SCFA LEAD LAB TECHNICAL ASSISTANCE AT OAK RIDGE Y-12 NATIONAL SECURITY COMPLEX:

EVALUATION OF TREATMENT AND CHARACTERIZATION ALTERNATIVES OF MIXED WASTE SOIL AND DEBRIS AT DISPOSAL AREA REMEDIAL ACTION (DARA) SOLIDS STORAGE FACILITY (SSF)

SCFA Technical Assistance Request #136
Oak Ridge, TN
July 17-18, 2002

Disclaimer

EXECUTIVE SUMMARY

On July 17-18, 2002, a technical assistance team from the U.S. Department of Energy (DOE) Subsurface Contaminants Focus Area (SCFA) met with the Bechtel Jacobs Company Disposal Area Remedial Action (DARA) environmental project leader to review treatment and characterization options for the baseline for the DARA Solids Storage Facility (SSF). The technical assistance request sought suggestions from SCFA's team of technical experts with experience and expertise in soil treatment and characterization to identify and evaluate 1) alternative treatment technologies for DARA soils and debris, and 2) options for analysis of organic constituents in soil with matrix interference. Based on the recommendations, the site may also require assistance in identifying and evaluating appropriate commercial vendors.

The technical assistance team was composed of leading technical experts from Oak Ridge National Laboratory and other national labs and was assembled by SCFA's Lead Lab in response to a technical assistance request from Paula Kirk, Environmental Technology Manager for Bechtel Jacobs Company, and David Adler, DOE-Oak Ridge Operations Y-12 Project Manager (Technical Assistance Request #136, attached as Appendix A). A list of the technical assistance team members and contact information for all meeting participants are provided in Appendix B. Background information on the expertise of each technical assistance team member is in Appendix C.

On the morning of July 17, Holly Clancy, Bechtel Jacobs Company DARA SSF project manager, led a team of experts from the site in giving presentations to the technical assistance team on the history, regulatory issues, stakeholder concerns, schedule, design and construction, soil characterization and analysis, and remediation alternatives that had been evaluated. The team was provided a tour and inspection of the facility. The team then identified the critical and unresolved issues that might affect characterization and remediation of the site and then developed a technology matrix of remediation alternatives (see Appendix D). On July 18, the team refined the critical and unresolved issues and the technology matrix and presented its initial findings to the customer in a closeout session.

The DARA SSF was constructed in early 1989 as part of the Resource Conservation and Recovery Act (RCRA) Closure and Post Closure Actions program. It was built to store contaminated sediments and excavation wastes generated during closure of the oil retention ponds in the Bear Creek burial grounds. Materials ranged from unsaturated to oversaturated sediments contaminated with polychlorinated biphenyls (PCBs), volatile organic compounds (VOCs), and uranium. The DARA SSF consists of a below-grade reinforced concrete vault 171 ft long, 76 ft wide, and 10 ft deep. The concrete bottom is lined with dual synthetic membranes separated by a liquid collection system for leak detection. An above-grade sheet-metal building covers the vault. Ceiling fans constantly ventilate the building. The vault was filled to its 4000 yd^3 capacity shortly after construction was completed. The pile is drained by two sumps at the east and west ends of the building. Liquid from the pile was pumped to the adjacent DARA Liquids Storage and Treatment Unit. The soil in the pile dried out within 6 months and little or no leachate has been detected since. The building also includes 50 yd^3 of debris from closure activities that are stored on the internal ramp.

The waste in the facility is regulated under RCRA Part A interim status as a waste pile and contains F001, F002, F005, and F039 waste. The plan is to close the waste pile under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in compliance with RCRA Applicable, Relevant and Appropriate Requirements. The Record of Decision for Phase I activities in Bear Creek Valley was signed in June 2000 and includes closure of the facility, removal of DARA soils, and disposal at an off-site commercial facility. The DARA SSF is also regulated as a Toxic Substances Control Act PCB Storage Area.

During Fall 2000, an extensive sampling and analysis program was conducted to characterize contaminated soil and debris in the facility. The sampling and analysis demonstrated high concentrations of PCBs in some areas and some hits of the pesticide Endrin; however, the data were inconclusive for many other semi-volatiles because matrix interference did not allow the laboratory to achieve the required detection limits. The lifecycle baseline cost estimate for off-site treatment and disposal of the mixed waste was estimated at more than $28 million (cost estimate for treatment alone was $14.7 million). Since the initial cost analysis, the CERCLA onsite disposal facility (the Environmental Management Waste Management Facility (EMWMF)) has opened and is receiving waste for disposal. If the DARA SSF waste is treated to meet the Land Disposal Restrictions (LDR) treatment standards, it could be treated for organic contaminants and disposed of in the EMWMF at a much lower cost.

The technical assistance team identified several critical and unresolved issues related to the DARA SSF. Critical issues are overriding factors that will guide the remediation of the facility, while unresolved issues are questions that must be addressed before selecting the final remediation strategy.

Critical Issues

1. Closure of this facility is currently a low priority because the contaminated material is contained and represents little risk.
2. The baseline estimate of total lifecycle costs is high at $28+ million, projected to 2007 dollars.
3. The DARA soils are a mixed waste with uranium, PCBs, and other hazardous organics.
    a. It is uncertain whether the waste meets the treatment standard for F-listed solvents due to detection limits above the treatment standard.
    b. The waste does not meet the LDR treatment standard for F039.
    c. The waste may also be characteristic for Endrin (D012) and other D-listed organics and probably does not meet the LDR treatment standard for those wastes.
    d. The waste must meet LDR treatment standards prior to land disposal.
    e. The alternative soil treatment standards under LDR are applicable to the DARA soils, allowing treatment to 10 times the Universal Treatment Standards level.
    f. The alternative debris treatment standards under LDR are applicable to the DARA debris, allowing the use of macroencapsulation technologies.

Unresolved Issues

1. The regulatory driver for treatment requires resolution to determine the appropriate treatment standards that must be met prior to disposal. If both the F039 and the D codes can be removed and/or are inappropriate and the waste met the F-listed solvent treatment standards, then the soils could be disposed without treatment.
2. It is unclear whether the F039 code can be removed from the DARA soils.
    a. If not, it should be determined whether the pile of F039 waste under the ramp can be removed from the bulk of the DARA soils, taking the F039 classification with it for the bulk of the waste.
    b. Any changes require regulatory concurrence.
    c. The site has investigated this option and may have already decided that the effort outweighs the benefits.
3. If the F039 code can be removed, it should be clarified whether the waste meets the treatment standard for F-listed solvents and should the waste carry D-codes, such as for Endrin (D012).
    a. This only drives the treatment standards if waste is shipped off-site for treatment or the F039 code can be removed.
    b. Are the data reported for the F-listed solvents above the treatment standards and the Endrin and other D-listed organics really above the characteristic levels?
    c. Are they representative of the bulk of DARA soils?
    d. This may require resolution of matrix interference levels for semi-volatile organic analysis.
4. It must be determined whether treatment at the East Tennessee Technology Park (ETTP) by a commercial vendor (Perma-Fix) causes the DARA soils to lose their CERCLA designation, precluding their disposal at the Oak Ridge CERCLA disposal facility.
5. Uranium-235/238 concentration data should be reanalyzed and clarified.
6. Whether leakage from the liners reaches the environment should be determined. The issue is that assurances are needed that adding moisture during in situ treatment will not create a hydraulic force driving contamination to the environment. Even if there are leakage pathways, there are ways to control leakage through engineering controls (e.g., controlling the amount of moisture being added and monitoring the leachate collection system beneath the building).
7. The operability of the sumps in the DARA SSF must be evaluated.

Remediation Technology Matrix

An array of biological, chemical, and physical remediation technologies were considered in a matrix evaluation (see Appendix D). Each technology was compared and ranked using the following criteria: effectiveness, permitting risk, implementability, health and safety issues, cost, stakeholder acceptability, long-term acceptability, technical maturity, and the generation of secondary waste. The recommended technologies considered in rank order were: aerobic bioremediation, low-temperature thermal desorption, thermal vacuum desorption, onsite disposal with treatment (Perma-fix), anaerobic bioremediation, chemical oxidation (using permanganate, Fenton's reagent, or peroxide), chemical reduction (using iron, inorganic alkali, or nucleophilic reagents), solvent extraction, thermal soil vapor extraction, and off-site disposal (the current baseline). Electrochemical treatment and stabilization (microencapsulation) were also considered but not recommended. On-site disposal at the EMWMF after treatment was deemed to be the best overall strategy. Aerobic bioremediation using a layered and phased removal was believed to provide significant advantages in nearly all criteria over all the other technologies considered.

The technical assistance team provided additional information to the site, including technology brochures from vendors, websites, and other reports and references. A list of these items is included in this report as Appendix E.

Characterization

The matrix interference that was observed in the Fall 2000 sampling for the semi-volatiles is an issue that is not easily addressed. The team felt that since none of the organic components identified were more recalcitrant than the PCBs, matrix interference might not represent a significant issue in terms of the remediation or treatment used. However, it may need to be readdressed in subsequent analyses after treatment intervals. Laboratories equipped to do column chromatography cleanup of extracts might be able to minimize the suspected interferences, although the additional sample preparation is expected to increase analytical costs. The team felt that successful treatment of the PCB contaminants should degrade the heavy oils, which are the likely source of matrix interference, and allow successful analysis of the waste to demonstrate compliance with the LDR treatment standards. Only if the recommended treatment process is not undertaken or fails, should significant efforts be made to resolve the characterization issues.

