund Sites*, EPA/540/2-88/002, U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C., August 1988.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Organics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Incineration. Incineration is the thermal destruction of hazardous wastes in the presence of adequate oxygen for combustion. Toxic organic contaminants are permanently destroyed by high-temperature oxidation; however, a residual ash is created which may contain heavy metals and toxic products of incomplete combustion. The basic process chemistry of incineration consists of oxidation of the organic constituents of the waste material to form carbon dioxide, water vapor, sulfur oxides, phosphorus oxides, and hydrogen halides. The waste material to be incinerated may be supplemented with a fuel to provide supplemental heating. Incineration systems consist of a feed system, a combustion chamber, and an ash removal system. Air pollution control systems frequently must be incorporated into the design. These may include quench chambers, baghouse filters, gas absorbers, and mist eliminators. Some types of incinerators include multiple hearth incinerators, a liquid injection furnace, a rotary kiln, a fluidized bed, cement kilns, etc. Destruction of volatile organic waste constituents has been measured from 90% in some flares to more than 99.99999% in hazardous waste incinerators. Destruction of semivolatile and nonvolatile organic constituents has also been measured for hazardous waste incinerators and typically exceeds 99.99%.

Status: Accepted by industry. The potential for a low Btu content in the buried waste may limit application of incineration. An incinerator licensed for low-level radioactive waste is currently operated by Scientific Ecology Group.

Science/Technology Needs: These include the following:

- Site topography, site access, and site utilities need to be assessed.
- A soil sieve analysis is used in determining ash handling and air pollution control equipment.

- Waste characteristics are required to determine air and fuel requirements and the basic size of the air pollution control devices. These include heating value, moisture content, ash content, metals content, chlorine content, sulfur content, nitrogen content, PCB/dioxin content, physical form, and reactivity data.

Implementation Needs: These include the following:

- Significant permitting and trial burn efforts are needed to demonstrate acceptable environmental impacts for stack emissions.
- Incineration generates an exhaust gas stream requiring treatment. Primary emissions constituents of concern are particulates, heavy metals, acid gases, tritium, carbon monoxide, and nonmethane hydrocarbons. Other pollutants may also be present.
- An ash stream containing inorganic and radioactive constituents may be produced. Disposal of this ash is needed.

Author: Julie Pfeffer/615-482-5045

References:

1. J. Basilco, *Assessment of Incineration as a Treatment Method for Liquid Organic Waste Streams*, EPA-230-01-86-004, Office of Policy, Planning, and Evaluation, U.S. Environmental Protection Agency, Washington D.C., 1985.
2. C. R. Brunner, *Incineration Systems: Selection and Design*, Van Nostrand Reinhold Co., New York, N.Y., 1984.
3. M. Exposito, *Incineration of a Chemically Synthetic Soil Matrix Using a Pilot-Scale Rotary Kiln System*, Cincinnati, Ohio, 1988.
4. H. Freeman, *Incinerating Hazardous Wastes*, Technomic Publishers, Inc., Lancaster, Pa., 1988

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Trench subsidence

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Structural stabilization

Technology: Structural caps. Structural caps would include precast concrete beams, H-piles, steel frames, or other materials which would support a cap over a subsiding waste trench. For example, a series of precast concrete beams could be placed over waste trenches before capping, and the precast beams would support the cap, even if substantial subsidence of the waste took place.

Status: Accepted. This is commercially available technology. Most of the materials and methods are used routinely in highway and railroad construction. Adapting these materials to support waste area caps would require minimal development.

Science/Technology Needs: The greatest development need is in adapting bridge deck systems for direct contact with the ground. Appropriate coating methods need to be developed to ensure the greatest possible lifespan for the structural systems.

Implementation Needs: Field demonstration to show that support will be maintained over time.

Author: Bill Barton/615-576-0519

References: Martin Marietta Energy System, Inc., staff members.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Trench subsidence

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment/isolation

Alternative: Structural stabilization

Technology: Thermal set resin impregnation. This technology envisions the filling of voids in buried waste with a thermal-set resin. This void filling after setting would provide structural stabilization against trench subsidence. In addition, the thermal regime necessary for resin impregnation would result in melting of indigenous plastics (i.e., polyethylene or polyvinylchloride) in the waste resulting in further void reductions within waste packages. The resins could be the traditional thermal setting grouts such as paraffin, sulfur, or bitumen¹ or synthetic polymer resins such as polyethylene with similar melting ranges. The buried waste would need to be preheated, most likely with steam, to temperatures well above the thermal set temperature of the particular resin before its injection into the waste. Distribution and homogenization problems, as typical of other grouts, would also be encountered. Such technology could also be used to form in situ hydrophobic seals within waste and the surrounding or overlying soil formation.

Status: The technology is only conceptual at present, although ex situ application of thermal-set polymers is a more developed technology.

Science/Technology Needs: Techniques for coupling in situ steam heating and thermal-set resins need to be developed. In situ steam stripping of soil and ground water, which would result in the required heating, is well developed, although direct application to buried waste has not been attempted. Compatibility of various resins with waste components and contaminants would need to be established in a research and development effort. Permeability into various types of soil formations and waste configuration also need to be developed. Obviously, field demonstrations would be desirable.

Implementation Needs: Many of the machine components for implementing such thermal-set resin impregnation are presently developed for ex situ applications (e.g., steam generators, polymer heaters and extruders, and grout injection equipment). However, their integration into a compatible operation would require considerable design and specification development. Field monitoring of thermal heating of buried waste would be required to

ascertain resin impregnation. Likewise, preheating of buried waste would generate off-gas, likely containing volatile organic contaminants, which would need to be collected and scrubbed. Thus, costs for implementation would be quite high (\$20M).

Author: Brian Spalding/615-574-7265

References:

1. P.A. Spooner, G.E. Hunt, V.E. Hodge, and P.M. Wagner, *Compatibility of Grouts with Hazardous Wastes*, EPA-600/2-84-015, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1984.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Organics, Low-Level Wastes, Heavy Metals

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Calcining/sintering. Calcining is the process of heating a material to high temperature but without fusing to effect a change, in this case, to decrease leachability of radionuclides or heavy metals. Sintering is the process of heating a material to a cohesive mass without melting. Thus, the processes are similar, and many conceptual approaches exist to apply the requisite heat. Conceptually, such ex situ heating would destroy hazardous organic constituents as well as combust other organic materials (wood, paper, plastic, etc.), resulting in both a hazard and volume reduction of the waste. Most inorganic constituents and, in particular, radionuclides¹ would be calcined to a state of lower leachability within the waste-associated soil. Significant decreases in leachability occur as low as 500°C and continue to show improvement up to a maximum at vitrification, the ultimate point for calcining/sintering. In an ex situ process, calcining could be carried out to higher temperatures to effect sintering. However, depending on the temperature regime required, many inorganics might be volatilized (e.g., Hg, Cd, Pb). Techniques for achieving ex situ calcining/sintering (ESC/S) could vary enormously and include microwave or radio frequency heating, fossil-fuel-powered heating, and electric induction heating.

Status: The technology for ESC/S (other than total vitrification) for buried low-level solid waste at Y-12 is only conceptual at this stage. Although many of these techniques have been established for ex situ waste and materials processing (U.S. EPA 1989), none have been developed beyond the conceptual stage for treatment of buried waste.

Science/Technology Needs: ESC/S technology needs to be demonstrated on the laboratory, pilot, and field scales for application to buried waste. Because of the high temperatures that would be involved, off-gas capture and handling would be an obvious need. Unlike the ultimate vitrification technology, techniques for ESC/S would need to establish limitations for buried waste with its myriad of components. In addition, the product "quality" of buried waste after treatment to a selected temperature would need to be established as well as its ultimate disposal point or location.

Implementation Needs: Safety, product quality, and field process operations all need to be established for any particular ESC/S technique before implementation needs can be addressed. Secondary waste streams would be highly technique-dependent and remain to be established. Engineering design for field-scale operations and specific hardware would need to be developed after feasibility has been established.

Author: Brian Spalding/615-574-7265

References:

1. B.P. Spalding, G.K. Jacobs, and E.C. Davis, *Evaluation of an In Situ Vitrification Field Demonstration of a Simulated Radioactive Liquid Waste Disposal Trench*, ORNL/TM-10992, pp. 139-147, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1989.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Organics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: In situ heating. The technology for in situ heating (ISH), other than in situ vitrification, for buried low-level solid waste at ORR is only conceptual at this stage. Conceptually, in situ heating would destroy hazardous organic constituents as well as combust other organic materials (wood, paper, plastic, etc.), resulting in both a hazard and volume reduction of the waste. Most inorganic constituents and radionuclides¹ would be calcined (i.e., thermally altered without fusing materials) to a state of lower leachability. Sintering (fusing of materials without total melting) could also be attained and result in reduced leachability. However, depending on the temperature regime planned, many inorganics might be volatilized (e.g., Hg, Cd, Pb). Techniques for achieving ISH could vary enormously and could include microwave or radio frequency heating, fossil-fuel-powered heating, and electric induction heating.

Status: Although many of these techniques have been established for ex situ waste and materials processing,² none have been developed beyond the conceptual stage for in situ treatment of buried waste.

Science/Technology Needs: ISH technology needs to be demonstrated on the laboratory, pilot, and field scale for application to buried waste. Because of the high temperatures that would be involved, off-gas capture and handling would be an obvious need. Unlike the ultimate ISH technique (in situ vitrification), other ISH techniques would need to establish their depth limitations for in situ buried waste. The problems of off-gas pressurization and transient combustible pyrolysis would also be of concern. In addition, the product quality of buried waste after treatment to a selected temperature would need to be established. If ISH were to have the objective of in situ combustion or in situ incineration, then verification of field effectiveness would be a significant need.

Implementation Needs: Safety, product quality, and field limitations all need to be established for any particular ISH technique before implementation needs can be addressed. Secondary waste streams would be highly technique-dependent and remain to be established.

Engineering design for field-scale operations and specific hardware would need to be developed after feasibility had been established.

Author: Brian Spalding/615-574-7265

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2. "Thermal Processes for Corrective Action," *Seminar Publication Corrective Action: Technologies and Applications*, EPA/625/4-89/020, pp. 47-57, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1989.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Fixation, destruction

Technology: In situ vitrification (buried waste)

Status: In situ vitrification for buried low-level solid waste is available but has not been demonstrated for ORR site waste. ISV will produce an excellent waste form from buried waste and its associated soil backfill which will contain most radionuclides and hazardous inorganics. ISV will destroy all hazardous and nonhazardous organic species in buried waste. Two significant concerns must be addressed for ISV to become acceptable for ORR buried waste. First, the presence of combustibles in buried waste poses a risk of pressurization of ISV off-gas and its containment during processing. Second, the possible presence of containerized fluids in buried waste also poses a risk for off-gas pressurization and possible splattering of molten glass during processing.

Science/Technology Needs: ISV needs two significant technology developments to make it acceptable for ORR buried waste. The problem of off-gas pressurizations (Callow, et. al., 1991) during ISV of buried waste seems to be caused by transient flash pyrolysis of combustibles (e.g., wood, paper, or plastics) when contacted by molten material of high temperature. As an ISV melt proceeds, molten glass will occasionally and unpredictably drop into voids within the buried waste, resulting in the flash pyrolysis and associated pressurization of off-gas. The problem is not the presence of combustibles, but rather their rate of combustion when a large amount is contacted rapidly by a large volume of glass. This problem could be largely overcome by in situ compaction of the waste before ISV. By eliminating large voids in the buried waste, rates of waste contact and pyrolysis can be made more gradual than eventful. The second problem of fluid pressurization within ambient containers (e.g., the 55-gal drum) in the buried waste can also be overcome by destruction of ambient containment via dynamic compaction of the waste before ISV. This destruction of potential ambient containment would eliminate the burping and glass splattering when pressurized fluids within containers finally lose their containment because of thermal expansion by contact with the molten product.

Implementation Needs: The implementation needs for ISV for buried waste center on the need for field-scale tests to demonstrate that combustible and container pressurization problems can be eliminated by prior in situ compaction of the buried waste. A combined dynamic compaction/ISV demonstration is planned for ORNL WAG 6 buried waste in conjunction with Pacific Northwest Laboratories (FY-94 to FY-96). Successful deployment of the ISV technology for buried waste would then require fabrication of site-dedicated hardware (about \$6M and 2 years of effort) and contractual arrangements with a private sector corporation to operate that equipment.

Author: Brian Spalding/615-574-7265

References:

1. *In Situ Vitrification Application to Buried Waste: Final Report of Intermediate Field Tests at Idaho National Engineering Laboratory*, EGG-WTD-9807, EG&G Idaho, Inc., Idaho Falls, Idaho, 1989.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Retrieval

Alternative: Excavation

Technology: Vacuum loader (buried waste). Vacuum loaders are large (up to tanker-truck size) vacuum systems used to pneumatically load bulk materials, sludges, granular materials, slurries, or liquids. Operating at around 5000 cfm, a vacuum loader can quickly load a 5000-gal tanker, then haul the material in the tanker which meets U.S. Department of Transportation standards for transportation of hazardous waste. Vacuum loaders are used extensively in asbestos removal projects because of their built-in high-efficiency particulate air filtration and complete containment.

Status: Accepted. Vacuum loader technology is commercially available and is used extensively in industrial cleanup of solid, semisolid, sludge, and liquid materials. The advantage of vacuum loaders is their ability to load a variety of materials, wet or dry—anything that will pass through an 8-in. suction hose. With a vacuum loader, accidental spreading of contaminants is greatly reduced.

Science/Technology Needs: A vacuum loader working with a shredding system would be an effective tool for retrieving buried waste and hauling it to a remote treatment location. The challenges in applying this technology are to get random waste materials shredded to a size that will pass through an 8-in. hose and to increase the speed of loading to production levels.

Implementation Needs: Need to demonstrate and field test this technology at an ORR site.

Author: Bill Barton/615-576-0519

References: Martin Marietta Energy Systems, Inc., staff members.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Organics

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: In situ biodegradation (buried waste). Biodegradation is potentially useful for destruction of organic constituents present in relatively low concentrations in soils and aqueous media. It is not a particularly attractive option for highly concentrated organics in containers in burial trenches.

The role of biotreatment will more likely be in treating residual contaminated soils, waters/leachates, and perhaps secondary wastes generated during other in situ processing techniques. In situ biotreatment of soils and waters in the vicinity of buried wastes may be a feasible option.

Status: Predemonstration. Limited work on this application to date.

Science/Technology Needs: Work is needed to develop delivery/mixing systems for contacting nonhomogenous waste. Impact of radioactive waste on process needs to be determined.

Implementation Needs: Process needs to be demonstrated on a laboratory- and pilot-scale, most likely in conjunction with other technologies (i.e., HMIP) for contacting.

Author: T. L. Donaldson/615-574-2210

References: Martin Marietta Energy Systems, Inc., staff members.

EM Problem: Remedial action

Y-12 Plant Problem: Ground water, surface water

Problem Area/Constituents: Ground water/surface water—nitrates

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: In situ biological denitrification. Anaerobic bacteria obtain energy for growth from the oxidation of an organic carbon source, and simultaneously convert nitrate to nitrogen gas. The use of bacteria that first convert organic nitrogen or ammonia to nitrate (nitrification) followed by denitrifying bacteria can reduce the toxicity of some nitrogen-containing organic compounds. For use in situ, both types of bacteria may need to be introduced along with any nutrients. There may be considerable difficulty in achieving the necessary effectiveness for in situ ground-water treatment because of the difficulty in achieving sufficient contact between the contaminants and the bacteria.

Status: Predemonstration. Biological denitrification has been used to treat nitrate-contaminated pond water in situ, but has not been used to treat ground water in situ. In situ biological denitrification was used to treat the S-3 ponds at the Oak Ridge Y-12 Plant.

Science/Technology Needs: Methods would need to be developed to inoculate the ground water with denitrification bacteria and to supply the required organic carbon source and other required trace nutrients.

Implementation Needs: Extensive development work would be needed to determine how to initiate and control the process. Treatment costs would probably be low.

Author: P.A. Taylor/615-574-1965

References:

1. I.W. Jeter, Oak Ridge Y-12 Plant, personal communication.
2. Metcalf and Eddy, "Wastewater Engineering: Treatment, Disposal, Reuse," McGraw Hill Book Company, 1979.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: Thermoplastic encapsulation

Status: Accepted (bitumen for low-level radioactive waste). Predemonstration (polyethylene). Two thermoplastics—bitumen and polyethylene—have been developed as encapsulation waste forms. Ostensibly, thermoplastics do not interact with the waste, so extensive testing to tailor the waste form is not needed and net volume reductions can result for liquid wastes. The waste must be dried and the dried solids encapsulated in the thermoplastic. The waste is exposed to higher temperatures during drying and mixing with the molten thermoplastic, so volatile species such as mercury may not be amenable to such treatment. The processing is more complex than cementitious sedimentation/solidification (S/S). The waste is not chemically immobilized or stabilized, but the thermoplastic is nonporous and, hence, less leachable. It is questionable whether such physical encapsulation waste forms will pass the Toxicity Characteristic Leaching Procedure (TCLP). Also, current Environmental Protection Agency guidance is that chemical fixation, rather than just physical encapsulation, is required. For this reason, cementitious S/S is the best demonstrated available technology for the Resource Conservation and Recovery Act metals.

Bitumen has been used extensively in Europe, and a couple of commercial vendors offered bitumen encapsulation in the U.S. However, bitumen creeps and requires a container (e.g., a 55-gal drum or concrete vault) for structural integrity. Bitumen absorbs water, swelling as it does so. Encapsulated soluble salts will set up large osmotic pressures within thermoplastic waste forms upon contact with water, causing further expansion for bitumen waste forms. Concern also exists about encapsulating nitrate salts (known oxidizers) in thermoplastics and the biodegradability of these waste forms. Once ignited, such a mixture may burn without access to air. The combination of these problems has made bitumen less popular, despite its superior leach resistance to cementitious waste forms. Polyethylene may overcome most, if not all, of these problems, but it is only a laboratory development. Polyethylene offers the structural integrity lacking in bitumen. Also, the Brookhaven National

Laboratory has studied polyethylene as a waste form for DOE and claims that nitrate salts encapsulated in polyethylene will pass fire and self-ignition tests. Brookhaven has not developed the technology for drying the waste before encapsulation in polyethylene or encapsulated actual wastes. They have mainly studied the properties of dry salts encapsulated in polyethylene. So, the technology is mainly a laboratory development. Passing the Toxicity Characteristic Leaching Procedure (TCLP) remains to be demonstrated, as well as production with actual wastes on the laboratory scale and pilot scale and a demonstration at an actual site.

Silvey and Kaczmarzsky (1988) estimate that asphalt encapsulation of spent beads and powdered resin from a boiling-water reactor (BWR) will result in volume reduction factors of 4.4 over S/S, of 2.22 over dewatering bead resin, and of 1.67 over Ecodex in high-integrity containers. Significant cost savings over the replaced technology are expected using volume reduction and asphalt encapsulation. Chalifoux, et. al., (1988) report ratios of initial waste volume to disposal volume (V/R) of 1.9 to 4.0 for different radioactive wastes from a BWR encapsulated in asphalt compared to a typical V/R range of 0.5 to 0.75 for BWRs that use volume-increase technology such as S/S. The spent resin V/R was 1.9, resulting in a volume reduction factor over S/S of 2.5 to 3.8, compared to the 4.4 reported by Silvey and Kaczmarzsky (1988).

Jacobs et. al., (1984) estimated the costs for treatment (including transportation and burial) of 12,700 ft³/year for 30 years of concentrated BWR waste for the following options:

1. Crystallization followed by S/S: \$37/ft³; \$4.95/gal
2. Drying followed by S/S: \$28.93/ft³; \$3.87/gal
3. Evaporation followed by encapsulation in asphalt: \$35.20/ft³; \$4.71/gal
4. Drying followed by encapsulation in DOW binder (VES): \$24.60/ft³; \$3.29/gal
5. Evaporation followed by S/S: \$89.21/ft³; \$11.93/gal

Science/Technology Needs: Passing the TCLP test needs demonstration along with development of technology to dry the waste before encapsulation (for polyethylene). Resistance to biological degradation needs to be demonstrated. A means for handling volatile species can be explored, such as conversion of mercury into nonvolatile species or incineration of organics. Materials susceptibility to corrosion at the elevated temperatures for the processing equipment needs to be explored, especially if chloride or fluoride species are present in the waste.

Implementation Needs: Laboratory development of the entire process, including drying of the waste, followed by pilot-scale development and site demonstration are needed.

Author: Roger D. Spence/615-574-6782

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Nostrand Reinhold, New York, N.Y., 1990.

2. *Environmental Aspects of Stabilization and Solidification of Hazardous and Radioactive Wastes*, edited by Pierre Cote and Michael Gilliam, ASTM STP 1033, 1989.
3. *Stabilization and Solidification of Hazardous, Radioactive, and Mixed Wastes*, edited by T. Michael Gilliam and Carlton C. Wiles, ASTM STP 1123, 1992.
4. M. H. Jacobs, C. C. Miller, and L. G. Young, *Low-Level Radwaste Engineering Economics*, EPRI NP-3577, July 1984.
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9. P. D. Kalb, J. H. Keiser, and P. Colombo, *Long-Term Durability of Polyethylene for Encapsulation of Low-Level Radioactive, Hazardous, and Mixed Wastes*, BNL-46359, presented at the American Chemical Society Symposium for Emerging Technologies for Hazardous Waste Management, Atlanta, Ga., October 1-3, 1991.
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EM Problem: Remedial action

Y-12 Problem: Buried Waste

Problem Area/Constituents: Low-level waste, organics, metals, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: Thermoset encapsulation

Status: Accepted for ion exchange resins. Predemonstration for ashes and other fine solids. Conceptual for liquid wastes (product acceptance doubtful, evaporation to solids more likely).

Polyurethane encapsulation was developed several years ago and is no longer used, because the acidic liquid produced during the polymeric reaction caused problems of container corrosion and contaminant release. The main thermoset encapsulation is currently vinyl ester styrene (VES) encapsulation, although theoretically other thermoset polymers could be used. The VES encapsulation is accomplished by infiltration of, or mixing with, the monomer followed by polymerization, thereby encapsulating the waste. The thermoplastic (polyethylene and bitumen) encapsulations require melting the polymer and mechanically mixing it with the waste and require elevated temperatures and dried wastes. The thermoset encapsulation does not require elevated temperatures or dried wastes. VES encapsulation was originally developed by Dow Chemical, but is now being developed and marketed by Diversified Technologies of Chestertown, Maryland. It has mainly been developed as a means of encapsulating ion exchange resin, without the matrix failure experienced by cementitious S/S when the resin shrinks and swells with wetting and drying. The process developed is quite simple and does not require resin drying or mechanical mixing. The resin bed is drained of the aqueous solution, the VES monomer mix is infiltrated into the bed of wet resin (displacing the residual water clinging to the resin beads), and finally, the monomer is polymerized, forming a monolith of VES with the wet resin encapsulated inside. VES encapsulation of a resin bed does not result in a net increase in bulk volume, an important economic advantage for ultimate disposal. It is also possible to encapsulate beds of other large solids in a similar manner. Fine solids such as ashes from incineration may be encapsulated, but mechanical mixing will likely be required to get a homogeneous mix. Ostensibly, no interaction occurs between the waste and VES, but some materials may interfere with polymerization of the monomers, especially organic materials. Liquid wastes cannot be handled as presently

developed, except by evaporation to solids; but conceptually, an emulsion could be formed, leading to liquid waste dispersed throughout solid VES. Technically, this does not meet some definitions of no liquid, for disposal purposes. Also, this is a physical encapsulation technique with no chemical immobilization of waste species. It is questionable whether VES encapsulation would pass a TCLP test.

Jacobs et. al., (1984) estimated the costs for treatment (including transportation and burial) of 12,700 ft³/year for 30 years of concentrated BWR waste for the following options:

1. Crystallization followed by S/S: \$37/ft³; \$4.95/gal
2. Drying followed by S/S: \$28.93; \$3.87/gal
3. Evaporation followed by encapsulation in asphalt: \$35.20; \$4.71/gal
4. Drying followed by encapsulation in DOW binder (VES): \$24.60; \$3.29/gal
5. Evaporation followed by S/S: \$89.21; \$11.93/gal

Science/Technology Needs: The need exists to try a Toxicity Characteristic Leaching Procedure test for Resource Conservation and Recovery Act metals. The need exists to develop a means to incorporate ashes into the monomer mix and to test the performance of the resulting product. The need exists to identify what materials will interfere with polymerization of VES or will weaken the resulting product. The need exists to quantify the residual monomer content after polymerization and the potential release rate of this monomer.

Implementation Needs: The need exists to qualify this waste form for use with hazardous waste via TCLP tests. The technology is already demonstrated and is used for disposal of ion exchange resins. The need exists for laboratory development, for pilot-scale development, and for demonstrations for ash and fine particles. Liquid wastes will likely require pretreatment of evaporation to solids.

Author: Roger D. Spence/615-574-6782

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1. Jesse R. Conner, *Chemical Fixation and Solidification of Hazardous Wastes*, Van Nostrand Reinhold, New York, N.Y., 1990.
2. *Environmental Aspects of Stabilization and Solidification of Hazardous and Radioactive Wastes*, edited by Pierre Cote and Michael Gilliam, ASTM STP 1033, 1989.
3. *Stabilization and Solidification of Hazardous, Radioactive, and Mixed Wastes*, edited by T. Michael Gilliam and Carlton C. Wiles, ASTM STP 1123, 1992.
4. M. H. Jacobs, C. C. Miller, and L. G. Young, *Low-Level Radwaste Engineering Economics*, EPRI NP-3577, July 1984.

EM Problem: Remedial action

Y-12 Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: Sulfur polymer cement (SPC) encapsulation

Status: Predemonstration. SPC encapsulation is like thermoplastic encapsulation in that the dried waste solids are encapsulated in the molten sulfur. The advantages are similar in that little interaction is anticipated, a nonporous waste form results in less leaching, and drying liquids result in a net volume decrease. Sulfur is resistant to acid attack so that SPC has been used as a construction material in aggressive acid environments. On the other hand, sulfur cannot be used in other environments, such as high alkalinity. These deleterious environments have been identified and must be avoided, illustrating the importance of waste characterization. SPC has been studied as a waste form by the Brookhaven National Laboratory and in Europe. These studies have been on a laboratory scale, so pilot-scale studies and demonstrations are still needed. As with thermoplastics, it is questionable whether SPC will pass the Toxicity Characteristic Leaching Procedure (TCLP) test as a purely physical encapsulation technique. It is being touted as a radioactive waste form. The Europeans succeeded in pretreating ion exchange resins, so that resin encapsulated in SPC could be immersed in water without resin swelling, causing breakdown of the SPC matrix.

Science/Technology Needs: Performance in the TCLP test needs to be tested. Again, the technology for drying the waste before encapsulation needs development along with scale-up of the encapsulation process.

Implementation Needs: Further laboratory development, pilot-scale development, and demonstrations are needed.

Author: Roger D. Spence/615-574-6782

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1. Jesse R. Conner, *Chemical Fixation and Solidification of Hazardous Wastes*, Van Nostrand Reinhold, New York, N.Y., 1990.
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6. *Stabilization and Solidification of Hazardous, Radioactive, and Mixed Wastes*, edited by T. Michael Gilliam and Carlton C. Wiles, ASTM STP 1123, 1992.
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POLYMER-IMPREGNATED CONCRETE/ POLYMER-MODIFIED CONCRETE

REMA-115-OZ

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: Polymer-impregnated concrete/polymer-modified concrete

Status: Evolving technology. Although polymer-modified concretes are well established in the construction industry, application to waste forms is only conceptual, and polymer impregnation is an evolving technology.

Basically, this technique is an extra step to achieve waterproofing after cementitious S/S. Polymer impregnation has been studied over many years and is usually restricted to treatment within a few millimeters of the surface; polymer modification has been developed over many years and introduces polymer throughout concrete during the mixing step. Both have been used as a means of waterproofing and environmental protection for structural concrete. Impregnation usually is attempted as remedial protection years after the concrete structure was made. A technique was invented at the Oak Ridge National Laboratory to achieve essentially complete monomer permeation throughout a waste form by adding polystyrene foam during mixing of the cementitious waste form. The same technique is used in polymer modification in which latex, for example, is mixed into the concrete. The foam bits introduce porosity into the waste form, potentially making a weaker product, not of great concern for waste forms. The styrene monomer collapses the polystyrene foam, helping to pull monomer throughout the cementitious matrix. The monomer then is polymerized, giving a waterproofing component throughout the waste form. This treatment protected cementitious waste form samples from attack by concentrated hydrochloric acid. Laboratory development still is needed to optimize the treatment and to test the properties of the resulting waste form. The product has the advantages of a cementitious waste form with the added protection of a waterproofing layer throughout the waste form. Leaching will still occur across the polymeric barrier from the porous cementitious waste form. Brookhaven National Laboratory (BNL) acquired a patent using polymer impregnation of cement as a means of disposing of treated water.

September 1994
Remedial Action

Science/Technology Needs: Further laboratory development, pilot-scale development, and demonstration as a waste form are needed.

Implementation Needs: The need exists for further laboratory development, pilot-scale development, and demonstration.

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1. Jesse R. Conner, *Chemical Fixation and Solidification of Hazardous Wastes*, Van Nostrand Reinhold, New York, N.Y., 1990.
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EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: Ceramic encapsulation

Status: Evolving technology (conceptual, some laboratory work). Ideally, mineral phases can be identified and generated for each waste specie, but this may not prove feasible, and some species may be encapsulated or limited to grain boundaries. One advantage of this waste form is its thermodynamic stability. The amorphous calcium silicate hydrate matrix of cementitious waste forms is thermodynamically unstable, although it may last for millennium in dry environments. Glass is a supercooled liquid. Ceramics are dense mineral phases, thermodynamically stable. As with glass, ceramics can be made with low porosity, making them less leachable than cementitious waste forms. As with cementitious waste forms, the chemical phases have low solubility, potentially making them less extractable than glass waste forms. Species relegated to grain boundaries (or physically encapsulated) may be just as extractable as before treatment. TCLP testing of specific waste forms is needed to verify this chemical stability. This technique is in its infancy. Some wastes are ready-made for conversion into ceramics, whereas others may require significant chemical conversion. The waste must not only be characterized as to elemental species, but also as to chemical species. This is a high-temperature technique with thermal destruction of organics, but it may not be amenable to some volatile and semivolatile species, such as mercury, tritium, iodine, cesium, and technetium.

Science/Technology Needs: The need exists for laboratory development to prove that the concept is feasible for some wastes, to prove the means of achieving a ceramic, to identify which species are incorporated into ceramic phases and which are not, and to prove the necessary organic destruction and means of handling nondestructible volatilized species. Need pilot scale and demonstration once necessary laboratory work done.

Implementation Needs: The concept needs to be definitively proven in the laboratory, and performance testing needs to be done. The need exists for Toxicity Characteristic Leaching

Procedure testing of Resource Conservation and Recovery Act metals. The need exists to establish which waste stream technique is applicable and which is not. Pilot-scale development and demonstration is needed after laboratory development.

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EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: Vitrification. This device adds glass-forming constituents to waste feed to produce a pool of molten glass at the bottom of a reactor in which solid wastes react. Gases produced during combustion are released from the surface of the glass pool. Ash remains in the pool and is periodically removed with the carrier glass matrix. The removed glass is collected in storage containers and solidifies upon cooling.

Status: Predemonstration. A large database exists for high-level radioactive wastes, but not for low-level radioactive wastes or hazardous wastes.

Vitrification is a physical encapsulation technique that has been accepted for high-level waste. Vitrification results in a net volume reduction, even starting with a bed of solids and no liquids. This results in significant economic savings for ultimate disposal to compensate for the higher capital and production costs required to generate this waste form (compared to cementitious waste forms). Ostensibly, no interaction with the waste occurs, but it is questionable whether vitrified waste will pass the Toxicity Characteristic Leaching Procedure (TCLP) test. The waste form is nonporous and less leachable than cementitious waste forms, but the RCRA metals may be just as extractable after treatment as before, if truly allowed to come to equilibrium, as intended in the TCLP test. Laboratory testing is required, as with cementitious waste forms, to identify the compatible melt compositions. This technique occurs at higher temperatures than for thermoplastic encapsulations. Thus, water is driven off, but it is inappropriate for volatiles and may not be appropriate for semivolatiles. Organics are likely destroyed, but other volatiles and semivolatiles that cannot be destroyed (e.g., mercury, tritium, cesium, and technetium) may not be amenable to vitrification. Such contaminants are commonly found in low-level radioactive wastes.

The white paper prepared for EG&G Idaho, Inc., (EGG-WTD-9449) evaluates the advantages, disadvantages, and costs of thermal treatment technologies, including vitrification by glass furnace and vitrification by microwave melting. Included among the disadvantages were

relatively high energy and capital costs and unproven technology for hazardous wastes. The capital cost and operating costs for glass furnace vitrification were estimated to be \$3.9M and \$0.78/kg feed. (Assuming a feed density of 1 kg/L, operating costs convert to \$780/m³ or \$2.95/gal.)

In making a case for vitrification of low-level wastes, Gimpel and Diggs have made economic assessments and have published several papers (1992), together or separately, either claiming that the costs for vitrification are comparable with those of solidification/stabilization (S/S) or that the costs for making the glass waste forms are higher, but the total life cycle costs (including disposal costs and monitoring costs for 100 y after disposal) are comparable for the two options because of the higher volumes that must be disposed and monitored from S/S. They estimate the direct costs to be \$90–\$220/m³ (\$0.34–\$0.83/gal) for S/S and \$400/m³ (\$1.51/gal) for vitrification, but total costs (including disposal) at \$1186–\$2090/m³ (\$4.49–\$7.91/gal) and \$922–\$1500/m³ (\$3.49–\$5.52/gal), respectively. The assumptions made regarding S/S appear reasonable, but are more questionable regarding vitrification. However, the authors make a valid point that most cost estimates are the direct costs of making the wastes and do not include disposal costs. The cost deficit from increasing the waste volume should be estimated for S/S or the cost benefit estimated from the volume decrease for vitrification.

Koegler et al. (1988) has the following insights into waste vitrification:

- Estimated capital cost of \$24.1M and total operating costs of \$73M for granular glass, or \$97M for casting into canisters, for a facility to vitrify 264K tons of waste over 6.5 y. This works out to \$91/ton capital costs and \$277–\$367/ton operating costs.
- "A favorable property of glass is its ability to accommodate a wide variety of compositional variations and still maintain its basic durability."
- "The amount of glass to be produced is expected to be determined by the fluoride solubility limit in the glass. Fluoride, a major constituent in the raffinate sludges, has a maximum glass solubility of about 5 wt%."
- "Of the priority pollutant metals, mercury is known to escape from the glass during vitrification due to its high vapor pressure."
- "On a cost-per-volume basis, the disposal costs are estimated at \$256/m³ or \$322/m³, depending on whether the glass product is fritted or placed in canisters."

Buelt (1985) has the following insights about vitrification:

- "The process is not amenable to waste solutions with significant concentrations of sulfates (i.e., <2% on a dry solids basis). Sulfate solubility in glass is limited to 0.5 wt%."
- "In addition to producing a geologically stable waste form, MEVS significantly reduces the volume of the waste to be destroyed." (MEVS stands for the Mobile Encapsulation and Volume Reduction System touted by the author. MEVS employs a joule-heated glass melter to vitrify low-level wastes.)
- "The cementation process actually increases the evaporated waste volume by a factor of 1.3, which increases the transportation and disposal cost."

- The estimated disposal cost for cementation, MEVS of resins, and MEVS of concentrated liquid are \$295, \$218, and \$191/ft³ wet wastes (\$39.44, \$29.14, and \$25.53/gal wet wastes), respectively, including amortized capital, processing, transportation, and disposal costs. (Processing costs for cementation in this reference are orders of magnitude higher compared to other sources.)
- "Burial costs are 1/3 and 1/2 of the cementation disposal costs for resins and concentrated liquids respectively."

Science/Technology Needs: The need exists to demonstrate the technology's effectiveness for those semivolatile species commonly found in low-level waste. For hazardous waste, incinerator efficiencies must be demonstrated for organics as well as the ability to handle volatile and semivolatile metals. Typically, mercury must be removed before vitrification, and Cs-137 has been found in the off-gas. Catholic University is studying this technique for DOE. Claims are made that vitrified wastes pass the TCLP test, but this must be verified, and the Resource Conservation and Recovery Act metal limits in the vitrified waste must be quantified.

Implementation Needs: Laboratory testing of a specific waste or waste stream is necessary to establish the glass composition. Some laboratory testing of certain wastes has been done, but these would need repeating for Y-12 wastes, and pilot-scale testing and demonstrations have not been done. Likely, this must be repeated on a case-by-case basis, just as with cementitious waste forms.

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3. *Stabilization and Solidification of Hazardous, Radioactive, and Mixed Wastes*, edited by T. Michael Gilliam and Carlton C. Wiles, ASTM STP 1123, 1992.
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EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediment

Problem Area/Constituents: Volatile organic compounds and fuel-based hydrocarbons in soil

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelements: Treatment

Alternative: Destruction

Technology: Soils treatment using bioremediation. Bioremediation refers to a wide range of biological processing options that rely on microbial transformation of organic contaminants to effect cleanup of soils. The microorganisms, principally bacteria, metabolize the contaminants into benign forms to obtain energy and/or carbon. Bioremediation can occur in situ (at the contaminant location) or ex situ (away from the contamination site), and can take place under aerobic (with oxygen) or anaerobic (without oxygen) conditions. Many organic contaminants, including polynuclear aromatics and nonhalogenated species, can be biodegraded more rapidly under aerobic conditions. Some halogenated compounds are more readily degraded anaerobically.

The activity of naturally occurring microorganisms is greatly affected by soil conditions such as moisture content, pH, redox potential, temperature, oxygen content, porosity, and most importantly, availability of nutrients. These soil properties can be manipulated to achieve optimal conditions for microbial activity, stimulating or accelerating the breakdown of target contaminants.

Techniques for manipulating properties of soils near the surface (less than 1.5 ft deep) include solid-phase treatment (i.e., conventional soil management practices such as tilling/mixing or irrigating), contained solid phase treatment (e.g., composting), and slurry-phase treatment. Techniques for bioremediation of subsurface soils include soil venting and fluid cycling. These techniques "push and pull" air or water, that have been generally amended with nutrients or other soil conditioners, through the soil with injection and extraction wells.

Besides using microbes that already exist at the contaminated site, one can introduce and adapt organisms normally found elsewhere to degrade the contaminant.^{1,2} The addition of microbes to the soil, or microbial augmentation, may be desirable if the native microbe

community lacks the metabolic capability to degrade target contaminants, or if native organisms capable of degrading contaminants exist in very low numbers or are poorly distributed throughout the soil. Augmentation of biological systems with exogenous (not native to the soil) microbes may be most effective against a single compound or a closely related class of compounds. Also, combining microbes may actually speed up degradation.³

Status: Predemonstration. Highly chlorinated compounds, like the TCE found in Y-12 soils, are not easily degraded, and in situ or ex situ remediation of soils with these contaminants is considered to be in the laboratory stage.

In situ bioremediation of contaminated soil has been attempted under variable conditions with several volatile compounds.⁴⁻⁸ Laboratory-, bench-, and pilot-scale testing are being done on various properties, but no testing is being performed on all parameters at the same time.

Excavated soils can be biologically treated using naturally occurring or genetically engineered bacteria to remove contaminants, including VOCs, SVOCs, and PAHs. Of the various potential ex situ methods, slurry-phase seems the most effective.^{9,10} Demonstration of slurry-phase has been carried out by BioTrol as a pilot study for EPA.^{1,11} An EPA Site Demonstration for BioTrol was set for the fall of 1991. No literature was found on the results.

The use of ex situ bioreactors offers better control over temperature, chemical, and biological conditions than in situ operations. It is more likely to be used with difficult contaminants. The bioreactor can be incorporated into a soil washing system. The difficulty of biodegradation depends upon the contaminants of interest, but recent demonstrations have worked with compounds that are normally resistant to degradation such as wood preserving chemicals.

There are various potential options for inoculating soil with microorganisms with a specific metabolic capability. These options are described below; however, only the first is readily available now. The others are in varying stages of development.

- **Commercially available cultures:** Presently, microbial inoculants (pure or mixed bacterial cultures) are commercially available that can degrade a wide range of compounds, including some chlorinated compounds.^{3,12,13} However, as mentioned previously, a particular culture is generally most effective in degrading one compound or a group of closely related compounds.
- **Cometabolic cultures:** These organisms have been demonstrated in field applications. They can, in the presence of a growth substrate, transform target contaminants even though they derive no direct benefit. Cometabolism of TCE, which is otherwise not biodegradable under aerobic conditions, in the presence of methane, phenol, or other growth substrates is in the development and demonstration stage. Cometabolism of carbon tetrachloride under denitrifying, anaerobic conditions is also in the development stage. Many cometabolic cultures are indigenous to soil, and may not need to be added.¹⁴
- **White Rot Fungus (Phanerochaete Chrysosporium):** This fungus is available from at least

one company; it has been used in the laboratory and in several full-scale decontamination operations.^{1,2} It reportedly can degrade halogenated compounds¹⁵ and a variety of recalcitrant organics.

- Genetically engineered microorganisms (GEMs): GEMs are currently in the development phase. There are two approaches to this method. One approach utilizes microbes that are known to degrade certain organics and adapts them to the environment of the contaminated site. This is not necessarily a genetic approach, but it can involve gene manipulation.^{1,2} The other approach involves genetically engineering bacteria that thrive in contaminated soils and adapting these populations to degrade certain organics. This approach is a recombinant DNA approach that involves gene manipulation.

For ex situ bioremediation, the waste produced will be minimal if the treated soil can be returned to the ground, or if the treated soil does not have to be handled as a waste. However, as with any ex situ treatment, if the treated soil is not permitted to be returned, the waste volume will be large. For those subsurface bioremediation treatments, where air or water is passed through the soil, the extracted air or water will probably need to be treated.

Science/Technology Needs: Identification of, and experimentation with, naturally occurring microbes is needed for Y-12 soils. Similar information will be needed on the ability of exogenous organisms to survive, grow, and function in Y-12 soils; especially important will be the effect of low levels of radiation on the microbes. This information will be helpful in the selection of local or manufactured strains with the traits to handle site contamination.

Soil characteristics should be explored to determine optimal conditions for degrading organics in microbiological populations. The relatively low porosity and high fractions of silt and/or clay in the Y-12 soil may limit in situ applications. Field-scale tests should be considered if laboratory results indicate significant organic reduction using bioremediation. Control/test plots at Y-12 sites should be designed so that adequate comparative analysis can be done to establish decay rates.

Ex situ techniques should be thoroughly evaluated for process flexibility and cost effectiveness when other, possibly less expensive, in situ applications are available. Particular emphasis should be given to improving the reliability of the treatment; this usually requires an understanding of the parameters that affect biodegradation.

Because of the high volatility of some of the organic compounds, it is not always easy to be sure that all (or any) decrease in VOC concentrations are due to biodegradation rather than vaporization. Great care must be given to handling the soils to prevent uncontrolled evaporation that could be confused with bioremediation. Treatment methods that handle the soil in "open" bioreactors probably will not be acceptable at Y-12 because the chlorinated volatile compounds most likely to be found at Y-12 generally can not be released to the atmosphere.

The technology of biodegradation and bioreactor design are developing rapidly, and improvements in cost and performance appear to be resulting from current activities. Most

organisms used in bioreactors have been developed from organisms found at similarly contaminated sites, but future modifications of the organisms may provide significant improvements. Innovative bioreactors that can handle solids, retain organisms, and optimize reactor conditions should be encouraged.

Implementation Needs: Biodegradation still is not understood well enough to avoid careful treatability studies, and the acceptable treatment level needs to be established. Then the capabilities of in situ bioremediation for chlorinated contaminants at Y-12 must be assessed and demonstrated. In situ bioremediation usually requires relatively few facilities. However, it does require time and suitable procedures to verify that the treatment was successful. For ex situ bioremediation, depending on the advancement of this technology, Y-12 will need a large water source and adequate sites for equipment and/or mobile equipment.

No literature was found to show results of large-scale testing or site demonstrations. In any event, such testing on Y-12 soils would be necessary to establish this approach, for both local and manufactured cultures, as a viable full-term soil remediation method. Ex situ bioremediation may prove to be an effective treatment method when applied in conjunction with extractive technologies, such as physical separation and soil washing. Large-scale tests and demonstrations should be part of an integrated approach that combines two or more treatment technologies that will accommodate the mixed waste problems that are likely to exist at Y-12.

At this time, bioremediation enhanced by manipulation of local conditions of soil contaminated with organic compounds appears very cost effective. Costs for the in situ method are generally lower than ex situ methods but vary considerably. Costs for remediating soils contaminated with highly chlorinated compounds is only conjectural since processes are not developed. However, in situ bioremediation for other less refractive compounds can be relatively inexpensive, perhaps much less than \$100/ton. Costs for ex situ bioremediation are likely to be moderate; e.g., costs in the range of \$100–\$200/ton may be achieved. One estimate suggested a cost of \$165/ton.¹¹ Development and demonstration costs are uncertain because both the probability of success and the difficulties to be encountered are more uncertain than for most technologies. These costs would probably be less than \$5M, could possibly be about \$3M.

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EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediment

Problem Area/Constituents: Organic compounds and metals in soil

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelements: Treatment

Alternative: Chemical separation

Technology: Soils treatment using solvent extraction. Solvent extraction consists of (1) contacting a solvent with contaminated solids (or sludges) to preferably dissolve the contaminants in the solvent, (2) separating the contaminant-rich solvent from the treated soil, and (3) removing the contaminants from the solvent and recycling the recovered solvent into the extraction process.

Both liquid and gaseous solvents can be used. Liquid solvents can be separated from the soils by letting the solids settle out and then decanting the liquid; gaseous solvents can be removed using vacuum pumping. Two typical solvents used in industry are triethylamine and kerosene. Desirable features for an extraction solvent are (1) that it have a high capacity for the target contaminant, (2) that it be selective in component extraction, (3) that it not pose a major flammability or explosion hazard, (4) that it be reclaimable/recyclable, (5) that it be relatively inexpensive, and (6) that it be nontoxic and noncorrosive.

Solvent extraction may use either in situ or ex situ techniques. In situ solvent extraction is similar to soil flushing where solvents are used as the flushing agent. The solvents are delivered to the contaminated soil using injection wells or a gravity system (e.g., flushing basin or trench). Recovery of the contaminant-laden solvent is accomplished using a series of shallow wells or subsurface drains. In situ extraction is most effective in homogeneous permeable soils, and in soils with low recharge or adsorptive capacity for contaminants. Since it is important, yet difficult, to recover completely the solvents from the treated soil, ex situ techniques are often preferred to in situ techniques.

Ex situ solvent extraction generally consists of transferring the contaminated soil to contacting equipment where the soil is mixed with the solvent. After adequate extraction, the solvent is removed from the contaminant-depleted soil via decantation, and distilled in an evaporator or column. The distilled vapor consists of relatively pure solvent that is recycled into the extraction process. The liquid residue, concentrated with contaminants, undergoes further treatment or disposal (e.g., incineration). The soil, after the solvent has been decanted

**Minimum of extraction stages for "complete"
extraction of organics from contaminated sludge*
using equal masses of wet sludge and extractant**

Solvent Extractant	Material Extracted	
	Oil and grease	Phenol
Triethylamine	4	1
Isopropyl alcohol	11	7
CFC 113	6	15
Acetone	22	5
Hexane	9	21
C ₁₅ Aliphatic		15
Tergitol (Aq)	43	6
Polyethyleneglycol (50% Aq)	2000	11
Aqueous pH 10.6	7000	16
Aqueous pH 9.58	8000	11
Aqueous pH 8.42	>115,000	13
Aqueous pH 7.62	>115,000	7

*Sludge contains 230,000 ppm oil and grease, and 6400 ppm phenols.

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Science/Technology Needs: Investigation is needed to determine the type, concentration, and solubility of the contaminants in order to select the appropriate solvent and to size the extraction equipment. The extent of contamination will also help size equipment, as well as determine throughput (the throughput rate may range from 2–5 ton/hour).

Implementation Needs: Soil pretreatment requirements, such as pH adjustment or size reduction equipment will need to be evaluated. Posttreatment or heating requirements of the soil must also be determined.

The efficiency of the extraction process will potentially decrease if the solvent reacts with the contaminants. In addition, the solvent and solute phases, as well as the aqueous residuals from the solvent stream, may form azeotropes that are difficult to separate via simple distillation or evaporation. In part for these reasons, field trials are necessary to discover the severity of potential technical constraints.

Solvents may extract metals and radionuclides as well as organics. Since multiple types of contaminants were discovered in Y-12 soil samples, solvent selection may need to take into account this multiplicity. If no single solvent or group of solvents addresses sufficiently the

off, is washed and dried to remove residual solvent. This may occur in the same vessel where the extraction was performed or a separate vessel. Final disposal of the soil depends on the type and concentration of the residual solvent remains in the soil.

An alternate ex situ solvent extraction method uses supercritical fluids as solvents. Solvents are made supercritical by manipulating temperature and pressure; such solvents may exhibit increased extraction capacity. The waste (in a pumpable form) and the supercritical fluid intimately mix in a counter-current extractor. When the contaminant-laden supercritical fluid leaves the extractor, it is depressurized; this significantly reduces solubility and induces contaminant precipitation.

Status: Predemonstration. The U.S. Environment Protection Agency has completed several pilot tests for application of solvent extraction to soils contaminated with petroleum hydrocarbons, PCBs, and other organics. Removal efficiencies varied significantly, approximately 50%–95% for petroleum and other hydrocarbons. Solvent extraction is being considered for use at various sites contaminated with organics and metals, but most applications are still in the predesign or design phase.

Soils flushing is a new and innovative technology. Few full-scale systems have been operated and little operating information is available. Field studies are planned and investigations are being conducted to determine appropriate solvents for mobilizing various classes and types of waste constituents.

Solvent extraction does produce residuals that will require disposal. The treated soil, if not sufficiently clean to be returned to its original location, may also require separate storage or disposal.

Y-12 soil contaminants, an integrated approach could be proposed and studied that would accommodate the mixed waste problems that are likely to exist. Large-scale tests and demonstrations should be part of the integrated approach.

Equipment and facilities will be needed to perform the ex situ solvent extraction and to store waste residuals. Facility and process costs will vary significantly depending on the pretreatment, extraction, and posttreatment required. Costs are likely to be moderate, perhaps \$200–\$300/ton. Development and demonstration costs are uncertain because both the probability of success and the difficulties to be encountered are difficult to predict; these costs could range from \$3M–\$5M.

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EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediment

Problem Area/Constituents: Organic compounds and metals in soil

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelements: Treatment

Alternative: Destruction

Technology: Soils treatment using oxidation or reduction. Chemical oxidation raises the oxidation state of a substance by the removal of electrons or the addition of oxygen to the substance. Reduction lowers the oxidation state of a substance by donating electrons to the substance. Oxidation or reduction may result in the transformation, degradation, and/or immobilization of the soil contaminants. The chemical transformations may occur naturally in a soil system or by the addition of an oxidizing/reducing reagents to the soil/waste complex.

For oxidation to occur naturally in soil systems, the reduction oxidation potential of the solid phase must be greater than that of the organic chemical contaminant. Therefore, the reduction oxidation potential of chemical contaminants needs to be below the reduction oxidation potential, approximately 0.8 volts of well-oxidized soil. Water-soluble compounds should be more readily oxidized in clay-catalyzed systems, because sorption to the hydrophilic clay mineral surface, which is the oxidation reaction site, precedes the oxidation process. Also, greater oxidation of chemical contaminants is expected in less saturated soils.

Another method of oxidizing wastes in soil is by the addition of oxidizing agents such as ozone, hydrogen peroxide, or potassium permanganate to the contaminated soil. All of these are strong oxidizing agents and are nonselective. Certain compounds, such as phenols, aldehydes, and aromatic amines, are more oxidizable in soils than compounds such as halogenated hydrocarbons, chlorinated insecticides, benzene, and saturated aliphatic compounds.

Chemical reduction is often used to convert metals to less soluble or toxic forms. Examples of this include the reduction of hexavalent chromium to trivalent chromium and the reduction of hexavalent selenium to selenium tetravalent or to elemental selenium. Chlorinated organics, unsaturated aromatics and aliphatics, and other organics susceptible to reduction are also amenable to treatment by reducing agents. Chemical reduction may be

accomplished using catalyzed metal powders and sodium borohydride. Several processes have been developed for the reduction and dehalogenation of PCBs and dioxins. These processes employ sodium- or potassium-based chemical reagents to remove chlorine from PCB and dioxin molecules.

Chemical treatments may be performed ex situ or in situ. Ex situ oxidation or reduction generally consists of transferring the contaminated soil to contacting equipment where the soil is mixed with the reagents. In situ treatment generally requires incorporation of the treatment reagent into the contaminated medium. The means by which this is done is largely dependent on the depth of the contamination. Conventional agricultural techniques (using implements such as plows, harrows, discs, sprayers, spreaders, and injectors) can be used in cases where the contamination is in the shallow subsurface zone. In cases of deeper contamination, the treatment reagent is typically introduced into the subsurface in an infiltration trench or injection well. The infiltration trench or injection well is often coupled with drains or production wells to induce flow of the reagent through the contamination. This "closed loop" approach can also be used to extract mobile contaminants from the subsurface and provides some degree of control of the migration of both contaminant and reagent.

Status: Limited Demonstration. In situ chemical oxidation with hydrogen peroxide has been demonstrated at the field level (Portsmouth X-231B Technology Demonstration) as an effective remediation technique for TCE contaminated soils and ground water. This approach included the delivery of hydrogen peroxide to the contaminated subsurface using deep soil mixing and reagent injection equipment.

Chemical oxidation of organics with potassium permanganate and ozone has been performed in aqueous matrices and on a limited basis with waste sludges. Relevant ORNL field tests have not been demonstrated.

Reduction of chromium and selenium in a soil matrix has been accomplished in laboratory studies, but the status of the treatment technique at full scale is conceptual.

Sodium reduction and dehalogenation of PCBs and dioxins have been applied to the ex situ treatment of contaminated soils, but is still in the developmental stage for in situ soil decontamination.

Chemical treatment may produce residuals that will require disposal. The treated soil, if not sufficiently clean to be returned to its original location, may also require separate storage or disposal.

Science/Technology Needs: Soil characteristics such as moisture content, porosity, and particle size distribution are used to evaluate the ability to deliver reagents to the matrix. Waste characterization is used to determine the suitability of the material for in situ treatment and to select the appropriate oxidizing agents. Hydrogeological data is used to determine the ability to recover untreated or unreacted material and to determine the injection locations. Chemical interactions are assessed to determine the reagent dose and its

impact on the contaminants of concern plus on other chemicals present. In many instances, the intermediate products of chemical oxidation can be further oxidized if sufficient oxidizing reagent is applied.

Implementation Needs: The soil contaminants at Y-12 include radionuclides that are not effected by chemical treatments. An integrated approach could be proposed and studied that would accommodate the mixed waste problems that are likely to exist at Y-12. Large-scale tests and demonstrations should be part of the integrated approach.

Safety and pollution control must be considered in the selection of particular reagents because of the potential for violent reactions and the possibility of hazardous reaction products.

There are two in situ chemical treatment scenarios. One involves mixing the chemical reagents into the soil matrix. This scenario typically does not involve recovery of the treatment residuals. The second scenario involves allowing the chemical reagents to travel through the zone of contamination. This scenario typically requires recovery and treatment of residuals. Final disposal of the soil depends on the type and concentration of the residual reagent and contaminant remaining in the soil. Equipment and facilities will be needed to perform the ex situ chemical treatment and to store waste residuals.

The cost of this technology could vary depending on cost of the oxidants and required reagent delivery systems. The reagent delivery systems requirements vary depending on the depth to contamination and the hydrogeological characteristics of the contaminated site. Both potassium permanganate and hydrogen peroxide are commercially available and can be obtained without much difficulty. Although the application of in situ hydrogen peroxide oxidation only requires weak peroxide solutions, many vendors deliver higher strength solutions to be diluted prior to use. There may be handling, storage, and disposal problems with these higher strength peroxide solutions. Overall, the unit cost for soil treatment would likely be low (roughly \$100-\$200/ton). Development and demonstration costs are uncertain, but could range from \$3M-\$5M.

Author: Dianne D. Gates/615-576-0427

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EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, metals, organics, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelements: Treatment

Alternative: Physical separation

Technology: Physical sorting. Waste is sorted into categories determined by planned treatment. In some operations, containers of waste are emptied onto a revolving table. Workers in protective clothing and respirators sort waste articles into predetermined treatment categories. Worker radiation exposure is monitored. Secondary wastes include protective clothing and respirators, liquid from decontamination of personnel and equipment, and original waste containers.

Because considerable characterization information must be provided prior to waste transportation or acceptance at a commercial facility, physical sorting of retrieved buried waste would likely be constrained to on-site operations. Currently, no commercial sorting operations are permitted to handle mixed waste. Consequently, waste must be characterized well enough to certify that no hazardous wastes are included. Additionally, surface radiation levels must be less than 200 mr/h, and sharps (including broken glass) must be excluded for acceptance at commercial facilities. Waste must also be characterized to satisfy transportation requirements. If physical sorting is utilized, it would thus need to be conducted on-site within the area of contamination, and provisions for protection of workers from radiological, chemical, and physical hazards associated with the uncharacterized waste would need to be provided, or on-site characterization and removal of nonconforming waste would be necessary.

Status: Predemonstration. Although physical sorting is routinely performed by the private sector for characterized radioactive waste, it is not available in the private sector for uncharacterized waste such as retrieved Y-12 buried waste, and no facilities are currently permitted to sort mixed waste.

Commercial operations process between 6,000 and 10,000 ft³ of characterized waste per 8-h shift, and corresponding costs are estimated at \$0.35/lb. Processing rates and costs for uncharacterized, retrieved waste are expected to be less attractive, with costs reaching \$1/lb

to accommodate additional worker protection.

Science/Technology Needs: If off site sorting is deployed, waste must be characterized to meet the acceptance criteria of the receiving facility and Department of Transportation (DOT) requirements. If uncharacterized retrieved waste is sorted on-site, equipment and procedures must be selected and/or developed to afford protection of workers from radiological, chemical, biological, and physical hazards. Some remote operations may be necessary.

Implementation Needs: On-site sorting would require construction of a facility with high-efficiency particulate air (HEPA) filtration. Presorting characterization instrumentation and/or remote-handling capabilities would need to be provided to identify and/or segregate excessive hazards.

Author: Cindy Kendrick/615-574-6332

References: Scientific Ecology Group, Oak Ridge, Tenn., personal communication.

EM Problem: Remedial action

Y-12 Plant Problem: Buried waste

Problem Area/Constituents: Low-level waste, metals, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelements: Retrieval/treatment

Alternative: Excavation

Technology: Modular excavation. A modular in situ retrieval and treatment system for buried waste trenches. The system would consist of multiple modules designed to excavate, shred, and process the buried waste on site. The equipment would be constructed on a scale large enough to excavate and treat entire trenches. The operating mechanism would begin at one end of a waste trench and progressively excavate the trench, shred the waste, process it, and discharge an acceptable waste form into the former trench location. Different unit treatment modules could be designed to handle different types of wastes. This equipment could become a very effective delivery system for a variety of existing treatment options.