Recommendations

1. The debris on the ramp should be sized as necessary, macroencapsulated, and sent to the EMWMF when time and money permit.
2. Characterization of the matrix interference issues should be re-examined, if necessary when verifying compliance with treatment standards post-treatment. A silica gel column chromatography cleanup step such as SW-846 Method 3630C could be employed by the contractor to solve the matrix problem.
3. A regulatory issue to be evaluated is whether the F039 code can be eliminated through the removal of the F039 waste pile under the ramp. If this is possible, then further efforts should be made to resolve the questions of whether the F-listed solvent treatment standards have been met for the application of the D-codes for Endrin and the other Toxicity Characteristic Leaching Procedure organics. This could represent a large cost savings in terms of regulatory drivers because it could mean no treatment is necessary. If resolution of these issues presents significant regulatory challenges and increases cost and schedule, the site should consider defaulting to the LDR Alternative Soil Treatment standards.
4. As soon as possible, the first phase of aerobic bioremediation of the soils in the vault should be implemented. A surface soil moisture control system should be installed to keep the upper two to three feet of soil in the facility moist and biologically active. Amendments should be tilled or plowed into the upper two to three feet of soil.

Agricultural fertilizer, e.g. manure, would provide the best source to activate the soil to degrade organic components. The site should till or plow monthly or bimonthly to aerate the soil. After one year, effectiveness should be evaluated and the upper two to three feet of soil should be removed to the EMWMF. The site should repeat this process for the next two to three feet. Within three years, all the soil in the facility should be remediated at a very low life-cycle treatment cost (e.g. less than $1 million). The facility could then be reclaimed for other purposes or used to provide a long-term facility for low-cost treatment of mixed waste from other parts of Y-12. This solution could be implemented and evaluated for a year without a large financial commitment.

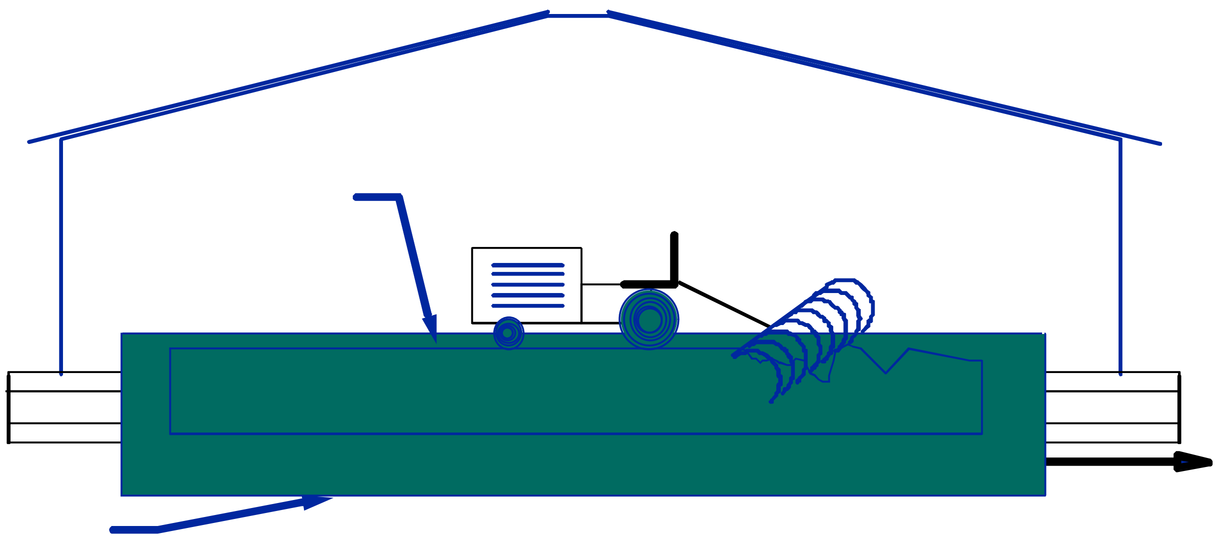

Figure 1. Aerobic bioremediation of the soils with plowing or tilling is the recommended remediation strategy for the DARA SSF.

1.0 BACKGROUND

1.1 Technical Assistance Process

On July 17-18, 2002, a technical assistance team from the U.S. Department of Energy (DOE) Subsurface Contaminants Focus Area (SCFA) met with the Bechtel Jacobs Company Disposal Area Remedial Action (DARA) Environmental project leader to review treatment and characterization options for the baseline for the DARA Solids Storage Facility (SSF). The technical assistance request sought suggestions from SCFA's team of technical experts with experience and expertise in soil treatment and characterization to identify and evaluate 1) alternative treatment technologies for DARA soils and debris, and 2) options for analysis of organic constituents in soil with matrix interference. Based on the recommendations, the site may also require assistance in identifying and evaluating appropriate commercial vendors.

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On the morning of the first day, Holly Clancy, Bechtel Jacobs Company DARA SSF project manager, led a team of experts from the site in giving presentations to the technical assistance team on the history, regulatory issues, stakeholder concerns, schedule, design and construction, soil characterization and analysis, and remediation alternatives that had been evaluated. The team was provided a tour and inspection of the facility. The team then identified the critical and unresolved issues that might affect characterization and remediation of the site and then developed a technology matrix of remediation alternatives. During the second day, the team refined the critical and unresolved issues and the technology matrix and presented its initial findings to the customer in a closeout session.

1.2 DARA SSF History

The DARA SSF was constructed in early 1989 as part of the Resource Conservation and Recovery Act (RCRA) Closure and Post Closure Actions program. It was built to store contaminated sediments and excavation wastes generated during closure of the oil retention ponds in the Bear Creek burial grounds. Materials ranged from unsaturated to oversaturated sediments contaminated with polychlorinated biphenyls (PCBs), volatile organic compounds (VOCs), and uranium. The DARA SSF consists of a below-grade reinforced concrete vault 171 ft long, 76 ft wide, and 10 ft deep. The concrete bottom is lined with dual synthetic membranes separated by a liquid collection system for leak detection. An above-grade sheet-metal building covers the vault. Ceiling fans constantly ventilate the building. The vault was filled to its 4000 yd^3 capacity shortly after construction was completed. The pile is drained by two sumps at the east and west ends of the building. Liquid from the pile was pumped to the adjacent DARA Liquids Storage and Treatment Unit. The soil in the pile dried out within 6 months and little or no leachate has been detected since. The building also includes 50 yd^3 of debris from closure activities that are stored on the internal ramp.

1.3 Regulatory History

The waste in the facility is regulated under RCRA Part A interim status as a waste pile and contains F001, F002, F005, and F039 waste. The plan is to close the waste pile under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in compliance with RCRA Applicable, Relevant and Appropriate Regulations. The Record of Decision for Phase I activities in Bear Creek Valley was signed in June 2000 and includes closure of the facility, removal of DARA soils, and disposal at an off-site commercial facility. The DARA SSF is also regulated as a Toxic Substances Control Act (TSCA) PCB Storage Area.

The current lifecycle baseline cost, $28 million, for DARA was calculated for chemical oxidation of the waste stream at Perma-Fix (former Materials & Energy Corporation facility) at the East Tennessee Technology Park (ETTP) and disposal at Envirocare in Utah. Treatment at ETTP was recently changed to soil washing, with the intention of achieving cost benefits, but no cost estimate is available yet for this change. It is not clear whether soil washing will separate PCB from most of the soil and what treatment is planned for the PCB fraction. The target reduction in average PCB concentration is low enough for this treatment to possibly work. The estimate includes the assumption of a 15% large volume discount and totals $14.7 million for treatment alone. Due to the high estimated costs and the fact that the waste is contained with minimal risk, the DARA remediation is not scheduled to begin until 2007. The existing, signed Record of Decision states that the waste will be treated and DARA will be closed. A change in the Record of Decision would be required to include treatment of soils onsite prior to disposal of treated soil at the Environmental Management Waste Management Facility (EMWMF).

3.0 ISSUES ANALYSIS

A number of critical and unresolved issues emerged during the briefings and subsequent discussions.

3.1 Critical Issues

1. Site Priority – Work already completed at the DARA SSF has demonstrated that the site is stable and represents a relatively low risk. While expedited closure of the site is clearly desirable, other higher priority sites are currently receiving the available funding, so activities at the DARA site are minimal. The DARA SSF is currently ranked number 12 out of 13. This low priority suggests that any short-term remedies will need to be innovative and represent substantial cost savings in order to proceed.

2. Baseline Costs – The current technology baseline consists of off-site shipment, treatment and disposal for the entire 4000 yd^3 of soil. This is a high cost option, with the current total life cycle cost estimate at around $28 million in 2007 dollars and an estimated remediation cost alone of over $14.7 million. A more cost effective approach is needed.
3. Mixed Waste – The waste is low-level mixed-hazardous waste. Radioactive components include enriched uranium, technetium-99, and several other radionuclides most likely associated with fallout. The primary hazardous component is PCB-1254. Two samples (out of 40) exceeded the characteristic level for the pesticide Endrin (D012). A small quantity of multi-source leachate (F039) was added after the initial filling of the facility. It may be possible to separate this material (and thus, the code) from the rest of the waste. This assumes that the rest of the waste should not be classified as F039 based on the original DARA soils. The situation is complicated by the fact that if F039 waste and associated code can be removed, the F-listed solvent treatment standards are met, and the Endrin is not present at characteristic levels, then the waste does not require treatment under RCRA or TSCA. The appropriate waste coding must be resolved prior to determining the appropriate treatment standard to allow disposal of the waste. Application of the Alternative Soil Treatment Standards negates the need for resolving this issue prior to the treatment of the waste.

3.2 Unresolved Issues

1. Regulatory Driver – From a regulatory perspective, the question remains as to what is driving the need for treatment of the DARA soils. The question is of particular importance since there is a possibility that no treatment may be necessary. Depending on the expected level of difficulty in resolving this issue along with cost and schedule implications, the site should consider defaulting to the LDR Alternative Soil Treatment Standards. Deciding to use this alternative set of treatment standards would remove the uncertainty in trying to resolve difficult regulatory and analytical issues, which in turn would allow the project to proceed with the proposed approach. The potential drivers for requiring treatment to meet the LDR treatment standards are F-listed solvents, F039 multi-source leachate, and the Toxicity Characteristic Leaching Procedure organics, primarily D012 Endrin. However, the existing analytical data are insufficient to demonstrate compliance with the F-listed solvents. The F039 code requires compliance with a long list of hazardous contaminants. The analytical data demonstrated that several of these contaminants, primarily PCBs, required treatment prior to disposal. The LDR treatment standard for D012 also requires treatment for Underlying Hazardous Constituents. In this case, PCBs again require treatment. The soils in the DARA SSF are eligible to utilize the alternative soil treatment standard that requires either a 90% reduction in contaminants or treatment to a level 10 times the Universal Treatment Standard level. In this case, where the average PCB concentration is less than twice the Universal Treatment Standard limit, the appropriate treatment standard for PCBs is 100 ppm. In its evaluation, the technical assistance team has presumed that if a treatment process is

effective for the relatively recalcitrant PCBs, then the treatment process will also be effective for the other organic contaminants that are typically much easier to treat.