Status: Conceptual. No specific development work has been done thus far on this type of system. However, many of the components of the technology are similar to existing equipment. The development effort would focus on three major areas: (1) design and fabrication of an excavation/shredding module; (2) development of unit treatment operation modules; and (3) real-time monitoring of waste as it travels through the unit treatment processes.

Science/Technology Needs: The initial effort on this technology would be to perform studies to prove the concept, followed by design development and, finally, prototype construction. A significant development and fabrication effort will be required to produce a remediation/treatment system. The primary needs include the following:

- Mechanical design of the modules, especially the excavator/shredder.
- Definition of an acceptable post-treatment waste form. Regulatory requirements for disposal of the treated waste product.
- Development of the real-time monitoring equipment.

- Adaptation of the appropriate unit treatment operations to the mobile modules. Development of unit treatment modules to accept the wide variety of wastes present in the mixed waste trenches.

A limited study to evaluate the feasibility of this technology is planned for FY 94 at ORNL.

Implementation Needs: The implementation needs are primarily for a mechanical and process engineering development effort to design the equipment and unit treatment modules. This would be a very large design and construction project.

Author: Bill Barton/615-576-0519

References: Discussions with Y-12 Engineering staff.

EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediments

Problem Area/Constituents: Low-level waste, metals, organics, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelements: Retrieval

Alternative: Excavation

Technology: Entombed clamshell. Modified clamshell bucket used to dredge contaminated sediments. The unique feature of the clamshell is related to the articulated sealed joints and bucket cover assembly. When the jaws of the clamshell are closed, the contents inside the bucket are totally entombed within the steel structure of the clamshell.

Status: Demonstrated. A 4-yd clamshell bucket was fabricated and used by a chemical company to dredge approximately 20,000 yd³ of chlorinated hydrocarbons from the bottom sediments of their harbor docking facilities. The fabrication cost of the clamshell was \$90,000 (1990 dollars).

An entombed clamshell excavation was selected over other dredging techniques due to the clayey nature of the bottom sediments and requirements to minimize any release of contaminants into the water column of the harbor as the sediments are excavated.

The trial tests with the clamshell resulted in excavated spoil having a large portion of water being extracted with the contaminated soil. The low production rate was due to water (and air) being trapped under the hood of the cover assembly. The hood prevented water displacement as soil moved into the clamshell. Narrow slots were cut into the hood to allow water displacement as excavation proceeded. Production rate increases were realized. However, narrow slots in the hood of the clamshell were not consistent with the original intent of the entombed clamshell.

Science/Technology Needs: An entombed clamshell is an attractive alternative for dredging contaminated clayey soil, especially if localized areas of spoil require removal. Modifications to the existing technology must allow for controlled removal of water from under the hood of the clamshell as the jaws are closed. The control may be accomplished by constructing the hood with brass porous plates that are attached to pressure relief hoses on the outside of the clamshell hood. The hoses could be made part of the hoisting lines for the clamshell. As the

clamshell is lowered under the water, compressed air could be pumped down the hoses to prevent water infiltration into the hose. This will assure minimal leachate handling due to water inside the hoses. Once the clamshell jaws begin to bite into the soil and seal the face of the clamshell, the compressed air can be turned off and water in the top of the hood can be evacuated into the hoses. When the contaminated soil is dumped into muck barges, the water in the hoses will back flush the brass porous plates and assure free flow of water into the hoses when the next cycle of excavation is performed. If clayey soil becomes logged within the pores of the brass plates, then compressed air can be applied to the hoses to clear any blockage.

Implementation Needs: Fabrication of entombed clamshell with suggested modifications. Gross weight of clamshell is 13 tons. Estimated fabrication cost is approximately \$100,000, with a 10-week delivery date. Coordinate with Army Corp of Engineers for dredging schedule of Clinch River. Corp could utilize entombed clamshell in an uncontaminated reach of the Clinch River. Data gathering and evaluation could be performed by Martin Marietta Energy Systems, Inc. (MMES). Underwater photography should be considered for visual observation of clamshell performance during production. The estimated costs for implementation are:

Clamshell fabrication	\$100,000
Engineering support during fabrication	10,000
(2) Environmental scientists	30,000
(1) Geotechnical engineer	15,000
(1) Commercial diver with camera (2 weeks)	10,000
MMES management	50,000
U.S. Army Corp (negotiate)	
 Total (excluding USAE costs)	 \$215,000

Author: Joe Kauschinger/404-421-3400

References: Intergy, Inc., Fabrication Drawings of Entombed Clamshell, Brecksville, Ohio, 1990.

EM Problem: Remedial action

Y-12 Plant Problem: Buried wastes

Problem Area/Constituents: Bulk equipment and large items previously buried or stored in ways currently deemed to be unacceptable

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelements: Retrieval

Alternative: Excavation

Technology: Bulk item exhumation. The mechanical removal of bulk equipment and large objects. These objects at Y-12 may include; contaminated piping, glove boxes, drums, packaged waste, process columns, and pressurized gas cylinders. In situ site characterization by a remote characterization system is essential to minimize the risk involved in excavating such objects. The present status of site characterization systems is that they can vaguely detect that "something is somewhere," and whether it's metal or not. Object identification has not been achieved, nor has exact location. In exhuming bulk equipment and large objects, it is likely the best approach is to perform surgical, localized excavation, removing as little of the surroundings as possible. Typical excavation equipment includes clamshells, backhoes, front-end loaders, trenchers, forklifts, and overhead and treaded vehicle cranes. Tool attachments necessary to do selective digging, like a manipulator or barrel-grabber are also needed.

Depending upon site location, environmental conditions, and nature of hazards encountered, many other technologies may be needed either as a preparation or substitute for use of the above. Necessary removal technologies, whether in the alternative category of destruction, fixation, physical and chemical separation, or excavation, must be decided on a case-by-case basis. Many of these technologies are written for specific buried waste applications, but their use is not limited to these. For example, in situ vitrification (REMA-18-OZ) has been identified as a means of fixing radioactively contaminated soils and sediments. Also it may be more effective than freezing and mining (REMA-10-OZ) in recovering a ruptured drum and contents release during the initial exhumation attempt. However, some tanks must be emptied prior to excavation, an issue addressed by REMA-27-OZ, REMA-28-OZ, and REMA-29-OZ. Precision (REMA-9-OZ) or remote (REMA-38-OZ) excavation may be necessary in some cases. In the event of a crane or clamshell failure resulting in a contaminated piece of equipment contacting previously uncontaminated ground, a vacuum loader (REMA-101-OZ) might be the best choice.

Status: Accepted. This technology is currently in use.

Science/Technology Needs: Research and development of in situ site characterization techniques that will produce shape imaging of buried objects. Possible need for retrofitting commercially available excavation equipment with remote or automatic control systems. May want to develop attachments for handling tools not commercially available.

Implementation Needs: Site characterization and procurement of any available burial records and documents. Need access to larger scale excavation equipment than what is currently available at Y-12 to enable handling of large items. Overhead bridge system or crawlers may be needed for crane deployment. Drag lines and trenchers may be needed to improve deployment logistics in general. Need to be able to modify equipment, such as combining a backhoe with a front end loader or replacing a bucket on a backhoe with a barrel-grabber. The presence of high levels of contamination or certain hazardous substances may require containment protection during excavation, should a rupture or equipment failure occur.

Author: Linda J. Talarico/615-574-9736

References:

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2. William Key, ORNL Applied Technology Division, 615-576-0278, personal communication.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Chemical Separation

Technology: Sulfur-Impregnated Carbon (Hg). Adsorption/reaction of mercury on beads of activated carbon impregnated with sulfur. Contacting is typically done by passing the liquid through the columns. Limited to solution pHs above 3 or 4 to avoid hydrogen sulfide production. The in situ application of this technology for treatment of contaminated groundwater is theoretically possible.

Status: Accepted. The material is available as "Mersorb" from Nucon International and from the Calgon Corp. A few bench-scale tests were reported in the ORNL Chemistry Division Annual Report (ORNL-6152) of 1985. Distribution coefficients of 10^5 to 10^6 liters/kg were measured. Vendor literature gives a rule-of-thumb design throughput of 1 gpm/cu ft of sorbent. Maximum theoretical capacity of Mersorb is 75 wt. percent. The in situ treatment of contaminated groundwater by this technology is in the conceptual stage of development. For additional information, see REMA-67-OZ, In Situ Activated Carbon.

Science/Technology Needs: Engineering development tests are required with actual wastewaters to determine kinetic and equilibrium parameters for design and analysis work.

Implementation Needs: Characterization of Y-12 wastewaters need to be evaluated to determine where this technology can be implemented. Treatability tests using actual wastewaters are needed to determine pretreatment requirements and design parameters.

Author: J. Perona, 576-9280

References: Citation above and vendor's literature from Nucon International, Inc.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, and surface water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Chemical Separation

Technology: Activated Carbon (Hg). Liquid-phase adsorption technology encompasses those processes that use a solid material of high surface area or permeability to selectively adsorb organic and inorganic contaminants from aqueous streams. Liquid-phase adsorption works on the principle that the concentration of certain organics and inorganics will be higher on the surfaces of certain solids than in the bulk-liquid phase. The principal mechanisms involved in adsorption of organics are physical absorption and chemisorption. Physical adsorption occurs between the dissolved compound and the surface because of weak atomic and molecular forces such as Van der Waal forces. Chemisorption involves a chemical reaction between the compound and the surface of the solid. Most adsorbents also possess ion exchange sites which involve the exchange of ions. Granular activated carbon is, by far, the most commonly used adsorbent and system used in industrial waste treatment applications. It is invariably used in packed column systems. Contaminated water is passed through the column until the key contaminant is detected at some predetermined level in the effluent. Usually two or three columns are placed in series, so that the first column can be loaded to its maximum capacity while residual levels of the contaminant are removed in the subsequent columns. This technology may be applied for the in situ treatment of groundwater by passing contaminated groundwater through a permeable trench filled with activated carbon.

Status: Accepted. Activated carbon is often used for the treatment of mercury contaminated groundwater and surface water. Activated carbon adsorption can remove up to 90% of a variety of dissolved mercury compounds and species from ground water and surface water. These include mercury (II) chloride and methylmercury chloride, from water. These methods, which use either granular or powdered activated carbon, are primarily applied when the mercury concentrations are higher than 2 to 4 ug/L. Activated carbon may not be effective at removing mercury at concentrations lower than 2 ug/L.

Other physical sorption techniques that have been shown to remove greater than 90% of certain organic and inorganic mercury contaminants from water include treatment with

cellulose and cotton (for removal of mercury (II) chloride), chitosan (mercury (II) ion and mercury (III) chloride), iron sulfide adsorption and ground rubber (mercury (III) ion), and wool (mercury (II) chloride and methyl mercury chloride).

The in situ application of this technology is in the conceptual stage of development. For additional information on in situ activated carbon adsorption, see REMA-67-OZ, In Situ Activated Carbon Adsorption.

Science/Technology Needs: Flow rate is used to size the system. Column tests are used to design a full-scale system using information on adsorbent usage rates and competitive adsorption effects.

Implementation Needs: Some potential design parameters in a capacity of 15-100 gal/min and hydraulic loadings of 0.25 -2.5 gal/min/cf are needed. Linear flow rates may be 0.4 to 3 gal/min/sf cross-sectional area. Typical bed depths vary from 8 to 40 ft., with a height-to-diameter ration of 2:1. An enclosed area is used to protect the carbon columns and ancillary equipment. A regeneration facility or disposal means for the used carbon is needed. A means of conveying groundwater or surface water to the treatment facility is needed.

The suspended solids content should be reduced to less than 50 mg/L which may require pretreatment. Oil and grease concentrations above 10 mg/L are generally undesirable because of fouling characteristics. Calcium or magnesium concentrations above 500 mg/L can precipitate out and foul or plug granular-activated-carbon columns. Cost (capital plus operating cost) is \$1.20/1000 gal. Disposal costs could be significantly greater, \$5-\$10/1000 gal.

Author: Joseph Perona, 576-9280; C. M. Goddard, 241-4383

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1. *Control of Organic Substances in Water and Wastewaters*, EPA-600/8-83-022, SRI International, Menlo Park, CA, June 1983.
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4. W. J. Weber, *Physicochemical Processes for Water Quality Control*, John Wiley and Sons Publishing, New York, NY, 1972.
5. S. D. Faust and O. M. Aly, *Adsorption Processes for Water Treatment*, Butterworth Publishers, Boston MA, 1987.
6. *Treatment Technologies for Solvent Containing Wastes*, Noyes Data Corporation, Park Ridge, NJ, 1988.
7. *Critical Review of Mercury Contamination Issues Relevant to Manometers at Natural Gas Industry Sites*, Gas Research Institute, GRI-93/0117.
8. Lanning, Michael J., *Aqueous Mercury Treatment Technology Review for NPDES Outfall*

49, Y-12 Plant, MMES Y-12 Development, Y/DZ-1043, April 1993.

9. *Treatability Study Report for Mercury in East Fork Poplar Creek, Oak Ridge, Tennessee*, Radian Corporation, Doc. # D930129.1PS51, February 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Chemical Separation

Technology: Biosorbents: Adsorption on biomedica (Hg). A patented immobilized algal biomass sorbent material is available commercially from Biorecovery Systems, Inc. in bead form for packed column operations. Sorbent can be tailored for different contaminants according to the manufacturer. Biorecovery Systems, Inc., of Las Cruces, New Mexico, is developing a technology that uses algae to remove ionic mercury from water. This technology has been tested on both the laboratory and pilot scale. The technology consists of incorporating an algal biomass into a permeable polymeric matrix. The resulting material, AlgaSORB, is then packed into adsorption columns and functions as a "biological" sorbent. In the tests conducted, AlgaSORB frequently lowered the dissolved mercury concentrations in the groundwater samples (ranging from 144 to 1550 ug/L) to below 10 ug/L. However, use of a single AlgaSORB preparation yielded unpredictable results with samples collected at different times of the year. A strategy was then developed to sequentially extract the contaminants from the groundwater through two columns containing different preparations of AlgaSORB. This proved successful in both laboratory and field studies.

This technology may be applied for the in situ treatment of groundwater by passing groundwater through a permeable trench filled with biomass material.

Status: Predemonstration. Material is available from Biorecovery Systems, Inc. Under the auspices of the USEPA Site Program, uptake tests were done on groundwaters at the Oak Ridge Y-12 Plant, giving a relatively low equilibrium loading of 0.0001 mol/kg of sorbent. Given the contaminant concentration in the wastewater, waste volume can be calculated from the equilibrium loading. Other companies are investigating the use of biosorbents for mercury removal. The Westinghouse Savannah River Co. in Aiken, SC, is evaluating algal strains for toxic metal bioremoval applications and the Energy and Environment Division of Lawrence Berkeley Laboratory in Berkeley, CA have researched Biotransformation and Biosorption Strategies for recovery of heavy metals from wastewaters.

The in situ application of this technology is in the conceptual stage of development. For

additional information on in situ biosorbents, see REMA-74-OZ, In Situ Biomedial Adsorption.

Science/Technology Needs: Better characterization of the wastewaters is needed to determine mercury speciation and competing ions. Uptake experiments are required to provide data for pilot-scale tests.

Implementation Needs: Pilot scale testing is needed to determine pretreatment needs, design parameters, and demonstrate the effectiveness of this technology. Costs are unknown pending engineering development, but are expected to be comparable to conventional adsorption/ion exchange.

Author: Joseph Perona, 576-9280; C. M. Goddard, 241-4383

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4. *Remediation of Groundwater Containing Radionuclides and Heavy Metals Using Ion Exchange and the AlgaSORB™ Biosorbent System*, SAIC, Paramus, NJ, Biorecovery Systems, Las Cruces, NM, 1993.
5. *Binding and Removal of Metal Ions in Solution by an Algae Biomass*, American Environmental Laboratory, 10/91.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Chemical Separation

Technology: Precipitation (Hg). Precipitation is a chemical treatment process by which soluble contaminants are removed from water by converting them into insoluble compounds. Soluble contaminants may include metals, alkaline earth ions (hardness), or other inorganic anions. Several precipitating reagents may be used to precipitate mercury from ground water and surface water. These include insoluble starch xanthate, TMT-15, and Thio-Red. Sulfide precipitation is discussed in REMA-132-OZ.

Insoluble starch xanthate (Stout's Supply, Ainsworth, Iowa) exchanges sodium and magnesium ions for all heavy metals, i. e., it is not selective for mercury. The material is then removed from the water by sedimentation or filtration. ISX can be used over a pH range of 3 to 11. Disposal of the spent ISX must be determined, but it probably will require incineration.

TMT 15 (Degussa Corporation, Ridgefield, NJ) is a high molecular weight precipitant incorporating sulfur molecules in its structure. It reacts with dissolved heavy metals, i. e., it is not selective for mercury. Adjustment of pH is required if the water to be treated is outside the range of 6 to 9. Disposal of spent TMT 15 containing mercury might be a problem if it does not meet the RCRA toxic characteristic leaching procedure standards.

Thio-Red (Environmental Technology, Sanford, Florida) is a concentrated liquid organic precipitant for the recovery of metals from process waters, waste oils, and other polar solvents, including strongly chelated and complexed ions. Low metal discharge levels can be attained due to the unique chemical binding characteristics of the precipitant. The organo-metallic by-product is extremely stable and meets TCLP stabilization requirements. Thio-Red is not pH dependent, however, a pH of 8.5 is recommended for optimum utilization as a polishing chemical. M-25 polymer is recommended. Oxidizers in the waste stream, such as chlorine, peroxide, permanganate, etc., will decrease the effective strength of precipitating reagents. Oxidizers should be eliminated from the waste stream. Cyanide and Cr^{+6} will need to be removed and reduced respectively, if present in the waste stream before metals recovery.

Status: Demonstration. These agents are available commercially, but applications for mercury removal including satisfactory disposal of the spent agents must be demonstrated. Dosages depend on mercury concentrations in the waters to be treated. For a surrogate waste containing 100 mg/liter of Hg, an ISX dose of 0.64 grams was used. The recommended dose of TMT 15 for mercury is 4.8 gal./million gal. water/ppm of Hg. The recommended dose for Thio-Red is 4 mL/gallon. Thio-Red costs approximately \$300/55 gal.

A laboratory treatability study was conducted by Ralph R. Turner (ESD, June, 1993) using water from Y-12's Outfall 49 to determine the effectiveness of Thio-Red in precipitating out mercury. Kaolinite #5 clay mineral standard was obtained from Larmer Pit in Bath, SC., and used as a filter aid in this study. The initial mercury concentrations in the Outfall 49 water were 26, 27, and 28 ug/L. When Thio-Red was used, these concentrations were reduced to 1.1, 0.94, and 1.0 ug/L. When the filter aid (Kaolinite) was used in conjunction with the Thio-Red, the initial mercury concentrations were reduced to 0.27, 0.30, and 0.27 ug/L. No M-25 polymer was used in these experiments.

Science/Technology Needs: All the metal ions in candidate waters must be known to calculate dosages of these agents. Disposal of the spent agents must be worked out. Treatability tests are required to determine if satisfactory levels of residual mercury can be attained.

Implementation Needs: Characterization of Y-12 wastewaters is needed to determine feasibility. Treatability testing is also needed to determine design parameters and disposal options.

Author: Joseph Perona, 576-9280, C. M. Goddard, 241-4383

References: Vendor's literature

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Chemical Separation

Technology: Sulfide Precipitation (Hg). Precipitation is a chemical treatment process by which soluble contaminants are removed from water by converting them into insoluble compounds. Soluble contaminants may include metals, alkaline earth ions (hardness), or other inorganic anions. Sulfide precipitation uses sulfide ions as the precipitation agent. Base or acid is added to adjust the pH to the point where the constituents to be removed have the lowest solubility. This treatment results in a metal sludge and a treated effluent that has an elevated pH. Metal sulfide precipitation is used to remove Hg to lower effluent concentrations than can be achieved using hydroxide precipitation. The extremely low solubility of mercuric sulfide in neutral to acidic solutions is the basis for this technology as the BDAT for K071 wastewaters. Mercuric sulfide is soluble in strongly alkaline sulfide solutions. Sodium or ferrous sulfide is added as a precipitating agent. After precipitation, excess sulfide ions must be removed by oxidation. Effluent metal concentrations of less than 1 mg/L (and sometimes lower) are achievable. Mercuric sulfide tends to be colloidal when first precipitated, and very difficult to filter or flocculate, although ultrafiltration has been demonstrated for this application. Other precipitating reagents are discussed in REMA-131-OZ.

Contaminated wastewater is fed continuously or batch-wise into a rapid mix tank. Treatment chemicals may include acids or bases for pH adjustment and other coagulants such as alum or ferric chloride and polymers. As an option, polymers can be fed in-line downstream of the rapid mix tank. Polymers may be organic polymers which promote flocculation through hydrogen bonding and electrostatic forces or synthetic polyelectrolytes with anionic or cationic functional groups which promote agglomeration.

Status: Accepted. This is the BDAT for K071 wastewaters. Accepted for heavy metals. Treatment units are commercially available. Specific wastewater streams would need to be tested to determine the treatment levels that could be achieved. Sludge generated from precipitation requires dewatering and disposal.

Science/Technology Needs: The flow rate needs to be estimated to properly size unit

processes. Characterization of the waste stream allows the technology to be selected and the effectiveness to be estimated. Characterization parameters include metals, other cations, anions, and complexing and chelating agents. Total suspended solids and total dissolved solids are used to predict the solids generation rate and to properly size the sedimentation process. The alkalinity and acidity of the stream are used to predict the chemical requirements for pH adjustments. Better characterization of DOE mercury-containing wastes is needed to determine if sulfide precipitation will separate mercury from other constituents of the waste.

Implementation Needs: The addition of coagulants such as aluminum or iron salts and polymers sometimes are used to help form precipitates. Precipitation also can result in lower effluent concentrations through coprecipitation. Often, iron is added to enhance the coprecipitation effects.

Sludge recovered from precipitation requires dewatering and disposal. Treated effluent from metal sulfide precipitation may require sulfide removal before discharge. Estimate of waste volume is needed.

Author: J. Perona, 576-9280, P. A. Taylor 574-1965

References:

1. Rosengrant, L. and J. Labiosa, "Final BDAT Background Document for Mercury-Containing Wastes," EPA/530-SW-90-059Q (May 1990) PB90-234170.
2. Taylor, P. A., and Robinson, S., *Oak Ridge National Laboratory Nonradiological Wastewater Treatment Plant Optimization Report*, ORNL/TM-11877, Oak Ridge National Laboratory, Oak Ridge, TN, June, 1991.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Chemical Separation

Technology: Ion Exchange (Hg). Ion exchange is an ex situ volume and toxicity reduction technology to remove ionic species, principally inorganics, from aqueous waste streams. Ion exchange is based on the use of specifically formulated resins and natural inorganic materials having an "exchangeable" ion bound to the resin with a weak ionic bond. If the electrochemical potential of the ion to be recovered (contaminant) is greater than that of the exchangeable ion, the exchange goes into solution and the ionic contaminant binds to the resin.

Typically, four operations are carried out in a complete ion exchange cycle: service, backwash, regeneration, and rinse. In the service step, the ion exchange resin is contacted with solution containing the ion to remove. After a critical relative concentration of contaminant ion to exchange ion in solution is reached, the resin is said to be spent. A backwash step is then operated to expand the resin and to remove fines that may be clogging the bed. The spent resin is regenerated by exposing it to a very concentrated solution of the original exchange ion, so that a reverse exchange process occurs. The rinse step removes excess regeneration solution before the next service step.

Resin containing the iminodiacetic acid group will pick up cationic mercury selectively from calcium and magnesium, but copper and cobalt are also picked up. Mercury in the form of anionic complexes, e.g. HgCl_3^- or HgCl_4^- can be picked up by anion exchange resins, but not selectively. Savannah River Plant uses a thiol resin (Duolite GT-73, Rohm & Haas) which is very selective for mercury in any of its three oxidation states.

Chelating resins. Processes using these resins would be similar to conventional ion exchange operations, except chelating resins cannot be regenerated or are regenerated with some difficulty. A resin containing an isothiuronium was studied in 1971 for removal of both Hg^{2+} and CH_3Hg . The selectivity in the presence of dissolved iron, nickel, copper and zinc at concentrations up to 10 mg/L was complete. A second account of chelate resin application was found in a US patent assigned to a Japanese company.

Status: Accepted. The technology is fully developed, although applications have been very waste-stream-specific. Literature reviews indicate that extractions of mercury (II) chloride and other compounds of greater than 90%, down to 5 mg/L. Applications have included the removal of radionuclides from power plant waste streams, recovery and removal of metals, and deionization/softening of process water. Promising applications include removal of cyanides from mixed waste streams and selective removal of heavy metals without complete deionization. Assume 3000 to 5000 bed volumes of wastewater processed before bed replacement or regeneration.

Science/Technology Needs: Laboratory-scale performance tests provide data for resin selection, estimates of resin loading and regeneration requirements, and other needed parameters for column design. Wastewater characteristics, such as the presence of competing ions or chelating agents, are used in the design of an ion exchange system. The solubility of the metals, and hence, the effectiveness of the system is affected by the acidity/alkalinity of the wastewater. The presence of suspended solids may indicate the need for pretreatment.

Implementation Needs: Resins exhibit different selectivities for specific contaminants. In a mixed contaminant stream, one metal may be effectively removed from solution while another will not. Ion exchange may be difficult without pretreatment to remove organics, to destroy chelating agents, or to destroy the chelant metal bond. Pretreatment may also be needed to remove solids (to prevent blinding of the column), to modify the pH of the influent stream for optimum removal efficiencies, or to remove competing ions.

The process yields a large volume of purified solution, regenerated zeolite, and a concentrated solution of removed ions which can then be further processed for recovery or disposal. The system uses columns containing the resin and various pumps and piping to carry the waste streams and potentially new and spent resin. Cost (capital plus operating) is estimated to be \$10-\$20/1000 gal.

Author: Joseph Perona, 576-9280

References:

1. *Remedial Investigation Plan for Waste Area Grouping 2 at ORNL*, ES/ER-14&D1, Oak Ridge National Laboratory, Oak Ridge, TN 1990
2. Calmon, C. (ed.), *Ion Exchange for Pollution Control*, CRC Press, Boca Raton, FL, 1979
3. *Critical Review of Mercury Contamination Issues Relevant to Manometers at Natural Gas Industry Sites*, K. R. Henke, et al., Environmental Safety Research Department, Gas Research Institute, August, 1993
4. Bibler, J., R. Wallace, and M. Ebra, "Mercury Removal from SRP Radioactive Waste Streams Using Ion Exchange," *Waste Management, High Level Waste, Volume II*, 1986, page 471.
5. McGarvey, F. X., "Mercury Removal with IONAC Ion Exchange Resins," R. J. Turner and J. Labiosa, eds., *Arsenic and Mercury: Workshop on Removal, Recovery, Treatment and Disposal*, EPA/600/R-92/105, August, 1992.

6. US Patent No. 3,790,535, Feb. 5, 1974. Assigned to Tokuyama Soda KK, Japan.
7. Lanning, Michael J. *Aqueous Mercury Treatment Technology Review for NPDES Outfall 49, Y-12 Plant*, MMES, Y-12 Development, Y/DZ-1043, April 1993.
8. *Treatability Report for Mercury in East Fork Poplar Creek, Oak Ridge, Tennessee*, Radian Corporation, Doc # D930129.1PS51, Feb. 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Chemical Separation

Technology: Artificial Wetlands (Hg). Ex situ bioaccumulation technologies include use of constructed or natural wetlands. Wetlands have been used for disposing and treating contaminated wastewater since the 1950s in a wide variety of applications: municipal wastewater, industrial wastewater, storm water runoff, mine discharge and surface mine runoff, agricultural nonpoint source runoff, and groundwater. Documented treatment effectiveness varies relative to the parameter in question (e.g., loading rates, detention times, flow-path length, and age of the system). Constructed systems are generally more effective than natural systems because the hydraulics and detention times can be controlled and optimized. Natural wetlands may also become degraded as a result of contaminant additions and high loadings. Documented wetland treatment efficiencies range from 30% to 95% on an annual, mass-removal basis

Artificial wetlands provide treatment through physical, chemical, and biological processes. Plant uptake consists of planting a plant species which concentrates the contaminant in a harvestable portion of the plant. The plant tissue is then removed seasonally and disposed. This is a fairly slow process, depending on the plant species used, the biomass produced, timing of the harvest, and the contaminant. In biodegradation, microorganisms use the contaminants (usually organic compounds and some inorganic compounds such as ammonia) as part of their metabolism.

Specifically, rooted water plants, such as the bulrush, and floating plants, such as the water hyacinth, are known to uptake unspecified forms of mercury from waters in natural and artificial wetlands. The other physical, chemical, and biological processes, such as sorption, chemical precipitation, ion exchange, oxidation/reduction, pH changes, and bacterial and fungal conversion, that are active in most wetlands can assist in immobilizing mercury contaminants. Mercury methylation may occur in this environment and create serious environmental problems if the situation is not carefully planned and monitored. Methods to control mercury methylation are still undetermined.

Status: Predemonstration for mercury. Mercury-bearing plants may require harvesting, treatment and disposal.

Science/Technology Needs: The forms of potentially toxic contaminants and degradation products needs to be determined. Flow volumes and average contaminant concentrations in water and soil are used to assess potential loading rates. Climate conditions, such as the length of the growing season, the average winter temperature, the length of period when pipes and ponds may freeze in winter, the summer evapotranspiration rate, and precipitation, are used to assess the effectiveness of the technology and to determine design parameters. Local surface and groundwater hydrology, such as topographic setting, water budget, depth to average and high groundwater table, groundwater chemistry, and distance to natural water bodies, also include important variables. Soil conditions and organisms in the soil will determine the success of the technology or what type of additives are needed.

Implementation Needs: The soil may need amendments to support vegetation. Microbial stimulation is accomplished by providing a conducive environment for growth. Properties that can be altered physically or chemically include moisture, oxygen content, carbon, nutrients, hormones, enzymes, pH, availability of substrate compounds, solubility, competing organisms, concentration of organisms, and concentration of contaminants. Year-round vegetation cover needs to be maintained for maximum treatment and to avoid water and wind erosion and resultant contaminant mobilization. Artificial wetlands typically require a surface area of 4 to 12 ha/1000 m³ wastewater/day. Construction costs were about \$100,000/ha in 1990, but operating costs were low.

It may be highly unlikely that an environmental regulatory authority would permit a constructed wetland for mercury treatment. The uncertainties are enormous and eventually the wetland itself would need to be remediated due to the accumulation of mercury in the plants and sediments.

Author: P. A. Taylor, 574-1965; C. M. Goddard, 241-4383

References:

1. D. A. Hammer, *Constructed Wetlands for Wastewater Treatment*, Lewis Publishers, Ann Arbor, MI, 1989
2. *Critical Review of Mercury Contamination: Issues Relevant to Manometers at Natural Gas Industry Sites*, GRI-93/0117, Natural Gas Institute, August, 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Chemical Separation

Technology: Reverse Osmosis (Hg). Reverse Osmosis (RO) will remove dissolved mercury from groundwater and surface water. Reverse osmosis involves the selective transport of water through the membrane under sufficiently high pressure to overcome the natural osmotic pressure of the solution. Water passes from the side of the higher contaminant concentration to the side of lower concentration, leaving behind a highly contaminated brine stream. Reverse osmosis membranes typically pass uncharged materials with molecular weights less than 200. Reverse osmosis can be used to treat waste streams with TDS (Total Dissolved Solids) concentrations up to 50,000 ppm. The technology is well developed and commercially available.

Status: Accepted. An appropriate treatment technology for removal of some inorganics, including mercury, chromium and copper¹. To avoid membrane fouling, feed precipitation and filtration pretreatment is generally required (ultrafiltration is an option for pretreatment).² The possibility of metals precipitation in the concentrate should be considered: one authority says RO is not for precipitable metals.³ RO produces a concentrated liquid stream, not a solid suitable for disposal. The RO process is non-specific and will remove dissolved solids in the liquid stream. The waste volume will depend upon the technique used to remove the metals from the concentrate. Both commercial membranes and commercial RO systems are available. Costs are likely to be relatively high, perhaps several dollars per 1000 gal. The costs required for further treatment of the concentrate will need to be added to the costs attributed to the RO.

Science/Technology Needs: Treatability studies are needed for any specific wastewater/groundwater to determine the degree of metal removal, the allowable degree of concentration, and any causes of membrane degradation. A suitable method for handling the concentrated stream of rejected electrolyte will be needed. The materials could be incorporated into a waste form and/or recycled for other uses.

Implementation Needs: Characterization of Y-12 contaminated waters is needed.

Treatability tests are needed to determine design parameters and estimate treatment costs. RO is usually effective for removal of most metals, but it still leaves a liquid concentrate that must be handled. Waste treatment and disposal is an important question and could add significantly to the overall costs. The volume of waste produced will be determined by the way this concentrated stream is treated. Generally, RO is not selective, so all electrolytes from the original groundwater will be in the concentrate. Thus the volume of waste is determined by the electrolyte in the groundwater, not by the amount of contaminant in the groundwater. The cost of RO can be moderate to high because of the high pressure and capital cost of the membrane system. The lifetime of the membrane with the particular groundwater in question can be an important factor in determining the cost. Waste volume and waste handling costs will depend upon the treatment process used on the concentrate.

Author: D. E. Beck; C. M. Goddard, 214-4383

References:

1. B. R. Wiley, "Finding Treatment Options for Inorganics." *Water/Engineering & Management*, October 1987, pp 28-31.
2. A. V. Metzner, "Removing Soluble Metals from Wastewater," *Water and Sewage Works*, April 1977, pp 98-101.
3. Alley, Young, and Baumgartner Consulting Engineers, Nashville, Tennessee, communication in a class on wastewater treatment, GWU, Washington, DC, July 25-27, 1990.
4. Remedial Action Assessment System, Version 2.1, prepared for DOE by Battelle Memorial Institute, Pacific Northwest Laboratory, 1993.
5. Lanning, Michael J., *Aqueous Mercury Treatment Technology Review for NPDES Outfall 49, Y-12 Plant*, MMES, Y-12 Development, Y/DZ-1043, April 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Chemical Separation

Technology: Borohydride reduction and filtration (Hg). Twelve percent sodium borohydride in 40% sodium hydroxide is fed with the wastewater into a static mixer. The solution pH is held to between 9 and 11 because the process is not critically pH dependent. Direct reduction of Group VIII and IB metals (ruthenium and above) with borohydride occurs across this pH range. Preoxidation step with hypochlorite may be required to break mercury complexes. Reduction of the mercury compounds yields metallic mercury and hydrogen gas. The metallic mercury can be removed by filtration, adsorption, and or air purging. Mercury that is not removed in the sludge may be recovered from the effluent by vacuum distillation. If ruthenium is present, some of it will accompany the mercury. REMA-164-OZ provides further information on chemical reduction processes for the removal of mercury.

Status: Demonstration. Currently used commercially to recover silver from spent photographic film and gold from jewelry scrap. Morton International sells a sodium borohydride solution under the VenMet trademark and is working with the Chlorine Institute to develop a process for mercury recovery from K106 wastewaters. The intent is to replace the current BDAT with borohydride reduction. The chlorine/caustic soda industry is the second-largest uses (after batteries) of mercury. The mercury and other metals filtered out of solution must be disposed.

A New Jersey mercury chemicals manufacturing facility reported treating 15,000 gpd of a 100 mg/l soluble mercury wastewater stream. After polishing with activated carbon, followed by treatment with a chelating resin, the effluents contained less than 5 ug/l mercury.

Science/Technology Needs: Better characterization of DOE wastes to determine mercury speciation and competing ions. Mercury metal may be produced in colloidal form, and engineering development may be required to identify optimal means of recovery. The option of air stripping to remove reduced mercury needs to be explored.

Implementation Needs: Characterization and treatability testing is needed to determine

pretreatment requirements and design parameters. A demonstration of this technology is also required.

Author: Joseph Perona, 576-9280, C. M. Goddard, 241-4383

References:

1. Robert S. Stennick et. al, *Proc. 1991 Ind. Waste Conf. (46th)*, pp 325-327
2. J. Michael Lanning, Aqueous Hg Treatment Technology Review for NPDES Outfall 49, Y-12 Plant, Y-12 Development, April 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Chemical Separation

Technology: Cementation (Hg). This technology is used for the recovery of mercury for mercury/metal amalgams. More active metals, e.g. aluminum, copper, iron, and zinc, will reduce mercury to metallic form as they are dissolved. In the Innochem process, ground steel scrap is used in a rotary contactor.

Status: Accepted. This technology has been used in the mining industry for many years.

Science/Technology Needs: Mercury reduced and removed from solution is replaced by the more active metal. Potential applications of this technology must be compatible with increased concentrations of active metal ions. Tests are required to determine the efficacy of the process for this application.

Implementation Needs: Characterization of Y-12 wastewaters is needed. Treatability tests are needed to confirm the applicability of the process, determine design parameters, and estimate treatment costs.

Author: Joseph Perona, 576-9280

References:

1. Perry, R., "Mercury Recovery from Contaminated Wastewater and Sludges," USEPA 660/2-74-086 (December 1974)

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Chemical Separation

Technology: Empore Process (Hg). This is a 3M proprietary process under the Empore trademark, consisting of Crown ethers attached to silica particles embedded in a coherent fibrous matrix membrane. Crown ethers can remove Hg^{++} and methyl mercury according to 3M. Use of 5 to 10 micron particles gives extremely high surface area in a controlled porosity membrane. Membrane matrix is PTFE (teflon). The Empore membrane has the potential to accomplish better separations than packed columns in a much more compact apparatus. As with all membrane processes, feed solution must be clean. Very compact, high throughput, highly specific separation technology.

Status: Predemonstration. Development is at the bench-scale level for mercury separation applications. Battelle PNL and IBC Advanced Technologies, Inc., are working with 3M to develop an Empore membrane for strontium and cesium removal. EPA has allowed five test methods involving Empore extraction disks with seven more pending (all for organic compounds).

Science/Technology Needs: Mercury separation applications just recently targeted by 3M, therefore, there are significant science and technology development needs. Development might be accelerated through a DOE Cooperative Research and Development Agreement (CRADA).

Implementation Needs: Characterization and treatability testing on Y-12 wastewaters is needed to confirm applicability, pretreatment needs, design criteria, and estimated treatment costs.

Author: J. Perona, (615) 576-9280

References: Vendor's literature

EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediments

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: Immobilization/Fixation (Hg). Immobilization involves the mixing of contaminated soils and sediments with binders to promote chemical reactions, decreasing the permeability, porosity, and solubility of the wastes so the contaminants are less mobile. Typical binders include cement, coal combustion fly ash, clay or organic materials. In some cases, the wastes are chemically treated before they are mixed with the binders to reduce mobility of the contaminants. This technology may be used for both in situ and ex situ applications.

Immobilization technologies may not be effective in treating geologic materials with high concentrations of elemental mercury and mercury compounds. However, they are used to treat D009 soils and sediments containing less than 260 mg/kg of mercury contaminants. The treatment of mercury-contaminated soils and sediments with immobilization techniques can be done on site. Frequently the techniques involve pretreating the materials with a chemical additive such as sulfide compounds, and then adding a cement binder. Chemical pretreatment with sulfide compounds, for example, would produce low-soluble mercury (II) sulfides that, when mixed with cement, would result in a product very resistant to leaching and contaminant leakage.

Status: Accepted. Commercial immobilization technology is available from a large number of firms, including Funderburk and Associates of Fairfield, TX. Several other companies, such as Itex Enterprises of Addison, TX, and MaECORP, Inc. of Chicago, IL, are also developing immobilization technologies for this application. Long-term leachability of solidified mass may be uncertain. Process generates a potentially voluminous product that requires disposal.

Science/Technology Needs: Effectiveness depends on the contaminant speciation and the reaction products formed. Sufficient mixing also conditions effectiveness. Ex situ application is easier to monitor than in situ.

Implementation Needs: Characterization of Y-12 contaminated soils and sediments is

needed to determine effectiveness (potential for interferences), binder mixtures, and mixing requirements. Soil mixing/grout injection techniques need to be demonstrated. Funderburk and Associates reports costs of \$50/ton for their treatment process.

Author: C. M. Goddard, 241-4383

References:

1. *Critical Review of Mercury Contamination Issues Relevant to Manometers at Natural Gas Industry Sites*, GRI-93/0117, Gas Research Institute, August, 1993.
2. *A Review of Remediation Technologies Applicable to Mercury Contamination at Natural Gas Industry Sites*, GRI-93/0099, Gas Research Institute, September, 1993.
3. *Treatability Study Report for Mercury in East Fork Poplar Creek, Oak Ridge, Tennessee*, Radian Corporation, Doc # D930129.1PS51, February 1993.
4. McWhinney, et al., *Cement and Concrete Research*, V. 20, pp 79-91, 1990.

EM Problem: Remedial action

Site Problem: Contaminants in water

Problem Area/Constituents: Heavy metals, low-level radionuclides, uranium, transuranics in surface water, groundwater, and wastewater.

Reference Requirements: Refer to EPA Drinking Water Standard, Section 275 AEC, Section 206 UMTRA, Section 121 CERCLA, 10 CFR 20, 50, 51, 40 CFR 190, 40 CFR 260, Low-Level Radioactive Waste Policy Act, The Public Health and Welfare Act, and state and local regulations.

Subelement: Treatment

Alternative: Chemical treatment and polishing

Technology: Colloid Polishing Filter (CPF). See Figure 1. Heavy metals and nontritium radionuclides are removed from contaminated water by either: 1) pumping the water through a prefilter, such as a bag filter, and then directly through the CPF beds or 2) using primary flocculation and suspended solids removal, via either a clarifier or sand filter, and then pumping through the CPF beds. The bed material has a high affinity for inorganic metals, especially higher valence forms, chelated forms, and complexed forms, including radionuclides. Inorganic, metallic pollutants are removed through sorption, chemical binding, and microprecipitation reactions *that occur in repetitive, sorption beds* that are engineered for *fluidics* control and reduction of microchanneling. The CPF consists of a series of vertical sorption beds within polypropylene "filter packs" that are suspended with support plates and o-ring sealed, under pressure. Heavy metals and radionuclide pollutants extracted by the sorption beds can be removed and concentrated by using dilute acid backwashing and rinsing or the bed material can be dewatered and stabilized to meet the EPA TCLP land disposal restrictions for low-level radioactive waste.

Figure 1. Schematic Diagram of the Colloid Polishing Filter Method (Ref. 7).

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September 1994
Remedial Action

Status: Accepted. Commercially available. More than 90 bench tests and 6 pilot tests have been carried out. An EPA SITE demonstration has been performed on groundwater contaminated with heavy metals from breached solar waste ponds at the Rocky Flats Plant in Golden, Colorado. The CPF has also been used in the remediation of uranium contaminated wastewater at the Hanford Site in Richland, Washington, to treat low-level radioactive wastewater at Oak Ridge National Laboratory in Oak Ridge, Tennessee, and for groundwater and wastewater remediation at more than a dozen other sites throughout the United States. Some studies have been performed on CPF's ability to remove radionuclides from Rocky Flats feed water that was spiked with uranium, radium-226, plutonium-239, americium-241, cesium-137, cobalt-60, and strontium-90.¹ (The water was taken from a storage tank on site. It had heavy algae content and pH of approximately 8.0)

Efficacy: The concentrations of the following heavy metal contaminants from Rocky Flats groundwater were analyzed before and after CPF treatment:

boron	iron	selenium +4	tellurium
cadmium	lead	selenium +6	thallium
chromium +3	mercury	silicon	vanadium
cobalt	molybdenum	silver	zinc
copper	nickel	strontium	

The removal efficiency for 18 heavy metals was 99.4–99.9%; mercury was removed below detectable limits. Removal efficiencies ranging from 85–99% were achieved for the Rocky Flats feed water that was spiked with radionuclides.

Design capacities for the process equipment range from 1 to 100 gal/min. High ammonium, suspended solids, grease, and elevated hydrocarbons can interfere with the CPF, and, therefore, need to be considered in the primary stages of the overall treatment process. The CPF can be used to remediate inorganic, metallic water pollutants at flow rates of 1 gpm to more than 100 gpm but requires an average bed residence time of 2.5–3 minutes. The equipment necessary for this process is mobile and can be trailer- or skid-mounted; in-line systems can also be fabricated.

Waste: The CPF process generates a secondary solids waste stream consisting of dewatered solids, in the form of filter cake, representing "spent" bed material². Waste varies in composition and, therefore, classification, depending on the constituents of the particular waste stream processed. The bed capacity and life typically exceed those for conventional ion exchange resins used in radionuclide removal; thus, the quantity of spent bed material generated in a year also is comparatively lower, resulting in less waste generation. For example, at continuous 24 hr/day treatment for an influent groundwater stream having 50 mg/L total dissolved solids (inorganic metallics) and <30 mg/L total suspended solids, only 200–250 lbs of waste would be generated annually.

Science/Technology Needs: For the Rocky Flats Site, CPF accounted for gross beta contamination removal of only 54%¹ [i.e., 54% of the total beta decay contribution to the

radioactivity of the volume of contaminated water, from those contaminants that are beta emitters (specific, problematic contaminants were not specified), was removed.] CPF is a volume reduction process that produces a stabilized waste form (dewatered filter cake that is waste-stream specific) as an end product. This waste form is then sent to a disposal site.

Increased gross beta removal is desired. Research must continue in this area. Also, land disposal as a permanent solution, for even a "stabilized" waste form, is less preferable than destruction of that form. Research into possible means of destruction of the filter cake without environmental insult is advisable.

Implementation Needs: Primary wastewater treatment equipment, such as a mixing tank, clarifier, filter press, and prefilter (i.e., a bag filter for removal of solids not removed by the clarifier) and system controls are needed. CPF also uses an inorganic, insoluble filter bed material and an effluent pH adjustment tank.

A turnkey, semiautomatic, 25-gpm, vertical CPF has a capital cost of \$70,000. Three-inch lead shielding for systems designed to treat gamma-emitting radionuclides costs an additional \$10,000. Operating cost per 1,000 gal of water treated ranges from \$0.50, for most heavy metals, to approximately \$1.50 for uranium, transuranics, and other low-level nuclear reactor wastes.

Technology Integration: RCRA organics must be destroyed or removed before mixed waste water treatment. Also, oil-water separation and/or trace hydrocarbon removal must be achieved before the removal of naturally occurring radioactive materials (NORM) in water.

Authors: T.S. Tomascik, R. L. Fellows/615-576-5632,

References:

1. Demonstration Bulletin: Colloid Polishing Filter Method, USEPA, Washington, D.C., EPA540/MR-94/XXX.
2. T. S. Johnson, 122 Texas Avenue, League City Texas 77573, (713) 554-5405.
3. Johnson, T.S., "Colloid Polishing Filter Removal of Heavy Metals, Uranium and Transuranic Water Pollutants," 87th Annual Meeting Air and Waste Management Association, Cincinnati, Ohio, June 19-24, 1994.
4. Johnson, T.S., "Colloid Polishing Filter Removal of Heavy Metals, Uranium and Transuranic Pollutants from Groundwater at the DOE Rocky Flats Plant," Fifth Forum on Innovative Hazardous Waste Treatment Technologies: Domestic and International, Chicago, Illinois, May 3-5 1994.
5. Johnson, T.S., et al, "NORM in produced Water Offshore," Produced Water Seminar, League City, Texas, January 1993.
6. Johnson, T.S., et al, "Removal of Trace Heavy Metals, Uranium, and Transuranic Pollutants From Water Using the Colloid Sorption Method," International Symposium on Environmental Contamination in Central and Eastern Europe, Budapest, 1992.

7. Laul, J.C., et al, "Removal of Uranium, Plutonium and Americium From Rocky Flats Waste Water," International Topical Meeting, Nuclear and Hazardous Waste Management, SPECTRUM '92, August 23-27, 1992, Boise, Idaho.
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EM Problem: Remedial action and waste management

Site Problem: Radioactive particles in soil.

Problem Area/Target Constituents: Radiologically contaminated soils.

Reference Requirements: EPA520/4-77-016, "Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment,"³ EPA land disposal requirements, and state and local laws. Cleanup criteria for the "end state" is based on the following EPA activity limits: 1) *distributed contamination* (i.e., finely divided material dispersed nonuniformly throughout the soil), <500 Bq/kg; 2) *"hot" particle contamination* (i.e., discrete, individual particles of radioactive material), <5000 Bq.

Subelements: Processing, Minimization, Decontamination

Alternative: Physical separation

Technology: Segmented Gate Sorting System (SGSS). See Figure 1. SGSS is a separation technology that physically removes radiologically contaminated particles, such as ^{239}Pu and ^{241}Am , from a soil matrix. Conventional material-handling equipment (i.e., shaker screens and motor-driven conveyor belts) is used in tandem with SGSS equipment, which consists of an array of 15 sodium iodide FIDLER-type detectors, PC-based microprocessors and software, 8 diversion chutes, and a master control board⁴.

Contaminated soil is excavated with standard heavy equipment and bulk metals are removed by a large magnet mounted over the feed conveyor belt. A shaker screen is then used to size the feed material to less than 0.5 in. The sized material is then layered across the width of the conveyor belt to a depth of 0.75 in. and a length of approximately 31 in.⁴. The belt conveys the material under an array of NaI detectors at a rate of 30 ft/min. The detectors are arranged in two overlapping rows of 7 and 8 detectors, respectively. The second row of 7 detectors is offset from the first row to prevent "hot" particles from passing undetected between adjacent

Figure 1. Segmented Gate Sorting System.³
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Nuclear Assay Systems.

detectors. Each detector has an active measuring area of 10,000 mm² and is linked to a separate microprocessor that determines whether a "hot" particle is detected. The data is sent to a master control board that activates one or more of the diversion chutes located at the end of the conveyor. The chutes remove as little as one pint of material per "grab" at a continuous feed rate of 30 ft/min³. Hot particles are diverted to a soil washing system that removes fine particles, diverting them to holding ponds where they await further treatment. The remaining "clean" material is manually reassayed with standard radiation detection equipment (GM-counters, etc.) to verify that it meets EPA-prescribed release criteria.

Status: Demonstration. SGSS has been in use on Johnston Atoll since January 1, 1992. The technology is owned by TMA/Eberline, Thermo Analytical, Inc., which has operated the Johnston Atoll Plutonium Cleanup Project since its inception in 1991 for the Defense Nuclear Agency under contract DNA001-93-C-0148³. The primary contaminants of concern on Johnston Atoll are ²³⁹Pu and ²⁴¹Am, introduced to the atoll during high-altitude atmospheric nuclear testing and a ground level nuclear device detonation, from the late 1950s to the early 1960s. The atoll's radiological control area encloses 27 acres and contains approximately 100,000 cubic yards of contaminated coral soil.

Efficacy: On-site soil processing is ongoing at a rate of more than 2,100 metric tons per week. Two segmented gate systems have been operating in parallel to speed the cleanup for the past year. SGSS has accounted for a contaminated soil volume reduction of more than 98% for the 55,000 metric tons of soil processed at Johnston Atoll since January 1992. Three million kilobecquerels of plutonium and americium contamination have been separated from the coral soil³. Manual sampling, carried out continuously on an hourly basis for quality control purposes, has shown no radioactivity above the release criteria in the "clean" soil.¹ SGSS can be adapted to remediate other forms of radioactive contamination in soil because it is detector-based and does not discriminate based on specific radionuclides; it responds only to the presence of radioactivity. SGSS can also be coupled as a pretreatment with secondary downstream radiological decontamination methods, such as EPA's portable soil washing system, to effect further volume reduction. In this way, only the contaminated feed material need be sent to a further decontamination process.

Waste: SGSS is a separation technology that reduces the volume of disposed waste by 98% or greater. Hot waste extracted by the process is stored in steel drums and must be disposed of according to EPA land disposal requirements. Fine contamination that is diverted to holding ponds must also be treated via colloid polishing, ion exchange, ultrafiltration, reverse osmosis, or another process before release. The volume of waste generated is variable, depending on the amount of contamination that needs to be treated. Usually, waste volume is approximately 2% of the total volume of pretreated, contaminated soil.

Science/Technology Needs: Hot waste separated from the soil by SGSS and stored in drums is placed in radioactive disposal sites for indefinite storage, contributing to the growing national stockpile of hazardous radioactive waste. Research into alternative disposal and destruction technologies, such as rock melt disposal and high temperature plasma incineration, must continue.

Implementation Needs: SGSS is automated and requires minimal supervision. Material handling equipment such as conveyor belts and shaker screens (for bulk material separation) is required. The system itself consists of 15 NaI detectors, PC-based microprocessors and software, 8 diversion chutes, and a master control board. At this time, no "up front" costs are established for SGSS.

Nels Johnson estimated a total cost figure for one unit of \$60 to \$70/yd³, and said that TMA is considering the establishment of a total processing cost based on a flat percentage of the total cost savings, in terms of disposal fees, experienced by the contractor through the use of the SGSS². Costs for excavation, and pretreatment, if necessary, are additional and are highly variable depending on the individual site in question.

Technology Integration: A secondary soil washing system is often used with SGSS to help further decontaminate fine particulates.

Author: T.S. Tomascik, R. L. Fellows/615-576-5632

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1. "A Cost-Effective Approach to Remediation of Radiologically Contaminated Soil" (video), Thermo Analytical Inc., Albuquerque, NM, 1993.
2. Johnson, N., President, Thermo Analytical Inc., 5635 Jefferson Blvd., NE 87109, P.O. Box 3874, Albuquerque, NM 87190-3874, (505) 345-9931.
3. Moroney, et al., "Processing Plutonium Contaminated Soil for Volume Reduction Using the Segmented Gate System," Waste Management '94, Conference Proceedings, Tucson, AZ, March 1994.
4. Moroney, K., Moroney, J., and Johnson, N., "Remediation of Transuranic-Contaminated Coral Soil at Johnston Atoll, Using the Segmented Gate System," Waste Management '93, Conference Proceedings, Tucson, AZ, February-March 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediments

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Chemical Separation

Technology: Chemical Extraction (Hg). The General Electric iodine/iodide leaching process is one of many possible chemical extractants which may be used. This process is selective for mercury and is of particular interest for solids which might react extensively with acids. Preliminary tests by Radian Corporation on Lower East Fork Poplar Creek soils have shown the iodine/iodide solution to be by far the most effective of all solutions tested. While iodine is only slightly soluble in water, solutions concentrations of nearly 1M can be made in 1M KI. The reaction product for mercury and mercury salts is the HgI_4^- complex, which is also very soluble in KI solutions. Important reactions are:

Iodine is relatively expensive and GE has patented an iodine recovery and recycle process.

Status: Predemonstration. Bench scale studies have been made to determine concentration and temperature effects on kinetics. A complete process flowsheet has been established. Mercury is recovered as metal and the iodine is recovered and recycled, therefore the amount of waste produced is very small.

Science/Technology Needs: Treatability tests are required for each particular waste to determine the effects of other soluble waste constituents.

Implementation Needs: GE's estimated costs are approximately \$200 to \$500/ton of contaminated material. Costs will vary depending on conditions.

Author: J. Perona, 576-9280, C. M. Goddard, 241-4383

References:

1. *Extraction of Mercury and Mercury Compounds from Contaminated Material and Solutions*, General Electric patent, application serial number 07/963,225, filed on October 15, 1992.
2. *Treatability Study Report for Mercury in East Fork Poplar Creek, Oak Ridge, Tennessee*, Radian Corporation, 93-225-212-01, February 1993.
3. Radian Corporation.
4. General Electric Company, Schenectady, New York.
5. *A Review of Remediation Technologies Applicable to Mercury Contamination at Natural Gas Industry Sites*, GRI-93/0099, Gas Research Institute, September, 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediments

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical Separation

Technology: Beneficiation (Hg). Beneficiation and/or solids classification are physical processes utilized singly or in series to separate components in mixtures due to differences in specific gravity and particle size. These technologies can be used to prepare the waste for a "final" destructive thermal or chemical treatment or disposal. Processing is appropriate for the physical separation of solids, sediments and mixed debris. These techniques are appropriate when size reduction is required as a pretreatment step or when variations in physical characteristics of the mixed materials, i.e., size, magnetic, density, etc., allow contaminated and noncontaminated materials to be separated, thus reducing the volume of hazardous waste to be treated or disposed. Solids classification and beneficiation technologies include magnetic processes, screening, wet and dry classification processes, gravity separations, and flotation.

Magnetic separation consists of sorting one solid from another by means of a magnetic field. Many natural minerals have measurable magnetic susceptibilities but fewer than 20 are amenable to magnetic separation. Magnetic separation can be performed either wet or dry, or with either low- or high-intensity magnets. Common mercury minerals, such as cinnabar, have low magnetic susceptibilities.

Screens are used for size separations of coarse material, greater than 200 microns. However, special screening devices may be used for separations as fine as 44 microns. Numerous screening devices are available, e.g., stationary, mechanical, high-speed mechanical, and electrically vibrated.

Specific gravity-based separations methods have been used in the mining of precious metals. In mercury remediation, they are quite adequate when the mercury is in elemental or other discrete form and in which removal to background level is not required. These separations may also be used as a pretreatment step for the removal of elemental mercury prior to further soil or sediment processing with different technologies. Compared to thermal processes, these methods have a lower potential for airborne emissions. Representative technologies are

discussed below.

Classification is typically performed for finer-sized particles, i.e., less than 200 microns, and is accomplished using air or water as the suspending medium. For wet classification of large tonnages, hydrocyclones are used; however, cyclone separations are quite variable and depend on the specific cyclone configuration and operating conditions. Spiral and rake mechanical classifiers are basically a settling pool with an inclined ramp. The rake or spiral produces agitation in the pool to effect classification by differential settling. Hydraulic classifiers utilize the motion of the fluid as well as variance in specific gravity to classify the solids. Air classifiers are used in conjunction with shredders or screens.

Gravity separations utilize differences in specific gravity as the separation driving force. Separation processes can be accomplished dry or in a liquid medium.

Flotation is similar to a gravity separation process. Flotation utilizes an upflow of air to cause solids to float on a liquid medium. Flotation processes can use compressed air that dissolves in the liquid, usually water; or air at atmospheric pressure. Chemical additives can be used to increase separation efficiency.

Magnetic classification processes often require periodic stoppage to permit removal of material collected. Wet solids processing often requires a substantial effort to separate the carrier fluid from the solids after processing. Dry classification processes often result in the generation of airborne dusts.

Status: Demonstration. These technologies are commercially available and have been used in the mining industry but have not been used for this application. Some have been used for some manometer sites contaminated with elemental mercury. Companies such as Hunter Mining Company (Silver City, New Mexico), GZA Environmental, Inc. (Phoenix, Arizona) and KEERS Environmental, Inc. (Albuquerque, New Mexico), and TransMan (Spokane, WA), have developed physical separation processes to remove mercury from sediments. Since these are still in the demonstration phase for mercury, costs are unavailable.

Science/Technology Needs: Material handling needs specific to Y-12 soils/sediments need to be determined.

Implementation Needs: Waste characterization (metal specie, particle distribution, etc.) and pilot testing need to be performed to determine the applicability, design, and cost of this technology for Y-12 contaminated soils/sediments.

Performance depends strongly upon the form of mercury contamination. If mercury contamination is distributed across all soil/sediment particles, then physical separation will not be totally effective. Also, other form of treatment will be required in addition to beneficiation. The clean-up level needs to be established for Y-12 soils/sediments.