2. F039 Designation – It may be possible to obtain some relief on the F039 designation. A relatively small pile of F039 exists in an isolated area inside the facility (directly under the ramp) that was added after the facility had been filled and drained. It may be possible to remove that small amount of material for separate treatment. However, it is likely that the liquids associated with that waste stream will be more widely distributed, making it impractical to remove the F039 designation. Before much effort is expended on removing the F039 code, there should be an evaluation to determine if the F039 code would have been applied to the original excavation of the soils that are now in the DARA SSF, based on their original source of contamination and point of generation.
3. Due to high limits of detection, the analytical data are insufficient to prove that the F-listed solvent code treatment standards were met. The positive detection of Endrin was limited and may not be real; the two samples showing positive detection for Endrin were only slightly above the stated detection limit. A significant extra effort would be needed to change the designation since, in addition to the Endrin, analytical sensitivity was inadequate to rule out the presence of numerous other semi-volatile species of regulatory importance. Time and effort should only be spent on these issues if the F039 code is removed. Otherwise, it would not be economically justified to spend significant resources in this area. Because of the application of the alternative soil treatment standards to the F039 code, it is assumed that almost all of the underlying hazardous constituents will have to be analyzed to show compliance with the treatment standards.
4. Detection Sensitivity – Many of the semi-volatile organic analysis results were compromised by the high dilutions needed to bring PCBs on scale in the gas chromatography analysis procedure. It is probably not practical to do anything about this at this late date; however, in any future re-sampling and associated analytical work, it is important that this issue be resolved. Analytical specifications directed toward any laboratory performing such work should be prescriptive with respect to solving this problem. A review of the communications with the laboratory at the time the work was done showed that a major effort was made to resolve the issue without success. The extracts were viscous and contained both physical and chemical interferences, causing problems with sample introduction, gas chromatograph loading, and quality control failures. It is likely that the extracts contained oils as well as the PCBs. Because of the presence of the oils, a post-extraction cleanup step employing column chromatography with silica gel was warranted and should be considered in future work. A procedure such as Environmental Protection Agency (EPA) Method 3630C should provide adequate cleanup of the extract to meet required detection limits. The issue should be revisited following implementation of soil treatment, which should reduce interferences and may eliminate the need for a post-extraction cleanup. Nevertheless, any lab performing additional analytical work at this site should be prepared to do a cleanup of soil extracts if needed. In addition, future work should include a determination of total organic carbon. Total organic carbon measurements will allow comparison of the proportion of any consitiuent and

the total amount of organics present, suggesting the potential for interference and the potential for co-metabolic biodegradation or potential for biological activity.*)*

5. CERCLA Designation – The site should consider regulatory consequences of shipping the materials for treatment to an offsite vendor such as Perma-Fix. While Perma-Fix is actually located within the Oak Ridge Reservation at K-25, the act of shipment may formally change the CERCLA designation to RCRA, precluding disposal at the onsite CERCLA disposal facility (EMWMF). The issue is unimportant if the intention is to use an off-site disposal cell.
6. Uranium-235 Enrichment Level – Uranium is present at elevated levels in soil samples collected from the site. The isotopic analysis appears to show that the uranium is significantly enriched in U-235 and the DARA characterization report lists enriched uranium as a major contaminant. However, one staff member who is intimately familiar with the behavior of environmental releases of uranium in the Y-12 area has questioned this observation. It is possible that the conclusion that the uranium is enriched may be an artifact of the method used for data reduction and averaging. While the presence of enriched uranium has little impact on the regulatory situation or the choice of remedy, it would be prudent to re-examine the uranium data to settle this issue. A careful re-examination of the raw data is warranted.
7. Liner Leakage – While it is known that the double liner is not perfectly sealed, the exact amount of potential leakage through both liners is uncertain, as is the potential for liquid leakage to the environment. Gas tracer leak tests performed by Tracer Research showed that there was some degree of leakage to the subsurface environment by a gaseous route, but the tests were inconclusive for liquid leakage. To minimize the impact of the latter uncertainty, future work involving water addition should maintain a negligible addition of head.
8. Sump Operation – From discussions with the site project team, the exact operational status of the two liquid removal sumps was uncertain. It was stated that there was a potential for pore clogging near the sumps, which may render them ineffective for control and removal of liquids. Some of the treatment strategies discussed require addition of small amounts of water to be effective, but the sump may be required to control hydraulic head in the system. Resolution of the sump operation issue would be desirable before any liquids are added to the system.

3.0 GENERAL REMEDIATION APPROACHES

Three approaches to remediation of the soils in the DARA SSF were considered. These three approaches differ in where treatment and disposal occur. The first approach represents the current baseline in the Record of Decision and was established before Oak Ridge had developed a CERCLA disposal facility – the EMWMF. The creation and operation of such a facility creates new opportunities for reducing budget and schedule uncertainties while simultaneously protecting human health and the environment.

3.1 Current Baseline - Off-site Treatment and Disposal

An example of this approach would be to excavate the waste, ship it to Perma-Fix for thermal desorption (the original estimate was for chemical oxidation, but the site has shifted to thermal desorption), with subsequent shipment of the soils to Envirocare for disposal, and shipping the organic secondary waste to the TSCA incinerator for incineration.

This remediation approach calls for treatment at a commercial off-site facility such as the Perma-Fix facility in Tennessee, Waste Control Specialists in Texas, Envirocare in Utah, or Allied Technology Group in Washington. While all four of these mixed waste treatment facilities are moving to establish organic treatment processes that would treat this waste, only Perma-Fix offers a currently available option. The other treatment vendors may or may not complete their plans for organic treatment processes, depending on market demand. Perma-Fix's treatment would be based on solvent extraction or thermal desorption to separate the PCBs and other organics from the soil. This much smaller volume of separated PCB and other organics would then be sent to the TSCA incinerator at ETTP. Perma-Fix does have a permitted PCB dechlorination process (not yet installed), the operation of which would allow 1) dechlorination of the PCBs and organics to be treated at Perma-Fix, and 2) subsequent burning of the remaining organics in a boiler for energy recovery at the Diversified Scientific Services, Inc. facility. The deployment of this dechlorination process is on hold until sufficient PCB waste is accumulated under contract by Perma-Fix to justify the unit economically.

Because this approach calls for shipping the waste off the Oak Ridge Reservation and out of Tennessee, it is expected to receive a warm reception from the regulatory and public stakeholders. The approach is predicated upon destruction of the hazardous organics and therefore minimizes any long-term risk. All of the technologies currently being considered by these commercial facilities have proven track records. There is at least one complete treatment train (described above) wherein all necessary permits and processes are in place and operating. Permit risk should be low.

In this option, the soils will remain as low-level mixed waste after treatment because the F-listed codes will still be attached to the waste. The only off-site disposal facility currently available for the disposal of these soils, after they have been shown to meet the treatment standards, would be the Envirocare facility in Utah. DOE expects to open the Hanford and Nevada Test Site facilities within the next two years for the disposal of mixed waste meeting the LDR treatment standards. Waste Control Specialists is seeking appropriate legislation within the State of Texas to allow disposal of treated medium-level mixed waste at its facility in west Texas.

Off-site treatment and disposal was selected as the baseline approach prior to the development of the EMWMF at Oak Ridge. Now that the EMWMF is operational, the added costs of packaging and transportation to an off-site facility makes this option less economically viable.

3.2 Oak Ridge Reservation treatment at Perma-Fix followed by EMWMF Disposal

The second approach requires an assessment of the potential for maintaining the CERCLA designation of waste sent to the Perma-Fix treatment facility at ETTP. This could allow the treated waste to be returned to the EMWMF for disposal onsite. This would save significant transportation costs. Typically, if a CERCLA designated waste is removed from the "area of contamination" and shipped to an "off-site" RCRA treatment facility, the waste loses its CERCLA-based exemptions and must be disposed in a RCRA permitted disposal facility. As the EMWMF at Oak Ridge is a CERCLA authorized disposal facility, not a RCRA permitted facility, it might not be able to accept waste that does not have a CERCLA designation.

However, due to the unique location of the Perma-Fix treatment facility on DOE property within the National Priority List-designated Oak Ridge Reservation remediation site, it is possible that this waste could be treated at Perma-Fix and then returned to the EMWMF for disposal. This option should be evaluated with respect to the Oak Ridge Reservation's CERCLA agreement and discussed with the appropriate regulators.

3.3 Treatment at DARA SSF followed by EMWMF Disposal

The third treatment approach incorporates treatment at the DARA SSF with disposal at the EMWMF. The potential treatment options at the DARA SSF include biological, physical, and chemical options; these are described in the subsequent section of this report. These treatment options may include treatment within the SSF or treatment in a processing unit established next to the SSF. After confirmation that the soils have met the appropriate LDR treatment standards, the waste would be disposed in the EMWMF. This approach minimizes the transportation and packaging costs. Treatment costs will vary depending upon the specific technology selected to perform the organic destruction.

4.0 REMEDIAL ALTERNATIVES

The technical assistance team evaluated several remedial technologies for the DARA SSF. Appendix D lists the strategies in prioritized order. Below is discussion of the technologies, grouped by remedial strategy: biological, physical, or chemical.