Author: C. M. Goddard, 241-4383

References:

1. Remedial Action Assessment System, prepared for DOE by Battelle Memorial Institute, Version 2.1, Pacific Northwest Laboratory, 1993.
2. *A Review of Remediation Technologies Applicable to Mercury Contamination at Natural Gas Industry Sites*, GRI-93/0099, Gas Research Institute, September, 1993.
3. *Treatability Study Report for Mercury in East Fork Poplar Creek, Oak Ridge, Tennessee*, Radian Corporation, Doc. # D930129.1PS51, February 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediments

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical Separation

Technology: Roasting (Hg). Thermal treatment technologies such as conventional incineration, roasting or retorting, physically and chemically alter contaminants at elevated temperatures. In recent years, these technologies have been developed into mobile systems that can treat contaminated soils and sediments on site. The USEPA BDAT for the treatment of D009, high-mercury-contaminated materials is thermal roasting or retorting. Thermal treatment is based upon the vapor pressure and the low temperature at which mercury vaporizes. The vapor pressure of elemental mercury is relatively low at ambient temperatures. However, the vapor pressure increases rapidly, by orders of magnitude, with relatively small increases in temperature.

Thermal treatment of mercury-contaminated material involves purging the system of oxygen, heating the contaminated materials in either a nitrogen atmosphere or in a vacuum, collecting and condensing evolved vapors, and recovering elemental mercury. During thermal treatment, elemental mercury readily volatilizes, and many mercury compounds decompose to the gaseous elemental form.

The mobilization/demobilization of mobile thermal treatment systems can be costly and time-consuming. Thermal technologies are energy-intensive, and may produce other contaminant condensates that will require subsequent treatment and disposal. Transportation of the contaminated soil can be expensive if the process is not located at a centralized site. Additionally, mobile mercury restoring units are not presently designed to process large volumes of mercury contaminated soil.

Status: Accepted. For nonradiologically contaminated hazardous wastes. Process is under serious consideration for utilization in site remediation activities at INEL Pit 9. Utilized treatment technology for Resolve Superfund Site in Massachusetts, in which PCBs were removed from soil. Laboratory scale testing of mercury and uranium contaminated soil was performed at the Oak Ridge National Laboratory. Vapor emissions during the thermal process will have to be treated; condensate liquids from the thermal process may require additional

treatment or storage; recovered mercury will have to be disposed of or stored. There are several vendors that have, or are currently developing thermal treatment technologies. Costs for these technologies are dependent upon waste characteristics, concentrations, and soil types.

Science/Technology Needs: Design and demonstration of feed systems and treated waste handling systems. Separation systems design for waste-specific off gas from roaster. Volatile metals such as mercury are carried over in the vapor phase. Determination if the soils can be returned in place after treatment by roasting.

Implementation Needs: A demonstration at the Y-12 Plant on contaminated soils is planned. Implementation needs will be determined after the demonstration. Treatment costs should be fairly low, but will be strongly dependent on secondary treatment options, which are waste specific. Verification that the off-gas treatment system will be adequate.

Author: Sylvester Losinski, (208) 526-5962; C. M. Goddard, 241-4383

References:

1. Vendor contact: Chemical Waste Management, Inc.
2. *Critical Review of Mercury Contamination Issues Relevant to Manometers at Natural Gas Industry Sites*, GRI-93/0117, Gas Research Institute, August, 1993
3. *A Review of Remediation Technologies Applicable to Mercury Contamination at Natural Gas Industry Sites*, GRI-93/0099, Gas Research Institute, September, 1993.
4. *Treatability Study Report for Mercury in East Fork Poplar Creek, Oak Ridge, Tennessee*, Radian Corporation, Doc # D930129.1PS51, February 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediments

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Chemical Separation

Technology: Electrokinetic removal. Electrokinetic remediation of soils involves application of direct current between two electrodes inserted in the soil. Passing of direct current through the soil produces three general electrokinetic effects. These are (1) electroosmosis, (2) an electroosmotic transport of contaminants, and (3) reactions at the electrodes. Electroosmosis involves the movement of pore water through the soil by virtue of the applied electrical field. The influence of electroosmosis is greatest in heavy, textured soils (soils with high concentrations of silts and clays and low permeabilities). Thus, electrokinetics offers a method to enhance movement of water in low-permeable soils. Electroosmotic transport of contaminants results as charged anions and cations move in an electrical field. Cations move with the water toward the cathodes, and anions generally move toward the anode by electrical conduction. Some anions may be transported to the cathodes because of convective transport of water by the electroosmosis effect. Gaseous hydrogen and OH⁻ anions are generated at the cathode while protons (H⁺) are generated at the anode, creating a significant pH gradient between two electrodes. Metal hydroxides will precipitate and poison the system unless the electrolyte chemistry near the cathode is managed effectively. For mercury, the major barrier to electrokinetic removal is mobility of the mercury in soil. In the absence of addition of a lixiviant, such as the GE Iodine/iodide (REMA-142-OZ) mercury is unlikely to occur in soils in forms subject to migration in an electrical field.

Status: Predemonstration. Exploratory studies have moved toxic metals through soil under electrostatic potential.¹ A DOE-sponsored workshop was held recently in Atlanta to evaluate the potential of this concept. This appears to be a concept, not a proven technology.

Science/Technology Needs: As previously mentioned, much remains to be learned about this concept before its applicability can be evaluated. The previously mentioned questions should be addressed. The technology, if operated in situ in shallow soils (near the surface) as expected, would have to operate under conditions ranging from drought to heavy rainfall. Although the technique could also be considered an ex situ method, excavation and placement in treatment bins will increase the cost and the need for more rapid treatment

rates. Concepts need to be developed and tested for recovering mercury from the electrodes (of the electrode region).

Implementation Needs: Much needs to be learned about this technology before all implementation needs can be assessed. Costs are very uncertain now, because the concept is not sufficiently defined. Costs are not expected to be low even once the entire removal scheme is defined. Costs could exceed \$100/t. Development and demonstration costs probably will be moderate, perhaps \$1M to \$10M.

Author: Chet Francis, 574-7257

References:

1. Y. Acar, R. Gale, et al., *Electrokinetic Soil Processing: Project EKSITE*, EK-BR-008-079, 1991

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Physical Separation

Technology: Membrane Filtration (Hg). Membrane filtration processes have two features in common: a selective semipermeable membrane and a driving force. When the driving force is applied, the semipermeable membrane preferentially allows certain components of a fluid mixture or solution to pass. Processes differ in the membrane's function and type of driving force used, but each process results in the production of a dilute and a concentrate stream. The membrane separation processes discussed include dialysis, ultrafiltration, facilitated transport membranes including supported liquid membranes, and electrophoresis. Reverse osmosis is covered separately in another data sheet, REMA-135-OZ.

Dialysis involves the selective transport of solute molecules through a membrane. The driving force is the concentration gradient of the solute across the membrane. Dialysis is typically limited to high concentrations, typically 5 to 20 percent, of low-molecular weight dissolved solids. It is not suitable for treating wastewaters containing less than 1000 ppm Total Dissolved Solids (TDS). Dialysis is a well developed technology, but because of its limitations, has few applications for hazardous waste treatment.

Ultrafiltration selects on the basis of molecular shape, size and flexibility. The driving force for ultrafiltration is pressure. Ultrafiltration passes water and retains suspended colloidal solids and materials with molecular weights greater than 500. The process has been successfully applied to heterogeneous colloidal suspensions which are difficult to separate using other technologies. Ultrafiltration membranes typically retain all materials larger than 10^{-3} to 10^{-2} microns. Ultrafiltration is a well developed technology and is commercially available.

Status: Commercially available. Colloidal solids with molecular weights between 500 and 500,000 are usually recommended for ultrafiltration. The membrane area requirement for ultrafiltration is typically between 20 and 50 gal/day/ft². The operating pressure for ultrafiltration is typically between 10 and 115 psi. Typical recovery for ultrafiltration is 95%. Dialysis is limited to waste streams with total dissolved solids concentrations greater than

1000 ppm.

Membrane filtration technologies produce a concentrated liquid stream not suitable for disposal. The volume is dependent on the technique used to remove the metals from the concentrate.

Science/Technology Needs: Evaluation of membrane systems to determine their effectiveness on removal of different mercury species and compounds. This would also include evaluation of methods (use of amalgamation) to enhance mercury removal.

Implementation Needs: Waste stream characterization is required to determine suitability of membrane processes to select appropriate membrane technology, to determine whether pretreatment is required, and to estimate reject rate and reject treatment requirements. Operating costs are expected to be moderate to high since membrane processes are energy dependent.

Author: C. M. Goddard, 241-4383

References:

1. Remedial Action Assessment System, Version 2.1, prepared for DOE by Battelle Memorial Institute, Pacific Northwest Laboratory, 1993.
2. Lanning, Michael J., *Aqueous Mercury Treatment Technology Review for NPDES Outfall 49, Y-12 Plant*, MMES, Y-12 Development, Y/DZ-1043, April 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Physical Separation

Technology: Filtration Systems (Hg). Media filtration is used to remove small quantities of suspended solids from liquid streams by trapping solid particles within the pore structure of the filter medium. The type of filter media used depends on the solids loading rate and application. Common media are sand, diatomite, calcined rice hulls, coal, cotton or wool fabrics, and wire cloth. Two types of filters are cartridge and granular media. The effectiveness of these filters for soluble contaminants may be increased by using precipitants. These precipitants are discussed in Data Sheets REMA-131-OZ and REMA-132-OZ.

Cartridge filters consist of one or more replaceable or renewable cartridges that contain the active element. The cartridges are put inside a filter housing. The liquid is fed to the filter under pressure, with the solid particles trapped in the element as the liquid passes through. Filter elements and housings can be constructed from many different materials, making them capable of handling a variety of fluids. Cartridge filters are applicable to the removal of relatively small quantities of suspended solids because there is minimal room for accumulated solids within the cartridge. When a cartridge filter becomes saturated with solids, it is usually replaced or cleaned by air scouring backwashing. When the pressure drop becomes too high or the solids content in the effluent is unacceptable, the bed is cleaned by backwashing. Cartridge filtration is not optimum or economical for clarifying liquid streams with a solids content greater than 10 mg/l.

Granular media filters are used to remove suspended solids from liquid streams. A liquid carrying suspended particles is passed through a bed of granular material that filters out the solids. The filter bed may be a single medium such as sand, dual media such as sand with an upper layer of anthracite, or multimedia including garnet, sand, and anthracite, from bottom to top. As the solids accumulate, the pressure drop across the filter bed increases. Granular media filtration is not optimum or economical for clarifying liquid streams with a solid content greater than 200 mg/l.

Most filters operate in a batch mode and are taken out of service for backwashing. Filter

systems are usually designed with extra capacity so that a filter can be taken off line for backwashing without disrupting flow through the overall system. Backwash cycles are often automated and require little or no operator attention. Numerous designs and configurations are available. Filters are designed to operate with gravity flow in open vessels or as pressure vessels with a constant, pumped stream. In either case, the most common flow is from top to bottom. Upflow pressure filters are available, but they are more expensive, difficult to clean, and not widely used. Filtration design depends on the characteristics of the wastewater and the solids content as well as on effluent requirements and economic restraints.

Status: Accepted, commercially available. The effectiveness of this technology is primarily limited to particulates. May be used as a pretreatment step for systems designed to treat soluble forms of mercury.

Cartridge filters can be designed to remove particles down to 1 micron or less. As the desired particle size retention decreases, the pressure drop across the filter increases and the solids retention capacity decreases. Granular media filters can typically remove particles down to the 10 to 20 micron size. The actual particle size limitation depends on the nature of the granular media used. Scaling compounds, like calcium, magnesium and iron may cause scaling problems at alkaline pH during operation.

Science/Technology Needs: Evaluation of sulfur impregnated filter systems and addition of precipitants for removal of soluble mercury compounds. Research is needed to determine if filter systems can be regenerated.

Implementation Needs: Characterization of mercury contaminated waters is needed to determine the form of mercury and particle size range to determine if this technology will be effective.

Author: C. M. Goddard, 241-4383

References: Remedial Action Assessment System, Version 2.1, prepared for DOE by Battelle Memorial Institute, Pacific Northwest Laboratory, 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediments

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment

Alternative: Capping

Technology: Revetment Systems. A combination of geotextile fabric and revetment mat provides in-place containment of contaminated sediments by preventing scour of stream bed sediments. The permeability of the geotextile fabric is such that the fabric retains the fine soils and sediments while relieving hydrostatic pressure. The concrete block revetment mat provides weight to hold the fabric in place and armoring to prevent damage due to the forces of moving water.

Status: Accepted. Commercially available. Can be used on steep slopes and when properly installed can maintain hydraulic stability under high velocity flows. A cable network is used when placing this system on steep slopes. The real advantage of the fabric and revetment system is that it provides containment of waste while requiring no excavation and generating no waste. A fabric and revetment system is much less expensive than excavation, treatment and disposal options, and it results in containment of waste with minimal construction activity. However, a fabric and revetment system would not work for containment of leachable or highly mobile waste materials.

Science/Technology Needs: Testing of sediments for grain size and chemical constituents is required before this method can be effectively used. Also, hydraulic modeling of the system through a variety of flow rates and stream bed geometries is needed. This technology is commercially available and accepted technology for erosion control. It has not yet been used for contaminated soils and sediment containment. Thus, its acceptability as a permanent solution needs to be investigated.

Implementation Needs: None

Author: Bill Barton, 576-0519

References: Vendor literature from ConLock, Armorflex, Dycel and PetraFlex companies.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: DNAPLs

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: In Situ Bioremediation. Bioremediation of the saturated zone uses water to deliver the electron acceptor, usually oxygen. Water amended with an electron acceptor, nutrients, and optional microorganisms is introduced into the contaminated groundwater zone via one or more injection wells to stimulate biodegradation. Extraction wells are normally used to pull amended water horizontally through the contaminated zone. The extracted water may require further treatment. A variety of methods is available for delivering oxygen to the subsurface via recharge water. Air or oxygen can be transferred to water using an aboveground or in-well sparging system. The disadvantage of these techniques is the limited amount of oxygen that can be transferred to water. Use of hydrogen peroxide can greatly increase the oxygen-carrying capacity of injected water since molecular oxygen is liberated during the natural decomposition of hydrogen peroxide. Hydrogen peroxide is toxic to bacteria at high concentrations, but microbial activity is not inhibited at dilute concentrations. Hydrogen peroxide at 40 mg/l of groundwater is reported to release sufficient oxygen to sustain in situ biodegradation.

Status: Demonstration. In situ bioremediation is being tested extensively at superfund sites for destroying organics in groundwater. Fluids-cycling bioreclamation has been used most frequently to treat soil/water systems contaminated with gasoline, diesel, jet fuel, and BTEX such as at the Kaispel Construction Site in Horseheads, New York. However, the DNAPLs found at the Bear Creek burial Ground (PCE, TCE, and PCBs) are not readily biodegraded by conventional in-situ bioremediation. In cometabolic biodegradation, a substrate such as methane is provided for use by the organism as a carbon source, and the enzymes used to metabolize the substrate also degrade chlorinated solvents. This process has been shown to degrade TCE in lab experiments and limited bioreactor experiments, but has not yet been proven in in-situ experiments.

A limitation of in situ treatment methods at the Bear Creek burial grounds is the depth of the DNAPLs (>270 ft.) and the fractured rock underlying the Burial Grounds. The depth would make it difficult to reach the DNAPLs with microorganisms, substrate, and oxygen; and it is

likely that some DNAPL is present in dead-end pores of the rock matrix that are not part of the active groundwater flow system.

Science/Technology Needs: To implement in situ aerobic biodegradation, the dissolved oxygen concentration must be greater than 1 mg/l and the minimum air-filled pore space should be about 10%. The redox potential should be greater than 50 mV, the pH between 4.5 and 8.5, and the carbon-to-nitrogen-to phosphorus ratio about 120:10:1. Microbial toxicity and inhibition is also determined as is bacterial characterization. If native organisms are not present, cultured biomass must be added. Another issue is the effective porosity and nature of fractures (e.g., fracture width and surface asperities) in porous and fractured media, respectively. Tight formations that do not permit flushing of the pores and/or fractures will inhibit exposure of contaminants to induced biological activity. More control over the in situ addition/removal process needs to be obtained. Studies to improve the contact between contamination, bacteria, and oxygen are needed.

Implementation Needs: Development work would be needed to evaluate in situ treatment of DNAPLs at the Bear Creek Burial Ground. In situ biological processes are usually considered to be relatively inexpensive.

A means for injecting oxygen-laden water to the depth of the DNAPLs is needed along with a means of controlling the water movement through hydraulic controls, if appropriate. Nutrients and bacteria may be needed to supplement subsurface conditions. Nitrogen and phosphorus are most frequently the rate-limiting nutrients.

Author: P. A. Taylor, (615) 574-1965; K. S. Jones, (615) 576-0645

References:

1. E. Riser-Roberts, *Bioremediation of Petroleum Contaminated Sites*, C. K. Smoley and Sons, Chelsea, MI, 1992
2. Kueper, B. H., C. S. Haase, and H. L. King, "Leakage of Dense, Non-aqueous Phase Liquids from Waste Impoundments Constructed in Fractured Rock and Clay: Theory and Case History," *Can. Geotech J.*, Vol. 29, 1992, pp 234-244.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: DNAPLs

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: In Situ Oxidation. KMnO_4 is a powerful oxidant that remains stable in water, yet reacts quickly when it contacts organic matter such as PCE and TCE. The oxidation of PCE and TCE by KMnO_4 involves cleaving the double bond between the two carbon atoms, followed by further oxidation of the two chlorinated carbon atoms. The products of complete destruction include carbon dioxide (CO_2) in solution or gas phase, potassium chloride (KCl), chlorine (Cl_2), hydrochloric acid (HCl) and manganese dioxide (MnO_2).

The remediation scheme would involve pumping a solution of KMnO_4 into an aquifer contaminated with PCE or TCE for the purpose of in-situ oxidation. By-products of the reaction would be treated on the surface.

Status: Demonstration. Experiments have been performed both in the laboratory and at the Borden aquifer in Canada, a sandy aquifer approximately 30 feet thick, generally 10 to 15 feet below ground surface, using KMnO_4 to oxidize PCE. Results of these experiments indicate complete removal of PCE in aqueous solution, but not PCE as an immiscible phase. Similar results were obtained in other experiments with TCE.

A limitation of in situ methods at the Bear Creek Burial Ground is the depth of the DNAPLs (>270 feet) and the fractured rock underlying the burial grounds. The depth would make it difficult to reach the DNAPLs with the KMnO_4 solution, and it is likely that some DNAPL is present in the rock matrix that is not part of the active groundwater flow system.

Science/Technology Needs: In order to utilize this technology, the practicality of developing a method of dissolving the DNAPLs into the groundwater must be determined.

Implementation Needs: Complete hydraulic control is required in order to prevent migration of by-products. Also, treatment processes for the oxidation products must be available.

Author: K. S. Jones, (615) 576-0645

References:

1. Schnarr, M. J., and G. J. Farquar, "An In-Situ Oxidation Technique to Destroy Residual DNAPL from Soil," presented at the Subsurface Restoration Conference, The 3rd International Conference on Ground Water Quality, Dallas, TX, June 21-24, 1992.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: DNAPLs

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment

Alternative: Isolation

Technology: Clay Expansion. Organophillic clays, which expand on contact with organics, can be injected into the fractured rock to seal off the contaminated area.

Status: Conceptual. The use of expanding clays such as bentonite, which swell on contact with water, is an established practice in unconsolidated aquifers. Organophillic clays expand on contact with DNAPLs just as bentonite expands on contact with water. These have not been used in fractured rock, nor at a contaminated site.

Science/Technology Needs: A method of injecting the organophillic clay into the fractured rock at depths greater than 270 ft. must be developed.

Implementation Needs: Testing of clays with DNAPLs to determine dosage and injection system.

Author: K. S. Jones, (615) 576-0645

References: Phone conversation. Radian Corporation.

 

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: DNAPLs

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Reactive Gates. A permeable wall containing reactants is constructed across the path of the contaminant plume and as the contaminated water passes through the wall, the contaminants are removed/degraded, allowing uncontaminated water to emerge on the downstream side. The reactive material can be activated carbon, ion exchange resins, or zero-valence metals. For organic contaminants such as those found at the Bear Creek Burial Ground (e.g., PCE, TCE), one possible reactant is metallic iron (Fe^0), which is known to promote the degradation of various pure-phase organic liquids. Installation of the reactive walls is usually achieved via adaptations of conventional construction methods for impermeable barriers (open trenches, polymer slurry trenches, overlapping caissons).

An adaptation of the reactive gate concept is the funnel-and-gate system, whereby an impermeable section of wall is used to direct groundwater flow through relatively narrow zones of reactive material.

Status: Demonstration. Controlled in situ tests have been conducted at the Borden aquifer in Canada, a sandy aquifer approximately 30 feet thick, generally 10 to 15 feet below ground surface, but no reactive walls have been installed at a subsurface contamination site. Conceptual planning for a demonstration at the Paducah Gaseous Diffusion Plant is currently under way. Because installation methods are limited to unconsolidated surficial materials at depths no greater than 50 m (164 ft), this is not likely to be implementable at the Bear Creek Burial Ground where DNAPLs are in fractured bedrock to depths exceeding 270 ft.

In situ treatment walls require a high initial capital investment, with the benefits to be derived from greatly reduced long-term operating and maintenance costs. Because this has never been implemented at a contaminated site, the long-term performance cannot be predicted. For example, it is not known how often the reactive material must be replaced.

Science/Technology Needs: Before this technology can be implemented at the Y-12 Plant, the practicality of developing new installation methods which will allow excavation into

bedrock to depths exceeding 270 ft must be evaluated. Also, there is a significant need to develop an understanding of the nature of the reaction between contaminants and reactive media and the kinetics of these reactions.

Implementation Needs: In situ treatment walls require a high initial capital investment, with the benefits to be derived from greatly reduced long-term operating and maintenance costs. Because this has never been implemented at a contaminated site, the long-term performance cannot be predicted. For example, it is not known how often the reactive material must be replaced.

Author: K. S. Jones, (615) 576-0645

References:

1. Gillham, Robert W., and David R. Burris, "Recent Developments in Permeable In-Situ Treatment Walls for Remediation of Contaminated Groundwater," Proceedings from the Subsurface Restoration Conference on Ground Water Quality Research, Dallas, TX, June 21-24, 1992.
2. Gillham, Robert W., Stephanie F. O'Hannesin, and W. Scott Orth, "Metal Enhanced Abiotic Degradation of Halogenated Aliphatics: Laboratory Tests and Field Trials," presented at the 1993 HazMat Central Conference, Chicago, IL, March 9-11.
3. the envirometal process: metal-enhanced abiotic degradation of chlorinated organic compounds, brochure published by envirometal technologies, inc.
4. Starr, Robert C., and John C. Cherry, "Funnel and Gate System Directs Plumes for In Situ Treatment." Ground Water Currents, EPA/542/N-93/006, June 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: DNAPLs

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical Separation

Technology: Soil Vapor Extraction. Soil Vapor Extraction (SVE), also called in situ air stripping or enhanced volatilization, is a proven in situ method for removing volatile organic compounds (VOCs) from a soil matrix above the water table. It uses vacuum wells to induce a flow of air through the soil to remove volatile compounds. The system consists of a network of wells with perforated well screens potentially extending into the groundwater. These wells are packed with gravel and sealed at the top with bentonite to prevent short-circuiting. The extraction wells are connected to the suction side of a vacuum extraction unit through a surface collection manifold. The vacuum extraction unit induces a flow of air from the subsurface into the extraction wells. As air is pulled through the soil, contaminants are volatilized from both the soil and water in pore spaces. The vacuum not only draws vapors from the unsaturated zone, but also decreases the pressure in soil voids, thereby causing the release of additional VOCs. In general, the vapor concentration in soil gas is the same when water separates the DNAPL from the soil gas as when DNAPL is in direct contact with soil gas. The extracted vapor flows through the surface collection manifold and is either vented to the atmosphere, connected to a vapor-phase carbon absorption system, or flared, depending on the nature and extent of VOC contamination.

Status: Demonstration. A pilot project was conducted at a facility in Virginia to remove PCE from a fractured rock vadose zone over 90 ft. thick.

Science/Technology Needs: Methods for air delivery to, and extraction from, deep fractured rock need to be developed before this technology can be used to remove DNAPLs at the Bear Creek Burial Grounds.

Implementation Needs: Subsurface characterization and injection/recovery system.

Author: Oliva West, (615) 576-0505; K. S. Jones, (615) 576-0645

References:

1. G. R. Allen and D. L. Anderson, "Case Study: Vacuum Extraction to Remediate Contaminated Soil-Selection of Optimum Extraction and Emission Control Equipment," *Proceedings of the 1992 US EPA/A&WMA International Symposium on In Situ Treatment of Contaminated Soil and Water*, pp 278-290, Dublin, OH, 1992
2. G. P. Treweek and J. Wogec, "Soil Remediation by Air/Steam Stripping," *Proceedings of the Fifth National Conference of Hazardous Wastes and Hazardous Materials*, pp 147-153, 1988
3. O. R. West, R. L. Siegrist, H. L. Jennings, A. J. Lucero, S. W. Schmunck, D. W. Greene, "Laboratory Evaluation of In Situ Vapor Stripping," *Report from the X-231B project for In Situ Treatment of Clay Soils Contaminated by Volatile Organic Compounds and Radioactive Substances*, ORNL/TM-12260, Oak Ridge National Laboratory, Oak Ridge, TN 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: DNAPLs

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Retrieval

Alternative: Product Recovery

Technology: Surfactant Flooding. This technology relies on the injection of a chemical agent (surfactant) to alter the physical or chemical properties of the DNAPL. The objective of surfactant flooding is to directly remove immiscible phase DNAPL from the subsurface (removal of "source" zones rather than management/extraction of dissolved phase plumes). It relies on a lowering of interfacial tension to physically displace DNAPL and/or an enhancement in DNAPL solubility to accelerate dissolution. The technology includes steam injection, surfactant enhanced mobilization, surfactant enhanced dissolution, and alcohol flooding.

Status: Demonstration. Although the technology is established by the oil industry for enhanced oil recovery from petroleum reservoirs, it is still in the demonstration phase for DNAPL recovery. A demonstration is planned at the Paducah Gaseous Diffusion Plant, but no schedule is available at this time.

However, Paducah's site conditions are quite different from those at Y-12. The zone contaminated with DNAPL at Paducah is a sandy porous aquifer, whereas DNAPL at Y-12 is in fractured rock. A lowering of interfacial tension will bring about a proportional decrease in entry pressures, thus reducing the hydraulic gradient required to mobilize a pool. There is some concern that lowering in interfacial tension by surfactants could cause the DNAPL to migrate deeper into the subsurface in response to gravity driving forces. This could be especially risky at the Bear Creek Burial Ground since the principal direction of bedding-plane fractures dip steeply downward. Experiments have shown that upward hydraulic gradients can arrest downward DNAPL migration. Alcohol flooding, however, in theory, leads to the development of an alcohol-DNAPL mixture that is immiscible in and less dense than water. Therefore the mixture rises buoyantly and floats on the water table where it can be removed more easily.

Science/Technology Needs: More research is required for determining which surfactant to use, especially for multicomponent DNAPLs such as those at the Bear Creek Burial Grounds, that will minimize the potential for enhanced downward migration of the DNAPL.

Implementation Needs: Characterization of location/analysis of DNAPLs.

Author: K. S. Jones, (615) 576-0645

References:

1. Cherry, J. A., et. al., "Status of In Situ Technologies for Cleanup of Aquifers Contaminated by DNAPs Below the Water Table." Prepared for International Specialty Conference on How Clean is Clean?, Cleanup Criteria for Contaminated Soil and Groundwater, Air and Waste Management Association.
2. Kueper, Bernard H., C. Stephen Haase, Helen L. King, "Consideration of DNAPL in the Operation and Monitoring of Waste Disposal Ponds Constructed in Fractured Rock and Clay", First Canadian Conference on Environmental Geotechnics, Canadian Geotechnical Society, Montreal, Canada, May 14-16, 1991.
3. Kueper, Bernard H., lecture given at "Diagnosis and Remediation of DNAPL Sites," a Waterloo Centre for Groundwater Research short course, Arlington, VA, November 15-19, 1993.
4. Department of Energy Technology Development Data Sheet "In-Situ Decontamination of Sand and Gravel Aquifers by Chemically Enhanced Solubilization of DNAPLs with Surfactant Solutions," September, 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: DNAPLs

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Retrieval

Alternative: Product Recovery

Technology: Air Sparging. Air Sparging is the injection of air below the water table in order to volatilize organics in the vadose zone, and allow them to be extracted along with the air.

Status: Conceptual. Although the technology has been used successfully in highly permeable soils, it has not been proven to work in fractured rock such as that underlying the Bear Creek Burial Ground. However, a more promising use of this technology is the removal of near surface residual DNAPL contamination.

Science/Technology Needs: Additional techniques for dispersion or injection of air into fractured bedrock at depth are needed.

Implementation Needs: Subsurface characterization and injection system.

Author: K. S. Jones, (615) 576-0645

References:

1. D. B. McWhorter, lecture at "Diagnosis and Remediation of DNAPL Sites," a Waterloo Centre for Groundwater Research Short Course, Arlington, VA, November 15-18, 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: DNAPLs

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Retrieval

Alternative: Product Recovery

Technology: Pump and Treat

Status: Accepted. Pump and Treat has been generally ineffective in removing the contaminant source within reasonable time spans due to the low solubility of the DNAPL compounds and the fact that residual zones and pools can represent a very large mass of chemical. When attempts are made to clean fractured rock aquifers such as that at the Bear Creek Burial Ground, major improvements in water quality are very slow because little or no water flushes through dead end pores located within the rock matrix, which is likely to contain the bulk of the contaminated mass. However, pump and treat systems can be effective for control of off-site migration of dissolved plumes emanating from the DNAPL sources.