4.1 Biological Strategies

Presuming that either the F039 or the D012 code remain, the application of the LDR alternative soil treatment standards clearly identifies PCBs as the driver for treatment selection for organic degradation. For the purposes of this evaluation, the target concentration for bioremediation is assumed to be 100 parts per million (ppm) for PCBs (the alternative soil treatment standard). Another possible organic driver is the pesticide Endrin. However, this compound was only detected in two of the 40 samples and it is likely to be more degradable than the PCBs.

Application of the alternative soil treatment standards based on the waste being characteristic for Endrin still shows that the selected treatment process will be driven by the PCBs. Bioremediation approaches that degrade PCB will also likely degrade Endrin. Many other semi-volatiles were not ruled out as problems by the 2000 characterization data. However, the technical assistance team believes that a different analytical scheme that addresses the matrix interference problems but does not rely on a high degree of dilution would rule out most, if not all, of these compounds as regulatory concerns.

As bioremediation of PCBs is known to occur in both anaerobic and aerobic environments, both modes should be considered (Focht, 1993). In aerobic environments, chlorines can be removed and ring cleavage may occur in many congeners with relatively few chlorine substitutions. For congeners with higher numbers of chlorines, aerobic degradation is either slow or not feasible. Thus, removal of a high percentage of the PCBs is not likely with aerobic degradation alone, but removal of small fractions of the PCBs (primarily congeners that have fewer substitutions and are also more mobile) via aerobic degradation is achievable. The DARA SSF soils are apparently very dry, so the addition of water would be required for either anaerobic or aerobic degradation. Bioremediation of PCBs in many applications is ruled out due to high concentrations and the low efficiency of most PCB biodegradation. However, in this situation, relatively little decrease in PCB concentration is required, making bioremediation feasible. In addition, essentially no extra secondary waste would be generated by bioremediation.

Aerobic and anaerobic bioremediation strategies are described and evaluated below.

4.1.1 Aerobic Bioremediation

Aerobic bioremediation is a proven technology in which aerobic microorganisms degrade chlorinated compounds by various mechanisms. Deployment of aerobic bioremediation requires sufficient oxygen and inorganic nutrients (Hazen, 1997). In addition, the presence of easily degradable organic carbon is sometimes necessary or can increase rates of degradation of target compounds. In some cases, contaminated soils may contain sufficient levels of degradable carbon and only oxygen addition is required. In other cases, oxygen is provided in addition to degradable organic substrates, delivered in solid, liquid or gaseous additions. The accumulation of unwanted degradation intermediates does not usually occur with aerobic bioremediation, since degradation is usually complete to inorganic components (Focht, 1993)

The DARA soils appear to be good candidates for aerobic biodegradation. The soil would have to be moistened to add sufficient water to promote microbial activity. The soil would also likely need to be mixed or plowed to loosen the apparently tight material in the facility. An approach that treats the soil in lifts or layers of two or so feet is suggested. The top layer would be mixed (e.g., via plowing and/or disking) and water and nutrients added. The inorganic nutrient most likely to be needed is phosphorous, since the characterization data indicate high levels of nitrate and sulfate. An organic addition would probably also be needed to recruit populations of bacteria to this soil that has been subject to a long period of desiccation. After the initial additions, the site could be periodically watered and plowed over a one-year period. Although water would be added, the relatively small amount of water needed to promote aerobic degradation could be managed so as not to pose a leakage risk. This is especially true if only the first two to three feet of soil are targeted at each stage. At the end of a year, the soil could be sampled, and upon confirmation of meeting waste acceptance criteria, the top layer would be removed and sent to the waste isolation cell. Subsequently, treatment would begin on the next layer. As it appears that the average depth in the facility is less than nine feet, three years could be sufficient to treat all the soil. Upon completion, the structure could be used as a mixed waste treatment facility for other similar soils. This treatment option is both low cost and low risk. Failure at the end of the first treatment period would result in little added expense and would not impact future treatment options.

The other organic contaminants will be more degradable than the PCBs (Hickey, 1999). Thus, the aerobic treatment process should also address those other organic contaminants (e.g., Endrin) that might also be regulatory drivers.

Usually a biotreatability study would be recommended for aerobic bioremediation of soils. These studies are used to demonstrate feasibility and provide an opportunity to optimize the bioprocess for a site. However, this would increase the cost and time required for regulatory approval. Given the low cost of the recommended full scale process and the baseline knowledge of PCB degradation in general, it is likely not necessary to do a treatability study.

4.1.2 Anaerobic Bioremediation

Anaerobic bioremediation is a proven technology in which anaerobic microorganisms degrade chlorinated solvents by the mechanism of reductive dehalogenation. This microbial activity requires strongly anaerobic conditions and the presence of anaerobic microorganisms possessing reductive dehalogenation capability. In cases where natural conditions do not support anaerobic reductive dehalogenation, it is common to deploy biostimulation (addition of carbon sources to produce anaerobic conditions) as well as bioaugmentation (addition of anaerobic bacteria shown to degrade the contaminant) to achieve *in situ* anaerobic biodegradation of chlorinated compounds (Hickey, 1999).

In anaerobic environments, PCBs can undergo reductive dehalogenation that results in reduction of the average number of chlorines on the rings but does not necessarily result in ring cleavage. Typically, congeners with fewer substitutions undergo reductive dehalogenation at a slower rate. Thus, concentrations of congeners with fewer substitutions can rise as those with more substitutions fall. Thus, many scenarios for PCB degradation envision alternating anaerobic phases and aerobic phases to degrade congeners with fewer substitutions.

The DARA soils do not appear to be good candidates for anaerobic degradation due to the current site conditions. To establish an anaerobic environment in the current structure, the soils would have to be saturated and substantial organic carbon would need to be added. Although it might be possible to control and limit the potential for leakage and the slow rate of reduction of total PCB concentration with an anaerobic approach, it has limited utility at the site. However, if concentrations much lower than 100 ppm were required for waste acceptance, a combination of anaerobic degradation (to reduce chlorine substitution) and aerobic degradation (for ring cleavage and removal of chlorine from congeners with few chlorines) could be employed.

In summary, aerobic degradation appears to be a better option than anaerobic degradation and is a potentially viable low-cost option for the DARA soils. The effectiveness would likely be high due to the low amount of degradation required. The permitting should be relatively simple due to the general acceptability of bioremediation with naturally occurring bacteria. Aerobic degradation is a relatively simple technology, analogous to farming and will be easy to implement. The safety and health issues should be no more difficult than the baseline. Potential cost savings are high since the treatment should enable use of the onsite waste disposal cell. The technical maturity of aerobic degradation is not high, as the goal of high percentages of degradation has been limited in *in situ* degradation studies, but the levels of degradation targeted in this application are achievable. Secondary effects, such as mobilization of uranium via oxidation, should be minimal since the uranium is likely already highly oxidized due to the dry conditions. In fact, oxygen concentration should actually decrease during the treatment. Stakeholder acceptance should be high, as costs are low and the public generally views bioremediation favorably.

4.2 Physical Strategies

Physical strategies recommended are solvent extraction and three thermal processes: low-temperature thermal desorption, thermal vacuum desorption, and thermal soil vapor extraction. Stabilization-microencapsulation as a physical strategy is discussed, but not recommended.

4.2.1 Solvent Extraction

Solvent extraction processes use chemical reagents to separate PCBs and related contaminants from the soil and then recover the reagent. The result is a low volume secondary waste (i.e., the reagent and extracted contaminants) and a large volume cleaned soil residual. In the case of the DARA soils, it is likely that the residual would contain radionuclides that would need to be handled appropriately. Also, depending on the reagent and process selected, the extract may also contain radionuclides that would impact their handling and disposal.

Solvent extraction is generally performed as a batch process. The contaminated soil is loaded into a closed system where it is blended and/or contacted with the extracting reagent. A variety of reagents have been studied and reported in the literature, including various petroleum hydrocarbons, alcohols and other hydrocarbon solvents, and proprietary mixtures (e.g., Terra-Kleen and others). Non-hydrocarbon reagents such as supercritical water and carbon dioxide have also been studied. In a typical solvent extraction system, the solvent is separated from the soil by drainage, filtration, centrifugation, or by other standard methods. As commercial systems have been developed, additional steps to improve efficiency and effectiveness have been added. These include recycling solvents, maintaining a closed loop system to reduce emissions, and adding steps to concentrate secondary wastes to reduce volume. Several studies of solvent extraction have been reported with typical PCB and pesticide removal efficiencies > 95%. In an EPA Superfund Innovative Technology Evaluation demonstration (Sites 4 & 6 at the Naval Air

Station North in San Diego and a third site in Anchorage Alaska) PCB (Aroclor 1260) removal efficiencies ranged from 95 to 99%. A 1-ton batch was treated for each site in this demonstration and initial concentrations ranged from 17 to 640 mg/Kg. Larger scale follow-up studies showed consistent treatment to below 2 mg/Kg with removal efficiencies >98%. Based on the results, the Navy has selected solvent extraction for several PCB and pesticide contaminated sites.

Based on the literature, solvent extraction is clearly viable for the DARA soils. Because of the need to carefully control, mix and separate the extractant, it is unlikely that the soils could be treated in place. Thus, solvent extraction would need to be set up as a modular system onsite or performed at a remote facility. Significant soil handling, including multiple transfers would be needed. Several systems (e.g., supercritical fluids) are relatively immature and unlikely to be cost effective. Despite the number of technical papers on the topic, there are only a limited number of vendors with mature solvent extraction systems. Finally, solvent extraction generates a secondary waste that requires disposal. Because of this and the unique nature of the DARA soil problem, study of the behavior of nontarget constituents such as the radionuclides would be needed prior to final design and costing. Such studies would add to the cost and potentially delay implementation.

4.2.2 Thermal Processes

Thermal processes are a relatively promising category of technology for soil waste containing PCBs and related contaminants. For completeness, three types of thermal treatment are discussed below: low-temperature thermal desorption, vacuum desorption, and thermally enhanced soil vapor extraction. From a technical perspective, all of the listed technologies should be able to meet the waste cleanup criteria presented to the technical assistance team. As a class, these technologies are relatively mature and, with minor exceptions as noted below, should be commercially available or easy to implement. As noted below, the team believes that each of these technologies are viable but that they may not be as cost effective and safe as the simple aerobic bioremediation option described above. The technologies separate the waste into a PCB-rich and "clean" fractions. The PCB-rich fraction must still be treated, presumably as an oily liquid that can be burned in the TSCA incinerator at ETTP.

Low-Temperature Thermal Desorption

Low-Temperature Thermal Desorption (LTTD), also known as low-temperature thermal volatilization, thermal stripping, and soil roasting, is an ex-situ remedial technology that uses heat to physically separate volatile contaminants from excavated soils. Thermal desorbers are designed to heat soils to temperatures sufficient to cause constituents to volatilize and desorb (physically separate) from the soil. They are not designed to decompose organic constituents. The off-gas (air containing vaporized contaminants) is treated, if necessary, and discharged to the atmosphere in accordance with applicable permits. Some pre- and post processing of soil is typical when using LTTD. Excavated soils are screened to remove large objects (two-inch diameter and larger). After leaving the desorber, soils are cooled, re-moistened to control dust, and stabilized (if necessary) to prepare them for disposal/reuse. In the case of the target excavated and staged soil at Oak Ridge, the technology would be relatively efficient because the soil is currently relatively dry and required decontamination factors would be straightforward to achieve with LTTD. Further, LTTD can be run as a continuous feed process so that, if a mobile system was set up onsite, the staged soil could be processed for relatively efficient and rapid transfer to the onsite waste disposal facilities. The modular unit would need to be set up with the understanding that mixed waste was being processed. Thus, the supplier would need to have a post-Oak Ridge use planned that was compatible with processing waste containing radionuclides.

There are several variants of LTTD including rotary dryers, rotary kilns, asphalt plant aggregate dryers, thermal screws and conveyer furnaces. The mode of operation can often be discerned from the name. For example, a rotary dryer typically uses an inclined rotating drum that is heated – while the soil moves downward, it is heated and air moves in a countercurrent direction to remove the contaminants. While traditionally considered highly applicable to volatile compounds (such as solvents) and less effective for semi-volatile contaminants such as the PCBs targeted for the DARA soils, a properly designed system should be able to reduce PCB concentrations to levels well below 100 mg/Kg. Several of the variants would be appropriate for this application, making a range of vendors competitive (within the mixed waste constraint discussed above). Nonetheless, the procurement of equipment and/or services would be complex for this process and the technical assistance team felt that the technology would be more expensive than sequential aerobic bioremediation. Thus, this approach, while technically feasible, may not represent the optimal choice for this treatment need.

Vacuum Desorption

Vacuum-enhanced LTTD is a batch treatment that improves the efficiency of treatment over standard LTTD. Historically, the primary criterion for selecting a vacuum-enhanced system is to broaden the range of target contaminants that are effectively treated. The addition of a vacuum allows treatment of high levels of semi-volatile contaminants, such as pesticides and PCBs, to very low concentrations. The data suggest that initial levels (maximum of 300 to perhaps 1000 mg/Kg) and treatment targets (to < 100 mg/Kg) should not require the full robustness of vacuum-enhanced LTTD. A typical system includes a treatment chamber (operated under a vacuum of about 50 mm Hg and using an infrared heat source). By operating under a vacuum, the temperature required to desorb contaminants from the soil and the amount of oxygen present in the treatment chamber are lower than if the unit were operated under atmospheric conditions. This reduces the off-gas treatment volume and the potential for formation of oxidized byproducts. Systems can be implemented either onsite (mobile) or at a remote (fixed) facility. For example, Envirocare and TD*X Associates have combined to propose setting up a vacuum LTTD system to support their customers. This technology has been used successfully at several sites, some of which set up modular treatment systems. As with standard LTTD, this technology would be most appropriate if performed using an onsite modular system. The batch nature of the process should not adversely impact the orderly processing of the staged soils and disposal. In addition, parallel with standard LTTD description, any modular unit would need to be set up with the understanding that mixed waste was being processed.

Thermally Enhanced Soil Vapor Extraction

Thermally enhanced soil vapor extraction (SVE) could be applied in place, or in a staging building, and is analogous to traditional soil vapor extraction. The Environmental Protection Agency considers SVE a "presumptive remedy" for volatile contaminants (such as solvents). Without enhancement, however, it is not normally considered effective for semi-volatiles such as PCBs. Key modifications would include the addition of heat to allow slow removal of semi-volatile contaminants, large numbers of extraction points to minimize travel distances and maximize efficiency, and flexible operation (turning off extraction points that intercept desiccation cracks and wells that are pulling clean air). Further, for this "technology" to be appropriate, process control would need to be based on inexpensive screening level analysis (field gas chromatograph or nearby support lab) rather than expensive "certified" analysis. Heat could be provided by solar energy, electricity or propane, and off-gas treated with traditional techniques such as activated carbon. Alternative overall configurations such as soil mixing and less intensive and redundant well spacing are also possible but would likely be more expensive. If off-gas treatment is needed, standard carbon could be used and procured as part of the packaged treatment system. There are risks and difficulties associated with carbon-based off-gas treatment, so it should not be implemented if it is not needed. Particular common problems (all of which can be handled by proper operating procedures and care) include: 1) carbon concentrates radon gas from the soil gas, leading to potential radiation measurements/exposure for short periods (circa days) during radioactive decay, 2) carbon can overheat during shutdown if high organic concentrations are present (unlikely at this site), 3) carbon increases operating complexity, and 4) carbon generates an additional waste stream to handle.

The team felt that thermally enhanced SVE, while unusual, represents a potentially cost effective method to treat this target soil. There was consensus that the approach could meet a treatment goal of 100 mg/Kg in a reasonable period of time (circa a few years) but probably not reduce concentrations to low (e.g., <10 mg/Kg) levels.

In this setting, the advantages of thermally enhanced SVE include:

1. The DARA soil is already relatively dry and little energy would be expended evaporating water.
2. Waste soil is isolated and poses little threat (meaning that Oak Ridge does not need to rush or use a technology that processes the soil in a short aggressive campaign).
3. Except for areas of former stream and pond sludge, the soil did not appear to contain large amounts of natural organic matter.
4. The physical setting is well suited to effort.
5. No water would be added to perform remediation.

Disadvantages of this approach include:

1. The soil is physically heterogeneous (cracked) and would need to be treated by using robust over design or by mixing.
2. The soil contains debris such as plastic dump truck liners (over 300), tree stumps, and miscellaneous bags of personal protective equipment.
3. PCBs are difficult to remove by SVE (especially from organic-rich hot spots or areas protected by plastic liners).

4. Progress will be difficult to monitor because off-gas concentrations will be low.

This technology is low-cost, would utilize the existing facility and treat the waste soil in place on a schedule that is compatible with Oak Ridge's plans. It would require minimal equipment and soil handling and would not greatly increase the footprint of the facility. In addition, after the current soil is removed, the modified storage facility might be usable to stage and treat other VOC- or SVOC-contaminated soil. In general, this approach appears viable. It has several disadvantages, however, that make it less desirable than aerobic bioremediation.

4.2.3 Stabilization-Microencapsulation or Stabilization/Solidification (S/S)

Stabilization/solidification includes cement-based waste forms as well as polymer encapsulation (thermoplastic and thermoset) (Bleir 1997; Kalb 1991; Maio 1998), sulfur polymer cement (Mattus and Mattus 1994; Mattus 1998), phosphate immobilization (Ceramicrete™, soluble phosphates, phosphate minerals and sorptive agents) (Bleir 1997; Langton et al. 2002), glass waste forms (vitrification worthy of its own section but not included for this application by consensus), and ceramic waste forms (hydroceramic, nitrate to ammonia and ceramic (NAC)) (Bleir 1997; Siemer et al. 1998; Siemer et al. 1996; Mattus et al. 1994). Phosphate, glass, ceramic, and sulfur polymer cement were dismissed for this application, as they are inappropriate for organic treatment in general. The high temperature treatment during vitrification and some ceramic processes can destroy organics, but these do not immobilize the organics in the waste form. Such treatment only makes sense if another contaminant, such as a metal, needs to be immobilized in glass/ceramic. Immobilizing uranium can be done in this manner, but is not required for disposal in this application.

In general, typical cement formulations for waste treatment can encapsulate waste or media contaminated with organics, but do not usually interact strongly with organics to stabilize them against leaching, unless special agents that interact with organics and are compatible with cement are used (e.g., organophilic clays, surfactants/oils to create emulsions, activated charcoal) (Spence et al. 1990). Historically, cement stabilization/solidification has proven effective only on media lightly contaminated (<1000 ppm) with organics, as some organics are known to interfere with cement hydration and set (e.g., sugars retard set and oily phases coat cement, preventing hydration). The DARA SSF soil does not appear to be challenging from either perspective. The lack of confidence in treatment refers to this general history for significant organic concentrations. For the application in question, cement stabilization can be an effective alternative when the treatment target of 100 ppm of PCB is only slightly below the average soil contamination of 112 ppm. Presumably, no PCB will be destroyed or reacted for stabilization, but an equivalent modest treatment standard for leach resistance can be easily achieved with simple physical microencapsulation of the soil. However, regulatory approval is required to shift the treatment standard from destruction/removal to a target leach resistance during stabilization.

The contaminated soil does not appear to be oily enough to cause set problems. This low PCB concentration opens an opportunity for a well-established technique with commonly available mixing equipment to consolidate the soil into leach-resistant monoliths, perhaps at the lowest cost of any option other than aerobic bioremediation. Regulatory and stakeholder acceptance may not be high since the PCB is still present and the physical integrity of the waste form is the primary factor to prevent release. Polymers may interact more strongly with the organic contamination. This could have a negative effect of compromising the polymer structure and/or a positive effect of more strongly binding the contaminants.

For thermoplastic microencapsulation, special equipment is required to melt the plastic, mix soil into the molten plastic, and extrude the soil encapsulated into the plastic. Although this equipment is available, this requirement can significantly increase the cost. The target soil is already dry, as required for thermoplastic encapsulation, but must be excavated and fed into the polymer extruder, significantly increasing health and safety risks from potential dust.