Contaminants located within the matrix of fractured rock migrate very slowly by diffusion into the transmissive fractures during pump and treat. Therefore, removal of contamination from the environment by pump and treat is a very slow process that can continue for decades and be very expensive.

Science/Technology Needs: Development is needed on a method to increase groundwater flow in the vicinity of the DNAPL in order to accelerate the rate of DNAPL extraction. Physical techniques such as fracturing are not applicable since they may induce gravity-driven expansion of the DNAPL. Increased dissolution of the DNAPL into the groundwater could make pump and treat a more viable remediation technology.

Implementation Needs: Subsurface characterization and well recovery system.

Author: K. S. Jones, (615) 576-0645

References:

1. Cherry, J. A., et al., "Status of In Situ Technologies for Cleanup of Aquifers Contaminated by DNAPs Below the Water Table." Prepared for International Specialty Conference on How Clean is Clean?, Cleanup Criteria for Contaminated Soil and Groundwater, Air and Waste Management Association
2. Mackay, Douglas M., and John A. Cherry, "Groundwater Contamination: Pump-and-Treat Remediation," Environ. Sci. Technol., Vol. 23, No. 6, 1989, pp 630-636.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: DNAPLs

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Containment

Alternative: Isolation

Technology: Sequestering in the Brine Zone. At Y-12, below a depth of about 1000 feet is a region of very saline groundwater that may represent a zone of sluggish flow. It is thought that if the DNAPL can be made to migrate into the brine zone it will become trapped and further migration will be prevented. Injection of surfactants or other materials into the present zone of DNAPL accumulation would lower the interfacial tension, remobilizing the DNAPL, and permit its downward migration through the fracture system into the brine zone.

Status: Conceptual. This technology is purely speculative at this point. There is great hesitancy at this point to interfere in the brine zone when so little is known about it. Furthermore, it is very doubtful that it would be possible to remove all DNAPL from its present location and transfer it to the brine zone.

Science/Technology Needs: Further information about the brine zone, the present location of residual DNAPL, and the probability of success would be needed before any attempts are made to utilize this concept.

Implementation Needs: Subsurface characterization and injection system.

Author: K. S. Jones, (615) 576-0645

References:

1. Phone conversation with Tom Early (615-576-2103); phone conversation with Chris Smith (615-576-6526).

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: DNAPLs

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Lasagna Process. The lasagna process, named for the alternating layers of wastes and cleanup zones it involves, is a developing in situ treatment method for DNAPLs in low permeability soils such as clays and silts. The three components of the process are: electroosmosis as the driving force to move contaminants out of clay, in situ treatment zone formation, and treatment processes themselves. Hydraulic fracturing is used to create treatment zones in the clay by the injection of a water slurry. The pressure of the water being injected causes a horizontal, pancake-shaped fracture to form. These fracture zones can be stacked one above the other to become horizontal treatment zones.

If the top and bottom pancakes in the stack are formulated with a conductive material such as graphite, they can become the electrodes for the electroosmosis process. Thus, contaminants can be pumped to the treatment or adsorption. Since the contaminants never have to reach the cathode, the voltage gradient can be periodically reversed, allowing for multiple passes of the contaminant through the zone should it not be degraded or adsorbed on the first pass. Periodic voltage reversal also helps eliminate the problems associated with operating the DC voltage in one direction over long periods of time, such as alterations in the soil pH and moisture levels.

The third component of the Lasagna process is the treatment zone itself. Depending on the contaminants to be treated, the zones can be filled with microorganisms and nutrients for biodegradation, catalysts such as iron filings for dechlorination, or activated carbon for adsorption. For mixed DNAPLs, different treatment media can be injected into different layered zone of the lasagna. This overcomes another problem with electroosmosis alone—the expensive surface treatment facilities usually required.

The lasagna can be either horizontal, as described above, or, in the case of near surface contamination the treatment zones and electrodes can be inserted in a vertical array, using sheet piling technology. In this approach the electrodes would be sheets of metal driven into the ground using the same methods as used in the construction industry. Treatment zones

could be created with trenching technology or other technology or other technologies.

Status: Demonstration. In laboratory tests using about a yard of clay, 98% of p-nitrophenol were removed by electroosmosis in two phases. The test cell contained seven layers of material. The top and bottom layers were filled with graphite. Inside these electrodes were layers of clean clay, followed by layers of sand/carbon (the treatment zone), with contaminated clay placed in the center. When current was applied, water moved out of the contaminated zone to the cathode. When the water had moved from the center layer (after 6 days), the electrodes' polarity was switched and the water flowed in the opposite direction. Ninety-eight percent of the p-nitrophenol was recovered in the carbon zones, and 2% in the contaminated zones. Similar results were obtained in larger-scale laboratory tests.

A field test is scheduled for the fall of 1994 at a TCE contaminated site at the Paducah Gaseous Diffusion Plant.

Science/Technology Needs: Further development is needed on in situ treatment methods. Laboratories at the University of Waterloo in Canada have been working on the use of iron fillings for dechlorination of chlorinated compounds. Methods for creating treatment zones in fractured rock, such as that found at the Y-12 Plant also required development.

Implementation Needs: Development work would be needed to evaluate the feasibility of this technology in the treatment of DNAPLs at the Bear Creek Burial Grounds.

Author: K. S. Jones, (615) 576-0645

References:

1. Brodsky, Philip H., *The Lasagna Project: A Novel Process for Cleaning up Contaminated Soils*. Presented to the Council for the Advancement of Science Writing, November 4, 1993.
2. "Creation of Treatment Zones in Clay Formations to be Tested," *HazTECH News*, December 2, 1993, p. 187.
3. Ho, S. V., et al, *Innovative Soil Remediation Technology*. Preprinted Extended Abstract, presented at the I&EC Special Symposium, American Chemical Society, Atlanta, GA, September 27-29, 1993.
4. "EPA Helps Pick up Lasagna Tab," *Pollution Engineering*, April 1994, p. 18.

EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediments

Problem Area/Constituents: Mercury - Air*

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Chemical Separation

Technology: Activated Carbon (Air/Hg). Gas-phase adsorption technology encompasses those processes that use a solid material of high surface area and/or permeability to selectively adsorb contaminants from a gaseous stream. The adsorption process is classified as either physical adsorption or chemisorption. In physical adsorption, the gas molecules adhere to the surface of the solid adsorbent as a result of intermolecular attractive forces (Van der Waal's forces) between them. The advantage of physical adsorption is that the process is more easily reversed. By lowering the pressure of the adsorbate in the gas stream or by raising the temperatures, the adsorbed gas is readily desorbed without a change in chemical composition. Chemisorption results from a chemical interaction between the adsorbate and the adsorbing medium. The bonding force associated with this type of adsorption is much stronger than that for physical adsorption. Chemisorption is frequently irreversible. Granular activated carbon is, by far, the most common hydrophobic adsorbent used in industrial waste treatment applications. It is usually used in packed column systems and is often regenerated. Contaminated air is passed through the column until the key contaminant is detected at some predetermined level in the effluent air stream. Usually columns are placed in series, so that the first column can be loaded to its maximum capacity while residual levels of the contaminant are removed in subsequent columns.

Activated carbon is effective at physically adsorbing trace components of hydrophobic materials such as mercury from air streams due to a high population of micropores. Removal efficiency is 99% or greater. This is achieved at relatively low capital and operational costs. The process is also simple to operate and maintain. At low concentrations mercury will be adsorbed but the capacity is limited; adsorption capacity usually increases with concentration in the gas phase. Impregnants (such as sulfur, copper, silver and iodine) that can react or amalgamate with mercury are frequently employed to provide increased

*Treatment of offgases from remediation (roasting, etc.) of mercury-contaminated soils and sediments.

adsorption capacity and selectivity. For sulfur impregnated carbon, see REMA-161-OZ. Physically adsorbed mercury is "fixed" by reaction with the impregnant which effectively increases the capacity.

Status: In use. Commercially available from a number of manufacturers. The primary application for this technology is the treatment of mercury contaminated gas-phase secondary wastes from treatment of mercury contaminated soils/sediments. Spent activated carbon would require regeneration or disposal.

Science/Technology Needs: Treatment of the byproduct (spent carbon) will require research and development to ensure that the process will meet all regulations.

Implementation Needs: Testing to determine the adsorptive capacity of the carbon and to determine design parameters.

Author: C. M. Goddard, 241-4383

References:

1. Kenneth Wark and Cecil F. Warner, *Air Pollution: Its Origin and Control*, Harper and Row Publishers, New York, NY, 1976.
2. *Impact of Process Conditions on Mercury Removal from Natural Gas Using Activated Carbon*, Calgon Carbon Corporation.
3. *An Assessment of Off-gas Treatment Technologies for Application to Thermal Treatment of DOE Wastes*, DOE/MWIP-1, 9/92.

EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediments

Problem Area/Constituents: Mercury/Air*

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Chemical Separation

Technology: Sulfur-Impregnated Carbon (Air/Hg). Mercury removal with sulfur impregnated activated carbon is an established process for removal of mercury from natural gas and air, as well as from by-product hydrogen streams. There are other impregnating compounds such as iodate (see REMA-160-OZ) which may be used instead of sulfur. The mercury removal process employs a single or dual vessel adsorption system designed to reduce concentrations to $<0.001 \text{ ug/Nm}^3$ in the treated gas. During the adsorption process, mercury is attracted to the activated carbon surface where a chemical reaction converts the mercury to mercuric sulfide. The sulfide product is then retained in the pores of the carbon granule.

Based on the chemical reaction ($\text{Hg} + \text{S} \rightarrow \text{HgS}$) the calculated theoretical adsorption capacity for Hg is 93% (w/w), based on 15% of elemental sulfur on the activated carbon. Based on laboratory tests conducted by Barnebey and Sutcliffe Corp., the actual adsorption capacity was observed to be between 18 and 20% weight percent with a removal efficiency greater than 99% with their sulfur-impregnated carbon, CBII(12x30) in air treatment applications. Based on tests conducted by Calgon Carbon Corporation, the adsorption capacity of their type HGR granular activated carbon was observed to be as high as 20 weight percent.

Status: In Use. Commercially available from several manufacturers. In a properly designed sulfur impregnated activated carbon system, the maximum attainable mercury concentration in treated air is not affected by changing the pressure or inlet mercury concentration of the air stream. However, lowering the gas temperature or moisture content of the inlet gas will improve the process and further reduce the mercury concentration in the treated gas. High humidity (greater than 50% RH) affected the sulfur impregnated carbon. The effect was due to the high adsorption capacity of water from the humid air stream. The adsorption capacity increases with humidity. Spent activated carbon would require regeneration or disposal.

*Treatment of offgases from remediation (roasting, etc.) of mercury-contaminated soils and sediments.

Science/Technology Needs: Research needs to be conducted to determine the effects temperature has on the impregnated carbon.

Implementation Needs: Testing to determine adsorptive capacity and design parameters. The spent carbon will need to be either disposed of or regenerated as dictated by additional research and testing.

Author: C. M. Goddard, 241-4383

References:

1. *Impact of Process Conditions on Mercury Removal from Natural Gas Using Activated Carbon*, Calgon Carbon Corporation.
2. Barnebey and Sutcliffe Corporation, Columbus, OH.

EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediments

Problem Area/Constituents: Mercury/Air*

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Chemical Separation

Technology: Selenium Sorbent (Air/Hg). A filter is being developed in Sweden that utilizes a reaction between mercury and selenium to contain the mercury. The flue gas entering the filter must first be conditioned by removing particulates, lowering the temperature to 140°F or less, and still keeping the gases from becoming saturated. Depending on the air pollution control devices used upstream of the selenium filter and the resulting condition of the flue gas, multiple flue-gas condition steps may be required. The filter unit consists of a cylindrical shell fitted with exhaust inlet and outlet connections, within which is a porous granular silica cartridge impregnated with selenium. A concentric inner layer of fine grain silica precleans the incoming gases before they are brought into contact with the selenium element. Here the mercury reacts to form highly stable mercury selenide (HgSe). Lifetime is very dependent on loading, varying between 1 and 50 years.

Status: Predemonstration. Because this is a new process that is being developed overseas, little is known about this process, however, because it does involve flow through a media similar to filtration technology, the operations and benefits of the selenium filter should be similar to dry filtration systems. The use of media to collect the pollutant should be very simple with no complicated equipment. Because the pollutant is contained within the media, the process should be relatively clean. For spent cartridges, Boliden Contech operates an exchange system. The company extracts the mercury as a concentrated product which it then converts to the pure metal.

The use of selenium to capture mercury poses a double threat in terms of disposal of the spent material. Both of these heavy metals are considered when determining whether a waste is characteristically hazardous in terms of the Toxic Characteristic Leach Procedure (TCLP). Therefore, when thermally treating radioactive wastes, the spent selenium filters would have

*Treatment of offgases from remediation (roasting, etc.) of mercury-contaminated soils and sediments.

a high probability of being a mixed waste.

Science/Technology Needs: Since little is known about this technology, much research is required. The optimum operating conditions and resulting performance needs to be determined. Work can be done to determine the best structure of the filter and how to manufacture the filter. Potential problems, such as filter binding and poisoning will need to be identified and resolved before full-scale application is practicable.

Implementation Needs: The disposition of the spent selenium sorbent needs to be determined. (Can it be regenerated or disposed of?)

Author: C. M. Goddard, 241-4383

References:

1. *An Assessment of Off-Gas Treatment Technologies for Application to Thermal Treatment of DOE Wastes*, (DOE/MWIP-1), 9/92
2. "Removes Mercury from Exhaust Gases," *Process Engineering*, November 1988.

EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediments

Problem Area/Constituents: Mercury/Air*

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical Separation

Technology: Particulate removal is required when gas streams contain particulate matter present in too high a concentration for direct discharge to the atmosphere. From the standpoint of gas treatment, particulate matter is any material that exists as a solid or liquid in the gas stream. Devices for gas particulate control generally fall into one of five categories: gravity settling chambers; cyclone, or centrifugal, separators; wet collectors; fabric filters; and electrostatic precipitation.

Gravity settling chambers are typically enlargements of a duct within a gas-handling system. These chambers function by decreasing the velocity of the gas enough to allow particles to fall to the bottom of the settling chamber before being carried out the downstream side of the settling chamber through the outlet duct. The minimum particle size is 10 to 50 microns for gravity settling. Gravity settling chambers typically have very low energy cost, low maintenance cost, low capital costs, excellent reliability, very large size, and low particulate removal efficiencies, particularly for smaller size particulates.

Cyclone separators are gas particulate removal devices that employ centrifugal force generated by a spinning gas stream to separate particulate matter from a carrier gas. The separator unit may be a single large unit, or a number of units arranged in a series or in a parallel configuration. The minimum particle size for standard cyclones is 10 to 25 microns, and for high-efficiency cyclones is 5 microns. Placing cyclones in parallel will generally increase the volumetric throughput, while placing them in series will result in higher removal efficiencies. Removal efficiency of greater than 99% is possible with conventional cyclones and a particle size of 50 microns.

Wet collectors use a liquid, usually water, to capture particulate dust or to increase the size

*Treatment of offgases from remediation (roasting, etc.) of mercury-contaminated soils and sediments.

of aerosols. Typical equipment which uses this contacting scheme includes spray chamber scrubbers, wet cyclonic scrubbers, and venturi scrubbers combined with aerosol separators, such as mist eliminators or vane separators. 0.5 micron size particles can be removed with venturi scrubber wet collectors and 5 micron size particles with spray chamber wet collectors. Efficient contact of the liquid phase with particulate is generally required with wet collectors. This requires a pressurized liquid, and possible high energy costs. Wet collectors remove particulates from a liquid stream, which can be pumped and typically handled more easily than dry streams. Liquid stream flow wet collectors can be recycled but must eventually be treated or disposed. With recycle, generally 500 to 1000 liters of secondary liquid waste is generated for every million cubic feet of gas treated.

Filtration of particulates from gases is one of the oldest and most widely used methods of removing particulate matter. Equipment which uses this particulate removal scheme include air sampling devices, respiratory protective equipment, filter boxes (including high-efficiency particulate air—HEPA filters) and bag houses. Particles as small as 0.01 microns can be effectively removed with fabric filters. Fabric filters require periodic cleaning to remove trapped particulates. Baghouse fabric filters can have efficiencies of greater than 99% when removing 0.5 micron particles. HEPA filters remove 95.993% by weight of particulates sizes 0.3 microns or larger.

Electrostatic precipitation uses mutually attractive forces between particles of one electrical charge and a collecting electrode of opposite charge. Both particles and aerosols can be removed from a gas stream in this way. Common electrostatic precipitator internal geometries include plate-and-wire and tube-type devices. Electrostatic precipitators have been effective over particle sizes ranging from 0.05 to 200 microns. Electrostatic precipitators typically exhibit low pressure drop (0.1 to 0.5 inches of water) and are capable of handling materials at very high temperatures (up to 1200°F).

Status: In use; commercially available.

Science/Technology Needs: Testing to determine the effectiveness of this technology for treatment of off-gases; enhancement of treatment effectiveness using sulfur/zinc impregnated filters.

Implementation Needs: Characterization of soils/sediment off-gases to determine applicability and design parameters.

Author: C. M. Goddard, 241-4383

References:

1. Remedial Action Assessment System, Version 2.1, prepared for DOE by Battelle Memorial Institute, Pacific Northwest Laboratory, 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Chemical Separation

Technology: Chemical Reduction (Hg). Chemical reduction of metals involves the lowering of the oxidation state of a metal by the addition of electrons to the atom. The reduction is pH-dependent. Depending on how well the pH is controlled, the reduction can be selective. Reducing agents include alkali metals, sulfur dioxide, sulfite salts, tin chloride, and ferrous sulfate. Reduction is more commonly applied to metals than to organics and is primarily used for reduction of hexavalent chromium, mercury, hexavalent selenium, and lead. Removal is seldom complete, producing effluent levels of from 0.5 to 1 mg/l, and the process is used for initial treatments rather than for polishing. However, two chemical reduction schemes, the Ventron sodium borohydride process (REMA-136-OZ) and the use of zinc dusts, appear to be able to improve waste waters to low ug/l mercury limits. In zinc reduction, metallic mercury forms an alloy with powdered zinc. The zinc is later recovered by heating the alloys and condensing the mercury vapors.

Status: Demonstration. In an investigation by New Jersey Zinc Company, solutions containing 10,000 ug/l of mercury were purified to 20 ug/l in 13 seconds, and to 5 ug/l in 110 seconds, by passing them through a 4.7 inch deep bed of granular zinc particles with average diameters of 2 mm. A problem with this method is the presence of residual zinc in the effluent. Some method of removing zinc will be required, adding to the cost and complexity of the system.

Science/Technology Needs: Better characterization of DOE wastes to determine mercury speciation and competing ions. Mercury metal may be produced in colloidal form, and engineering development may be required to identify optimal means of recovery.

Implementation Needs: Characterization and treatability testing is needed to determine pretreatment requirements and design parameters. A demonstration of this technology is also required.

Author: C. M. Goddard, 241-4383

References:

1. J. Michael Lanning, Aqueous Treatment Technology Review for NPDES Outfall 49, Y-12 Plant, Y-12 Development, April 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater, surface water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Physical Separation

Technology: Forager Sponge (Hg). Dynaphore, Inc., of Richmond, VA, has developed a Forager Sponge product which has been used in removing dissolved ionic mercury from water. One cubic foot of sponge will hold approximately 110 grams of mercury at saturation. The sponge is a porous open-celled sponge having a size of about 1 cm³ and containing a specialized polymer having selective affinity for certain dissolved species in aqueous solutions. Several cubes are confined within a net enclosure to form an in-ground sorption unit.

Status: Pilot. Dynaphore has conducted their own pilot studies on the product. Costs depend on the magnitude of the task, flowrate, concentration of dissolved mercury, the nature of other dissolved constituents, and whether the sponge is recycled. Generally, a one-time use of the sponge with conversion to phenolic-encapsulated mercuric would cost between \$0.60/gram and \$1.00/gram of mercury disposed of. A recycle approach might be less costly, depending on what is done with the HgCl₂ elution solution.

Science/Technology Needs: Better characterization of the wastewaters is needed to determine mercury speciation and competing ions. Regeneration/disposal options need to be explored.

Implementation Needs: Characterization and treatability testing is needed to determine pretreatment requirements and design parameters. A demonstration of this technology is also required.

Author: C. M. Goddard, 241-4383

References:

1. *A Review of Remediation Technologies Applicable to Mercury Contamination at Natural Gas Industry Sites*, Gas Research Institute, GRI-93/0099, September 1993.

EM Problem: Remedial action

Y-12 Plant Problem: Soils/sediments

Problem Area/Constituents: Mercury/Air*

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 Pt. A, B, or C as appropriate) for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Chemical Separation

Technology: Mercury Scrubbers (Air/Hg). By reacting mercury with chemicals such as sodium hypochlorite, permanganate and many others, or with a chelating agent and cupric chloride, water-soluble species of mercury are formed. As such, mercury can be removed from flue gas using conventional wet scrubbing technologies such as packed beds or spray towers. In this manner, mercury removal efficiencies of 90 to 95% have been obtained. While this technology is relatively new and little is known, it has excellent potential and may also be useful in removing other pollutants.

Because this is a wet process, cooler temperatures result, and therefore more mercury condensation occurs. This mercury condensation can improve mercury removal in both the mercury scrubber and in downstream air pollution control equipment. In addition, this technology has an excellent potential of being combined with other wet scrubbing processes to collect multiple pollutants in one step. For instance, acid-gas scrubbing and mercury removal have been combined by using a caustic scrubbing solution and a mercury scrubbing agent simultaneously. Nitrogen oxide reductions have also been demonstrated by adding bromine to the scrubber. In addition, some mercury scrubbing agents have the potential to remove NO_x without other additives.

Because this technology is basically the same as acid-gas wet scrubbers, except with different scrubbing agents, there are the same types of disadvantages as with other wet scrubbers. There are potential problems with packing fouling and gas channeling or poor liquid distribution when using packed-bed technology. Spray towers may have lower efficiency or problems with plugged nozzles. Further, if using other types of wet scrubbing technologies, the problems associated with these technologies will likely occur. A particularly difficult

*Treatment of offgases from remediation (roasting, etc.) of mercury-contaminated soils and sediments.

problem will be treatment of the mercury-containing liquids if required. Because the scrubbing liquids will likely have some salts from acid-gas neutralization, solidification and fixation of the mercury will require special processes.

Status: Predemonstration

Science/Technology Needs: Research is needed to find potential chemical reactants and to determine optimum operating conditions. Testing of various thermal treatment devices under various operating conditions is needed to demonstrate the applicability of this technology to potential treatment systems. Work to determine proper treatment and disposal of the spent scrub solution is also needed. In addition, investigation into the possibility of scrubbing other pollutants would be beneficial.

Implementation Needs: Treatability testing is needed to confirm the effectiveness of the technology and to determine the optimum wet scrubbing system.

Author: C. M. Goddard, 241-4383

References:

1. *An Assessment of Off-gas Treatment Technologies for Application to Thermal Treatment of DOE Wastes*, DOE/MWIP-1, 9/92.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater and Surface Water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Chemical Separation

Technology: Solvent Extraction (Hg). Solvent Extraction is the separation of the constituents of a liquid solution by contacting with another insoluble liquid. For example, if mercury is in solution in an aqueous liquid, it can be extracted into an insoluble organic liquid. The two liquids can be contacted in agitated vessels or columns to achieve mass transfer of mercury between the liquid phases. The liquids are then separated in quiescent vessels or settlers. If mercury is in a cationic form and no halides are present, long chain carboxylic, phosphoric or sulfonic acids may be used. Examples are oleic acid, dibutylbenzoylthiourea and dithiozone. Usually, however, $\text{Hg}(\text{OH})_2$ or HgCl_2 is present. In strong electrolyte solutions, especially halides, mercury will probably exist as an anionic complex. High molecular weight amines such as tertiary amines could be used at a low pH.

Status: Predemonstration. Solvent extraction is widely practiced industrially and an extensive variety of solvent extraction equipment is available commercially. Selection of a solvent requires complete waste characterization. Stripping the mercury from the solvent must be worked out. Contacting equipment must be matched to the system chosen and contactor hydrodynamics must be developed. Long-term stability of the solvent must be demonstrated.

Science/Technology Needs: Research is required to determine the amounts of solvent lost in the process and if the solvent can be regenerated. Need to identify low toxicity and low solubility solvents.

Implementation Needs: Testing is needed to identify the optimum solvent, contacting equipment, and determine pretreatment needs, and disposal requirements of the residue.

Author: Joseph Perona, 576-9280

References:

1. Larson, K. A. and J. M. Weincek, "Liquid Ion Exchange for Mercury Removal from Water over a Wide pH Range," *Ind. Engr. Chem. Research*, 31, p. 2714 (1992).
2. Weiss, S. and V. Grigoriev, "The Liquid Membrane Process for the Separation of Mercury from Wastewater," *J. Membrane Science*, 12, p. 119 (1982).

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater and Surface Water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Chemical Separation

Technology: Bioreduction/Purging (Hg). Reduction and volatilization of mercury in natural waters have been widely reported and appear to play a significant role in the net production of methylated mercury species and the rate of detoxification of contaminated waters. Utilization of enhanced natural microbial capacities to transform inorganic and organic mercury to volatile elemental mercury is an attractive potential wastewater treatment option. Both abiotic and biotic mechanisms of reduction are recognized. Abiotic reduction occurs as a consequence of the high potential of Hg(II) to undergo reduction to Hg(I) followed by the disproportionation of Hg(I) to Hg plus Hg(II). Biotic reduction occurs enzymatically in the presence of mercury-resistant microorganisms and may involve extracellular inorganic Hg(II) or intracellular Hg(II) cleaved from alkylated species. The product of these reactions, elemental mercury, is easily purged from water (Henry's Law Constant = 0.32 at 25 degrees C) and can be readily condensed or trapped on solid sorbents. Application of the bioreduction potential of microorganisms in wastewater treatment requires a fuller understanding of some of the environmental factors which limit or enhance this potential. Research to date has addressed the effects of substrate (mercuric ion) concentration, pH, suspended matter concentration, light, and nutrients on the process.

Status: Predemonstration (Development at Y-12 is at the bench-scale level, using bioreactors). For several years, ORNL staff have been formally and informally collaborating with staff from the EPA biotechnology group at Gulf Breeze, Florida, to explore the potential of bioreduction of mercury. Support for this work has originated mostly from the Electric Power Research Institute (EPRI) and the USEPA, but the DOE Office of Technology Development briefly supported the effort. The EPRI and EPA have been keenly interested in the Hg-contaminated site at Oak Ridge as a field laboratory for examining bioreduction. Consequently, most of the experimental work has employed water or sediment samples from Oak Ridge. In fact, one recent EPA experiment employed a microorganism isolated from East Fork Poplar Creek to evaluate bioreduction of mercury in groundwater on DOE sites, as a treatment option. Intense bioreactor work using water and sediment from upper East Fork Poplar Creek over the past year is currently being completed at the Gulf Breeze laboratory.

Preliminary conclusions from this work and from earlier studies indicate that sorptive processes are highly competitive with the bioreductive processes in Hg-contaminated aquatic systems and appear to limit the availability of mercury for bioreduction. The future of "stand alone" mercury bioreduction in wastewater treatment is uncertain, but, in combination with biosorption technology bioreduction would be promising.

Science/Technology Needs: Treatability tests are needed to confirm the applicability of the process in actual wastewater, determine design parameters, and estimate treatment costs. Important issues related to the competitive role of biosorption and process sustainability need to be resolved. Biosorption may produce Hg-contaminated sludges for disposal. No information is available about what specific conditions would have to be maintained in full-scale reactors to achieve a sustained evolution of mercury vapor. Off-gas treatment is likely to be required even though off-gas concentrations are expected to be well below regulatory thresholds.

Implementation Needs: Although the concept is relatively simple, the use of biological treatment systems inevitably require significant "life support" systems. The simplest system design would require two or more tanks or air-stripping towers with facilities for adding/monitoring nutrients. Use of biofilm technology would preclude/minimize losses of active microbial cells in a full flow-through system. Because mercury-contaminated waters at Y-12 may already possess active communities of mercury-resistant bacteria, addition and maintenance of an exogenous culture may not be required.

Author: R. R. Turner, 574-7856

References:

1. Barkay, et al., 1992, "Mercury Biotransformations and Their Potential for Remediation of Mercury Contamination," *Biodegradation*, 3:147-159.
2. Turner, et al., 1993. "Bioreduction of Mercury in Contaminated Effluents," Extended Abstracts, *Proc. American Chemical Society*, I&E Special Symposium on Emerging Technologies in Hazardous Waste Management, Sept. 27-29, 1993, Atlanta, GA. pp 38-41.
3. Hansen, C. L., and D. K. Stevens, "Biological and Physio-chemical Remediation of Mercury Contaminated Hazardous Waste," R. J. Turner and J. Labiosa, ed., *Arsenic and Mercury: Workshop on Removal, Recovery, Treatment and Disposal*. EPA/600/R-92/105, August, 1992.

EM Problem: Remedial action

Y-12 Plant Problem: Groundwater and Surface Water

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Chemical Separation

Technology: Electrowinning. Mercuric ions in solution can be reduced to the metal in an electrochemical cell. The electrochemical process of electrowinning involves passing mercury-contaminated wastewater through a porous electrode which is typically composed of carbon. Mercury is electrodeposited on the high surface area porous cathode as the solution is pumped through the electrode. It has also been demonstrated that elemental mercury can be used as the cathode opening the possibility of providing an indefinite useful electrode life. The latter arrangement is limited to removing mercury from wastewater down to the inherent solubility of elemental mercury at about 60 ppb. Nonetheless, for wastewaters that resist other treatment options, such as brines, the techniques could provide effective initial treatment. Followup treatment could involve nothing more than air purging to remove the dissolved elemental mercury in the product of the electrochemical process. Laboratory studies using porous carbon electrodes have shown removal of mercury down to about 20 ppb from solutions containing 55 ppb.