Thermoset polymer encapsulation does not have the same requirements for special processing equipment and heating to melt the plastic. In this case, the monomers infiltrate a bed of the soil, are activated, and then polymerize in place to encapsulate the soil inside the container. The monomers easily infiltrate ion exchange resin beds, but some mixing is needed for ashes. Therefore, it is assumed that some mixing is needed for the fine silt and clay soil in the DARA SSF. The mixing equipment can be simple. The dry soil can be wetted some to suppress dust (wet resin beds were encapsulated in the past) to alleviate health and safety concerns. The volatile monomers require good ventilation and have their own health and safety risks. These encapsulations will also not remove or destroy the PCBs but should easily meet modest leachate standards based on the average concentrations reported in the Fall 2000 Sampling and Analysis Plan.

4.3 Chemical Strategies

Recommended chemical strategies are oxidation with potassium permanganate, Fenton's reagent, or peroxide; and reduction with iron, inorganic alkali, or nucleophilic reagents. A third chemical strategy, electrochemical treatment, is described but not recommended.

4.3.1 Chemical Oxidation

Chemical oxidation has been used for wastewater treatment and has recently emerged as a viable technique for treating organics in contaminated soil and groundwater. There are a variety of specific oxidation methods that have been developed, as shown in the following overview of the types of oxidants that are used or being tested for PCBs. This is then followed by a brief discussion on how chemical oxidation can be applied to the Y-12/DARA waste and a preliminary assessment of its viability.

Direct Oxidation at Ambient Temperature

In this approach, an oxidant is directly applied to the soil either in a batch reactor or in situ. Three types of oxidants have been used most frequently for organics: (1) Fenton's reagent, (2) permanganate and (3) ozone.

1. Fenton's reagent has been investigated most extensively for the oxidation of PCBs although most of the published results are on its use as a pretreatment for subsequent

biodegradation of PCBs (e.g., Aronstein and Rice, 1995). The lack of published results using Fenton's reagent alone for removing PCBs may be an indication that this is not a viable process. There is, however, one vendor (ManTech-Clean-Tox) that claims to treat PCBs in soil using Fenton-like proprietary chemicals. Unpublished laboratory studies at ORNL showed that 76% of 2,5,2-TCB in artificially spiked sandy sediment (0.46 mg/kg initial) was removed in 5 hours using 3 mL of 8.5% peroxide on 3 g of sediment. Note that byproduct formation was not investigated in this study and complete mineralization of the 2,5,2'-TCB was not established. Furthermore, Sedlak and Andren (1994) showed that oxidation rate of PCBs by OH* was significantly slower when the PCBs were adsorbed to diatomaceous earth, particularly for the more highly chlorinated congeners. In their experiments, 2,5,2'-TCB was still oxidized in the presence of particulate matter but 2,2',4,2'-TeCB was not oxidized at all within the time-scale of their experiments. Thus, despite the positive results at ORNL, Fenton's reagent may have limited effectiveness for degrading more highly chlorinated PCB congeners.

2. There are no published studies on using permanganate for oxidizing PCBs. ORNL laboratory studies using permanganate on 2,5,2-TCB and 2,2',4,2-TeCB showed limited removal in soils (20 to 30%).
3. A recent publication (Cassidy et al., 2002) describes laboratory-scale ozonation of artificially spiked kaolinite and river sediment followed by biodegradation of ozonation byproducts. Significant PCB removals (>90%) by ozonation alone were achieved in 30 days. The reaction times were on the order of 30 to 50 days. One of the PCBs tested was a highly chlorinated congener, 2-,3-,4-,2'-,3'-,4'-hexachlorobiphenyl (HCB).

High Temperature Chemical Oxidation

Chemical oxidation of PCBs is significantly enhanced at high temperature and high pressure. Duffy et al. (2000) describe a wet peroxide process treating Hudson River sediments contaminated with PCBs. Aqueous slurries containing 2.5% or 10% (w/w) sediment were oxidized with oxygen and hydrogen peroxide in a 1-L, high-pressure, semi-batch reactor at temperatures up to 275 °C. At 225 °C and a pH of 2.6, addition of hydrogen peroxide at a mass ratio of hydrogen peroxide to sediment of 3:10 resulted in greater than 99% removal of the PCBs as compared to 73% removal for conventional wet air oxidation. The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology offers supercritical wet oxidation for treatment of PCB waste, although published results by this company were not found. There are references on the Internet to a patented (circa 1998) supercritical water oxidation process developed by SRI International, although further searches did not indicate commercial availability of this process.

Extraction Followed by Chemical Oxidation

Chiarenzelli et al. (2001) describe a combined treatment process utilizing steam distillation followed by electrochemical peroxidation that removed > 90% of the polychlorinated biphenyls (PCBs) in river sediment and destroyed 95% of the PCBs recovered in the condensate. Oxidation is primarily mediated by hydroxyl radicals produced by the reaction of hydrogen peroxide with electrochemically generated ferrous iron (Fenton's reaction).

Application of Chemical Oxidation at Y-12/DARA

Direct chemical oxidation using Fenton's reagent or ozone is possible. These can be applied either by excavating the soils/waste and placing them into a batch reactor, or by applying oxidants in situ. The advantage of a batch reactor is the ability to adequately mix reagents with the soil. However, a relatively rapid reaction time is required for the process to be feasible. The advantage of in situ application is its ability to accommodate slower reaction kinetics. However, homogeneous distribution of oxidant throughout the waste mass may be a problem.

There are other methods of chemical oxidation that are possibly available, including steam distillation/electrochemical peroxidation and supercritical oxidation. However, these techniques will require specialized equipment that may not yet be commercially available. Thus, only direct chemical oxidation using Fenton's reagent or ozone is considered below.

Effectiveness of chemical oxidation is low to moderate. Laboratory tests at Oak Ridge National Laboratory show reasonable kinetic rates to allow batch processing, but there is some doubt on the effectiveness of Fenton's reagent for degrading the highly chlorinated congeners that are adsorbed to the DARA SSF soil. Ozonation may be more effective, given results from Cassidy et al. (2002). In either case, complete mineralization will likely have to be achieved by biodegradation. Mobilization of uranium may be an issue.

Normal in situ applications of oxidants require permits. It is possible that a permit will be required if oxidants are applied in situ, although the site is well contained. If used in a batch processor, air permits may be necessary, especially for ozonation.

It would be fairly feasible to implement chemical oxidation at the Y-12/DARA site. A batch processing treatment train is viable for Fenton's reagent, though impractical for ozonation because of the reaction times, which are on the order of 30 to 50 days. Delivery of both ozone and Fenton's reagent to the waste in situ is feasible given the relatively shallow depth of the soil, but homogeneous reagent delivery may still be difficult because of the tight packing of the material in the containment structure. For Fenton's reagent, significant amounts of reagent liquid may have to be applied to the soil, given the levels of PCBs. The excess liquid will probably have to be drained or evaporated. If drained, the liquid will probably contain uranium and will have to be disposed of accordingly. Optimum pH for Fenton's reagent reactions is 3-4, but carbonate minerals in Y-12 soils may have too high a buffering capacity to achieve this range.

There are health and safety concerns due to the handling of reactive fluids. Excess liquids for Fenton's reagent will have to be handled appropriately, given the likely presence of mobilized uranium. These concerns, in combination with the relatively high cost, suggest that stakeholder acceptability would not be high. Costs would be primarily for the oxidant. Ozone generators are available (and not that expensive), but may incur energy and operator costs.

Long-term acceptability is moderate, as PCBs will be removed from soil and soil is disposed of at a local facility. Technical maturity is low to moderate, as there is little experience with PCBs, especially for ozonation.

Overall, oxidation is viable but problematic due to insufficient removal to achieve target levels, excess liquids from addition of Fenton's reagent, the need to control pH, and potential uranium mobilization. It may best be used as a pretreatment for bioremediation if needed.

4.3.2 Chemical Reduction

Several developers have been working on chemical-reduction based soil treatment systems. These systems use chemical reagents to abiotically reduce the organic contaminants, such as PCBs. Over the past several years, vendors have been coupling this process with traditional soil washing operations. This coupling of technology is appropriate since soil washing, normally effective because of physical particle size separation, requires the soil to be finely divided and mixed with fluids for transfer and elutriation. Such systems are positioned to perform chemical reactions, such as redox reactions, by simply adding the necessary chemicals to the existing equipment after assuring compatibility with process containers, pumps, etc. Alternative implementations are also possible, such as blending the soil with elemental iron and adding moisture. The result of any of the treatments is a large volume of cleaned soil residual, and depending on the implementation, a small volume of secondary process waste. In the case of the DARA soils, it is likely that the residual soil would contain radionuclides that would need to be handled appropriately. A potential advantage of chemical reduction versus chemical oxidation for these soils is that the treatment process will not oxidize and increase the mobility of uranium. The characteristics, advantages and disadvantages of chemical reduction using liquid reagents and chemical reduction using blended solids are addressed in turn.

Chemical reduction is generally performed as a batch process. The contaminated soil is loaded into a contained system where it is blended and/or contacted with the reducing reagent. A few reagents (a reagent mixture), mostly proprietary, have been proposed. These include "nascent hydrogen" generated from an elemental metal and acid, various implementations of a nucleophilic reagent and excess alkali (high pH), and a solid phase blending of zero-valent iron and moisture with the soil, followed a period of reaction. Only a few test results have been widely reported. Researchers in Norway reported that chemical reduction amended soil washing is relatively effective for appropriate soils (e.g., "400 ppm PCB treated to <10 ppm under ideal conditions"). Other research, while showing some promise, suggests caution in selecting this technology. For example, in the EPA Superfund Innovative Technology Evaluation program, the "original caustic based system" was "ineffective in destroying PCBs" and a final report was not published. According to the EPA project manager, the Superfund Innovative Technology Evaluation program technology developer (Trinity Environmental Technologies) has continued to investigate improvements, including temperature controls, better mixing, and more aggressive reagents and is developing a one ton per hour modular system for deployment. In general, bench scale lab experiments under ideal conditions show reasonable treatment (e.g., "2000 mg/Kg to <2 mg/Kg"). Nonetheless, additional work may be needed before this method can be reliably deployed for a reasonable and certain cost.

Addition of a granular reagent, such as zero-valent iron, and moisture to the soil will generate conditions to abiotically dehalogenate some chlorinated organic compounds. In this implementation, granular zero-valent iron would be mixed with the soil and with water to provide appropriate conditions for the abiotic contaminant destruction. It is likely that the quantity of reagent needed and need for homogeneity would require removal of the soil and external mixing. After mixing, the soil could be replaced to allow reaction time, if the aggressive chemistry in the soil (high pH and low dissolved oxygen) that would occur in the facility is acceptable. The current storage capacity would likely be insufficient, however, and additional capacity would be needed due to the increased volume. This technology would also increase the overall volume of soil sent to final disposal. Conditions in the soil would be monitored and optimized to insure sufficient degradation. Zero-valent iron has often been deployed in permeable walls and similar configurations and has been studied by a large number of university/federal laboratories and companies. Researchers from the University of Waterloo in Canada performed early development of the technology – the principal licensee of their work is EnviroMetal. Treatment of excavated soils as described herein represents an interesting and appropriate application if better alternatives are not identified and the process is sufficiently aggressive to treat the target contaminants. Importantly, zero-valent iron has not been extensively studied for treating PCBs and PCBs are not listed by the vendor on its table of compounds that have been tested as treatable by the reagent. Utilization of this technology would require mobilization of storage and mixing equipment and would expand the footprint of the soil storage. In addition, spatial limitations within the facility would challenge efficient implementation of this technology. This technology could generate intermediates that would extend the overall treatment period to reach adequate treatment. Significant efforts would be required to monitor for the presence of intermediates and to maintain optimal moisture conditions within the soil to encourage complete degradation. As a potential benefit, zero-valent iron may chemically reduce uranium in the soils and limit the more mobile U^{VI}. The core zero-valent iron technology is low-cost and could utilize the onsite Oak Ridge disposal facilities as the final disposal location, but implementation for this particular soil is limited by uncertainty in the effectiveness for dechlorinating PCBs, the need to mobilize equipment and materials and the associated costs.

Based on the literature, chemical reduction may be viable for the DARA soils. Because of the need to carefully control, mix and separate the reactants and the aggressive nature of the reactions (especially if liquid reagents are employed), it is unlikely that the soils could be treated in place. Thus, chemical reduction would need to be set up as a modular system onsite or performed at a remote facility. Significant soil handling, including multiple transfers, would be needed. Relative to the other technologies described in the matrix, chemical reduction is relatively immature and unlikely to be cost effective. Because of this and the unique nature of the DARA soil problem, additional scientific study would be needed prior to final design and costing. Such studies would add to the cost and potentially delay implementation.

4.3.3 Electrochemical Treatment

Electrochemical treatment is a recently proposed and implemented technology that uses electrical current as the central component of a system to decontaminate contaminated soil in place. Similar to the more aggressive direct energy thermal techniques (e.g., six phase heating and radiofrequency heating), these treatments rely on injecting electromagnetic energy directly into the bulk soil. Thus, the considerations of geology, water content, etc. are similar between these methods and the related thermal methods. The key difference in these "treatment" methods is the additional implementation and documentation of a destruction or detoxification mechanism in the deployment process. Two variants, at different levels of maturation, are discussed below. These are the Lasagna technology and the ElectroChemical Remediation Technology (ECRT).

The most successful electrochemical treatment to date is the Lasagna system developed and implemented by a consortium of federal researchers (DOE, EPA and others), industry and universities. Lasagna is primarily an electroosmosis process that relies on moving water through the subsurface. This technology exploits phenomena in which ions in the diffuse double layer near soil particles move in response to a DC electric field and induce water movement in a parallel direction via shear forces, or drag at the double layer interface. The unique feature of Lasagna is placing layers of treatment or capture material in the path of the moving water so that the contaminants are efficiently detoxified as they move over relatively short distances. The system also minimizes the problems sometimes associated with the chemistry near the electrodes by treating the contaminants relatively far away within the target treatment volume. While the basics of this technology are well established from industrial applications in dewatering and clay consolidation, fully reliable performance for remediation applications has yet to be established. The technology is most applicable to saturated or near saturated sediments with low permeability (e.g., $< 10^{-5}$ m/s hydraulic conductivity). Within this bound, the method has low power consumption and will induce a relatively uniform flow that is "independent" of heterogeneity. Because of potential leakage concerns, the optimal saturation conditions are unlikely to be met within the DARA storage facility. For organics, the method is limited to the soluble fraction and will not remove residual non-aqueous phase solvents in the system, nor will it treat tightly bound contaminants. This is a serious limitation for PCBs because of their relatively high affinity for soils and makes the Lasagna variant of electrochemical treatment nonviable for the DARA soil.

ECRT is a recent technology that has been investigated in Europe (P2-Soil Remediation, Inc) and in the United States (by Weiss and Associates in partnership with the developers). The technology advocates suggest that soil can be decontaminated using much lower current densities than Lasagna or heating methods. In particular, they indicate that organics such as PCBs can be effectively treated in place by "induced oxidation" processes that they designate Electrochemical GeoOxidation (ECGO). The claims are supported by patents (US 5,738,778 and 5,596,644) and by limited field data. Importantly, the developers do not have controlled documentation about the destruction process and do not know mechanism of destruction, nor its robustness. They speculate that "these reactions occur at any and all interfaces within the soil" and that "an induced polarization field is produced …{leading to} … disharges of electricity to occur … {and that} … in the electrical discharge, REDOX reactions take place." It is unlikely that "discharges" are occurring at the power densities employed; significant additional research is needed before this method can be reliably used. As with most other direct energy processes, the data suggest that reaction rate is inversely proportional to grain size and that moisture is needed in the system. Based on the case studies, the proposed technology is intriguing and, if substantiated by additional research, may be important in the future.

Despite their isolation and available environment, the conditions in the DARA facility do not appear ideal for ECRT/ECGO. The technology would require addition of large amounts of water to the sediment and the geochemical conditions appear substantially different than those of the anecdotal studies reported to date. Most importantly, however, the technology is sufficiently immature that the project could not be performed in any mode except a research mode – significantly increasing costs for monitoring and incurring potential schedule risk. Based on the available information, this technique would be viable if it performed as claimed by its vendor. These claims appear optimistic and deployments should be selected carefully to minimize potential downside risks if the technology fails, while at the same time encouraging disciplined technology development for this type of inexpensive and potentially revolutionary method.

According to Weiss Associates, the active redox zone reacts and destroys organics while metals migrate to both electrodes for easy collection and removal. Treatment is reportedly cost effective, but does take months and requires wetting of the soil volume being treated. For this application, treatment over several months is acceptable, as in bioremediation. In addition, the degree of treatment required is small for the DARA soil. Several examples of remediation using this technology in Europe, including one for PCB, are cited by the developers (Weiss brochure referenced in Appendix E). Despite the reported success in Europe, the team did not recommend this technology because of its immaturity and its limited track record. Even if the technology works, the understanding of the basic mechanisms is limited, despite the explanations in the vendor literature.

5.0 DEBRIS APPROACH

The debris type material on the ramp is considered contaminated with PCBs and other organic constituents and is also considered F-listed waste. Included within this debris is excess sample from the last sampling event in 2000. This excess sample material would likely best be treated in conjunction with the DARA soils. The sample containers should be treated along with the rest of the debris. The rest of the debris material will probably be more appropriately treated by application of the Alternative Debris Treatment Standards. The debris on the ramp should be segregated for treatment based on the following approach.

Porous debris will be difficult to decontaminate. This material should be macroencapsulated for disposal. This can be done at the DARA SSF or it can be shipped off-site for treatment. Macroencapsulation will meet the LDR treatment standards and it is expected to meet the Waste Acceptance Criteria for disposal at the EMWMF or any off-site mixed waste disposal facility such as Envirocare.

The other non-porous debris items, such as the boat, could be considered for decontamination using an extraction-based alternative debris standard. Approved technologies for this approach include high-pressure water or steam, or decontamination with a solvent in which the contaminants are at least 5% soluble. The criteria for decontamination require production of a clean debris surface. After decontamination, these materials may be disposed as low-level waste at the EMWMF. The rinsate would have to be treated to meet the appropriate treatment standard. If there is not significant material to be decontaminated, then this material should be size-reduced to fit in the macroencapsulation containers.

6.0 REGULATORY OPTIONS AND CONSIDERATIONS

The current Record of Decision (ROD) for the DARA soils is based on shipping the waste off-site for disposal and makes no mention of treatment. If onsite treatment is chosen, then that ROD will have to be amended through an explanation of significant differences prior to the disposal of any of the DARA soils onsite. Depending on the relationship Oak Ridge has with its EPA and State regulators, the site may be able to negotiate the start of the treatment process in the DARA SSF prior to completion of the changes to the ROD through the CERCLA treatability study exemption process. If the recommended approach is taken, in which the soils are treated biologically in 2-3 foot lifts in yearly stages, then the ROD amendment process should be initiated in the near future to allow disposal of treated waste at the end of the first year.

The current treatment requirements are based on the LDR treatment standards for F039 waste. The F039 waste code was added to the DARA soils after the SSF was filled. This waste code might no longer be applicable if specific minor quantities of soil are removed. Eliminating this code could be the first step in reevaluating the need for any treatment of this waste. However, discussions with DARA technical representatives indicate that removal of this code may not be easily resolved. An argument could be made that all of the soils, sludges, and water deposited in the SSF would have been considered F039 at the original point of generation. This would preclude removal of the F039 code. In any case, negotiations with the regulatory agency are required prior to removing any codes or treatment requirements.