Status: Predemonstration. This concept has been discussed and evaluated in the electrochemical literature for some time, but there are few examples of application to mercury treatment in wastewater.

Science/Technology Needs: One candidate wastewater (a lithium hydroxide solution containing 50 ppm Hg), already existing at Y-12, could potentially benefit from this technology. The solution has so far resisted most conventional treatment. Treatability studies involving electrowinning should be conducted on this wastewater.

Implementation Needs: Treatability studies, including evaluation of any hazardous off-gases from the electrochemical process and alternatives for recovery of the mercury for recycle.

Author: R. R. Turner/615-574-7856

References:

1. Matlosz, M., and J. Newman. 1986 "Experimental Investigation of a Porous Carbon Electrode for the Removal of Mercury from Contaminated Brine," *Journal of the Electrochemical Society, Electrochemical Science and Technology*, **133** (9), 1850-1859.
2. Dr. Stuart Janikowski, INEL, personal communication. Author: May I have a date for this communications?

EM Problem: Remedial action

Y-12 Plant Problem: Soil contamination

Problem Area/Constituents: Mercury-contaminated soils

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Chemical Separation

Technology: In Situ Emulsification/Amalgamation. Amalgamation of elemental mercury to copper/zinc alloys utilizing biodispersants. Bacterially produced biodispersants destroy soil fines, emulsify a variety of compounds, including mercury, and facilitate the desorption of these compounds from soil. Mercury can be effectively desorbed from soil and then emulsified using biodispersants. Once desorbed, the mercury can be amalgamated rapidly and efficiently to pennies which are composed of a copper/zinc core with a thick copper coating. Penny surrogates possessing an iron core, once they are developed, will facilitate recovery of mercury from a soil slurry first by amalgamation and then by removal with a magnet. Biodispersants are crucial to this process. They allow for the desorption of the mercury from soil. Without biodispersant, soil seems to have a greater affinity for mercury than does copper and amalgamation does not occur. Additional studies using metal piping that was contaminated with mercury showed that rinsing the pipes in a biodispersant solution removed two times more mercury than washing the pipe in water or even detergent solutions. Several commercially available dispersants, (Tween 80, T.N.T., etc) were not effective in emulsifying mercury which shows the uniqueness of our bacteria found here on the Y-12 site where much of the mercury contamination can be found.

Status: Predemonstration. Laboratory studies have successfully been completed demonstrating the efficacy of biodispersants in destroying soil fines, emulsifying mercury and facilitating the amalgamation of mercury in soil slurries to copper/zinc alloys.

Science/Technology Needs: Trial field studies need to be implemented on soils contaminated with mercury. Mercury, in other than in its elemental form, must also be surveyed in the laboratory to determine the feasibility of using this technology on older samples as well as different types, of soils. BBs with an iron core and coated with an alloy matrix of copper/zinc must be manufactured and tested in the laboratory prior to field implementation.

Implementation Needs: Field studies would most easily be performed with the aid of a

cement mixer which could be filled with mercury-contaminated soil. Biodispersant would then be added to create the slurry. Copper/zinc alloy BBs (after they are manufactured) could then be added to the slurry and allowed to amalgamate to the mercury directly inside the cement mixer. This material would then be allowed to drain from the mixer and the BBs coated with mercury will be recovered with a magnet.

Equipment needs:

- small cement mixer
- large magnet
- dozer etc. to excavate mercury-contaminated soil
- production of biodispersant
- production of copper/zinc BB's with iron core
- personnel and safety equipment needed to fill and recovery mercury-contaminated soils.

Final needs:

- \$0.4M to procure all the necessary equipment and materials, produce sufficient biodispersant, and continue laboratory studies before field testing. Analytical testing of the soil slurries must also be performed to determine the degree of mercury removal.

The cost-effectiveness of this procedure must still be determined, but appears feasible considering existing methodologies.

Author: Arpad Vass/615-574-0686, R. L. Tyndall/615-574-0686

References:

EM Problem: Remedial action

Y-12 Plant Problem: Soil/Sediments

Problem Area/Constituents: Mercury

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternatives: Fixation

Technology: Immobilization using Elemental Sulfur. Elemental sulfur has been used with some success to suppress mercury vapor emissions from contaminated surfaces and soils. This "technology" was reportedly practiced in the basement of 9201-1 several years ago, following unrecovered mercury spills related to the Colex pilot plant operation on this building in the early 1950s. Similarly, sulfur impregnated carbons have better sorptive capacity for gaseous mercury than activated carbon alone. Under favorable conditions, the respective elemental forms of sulfur and mercury should react to produce mercuric sulfide, an environmentally desirable compound of low vapor pressure and solubility in which to immobilize mercury. Adding the respective redox half reactions for the oxidation of mercury and the reduction of sulfur does not yield a thermodynamically favorable net potential or free energy. However, if the redox and precipitation (formation of HgS) reactions are added, the net free energy is negative, and the reaction should proceed spontaneously.

Status: Conceptual. Laboratory tests conducted by lightly grinding a small mixture of sulfur and elemental mercury confirmed the presence of mercuric sulfide (as metacinnabar) and elemental sulfur in the mixture by X-ray diffraction analysis. Even though excess sulfur was present, the mixture yielded sample headspace mercury concentrations which saturated the vapor monitor, indicating that not all of the mercury reacted with the sulfur.

Science/Technology Needs: The high surface tension of elemental mercury and the hydrophobicity of sulfur are considered to be significant barriers to effective mixing and reaction of these reactants in an in situ application. The development of the biodispersants discussed in REMA-170-OZ, which reduce the surface tension of mercury, could greatly enhance the desired reaction with sulfur.

Implementation Needs: Field studies will be needed to demonstrate this technology once science/technology needs are developed.

Author: R. R. Turner/615-574-7856, K. S. Jones/615-576-0645

References:

PNEUMATIC FRACTURING EXTRACTION & CATALYTIC OXIDATION

REMA-600-OZ

EM Problem: Remedial action

Site Problem: Groundwater, surface water

Problem Area/Constituents: Soil/sediments contaminated with volatile and semivolatile organic compounds (VOCs, SVOCs)

Reference Requirements: Refer to "Regulatory Compliance," Volume 1, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific, they provide characteristics for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical separation

Technology: Pneumatic Fracturing Extraction (PFE) and Catalytic Oxidation. The treatment occurs by forcing compressed gas into a formation to create a fracture network. The gases are at a pressure that exceeds the normal in situ stresses present. The fractures allow air to circulate faster throughout the formation, removing VOCs. Combining PFE with a catalytic oxidation unit equipped with special catalysts then destroys halogenated organics. Also, using PFE with Hot Gas Injection (HGI), an in situ thermal process, further enhances the VOC removal rates, and the HGI can return the energy generated during catalytic oxidation to the ground. VOCs and SVOCs from within the vadose and saturated zones can be treated in both soil and rock.

Status: Demonstration. The Technology was accepted into the Environmental Protection Agency's Superfund Innovation Technology Evaluation (SITE) Program and was demonstrated to effectively remove trichloroethene (TCE) and other VOCs from a siltstone formation. The project took place in 1992 at a New Jersey Department of Environmental Protection and Energy (NSDEPE) Environmental Cleanup Responsibility ACT (ECRA) site in Hillsborough, New Jersey. Results of this first phase demonstration are documented in a Technology Evaluation Report (EPA/540/R-93/509), a Technology Demonstration Summary (EPA/540/SR-93/509), a Demonstration Bulletin (EPA/540/MR-93/509), and an Applications Analysis Report (EPA/540/AR-93/509). The PFE^(sm)/HGI technology is being demonstrated in two phases. First, the incremental benefit of each technology, which took place in New Jersey, 1992. Second, it will be integrated with groundwater recovery and the catalytic technology to evaluate long term cost benefits. A second phase demonstration will be conducted.

Waste: Pneumatic fracturing leaves some drilling residue. Gaseous waste from catalytic oxidation.

September 1994
Remedial Action

PNEUMATIC FRACTURING EXTRACTION & CATALYTIC OXIDATION

REMA-600-OZ

Efficacy: The PFE^(sm) technology increased the effective vacuum radius threefold and increased the mass removal by 25 times compared to conventional extraction technology.

Science/Technology Needs: Commercially available.

Implementation Needs:

Costs: The treatment is considered to be a cost-effective treatment method where conventional methods are limited because of low-permeability geologic formations. The cost benefit analysis for the second phase will have to be reviewed by EPA.

Author: Todd P. DiNoia, R. L. Fellows /615-576-5632

References:

1. U.S. Environmental Protection Agency, SITE Program, *Technology Profiles, Sixth Edition*, EPA/540/R-93/526, Office of Research and Development, Washington, D.C., 20460, November, 1993
2. Further Documentation: Technology Evaluation Report (EPA/540/R-93/509), Technology demonstration Summary (EPA/540/SR-93/509), Demonstration Bulletin (EPA/540/MR-93/509), Applications Analysis Report (EPA/540/AR-93/509).
3. Further Information: EPA Project Manager: Uwe Frank, U.S. EPA, Building 10, MS-104, 2890 Woodbridge Avenue, Edison, NJ 08837, Tel: 908-321-6626, Fax: 908-906-6990.

EM Problem: Remedial action

Site Problem: Soils, sediments, buried waste

Problem Area/Constituents: High- and low-BTU solid wastes, soil/sediments, buried wastes contaminated with hazardous organics

Reference Requirements: Refer to "Regulatory Compliance," Volume 1, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Incineration, PYRETRON Thermal Destruction. Incineration is the thermal destruction of hazardous wastes in the presence of oxygen for combustion. The PYRETRON thermal destruction technology controls the heat input into an incineration process using oxygen-air-fuel burners to control levels of oxygen available for oxidation. It is computer-controlled to automatically adjust temperatures in combustion chambers and the amounts of excess oxygen based on changes in volatilization rates of contaminants. It can be fitted to any conventional incineration unit to burn liquids, solids, and sludges. Also, co-incineration can be used for solids and sludges when the burner is used with a rotary kiln incinerator or any other similar unit.

Status: Demonstration. The technology was accepted into the Environmental Protection Agency's Superfund Innovation Technology Evaluation (SITE) Program in 1987 at the EPA's Incineration Research Facility in Jefferson, Arkansas. The PYRETRON thermal destruction system treated a mixture of 40% contaminated soil from Stringfellow Acid Pit Superfund Site in California and 60% of decanter tank sludge from coking operations. The treatment program concentrated on six polynuclear aromatic hydrocarbons.

Waste: The emission levels in the scrubber discharge were significantly below the hazardous waste incinerator performance standard, 180 milligrams per dry standard cubic meter at 7% oxygen. All solid residues were contaminant free. Doubling the throughput with the PYRETRON oxygen-enhanced system did not change any transient carbon monoxide levels of emissions as would be expected with air-only incineration.

Efficacy: The PYRETRON technology achieved 99.99% destruction and removal efficiencies of the contaminants in the SITE program. It achieved double the waste throughput possible in any conventional incineration and could double the capacity of a conventional rotary kiln incinerator.

Science/Technology Needs: Commercially available

Implementation Needs: NA

Costs: The treatment can achieve cost savings when oxygen costs are reduced and operating and fuel costs are high.

Author: Todd P. DiNoia, R. L. Fellows / 615-576-5632

References:

1. U.S. Environmental Protection Agency, SITE Program, *Technology Profiles, Sixth Edition*, EPA/540/R-93/526, Office of Research and Development, Washington, D.C., 20460, November 1993
2. Further Documentation: Technology Evaluation Report (EPA/540/5-89/008), Applications Analysis Report (EPA/540/A5-89/008).
3. Further Information: **EPA Project Manager:** Laurel Staley, U.S. EPA, Risk Reduction Energy Laboratory, 26 West Martin Luther King Drive, Cincinnati, OH, 45268, Tel.: 513-569-7863, Fax: 513-569-7620. **Technology Developer Contact:** Gregory Gitman, 4476 Park Drive, Norcross, GA, 30093, Tel.: 404-564-4180, Fax: 404-564-4192.

INTEGRATED VAPOR EXTRACTION AND STEAM VACUUM STRIPPING

REMA-602-OZ

EM Problem: Remedial action

Site Problem: Groundwater, soils

Problem Area/Constituents: Groundwater, surface water, and soils/sediment contaminated with volatile organic compounds (VOCs), chlorinated hydrocarbons

Reference Requirements: Refer to "Regulatory Compliance," Volume 1, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical separation

Technology: Integrated Vapor Extraction and Steam Vacuum Stripping. Both Soil Vapor Extraction (SVE) and Steam Stripping are widely known and accepted technologies to remove VOCs. ORNL Technology Evaluation Data Sheets (see references) have been created for Soil Vapor Extraction, REMA-78-OL, and Steam Stripping, REMA-77-OL, separately. AWD Technologies, Inc., integrated the two technologies to create a system, the AquaDetox/SVE system, that simultaneously treats both groundwater and soil. The system consists of a moderate vacuum stripping tower that uses low-pressure steam and an SVE process. The combination creates a closed-loop system that eliminates air emissions. The AquaDetox is a high-efficiency, countercurrent stripping unit developed by DOW Chemical Company. The SVE system uses a vacuum for soil treatment, inducing a flow through the soil and removing vapor phase VOCs with the extracted soil gas. Carbon beds remove additional VOCs from the soil gas and the two units share a granulated activated carbon (GAC) unit that decontaminates the combined vapors. The closed-loop system also incorporates a vent header unit that collects noncondensable gases and the AquaDetox unit condenses and treats the steam used to regenerate the carbon beds.

Status: Demonstration. The technology was accepted into the U.S. Environmental Protection Agency's SITE, Superfund Innovation Technology Evaluation, demonstration program in 1990 at the San Fernando Valley Groundwater Basin Superfund site in Burbank, California. An Applications Analysis Report (EPA/540/A5-91/002) was written in 1991.

Efficacy: The SITE treatment has a 99.92–99.99% removal efficiency of VOCs from groundwater and a 98.0–99.9% removal efficiency of VOCs from soil gas when using AWD specifications. The effluent groundwater produced complied with discharge regulations for TCE and PCE (5 µg/L per compound). It also reduced steam consumption with lower tower pressures and the efficiency increased as operating tower pressures decreased.

September 1994
Remedial Action

INTEGRATED VAPOR EXTRACTION AND STEAM VACUUM STRIPPING

REMA-602-OZ

Waste: The only byproducts produced are a free-phase recyclable product and treated water. In use for more than 3 years, the AWD AquaDetox/SVE system has also been treating groundwater and soil gas at the Lockheed Aeronautical Systems Company in Burbank, California. It has been operating 95% of the time to treat 1200 gpm of contaminated groundwater (2200 ppb of TCE, 11,000 ppb of PCE), and 300 cfm of contaminated soil gas (6000 ppm of VOCs).

Science/Technology Needs: Commercially available.

Implementation Needs: NA

Costs: The cost of an AWD system is estimated to be \$3.2 million for a 500-gpm system, \$4.3 million for a 1000-gpm system, and \$5.8 million for a 3000-gpm system. Total annual operation and maintenance costs are approximately \$410,000 for a 500-gpm system, \$630,000 for a 1000-gpm system, and \$1.5 million for a 3000-gpm system.

Author: Todd P. DiNoia, R. L. Fellows / 615-576-5632

References:

1. U.S. Environmental Protection Agency, SITE Program, *Technology Profiles, Sixth Edition*, EPA/540/R-93/526, Office of Research and Development, Washington, D.C., 20460, November, 1993
2. ORNL Technology Evaluation Data Sheets are in: *Oak Ridge National Laboratory Technology Logic Diagram*, R. L. Fellows, Ed., ORNL/M-2751, September 1993.
3. Further Documentation: Applications Analysis Report (EPA/540/A5-91/002)
4. Further Information: **EPA Project Manager**, Gordon Evans, U.S. EPA, Risk Reduction Engineering Laboratory, 26 West Martin Luther King Drive, Cincinnati, OH 45268 Tel.: 513-569-7684 Fax: 513-569-7620. **Technology Developer Contact**, David Bluestein, 49 Stevenson Street, Suite 600, San Francisco, CA 94105, Tel.: 415-227-0822.

EM Problem: Remedial action

Site Problem: Soil and sediment contamination

Problem Area/Constituents: Highly contaminated inorganic hazardous wastes, sludges, and soils contaminated with metals and organic wastes

Reference Requirements: Refer to "Regulatory Compliance," Volume 1, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: Cyclone Furnace or Cyclone Vitrification. The furnace is designed for the combustion of high inorganic content coal. The cyclone combines high heat-release rates (45,000 Btu/ft³ of coal) and high turbulence to achieve high temperatures required for melting high-ash fuels. The inert ash exits as a vitrified slag. For dry soil processing, the soil along with natural gas enters tangentially along the furnace barrel. For wet soil processing, an atomizer is used with compressed air to spray the soil directly into the furnace. The soil is melted to destroy organics in the gas phase or in the molten slag layer, which is retained on the barrel wall by centrifugal action. The soil melts and deposits into a water-filled slag tank where it solidifies. A baghouse collects small amounts of soil and fly ash that remains in the flue gas, and controls particulates. Therefore, a heat exchanger is needed to lower gas temperatures to approximately 200°F.

The wastes may be in the form of solids, a soil slurry, or liquids. The ash or solid matrix must be able to flow within the cyclone at temperatures of 2400 to 3000°F.

Status: Demonstration. The technology was accepted into the Environmental Protection Agency's Superfund Innovation Technology Evaluation (SITE) demonstration program in 1991 at Babcock & Wilcox Co., the developers of the furnace. The EPA supplied a wet, synthetic soil matrix (SSM) spiked with heavy metals (lead, cadmium, and chromium), organics (anthracene and dimethylphthalate), and simulated radionuclides (bismuth, strontium, and zirconium). The demonstration processed approximately 3 tons of SSM at a feed rate of 170 lb/hr.

Efficacy: The vitrified slag toxicity characteristic leaching procedure (TCLP) leachabilities passed the EPA TCLP limits at 0.29 mg/L, 0.12 mg/L, and 0.30 mg/L for lead, cadmium, and chromium, respectively. Almost 95 percent of the noncombustible SSM was incorporated into the slag where greater than 75 percent of bismuth, 88 percent of strontium, and 97 percent of zirconium was captured. Volume reduced 28 percent on a dry weight basis and destruction

and removal efficiencies were 99.997 percent for anthracene and 99.998 percent for dimethylphthalate.

Waste: The fly ash collected in the baghouse can be recycled into the furnace to increase metal capture and to minimize the volume of the potentially hazardous waste stream. Stack particulates were well below the Resource Conservation Recovery Act of 0.08 grains per dry standard cubic feet reading 0.001 grains per dry standard cubic feet at 7% oxygen. Carbon monoxide and total hydrocarbons in the flue gas were 6.0 ppm and 8.3 ppm, respectively.

Science/Technology Needs: Commercially available.

Implementation Needs: The energy requirements for vitrification are 15,000 Btu/lb of soil treated for the pilot-scale model. A full-scale unit will have proportional lower energy requirements due to the model's large surface-to-volume ratio for a relatively small unit. The cyclone furnace can burn fuels with gas, oil, or coal. Heat input could also be generated from the waste.

Costs: The costs to remediate 20,000 tons of contaminated soil using a 3.3-ton/hr unit is estimated to be \$465 per ton if on-line for 80% of the time and \$529 per ton if on-line for 60% of the time.

Author: Todd P. DiNoia, R. L. Fellows/615-576-5632

References:

1. U.S. Environmental Protection Agency, SITE Program, *Technology Profiles, Sixth Edition*, EPA/540/R-93/526, Office of Research and Development, Washington, D.C., 20460, November, 1993.
2. Further Documentation: Technology Evaluation Vol. I (EPA/540/R-92/017A), Technology Evaluation Vol. II (EPA/540/R-92/017B), Application Analysis Report (EPA/540/AR-92/017), Technology Demonstration Summary (EPA/540/SR-92/017), Demonstration Bulletin (EPA/540/MR-92/017).
3. Further Information: **EPA Project Manager**, Laurel Staley, U.S. EPA, Risk Reduction Engineering Laboratory, 26 West Martin Luther King Drive, Cincinnati, OH, 45268, Tel: 513-569-7863, Fax: 513-569-7620%**Technology Developer Contact**, Lawrence King, 1562 Beeson Street, Alliance, OH, 44601, Tel: 216-829-7576.

EM Problem: Remedial action

Site Problem: Groundwater contaminated with organics

Problem Area/Constituents: Groundwater, surface water, and process water containing chlorinated hydrocarbons, solvents, pentachlorophenol (PCP), creosote components, phenolics, gasoline and fuel oil components

Reference Requirements: Refer to "Regulatory Compliance," Volume 1, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Biological Aqueous Treatment System (BATS). The BATS uses naturally occurring microbes and/or specially developed microorganisms to treat groundwater and process water. The technique is known as microbial amendment, in which the amendment microbes remove the target contaminant and the background organic carbon. The microorganisms are immobilized in a multiple-cell, submerged, fixed-film bioreactor in which the contaminants are biodegraded. Each cell is filled with a highly porous packing material to which the microbes adhere. The system may be run under aerobic or anaerobic conditions.

Status: Demonstration. The BATS, designed by Biotrol, Inc., was demonstrated with the EPA Superfund Innovation Technology Evaluation (SITE) program in 1989 at the MacGillis and Gibbs Superfund site in New Brighton, Minnesota, on wood preservatives in groundwater.

Efficacy: During the SITE demonstration, the system reduced pentachlorophenol (PCP) concentrations from approximately 45 ppm to 1 ppm or less in a single pass and reached 96–99% removal of PCP. It ran at three different flow rates of 1, 3, and 5 gpm, which resulted in PCP concentrations of 42.0, 34.5, and 27.5 ppm for the groundwater, 6.9, 19.0, and 24.2 ppm for the influent, and 0.13, 0.34, and 0.99 ppm for the effluent, respectively. Removal efficiencies were 99.8, 98.5, and 96.4% from the groundwater and 98.1, 98.2, and 95.9% from the influent for the 1-, 3-, and 5-gpm flow rates, respectively. The difference in concentrations between the groundwater and influent is primarily the result of backmixing occurring under the underflow weirs separating chambers. As the flow increases, backmixing decreases. The process eliminated biotoxicity in the groundwater and was unaffected by low concentrations of oil and grease (50 ppm reduced to less than 10 ppm) and heavy metals. The system was not effected by total suspended solids concentrations of 54 ppm for 1 gpm, 26 ppm for 3 gpm, and 18 ppm for 5 gpm.

Waste: The water contaminants are degraded to biological end products, mostly carbon dioxide and water. Biomonitoring was used and demonstrated that acute toxicity in the raw groundwater was removed. During the SITE demonstration, no air emissions of pentachlorophenol were detected, and the system produced minimal sludge and mineralized chlorinated phenolics.

In Use: BioTrol Inc. performed a successful pilot-scale run for 9 months of BATS at a wood preserving facility during 1986-1987. Since then, BioTrol Inc. has installed over 20 full-scale units that have successfully treated gasoline, mineral spirit solvent, phenol, and creosote-contaminated waters.

Science/Technology Needs: N/A

Implementation Needs:

Costs: Operational costs for the system were estimated at \$3.45 per 1000 gal for a 5-gpm unit and \$2.43 per 1000 gal for a 30-gpm unit. Capital costs for the BATS system, not including installation or pre- and post- treatment, were estimated at \$30,000 for a 5-gpm unit and \$80,000 for a 30-gpm unit. All costs were estimated by BioTrol, Inc..

Author: Todd P. DiNoia, R. L. Fellows/615-576-5632

References:

1. U.S. Environmental Protection Agency, SITE Program, *Technology Evaluation Report - Biological Treatment of Wood Preserving Site Groundwater*, EPA/540/5-91/001, Risk Reduction Engineering Laboratory, Office of Research and Development, Cincinnati, OH, 45268, October, 1991.
2. U.S. Environmental Protection Agency, SITE Program, *Technology Profiles - Sixth Edition*, EPA/540/R-93/526, Office of Research and Development, Washington, D.C., 20460, November, 1993.
3. Further Documentation: Applications Analysis Report (EPA/540/A5-91/001), Technology Demonstration Summary (EPA/540/S5-91/001), Demonstration Bulletin (EPA/540/M5-91/001).
4. Further Information: **EPA Project Manager**, Mary Stinson, U.S. EPA, Reduction Engineering Laboratory, 2890 Woodbridge Avenue, Edison, NJ, 08837, Tel: 908-321-6683, Fax: 908-321-6640. **Technology Developer Contact:** Dennis Chilcote, 10300 Valley View Road, Eden Prairie, MN, 55344-3456, Tel: 612-942-8032, Fax: 612-942-8526.

EM Problem: Remedial action

Site Problem: Buried Waste

Problem Area/Constituents: Soil/sediments, buried wastes contaminated with heavy metals, low-level nuclear wastes, electroplating sludges

Reference Requirements: Refer to "Regulatory Compliance," Volume 1, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: Pozzolan Stabilization. In this process, pozzolanic materials react with polyvalent metal ions and other waste components to produce a chemically and physically stable solid material. The entire pozzolanic matrix, when physically cured, decreases toxic mobility by reducing the incursion of leaching liquids into and out of the stabilized matrices. Process accelerators and precipitators may be soluble silicates, carbonates, phosphates, or borates. The end product may be solid mass or similar to a clay-like soil depending on waste characteristics and the desired properties in the end product. The total volume increase is 20-50% of the raw waste.

The process works by first blending waste with pozzolanic materials containing calcium hydroxide. The reagents react with one another and toxic metal ions to form ionic metal complexes. Water soluble silicate then reacts with the waste and the pozzolanic binder system where colloidal silicate gel strengthens assisting in the fixation of polyvalent metal cations. A large percentage of the heavy metals become a part of the calcium silicate and aluminate colloidal structures formed. Some of the metals adsorb to the surface of the pozzolanic structures. The final product is discharged as a pasty mixture that is stored for a curing period. The system can be modified to treat 10-100 percent solids, and when combined with special binders and additives, it can treat low-level toxic wastes.

Status: Demonstration. The technology, designed by Chemfix Technologies, Inc., was accepted into the EPA Superfund Innovation Technology Evaluation (SITE) demonstration program in 1988 at the Portable Equipment Salvage Co. site in Clackamas, Oregon. Soil to be treated contained lead concentrations ranging between 11,000 and 140,000 mg/kg of lead and copper concentrations of 18,000-33,000 mg/kg of copper. Toxicity characteristic leaching procedure (TCLP) extracts from the raw soil showed lead ranging between 390 and 880 mg/L and copper ranging between 4 and 12 mg/L. PCB concentrations in the soil ranged from 100 to 1940 mg/kg. Soil was processed at 40-75 tons/hr, 4-7 tons from four different sample

waste areas. The Chemfix process is based on a proprietary family of polysilicates (CHEMSET C-220) and dry calcium containing reagents (CHEMSET I-20).

Efficacy: The demonstration results showed that the concentrations of copper and lead in the TCLP extracts from the treated wastes were 94–99% less than those from untreated wastes. From all tested samples, 65% met the standard of 0.51 mg/L lead in the TCLP extracts and 75% met the standard of 5.0 mg/L lead in the TCLP extract. The total lead concentrations in the untreated waste were approximately 14%. Reduction of PCB mobility could not be determined since the PCBs did not leach from the raw waste with the extraction procedure used. The treated waste showed little or no weight lost when exposed to 12 cycles of wetting and drying or freezing and thawing. The unconfined compressive strength of the pozzolanic product varied between 27 and 307 *psi* after 28 days and hydraulic conductivity ranged between 1×10^6 cm/s and 6.4×10^7 cm/s.

The technology has certain limitations and requires a defined set of waste characteristics. It is generally not applied to wastes that have a water content greater than 95% or less than 25%, oil and grease concentrations greater than 15%, waste feed material greater than 1 in. in diameter, and a pH less than 2 or greater than 12. Therefore, pretreatment is necessary for all wastes that fall into these ranges.

Waste: Waste streams, such as large particles screened during the process and water used to decontaminate personnel and equipment, must also be treated and disposed of. Air monitoring data showed no significant volatilization of PCBs during the treatment process.

The process was also used on electroplating waste, spiked with metals by Chemfix, for a small business innovation project. Concentrations of cadmium, chromium, copper, zinc, and nickel were reduced 98% and concentrations of lead were reduced 94%. However, the mobility of arsenic, barium, selenium, silver, and vanadium were not diminished and the mobility of antimony and mercury increased. Certain unspecified additives may help in the stabilization of certain leachable metals.

Science/Technology Needs: More stringent leaching or extraction tests are needed to determine the effectiveness of this process on PCBs. If the system is to be used to treat waste with significant levels of VOCs, further emissions controls may be needed, such as a negative pressure air system, to prevent releases. Technologies are also needed to treat the screened large particles and the decontamination water produced. A system of crushing the large particles to make them suitable for Chemfix treatment is one option. Soil washing and/or extraction procedures are other technologies that may be integrated.

Implementation Needs:

Costs: The equipment can only be rented from Chemfix at a cost of \$5000 per week. With an estimated process rate of 160 tons per day, over a 7 day period, the rental/lease cost is approximately \$5 per ton of raw waste. Total fixed costs are estimated at \$110,500, giving a total fixed cost per ton of waste of \$3. This estimate includes site preparation, permitting

and regulatory, Equipment installation and startup, trailer transportation to site, mobilization/demobilization, and effluent treatment and decontamination. Total variable costs per ton are estimated at \$70, which included capital equipment rent/lease, labor, Chemfix reagents, utility and miscellaneous, and analytical. Therefore, total treatment cost per ton of raw waste is approximately \$73.