In addition, the analytical data present other regulatory issues with respect to whether or not the waste meets the treatment standard for F-listed solvents and whether it should be considered characteristic for Toxicity Characteristic Leaching Procedure organics. The average detection limit for 1,2-Dichlorobenzene (o-) and 2-Methylphenol are above the F-listed solvent treatment standard. There are also two positive measurements reported for characteristic constituent Endrin. There are many other cases where the detection level was above the RCRA characteristic level for Toxicity Characteristic Leaching Procedure organics, based on a 20:1 dilution of the total concentration to account for the dilution inherent in the Toxicity Characteristic Leaching Procedure analysis. If the DARA soils are characteristically hazardous for Toxicity Characteristic Leaching Procedure organics such as Endrin, then the waste must meet the Universal Treatment Standards for underlying hazardous constituents. While the treatment standards for F039 and the Universal Treatment Standards are very close, they are not identical. There are several underlying hazardous constituents in the Universal Treatment Standards that are not represented in the F039 treatment standards. These need to be considered and evaluated as potential underlying hazardous constituents. The technical assistance team believes that Oak Ridge is correct in selecting the LDR alternative soil treatment standards as the appropriate and relevant treatment standards that should to be met for the waste to be disposed of in the EMWMF. In the event that the F039 waste code can be removed as above, then the analytical question of meeting the F-listed solvent treatment standards and the D-characteristic codes would become the driver for treatment of the soils. Because of the inconsistencies in the semi-volatile data analysis, even these D-characteristic codes may not be applicable. If both the F039 and D-characteristic codes are eliminated and the waste met the F-listed solvent treatment standard, then the soils in their present conditions could be disposed without any further treatment.

7.0 SUMMARY AND CONCLUSIONS

During the closeout session, members of the technical assistance team conveyed to the site how impressed they were at the thoroughness of the site's investigation and consideration of cost options for remediation. The site has a lot of excellent documentation and background on the contaminated soils in DARA SSF, and how the facility was designed and constructed. The DARA SSF facility has contained these mixed waste contaminated soils for 13 years. With the construction of the onsite disposal facility (EMWMF), the site now has the option for treating and disposal of the soil in the facility and reusing the DARA SSF for other storage purposes. The high cost of off-site disposal and of most types of mixed waste treatment has kept the site from rapidly disposing of the soil. Newer techniques for remediation of PCBs, combined with the current waste acceptance criteria for the EMWMF, should provide a much more cost effective solution for complete dispositioning of the soil in the DARA SSF. The following overall recommendations were agreed upon:

1. The debris on the ramp should be sized to fit in macroencapsulation containers and sent to the EMWMF when time and money permit. Some items like the boat could be decontaminated and the decontamination solutions put onto the soil; however, the time and cost may outweigh any benefit when compared to cutting it up and shipping to EMWMF for disposal.
2. Characterization of the matrix interference issues should be re-examined when verification monitoring is done post-treatment. Future analytical work should include specification for matrix cleanup by column chromatography if needed.
3. A regulatory issue that could be evaluated is whether the discrete F039 waste pile can be removed and handled separately from rest of the waste pile. This could represent a very large cost savings in terms of regulatory drivers. It would then become critical to resolve the matrix interferences for the remaining soils because it could mean no treatment is necessary.
4. As soon as possible, the first phase of aerobic bioremediation of the soils in the vault should be implemented. A surface soil moisture control system should be installed to keep the upper two to three feet of soil in the facility moist and biologically active. Amendments should be tilled or plowed into the upper two to three feet of soil. Agricultural fertilizer, e.g. manure, would provide the best source to activate the soil to degrade organic components. The site should till or plow monthly or bimonthly to

aerate the soil. After one year, effectiveness should be evaluated and the upper two to three feet of soil should be removed to EMWMF. The site should repeat this process for the next two to three feet. Within three years, all the soil in the facility should be remediated at a very low cost (e.g., less than $1 million). The facility could then be reclaimed for other purposes or used to provide a long-term facility for low-cost treatment of mixed waste from other parts of Y-12.

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APPENDIX A TECHNICAL ASSISTANCE REQUEST

TECHNICAL ASSISTANCE BASELINE
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Evaluation of Treatment and Characterization Alternatives for Mixed Waste Soil and Debris at Disposal Area Remedial Action (DARA) Solids Storage Facility (SSF)

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At the Y-12 National Security Complex in Oak Ridge, the Disposal Area Remedial Action (DARA) Solids Storage Facility (SSF) is a building positioned atop a 10-ft concrete basin that houses a waste pile containing approximately 4,000 yd3 of soil and 250 yd3 of debris contaminated with PCBs, RCRA listed waste, and radiological constituents. Sampling of DARA SSF waste was conducted in FY 2000 to determine if the waste met land disposal restrictions (LDRs) and waste acceptance criteria for potential treatment/disposal facilities.

The sampling results were compared to process waste and soil LDRs. The results were sufficient to determine that at least half of the soil sampled will require treatment for PCBs prior to land disposal because results exceeded soil LDRs (100 mg/kg for PCBs). The highest concentration of PCBs detected in the soil was 360 mg/kg. A portion of the soil that exceeded soil LDRs for PCBs also exceeded soil LDRs for other organic constituents. The remaining half of the soil that met soil LDRs for PCBs will require additional sampling and analysis to determine treatment requirements because the laboratory was unable to achieve the detection limits for other organics necessary for comparison to LDRs due to matrix interference. The results were sufficient to determine that the debris portion of this waste stream will require treatment prior to land disposal because all results exceeded process waste LDRs (10 mg/kg for PCBs).

The treatment cost for 5,250 yd3 of soil/debris (25% swell factor assumed for soil) is estimated to be approximately $14.6 million. This is based on treatment by direct chemical oxidation, which uses a combination of low-temperature thermal desorption and chemical oxidation to destroy regulated organic compounds.

The site is requesting technical assistance from the Subsurface Contaminants Focus Area's team of technical experts with experience and expertise in soil treatment and characterization to identify and evaluate 1) alternative treatment technologies for DARA soils and debris and 2) options for analysis of organic constituents in soil with matrix interference. Based on the recommendations, the site may also require assistance in identifying and evaluating appropriate commercial vendors.

What resource(s) have been selected?

What resources were offered, but not selected?

APPENDIX B PARTICIPANTS AND CONTACT INFORMATION

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July 17-18, 2002

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- Permeable reactive barrier technologies
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- Data analysis for site characterization and remediation performance assessment
- Nucleation and stability of methane hydrates in geological environments
- Development of carbon dioxide injection technologies for ocean carbon sequestration

APPENDIX D REMEDIATION TECHNOLOGY MATRIX

Oak Ridge Disposal Area Remedial Action (DARA) Solids Storage Facility (SSF)

Note: Recommended remediation technologies are listed in priority order.

– tilling top layer with tractor, add fertilizer & water; remove 2-3 feet each year. Site could use SSF as MW facility	Biological	High in lifts of 2 feet. If 90% removal, difficult and would require amendment (manure) with water. If want PCBs down to 100 ppm, may be possible.	Low	Medium - High	Medium	Low	High	High	Medium because few examples where aerobic bio alone is effective	No Except for PPE from excavating in every option	Highly recommend ed. May oxidize small amount of uranium.
	Physical	High	Low	High	Medium - High	Medium	High	High	High	Yes Recovered PCBs to be treated (TSCA incinerator)	Better than off-site treatment but still expensive; less regulatory risk
	Physical	High	Low	High	Medium - High	Medium	High	High	High	Yes Recovered PCBs to be treated (TSCA incinerator)	Better than off-site treatment but still expensive
	Treat off site (Perma-Fix)	Medium - High Risk that Perma-Fix might not meet the contract	Medium - High	High	Medium	Medium	High	High	Medium	Yes Liquids from soil washing and/or oxidation	Better than baseline (but still expensive)
	Biological	Medium	Low	Low – Medium (add carbon source, prevent from going aerobic)	Medium	Low	High	High	Medium	Yes Leachates collected	Viable for amount of reduction needed; problems with maintaining

											aerobic. Lowers U.
	Chemical	Medium (uranium is mobilized)	Medium	Medium - High	High	Medium – High (taking into account H&S issues)	Low - Medium	Medium	Medium (not as much experience with PCBs)	Yes Expended solution of oxidizers	Viable but problematic because uranium is mobilized
	Chemical	Low – Medium (have doubts; need more info)	Medium	Low - Medium	Medium - High	Medium - High	Low - Medium	Medium	Low	Yes Expended solution of reductants	Problematic because low maturity and a complex process
	Physical	Medium – it is slow but works if designed well (more calculation to see if meet 2006)	Low	Medium	Medium	Low-Medium (depends on how long heating air)	High	High	Low - Medium	Yes Recovered PCBs to be treated (TSCA incinerator)	Better than off-site treatment but still expensive
(including surfactants, although likely worse because pick up more rad)	Physical	Medium (in soils, can get 90% removal; rads in secondary waste)	Medium; lot of secondary waste	Medium	High (dikes, protect workers from solvents)	Medium - High	Low - Medium	High	Low - Medium	Yes Large quantities of extract solvent containing PCB	Difficult because of secondary waste mgmt, cost is high
(current baseline)	No treatment on site	High	Low	High	Medium because of dust, packaging, transportation issues	High	Low: site owner wants to keep waste on site, use its own facilities	High	High	No Not on site, some generated during treatment off site	Not viable because treatment is required, cost very high

	Physical	Low if organics need to be destroyed, unless renegotiate treatment standards	High	High	Medium	Low - Medium	Low	Low; don't know how stable	Low	No Except for PPE from excavating in every option	Not recommended, PCB not destroyed, requires change to leach treatment standard
	Chemical	Low – Medium (must be wet)	High due to uncertainty	Low - Medium	Medium - High	Medium	Low	Medium	Low	Yes Electrodes, leachate collected, and off gas	Problematic because so many uncertainties

Cost: Low = Less than $5 million; Medium= $5-$20 million; High= Greater than $20 million
Stakeholders: includes site owners and the public

APPENDIX E ADDITIONAL INFORMATION PROVIDED TO SITE

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