Author: Todd P. DiNoia, R. L. Fellows /615-576-5632

References:

1. U.S. Environmental Protection Agency, SITE Program, *Applications Analysis Report - Chemfix Solidification/Stabilization Process*, EPA/540/A5-89/011, Risk Reduction Engineering Laboratory, Office of Research and Development, Cincinnati, OH, 45268, December, 1990.
2. U.S. Environmental Protection Agency, SITE Program, *Technology Demonstration Summary - Chemfix Solidification/Stabilization Process, Clackamas, Oregon*, EPA/540/S5-89/011, Risk Reduction Engineering Laboratory, Office of Research and Development, Cincinnati, OH, 45268, December, 1990.
3. U.S. Environmental Protection Agency, SITE Program, *Technology Profiles, Sixth Edition*, EPA/540/R-93/526, Office of Research and Development, Washington, D.C., 20460, November, 1993.
4. Further Documentation: Technology Evaluation Reports Vol. I & II (EPA/540/5-89/011 A&B) Demonstration Bulletin (EPA/540/M5-89/011a).
5. Further Information: **EPA Project Manager:** Edwin Barth, U.S. EPA, Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, OH, 45268, Tel: 513-569-7669, Fax: 513-569-7585. **Technology Developer Contact:** Sam Pizzitola, 161 James Drive West, St. Rose, LA, 70087, Tel: 504-461-0466, Fax: 504-466-9032.

COMBINED EVAPORATION AND CATALYTIC OXIDATION (PO*WW*ER TECHNOLOGY)

REMA-606-OZ

EM Problem: Remedial action

Site Problem: Groundwater contamination

Problem Area/Constituents: Groundwater, surface water, and wastewater contaminated with volatile and semivolatile organic compounds (VOCs and SVOCs), ammonia, and cyanide

Reference Requirements: Refer to "Regulatory Compliance," Volume 1, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Combined Evaporation and Catalytic Oxidation, PO*WW*ER Process. This technology uses a combined evaporation and catalytic oxidation technique to reduce the volume of an aqueous waste and to catalytically oxidize volatile contaminants. First, contaminated water is fed into an evaporator to reduce the influent wastewater volume. Contaminants are vaporized and then separated to concentrate the contaminants into a small volume for further treatment. The vapors are then passed over a catalyst and are oxidized and destroyed. Effluent vapors are treated in a scrubber to remove acid gases, depending on the composition of the wastewater. The exiting vapors are condensed to produce water that may be used in a boiler or cooling tower or discharged to surface water, if appropriate. The hazardous wastewater is thus separated into a small stream contaminated with metals and inorganics (nonvolatiles), brine, and a large clean water stream, the product condensate.

Status: In Use. Within the last couple of years, a full-scale PO*WW*ER process system was integrated as part of a waste management facility in Hong Kong.

The technology, developed by Chemical Waste Management, Inc. (CWM), was accepted into the EPA SITE demonstration program in 1991. The demonstration test took place at the CWM Lake Charles Treatment Center (LCTC) site in Lake Charles, Louisiana. During the SITE demonstration, the system treated landfill leachate contaminated with VOCs, SVOCs, ammonia, metal, and cyanide.

Efficacy: The feed waste contained average concentrations of critical VOCs between 350 and 110,000 µg/L, critical SVOCs between 6,000 and 23,000 µg/L, ammonia between 140 and 160 mg/L, and cyanide between 24 and 33 mg/L. After treatment, no concentrations of VOCs, SVOCs, ammonia, or cyanide were detected in the product condensate. The feed was also acutely toxic with median lethal concentrations below 10%. The product condensate,

COMBINED EVAPORATION AND CATALYTIC OXIDATION (PO*WW*ER TECHNOLOGY)

REMA-606-OZ

clean water stream, was nontoxic and had median lethal concentrations greater than 100% after the adjustment of pH, dissolved oxygen levels, and hardness and/or salinity.

Waste: Waste includes a small brine stream, consisting of nonvolatile metals and inorganics, and noncondensable gas vent emissions. The concentration ratio, the ratio of total solids (TS) in brine over the TS in feed waste was 32. Total solid concentration in the brine ranged between 50 and 56%. The gas emissions had average carbon monoxide emissions rates between .0011 and .00392 lbs per hour. Average sulfur dioxide emission rates less than .00055 lbs per hour, and average nitrogen oxide emission rates between .0346 and .0503 lbs per hour. These gas rates met the proposed regulatory requirements for the LCTC site.

Science/Technology Needs: N/A

Implementation Needs: A 50-gpm PO*WW*ER system occupies 4,000 square feet of land and needs approximately 50 feet of allowable height. Utilities for a 50-gpm and a 25-gpm system include electricity, 445 and 275 kilowatt hours per hour, and natural gas, 22,000 and 11,000 standard ft³ per hour, respectively. The system is useful for treating process wastewaters that produce recyclable brine. However, if the brine is not recyclable, a method for off-site treatment and disposal is needed.

Costs: Capital costs for a 50-gpm PO*WW*ER system are estimated at approximately \$4 million on a turnkey basis. Similarly, a 25-gpm unit is estimated at \$3.0 million. This includes treatability study costs; design costs; the system's components costs; all interconnecting piping, controls, and monitoring equipment; and all assembly and installation costs. Annual operating and maintenance costs were estimated at \$3.3 million for labor, consumables, utilities, analytical services, and waste disposal costs for the Superfund site. Waste disposal is approximately 70% of the annual cost. Total treatment cost was estimated for a 15-year project to be \$100 per 1,000 gal of aqueous waste treated and for a 30-year project to be \$73 per 1,000 gal of aqueous waste treated.

Author: Todd P. DiNoia, R. L. Fellows/615-576-5632

References:

1. U.S. Environmental Protection Agency, *Applications Analysis Report - CWM PO*WW*ER Evaporation-Catalytic Oxidation Technology*, EPA/540/AR-93/506, Office of Research and Development, Washington, D.C., September 1993.
2. U.S. Environmental Protection Agency, SITE Program, *Technology Profiles, Sixth Edition*, EPA/540/R-93/526, Office of Research and Development, Washington, D.C., 20460, November 1993
3. Further Documentation: Technology Evaluation Report (EPA/540/R-93/506)

4. Further Information: **EPA Project Manager:** Randy Parker, U.S. EPA, Risk Reduction Engineering Laboratory, 26 West Martin Luther King Drive, Cincinnati, OH 45268, Tel.: 513-569-7271, Fax: 513-569-7620. **Technology Developer Contact:** Annamarie Connolly, 1501 E. Woodfield Road, Suite 200 West, Schaumburg, IL 60173, Tel.: 708-706-6900, Fax: 708-706-6996.

EM Problem: Remedial action

Site Problem: Particulates in water

Problem Area/Constituents: Wastewater, groundwater and process water containing heavy metals and solids

Reference Requirements: Refer to "Regulatory Compliance," Volume 1, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Physical separation

Technology: Membrane Microfiltration. The system is designed to remove solid particles containing hazardous materials from liquid wastes. It uses an automatic pressure filter combined with a Tyvek[®] filter material made of spunbonded olefin, a thin, durable plastic fabric with tiny openings. The filter allows liquids and tiny particles to pass through as it collects any large solids. The automatic pressure filter is designed with two chambers. There is an upper chamber for feeding waste and a lower chamber for filtrate collection. Filtered solids collected on the Tyvek[®] filter form a filter cake that is then air-dried. The cake is then removed and can be collected along with the filtrate for further treatment if needed. This technology can be used for hazardous waste suspensions such as **liquid heavy metal-cyanide bearing** wastes, process waters containing uranium, and landfill leachates. It can separate any type of solid including inorganics, organics, and oily wastes.

Status: Demonstration. The technology was demonstrated at the Palmerton Zinc Superfund Site in Palmerton, Pennsylvania. The automatic pressure filter was developed by Oberlin Filter Company and the Tyvek[®] filter material was developed by E.I. DuPont De Numours & Company. It treated 6,000 gal of groundwater from a shallow aquifer contaminated with dissolved heavy metals at a feed rate of 1-2 gpm. Lime was added to adjust the pH and to precipitate some dissolved metals. Zinc was the major contaminant. A filter aid/cake stabilizing agent was also added.

Efficacy: The filtration system achieved removal efficiencies for zinc and total suspended solids (TSS) between 99.75 and 99.99%. Zinc concentrations were reduced from 400-500 mg/L to 0.1 mg/L and TSS from 6,560-18,900 mg/L to 8.4 and 31.5 mg/L. The filter cake averaged 30.5-47.1% solids. The technology is best for treating wastes with only solid concentrations less than 5,000 ppm, otherwise the cake capacity and handling become factors.

Waste: The dry filter cake produced passed the Resource Conservation Recovery Act (RCRA) paint filter liquids test. A composite filter cake sample also passed the extraction procedure toxicity (EP) and toxicity characteristic leaching procedure (TCLP) tests for metals. The filtrate produced met the National Pollutant Discharge Elimination System (NPDES) limits established for discharge for metals and TSS at a 95% confidence level. The pH level of the filtrate needed to be adjusted from 11.5 to the discharge limit of 9. The cake can be disposed of in a nonhazardous waste landfill and the filtrate can be disposed of in a local waterway.

In Use. Two units were constructed in 1991.

Science/Technology Needs: No set filter aid/cake stabilizing agent is designed for the system. The filter aid/cake stabilizing agent plays an important role in the performance of the system and should be chosen after thorough investigation of the waste characteristics and the kinds of stabilizing agents available. The agent has impacts on pH levels and can clog pumps and lines.

Implementation Needs: Thorough investigation of the waste and the selection of a filter aid/cake stabilizing agent is necessary. The waste characteristics need to be investigated thoroughly before treatment. It is important to measure the inorganic ligand concentration and properly design the pretreatment operation to properly precipitate metals. Metals may need to be oxidized or reduced prior to precipitation.

Costs: The following costs are based on the use of a 36 ft² unit that will treat approximately 8×10^6 gal per year. Capital equipment costs are estimated at \$231,800. Total one-time costs are estimated at \$1,251,200, which includes site preparation, permitting and regulatory, capital equipment, startup, fixed, and demobilization costs. Total annual operation and maintenance costs are estimated at \$549,100, which includes labor, supply and consumable, utility, monitoring, residual and waste shipping, handling, and transporting, analytical, and equipment repair and replacement costs.

Author: Todd P. DiNoia, R. L. Fellows/ 615-576-5632

References:

1. U.S. Environmental Protection Agency, SITE Program, *Applications Analysis Report - DuPont/Oberlin Microfiltration Technology*, EPA/540/A5-90/007, Risk Reduction Engineering Laboratory, Office of Research and Development, Cincinnati, OH, 45268, October 1991
2. U.S. Environmental Protection Agency, SITE Program, *Technology Evaluation Report - Site Program Demonstration of the DuPont/Oberlin Microfiltration Technology*, EPA/540/5-90/007, Risk Reduction Engineering Laboratory, Office of Research and Development, Cincinnati, OH, 45268, March 1992
3. U.S. Environmental Protection Agency, SITE Program, *Technology Profiles, Sixth Edition*, EPA/540/R-93/526, Office of Research and Development, Washington, D.C., 20460, November 1993

4. Further Information: **EPA Project Manager:** John Martin, U.S. EPA, Risk Reduction Engineering Laboratory, 26 West Martin Luther King Drive, Cincinnati, OH, 45268, Tel.: 513-569-7758, Fax: 513-569-7620. **Technology Developer Contact:** Ernest Mayer, P.O. Box 6090, Newark, DE 19714-6090, Tel.: 302-366-3652, Fax: 302-366-3220.

EM Problem: Remedial action

Site Problem:

Problem Area/Constituents: Wastewaters, aqueous and oily waste streams contaminated with polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), chlorinated dioxins and dibenzofurans, chlorinated solvents, chlorobenzenes, chlorophenols.

Reference Requirements: Refer to "Regulatory Compliance," Volume 1, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Gas-phase chemical reduction. The process uses gas phase reduction of organic and chlorinated organic compounds with hydrogen at elevated temperatures to convert aqueous and oily hazardous contaminants into a hydrocarbon rich gas product. The reduction takes place in a reactor as nozzles inject in a mixture of atomized waste, steam, and hydrogen. The temperature is raised to approximately 850° Celsius as the mixture swirls down through a central ceramic tube, over electrical glo-bar heaters. The reduction takes place as gases enter the tube and then flow toward a scrubber where hydrogen chloride, heat, water, and particulate matter is removed. Primary components of the scrubber's gas product are hydrogen, nitrogen, methane, carbon monoxide, water vapor, and other light hydrocarbons. When processing low organic content waste, 95% of the hydrogen-rich gas is recirculated through the reactor, the remaining 5% can be used as a supplementary fuel to produce steam. Processing high organic content waste produces excess gas that may be compressed and stored for later analysis and disposal.

Status: Demonstration. The technology was demonstration at the Middleground Landfill in Bay City, Michigan, under a Toxic Substances Control Act (TSCA) research and development permit. The waste feeds used were (1) a wastewater with an average PCB concentration of 4,600 ppm and (2) *a waste oily* containing an average of 24.5% PCBs.

Efficacy: During the test, 99.9999% destruction and removal efficiencies were achieved for PCBs and a 99.99% destruction efficiency was achieved for tetrachloroethene, a tracer compound. There was also net destruction of trace feedstock dioxin and furan compounds.

Waste: hydrogen, nitrogen, methane, carbon monoxide, water vapor, and other light hydrocarbons.

Science/Technology Needs: Commercially available

Implementation Needs: NA

Costs: Not Available

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References:

1. U.S. Environmental Protection Agency, SITE Program, *Technology Profiles, Sixth Edition*, EPA/540/R-93/526, Office of Research and Development, Washington, D.C., 20460, November 1993
2. Further Information: **EPA Project Manager:** Gordan M. Evans, U.S. EPA, Risk Reduction Engineering Laboratory, 26 West Martin Luther King Drive, Cincinnati, OH, 45268, Tel.: 513-569-7684, Fax: 513-569-7620. **Technology Developer Contact:** Jim Nash, 143 Dennis Street, Rockwood, Ontario NOB 2KO, Tel.: 519-856-9591.

EM Problem: Remedial action

Site Problem: Soil/sediment contaminated with heavy metals and organics

Problem Area/Constituents: Soil/sediment contaminated with heavy metals and organics

Reference Requirements: Refer to "Regulatory Compliance," Volume 1, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: Dechlorination and immobilization. This technology immobilizes heavy metals by mixing hazardous wastes with cement (or fly ash), water and "Chloranan," a patented reagent. The treatment reagents dechlorinate certain chlorinated organics. Chloranan is added to water in a blending unit that then mixes in waste. Cement or fly ash is next added and after approximately 12 hours, the material hardens into a concrete-like mass.

Status: Demonstration. The technology was accepted into the EPA SITE demonstration program in 1987 at a former oil processing plant in Douglasville, Pennsylvania. Soil to be treated contained high levels of oil and grease, 25,000 ppm, and heavy metals, 22,000 ppm. Low levels of VOCs, 100 ppm, and PCBs, 75 ppm, were also present. The technology has also been used to remediate a California Superfund site with zinc levels as high as 220,000 ppm.

Since 1987, the technology has been enhanced with the addition of 17 reagent formulations to dechlorinate PCBs, ethylene dichloride, trichloroethene, and pentachlorophenol.

Efficacy: The toxicity characteristic leaching procedure (TCLP) results of the stabilized wastes were very low with concentrations of metals, VOCs, and SVOCs below 1 ppm. Lead leachate concentrations decreased by a factor of 200 to below 100 ppb while VOC and SVOC concentrations in the TCLP leachate were not affected by treatment. Oil and grease concentrations increased in the TCLP leachate from below 2 ppm before treatment to 4 ppm after treatment.

Waste: The treated waste, a cement-like mass, recorded unconfined compressive strength (UCS) between 220 and 1,570 psi, and low permeabilities (1×10^9 cm/sec). Durability tests showed no changes after many freeze and thaw cycles. The waste volume increased 120%; however, new refinements now limit the volume increase to 15-25%.

Science/Technology Needs: Commercially available.

Implementation Needs: NA

Costs: Not available

Author: Todd P. DiNoia, R. L. Fellows/615-576-5632

References:

1. U.S. Environmental Protection Agency, SITE Program, *Technology Profiles, Sixth Edition*, EPA/540/R-93/526, Office of Research and Development, Washington, D.C., 20460, November 1993
2. Further Documentation: Technology Evaluation Report (EPA/540/5-89/001a), Applications Analysis Report (EPA/540/A5-89/001)
3. Further **Information: EPA Project Manager**, Paul dePercin, U.S. EPA, Risk Reduction Engineering Laboratory, 26 West Martin Luther King Drive, Cincinnati, OH, 45268, Tel.: 513-569-7797, Fax: 513-569-7620. **Technology Developer Contact:** Ray Funderburk, Route 1 Box 250, Oakwood, TX, 75855, Tel.: 903-545-2004, Fax: 903-545-2002

EM Problem: Remedial action

Site Problem: Organics in soil

Problem Area/Constituents: Soil/sediment contaminated with metals, organics, cyanides, corrosives, inorganics, PCBs, phenols, and volatiles.

Reference Requirements: Refer to "Regulatory Compliance," Volume 1, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Circular Bed Combustor (CBC). This technology uses high velocity air to circulate solids and create a highly turbulent combustion zone to destroy toxic hydrocarbons. The high turbulence produces a uniform temperature around the combustion chamber and hot cyclone, completely mixing waste materials. It operates at low temperatures, 1450–1600° Fahrenheit, to reduce emissions and operating costs. An auxiliary fuel such as natural gas, fuel oil, or diesel, is needed unless the waste stream has a net heating value greater than 2900 Btu/lb. Limestone is also fed in with waste to neutralize acid gases. Ash produced is removed by a conveyor belt and hot gases produced are cooled and passed through a bag house before being discharged to the atmosphere. The CBC can treat contaminated liquids, slurries, solids, and sludges.

Status: Demonstration. The CBC technology was demonstrated in 1989 to treat wastes from the McColl Superfund Site in California.

Efficacy: Destruction removal efficiencies were 99.99% for principal organic hazardous constituents.

Waste: Emissions met the Research Facility permit conditions and California South Coast Basin emission standards. Residual materials, such as fly ash and bed ash, were nonhazardous and there were no significant levels of hazardous organic compounds detected in the ash or exiting gases.

Science/Technology Needs: Unknown

Implementation Needs: Not Available

Costs: Not available

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References:

1. U.S. Environmental Protection Agency, SITE Program, *Technology Profiles, Sixth Edition*, EPA/540/R-93/526, Office of Research and Development, Washington, D.C., 20460, November 1993
2. Further Information: **EPA Project Manager:** Douglas Grosse, U.S. EPA, Risk Reduction Engineering Laboratory, 26 West Martin Luther King Drive, Cincinnati, OH, 45268, Tel.: 513-569-7844, Fax: 513-569-7676. **Technology Developer Contact:** Jeffery Broido, 3550 General Atomics Court, San Diego, CA, 92121-1194, Tel.: 619-455-4495, Fax: 619-455-4111

EM Problem: Remedial action

Site Problem: Organics in soils

Problem Area/Constituents: Soils and sediment contaminated with organics

Reference Requirements: Refer to "Regulatory Compliance," Volume 1, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Destruction

Technology: Infrared Thermal Destruction. The technology uses electrically powered silicon carbide rods to heat organic wastes to combustion temperatures. The system is made up of four main components: an electrically powered infrared primary chamber, a gas-fired secondary combustion chamber, an emissions control system, and a control center. The system can treat soils or sediments with organic contaminants. Waste is fed into the primary chambers where it is heated to approximately 1850° Fahrenheit. Air is delivered by a blower to control oxidation rates. Ash is produced, quenched with a **scrubber water effluent**, then conveyed to an ash hopper to be removed and stored for analysis. Volatile gases produced are fed into a secondary chamber that uses higher temperatures, residence times, turbulence, and supplementary energy for destruction. Gases exiting this chamber are sent through an emissions control system, which removes particulates using a venturi scrubber and neutralizes acid vapors in a packed tower scrubber. Clean gases are then blown into an exhaust stack, scrubber liquid effluents go into a clarifier, and scrubber sludges settle out for disposal. Liquid is sent through an activated carbon filter before discharge.

Status: Demonstration. The EPA SITE program evaluated the technology, developed by Shirco Infrared Systems, Inc. , twice. First, a full-scale unit that treated 7,000 cubic yards of waste oil sludge contaminated with PCBs and lead was treated at the Peak Oil Site in Brandon, Florida, . Second, a pilot-scale demonstration that treated soil contaminated with organics, PCBs, and metals was conducted at the Rose Township Demode Road Superfund Site in Michigan, .

At the Peak Oil Superfund Site, total sludge concentrations were 3.48–5.85 after mixing **original oily wasting** having 100 ppm of PCBs with clean soil, lime, and sand. Also present were several metals, such as aluminum, iron, lead, and zinc exceeding 1000 ppm, and several VOCs and SVOCs. PCBs in the furnace ash ranged between 0.007 and 0.900 ppm. EP Tox results for lead in the leachate ranged from 24 to 57 ppm for the feed and from 25 to 46 ppm for the furnace ash. The TCLP results ranged from 2.5 to 35 ppm for the feed and 0.008 to

0.84 ppm for the ash. The differences in these tests are a result of different procedures and alkalinity of the matrix.

At the Rose Township Demode Road Superfund Site, waste contained 626 ppm of PCBs, 560 ppm of lead, 55 ppb of tetrachlorodibenzo-p-dioxin (TCDD), and 4.2 ppb of tetrachlorodibenzofuran (TCDF). In addition to lead, which ranged between 290 and 3,000 ppm, there were several other heavy metals present with concentrations greater than 50 ppm. VOCs and SVOCs were present in some samples. Heavy metals remained in concentrations greater than 50 ppm in the furnace ash and PCBs ranged from 0.004 to 3.396 ppm in the furnace ash. Some TCDF remained in the ash only from low temperature (90° Fahrenheit) test runs.

Efficacy: Results from the two SITE demonstrations showed reductions in PCBs to less than 1 ppm in the ash, with a destruction removal efficiency (DRE) for air emissions of 99.99%.

Waste: Only in the pilot-scale demonstration at Rose Township Demode Road Superfund Site was the Resource Conservation and Recovery Act (RCRA) standard of 180 mg per dry standard cubic meter achieved for particulate emissions. At this site, total metals analyses of the feed, furnace ash, PCC off gas and stack-gas particulates, scrubber makeup water, scrubber water, and scrubber solids showed that most of the detectable metals that entered with the feed, including lead, remained in the furnace ash. Acid gas removals, for HCl emissions, achieved 99% and **showed to meet the RCRA performance standard** of 1.8 kg/hr.

In the other demonstrations, the technology can meet both RCRA and TSCA DRE requirements for air and particulate emissions, based on some optimal conditions. Optimal waste characteristics that are recommended for treatment include particle sizes between 5 microns and 2 in., moisture content up to 50% by weight, 30-130 lbs/ft³ of density, a heating value of 10,000 Btu/lb, chlorine and sulfur contents each below 5% by weight, phosphorus below 300 ppm, alkali metals below 1% by weight, and a pH between 5 and 9. From demonstrations, chlorine levels are an important factor to be maintained.

This technology has also been used to remediate PCB contamination at the Florida Steel Corporation Superfund Site and at the LaSalle Electric Superfund Site. At LaSalle, the unit used at the Peak Oil Site was newly modified and shown to run more efficiently. Shirco Infrared Systems, Inc., has produced a mobile unit of the system.

Science/Technology Needs: Not known

Implementation Needs: An evaluation of the waste characteristics, to meet optimal conditions, must be performed before the use of this technology.

Technology Integration: Gas-fired combustion and emissions scrubbing are other technologies needed for infrared thermal destruction.

Costs: Overall waste remediation costs are estimated to be \$800 per ton.

Author: Todd P. DiNoia, R. L. Fellows/615-576-5632

References:

1. U.S. Environmental Protection Agency, SITE Program, *Applications Analysis Report - Shirco Infrared Incineration System*, EPA/540/A5-89/010, Office of Research and Development, Washington, D.C., 20460, June 1989.
2. U.S. Environmental Protection Agency, SITE Program, *Technology Profiles, Sixth Edition*, EPA/540/R-93/526, Office of Research and Development, Washington, D.C., 20460, November 1993
3. Further Documentation: Technology Evaluation Reports (EPA/540/5-88/002a) and (EPA/540/5-89/007a), Applications Analysis Reports (EPA/540/A5-89/010) and (EPA/540/A5-89/007).
4. Further Information: **EPA Project Manager:** Laurel Staley, U.S. EPA, Risk Reduction Engineering Laboratory, 26 West Martin Luther King Drive, Cincinnati, OH, 45268, Tel.: 513-569-7863, Fax: 513-569-7620. **Technology Developer Contact:** Gruppo Italimpresse, Rome, 011-39-06-8802001, Padova, 011-39-049-773490.

EM Problem: Remedial action

Site Problem: Inorganics, organics in groundwater within low permeability geologic media

Problem Area/Constituents: Mobile contaminants in soil/sediment and groundwater

Reference Requirements: Refer to "Regulatory Compliance," Volume 1, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Retrieval

Alternative: Physical/chemical separation enhancement

Technology: Hydraulic Fracturing Technology. This technology is a physical process that creates sand-filled fractures in low permeability media to enhance fluid and vapor flow. It was designed to enhance remediation in low-permeability geological formations performed by other treatment processes such as soil vapor extraction (SVE), soil washing, bioventing, in situ bioremediation, or pump and treat systems. Through hydraulic pressurization at the base of a borehole, fractures are created at discrete depths increasing the effective area for remediation. Fractures may be created in both rock and relatively uniform silt clays that have low permeability and are overconsolidated. Clays are overconsolidated when the vertical stress is less than the horizontal stress. This technology is ineffective in normally consolidated clays. Overconsolidated clays allow the fractures to be placed perpendicular to the well. Fractures are usually 1 in. in width and can be as large as 50-60 ft in diameter.

Status: In Use. Hydraulic fracturing has been successfully used within the oil industry to enhance oil recovery from deep, low permeability rock formations. A company, FRX, has recently been formed by the University of Cincinnati for commercial use of hydraulic fracturing for remediation. It has been used for contaminants up to depths of 40 ft below ground surface (bgs). The technology was used in Texas, in swelling clays, to allow the free product recovery of groundwater contaminants that were unrecoverable without the fracturing technology. Currently, a detailed manual of the system is being produced.

The hydraulic fracturing technology was developed by the University of Cincinnati and the EPA Risk Reduction Engineering Laboratory, and has been demonstrated by the EPA SITE program at two different sites. First, it was integrated with two-phase SVE in Oak Brook, Illinois, at the Xerox Oak Brook Site. This site contained contaminants consisting of trichloroethene (TCE); 1,1,1-trichloroethane (TCA); 1,1-dichloroethane (DCA); perchloroethane (PCE); ethyl benzene; toluene; and xylene in silty clay till to depths of 20 ft bgs. Fractures were created to depths of 6, 10, and 15 ft bgs. It increased the vapor flow rate by approximately 1 order of magnitude compared with unfractured wells, significantly reducing

the number of wells needed for remediation. Vapor discharge was 15–30 times greater and the contaminate mass recovery rate was 7–14 times greater than in unfractured wells.

This technology was also integrated with in situ bioremediation in Dayton, Ohio, at the Dayton Site. This site contained benzene, ethyl benzene, toluene, and xylene concentrations ranging up to 622, 3,800, 10,400, and 41,900 µg/L, respectively. It also including a total petroleum hydrocarbon (TH) compounds in concentrations from 32–8,550 µg/L, and total lead concentrations from 21–150-µg/L. Fractures were created at depths between 5 and 12 ft bgs. Fluid flow rates were increased by 25–40 times higher in fractured wells compared with unfractured wells. Fluid flow increased moisture content 1.4–4 times greater around the fractured wells, reducing hydrocarbon concentrations around the fractured wells compared with no decrease in concentrations around unfractured wells.

Science/Technology Needs: Current research is being done at the University of Cincinnati to improve the efficiency of implacing fractures and to identify new materials and compounds for filling fractures, such as graphite and electrode fillers. Electrically conductive materials will possibly enable electroosmosis, electrophoresis, or electromigration of contaminants.

Implementation Needs: Certain conditions need to be evaluated for site remediation with this technology. The soil should be tested to determine if it is overconsolidated. If using SVE, the soil should be tested to see if unsaturation permits the flow of vapor through the fractured wells. Also, a determination should be made as to whether any sand or soft clay lenses produce steeply dipping fractures that vent to the ground surface.

Costs: Capital cost of hydraulic fracturing equipment is estimated to be \$92,000 and cost for rental equipment is estimated at \$1,000 per day. Total one-time costs, including permitting, regulation and demobilization, are estimated at \$5,400. Total daily costs, including site preparation, capital equipment rental, startup, labor, analytical and monitoring, are estimated at \$5,700. Estimated cost per fracture is \$950–\$1,425; however, this price is currently being reduced to approximately \$600 per fracture.

Author: Todd P. DiNoia, R. L. Fellows/615-576-5632

References:

1. U.S. Environmental Protection Agency, SITE Program, *Applications Analysis and Technology Evaluation Report- Hydraulic Fracturing Technology*, EPA/540/R-93/505, Office of Research and Development, Washington, D.C., 20460, September 1993.
2. U.S. Environmental Protection Agency, SITE Program, *Technology Profiles, Sixth Edition*, EPA/540/R-93/526, Office of Research and Development, Washington, D.C., 20460, November 1993.
3. Further Documentation: Technology Demonstration Summary (EPA/540/SR-93/505).

4. Further Information: **EPA Project Manager:** Naomi Barkley, U.S. EPA, Risk Reduction Engineering Laboratory, 26 West Martin Luther King Drive, Cincinnati, OH, 45268, Tel.: 513-569-7854, Fax: 513-569-7620. **Technology Developer Contact:** Larry Murdoch, 1275 Section Road, Cincinnati, OH, 45237-2615, Tel.: 513-556-2526

 