Treatability Test Plan for Deep Vadose Zone Remediation at the Hanford Site's Central Plateau

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ABSTRACT

A treatability test plan has been prepared to address options for remediating portions of the deep vadose zone beneath the U.S. Department of Energy's (DOE's) Hanford Site. The vadose zone is the region of the subsurface that extends from the ground surface to the water table. The overriding objective of the treatability test plan is to recommend specific remediation technologies and laboratory and field tests to support the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* and *Resource Conservation and Recovery Act of 1976* remedial decision-making process in the Central Plateau of the Hanford Site. Most of the technologies considered involve removing water from the vadose zone or immobilizing the contaminants to reduce the risk of contaminating groundwater.

A multi-element approach to initial treatability testing is recommended, with the goal of providing the information needed to evaluate candidate technologies. The proposed tests focus on mitigating two contaminants – uranium and technetium. Specific technologies are recommended for testing at areas that may affect groundwater in the future, but a strategy to test other technologies is also presented.

INTRODUCTION

In the course of decades of operation, the Hanford Site has released nearly two trillion liters (450 billion gallons) of liquid into the vadose zone and has the potential to contaminate the groundwater in the future. The composition of this liquid has ranged from clean Columbia River water to effluent containing high concentrations of chemicals and radionuclides from the processes used in the Site's Central Plateau (200 Areas) to refine plutonium.

A treatability test plan has been prepared to address technologies that are potentially viable for remediating portions of the deep vadose zone under the Central Plateau. The deep vadose zone is that region of the subsurface where surface remediation does not retard the migration of contaminants, which then pose a continuing threat to groundwater quality.

Conventional technologies such as pump-and-treat are currently being applied to remove contaminants from the groundwater. Contaminated soil near the surface of the Central Plateau may be remediated by removal, treatment, and disposal; surface barriers; or other methods. Contamination deep in the vadose zone, however, lies beyond the reach of conventional surface excavation technologies and is important because it has the potential to contaminate groundwater in the future.

The Central Plateau covers approximately 200 square kilometers (75 square miles) and has approximately 800 waste sites (including solid waste sites). The Central Plateau also contains approximately 900 buildings and other operational facilities, whose mission during Hanford's operation (1943 to 1989) was to process irradiated material produced in reactors near the Columbia River to extract plutonium. The byproducts of this activity were effluents contaminated with various types and concentrations of chemicals and radionuclides. The most virulent wastes were stored in 177 underground tanks. Some of this waste has been released to the vadose zone. Some concentrated waste was also discharged into engineered surface structures and allowed to percolate through the vadose zone.

Contamination in the deep vadose zone was, in most cases, driven there primarily by the liquid waste discharges themselves and/or other unplanned liquid releases (e.g., water line leaks). With the cessation of liquid waste disposal and improved water management controls, the primary driving force has been shifting to drainage of meteoric water from natural precipitation events (also known as natural recharge). Natural recharge could be as high as 92 millimeters/year or as little as a fraction of a millimeter, depending on soil type and vegetation [1].

HANFORD DEEP VADOSE ZONE ISSUES

This section establishes the context for applying technologies to remediate the vadose zone in the 200 Areas at the Hanford Site. The following subsections identify the contaminants for initial treatability tests, present subsurface conditions, and discuss uncertainties for applying remediation technologies.

Contaminants

Although characterization of vadose-zone soil in Hanford's Central Plateau has identified a large number of radiological and hazardous chemical contaminants, including technetium-99, this treatability plan focuses on two contaminants – uranium and technetium. These elements are long-lived, and in several locations, have reached the aquifer and already contaminated the groundwater. There are also a number of locations where significant inventories of these contaminants have been detected deep in the vadose zone but apparently have not reached the groundwater.

Technetium is generally considered to have a partition coefficient near zero and moves easily through the soil and groundwater without being adsorbed by particles in the soil. Technetium, therefore, can act as a surrogate for other highly mobile contaminants (e.g., nitrates and I-129) in remediation technologies that rely on physical sequestration or immobilization.

Unlike technetium, however, uranium does interact (e.g., adsorb) with sediment particles depending on the chemistry of the environment [2]. The presence of uranium in the groundwater at several locations under the Central Plateau is evidence that uranium and other compounds with similar partitioning behavior can be transported through the vadose zone.

Both uranium and technetium form compounds with transport properties that differ depending on their oxidation-reduction state. As such, these compounds are suitable to test technologies that alter the oxidation-reduction conditions.

Subsurface Conditions

The vadose zone is the region of the subsurface that extends from the ground surface to the water table. The vadose zone in the Central Plateau ranges in depth from about 50 meters (164 feet) in the western portion of the to 104 meters (341 feet) in the southern portion [3]. The geology and hydrology of the 200 Areas have been extensively studied because these areas are major historic sources of soil and groundwater contamination [4].

The major stratigraphic units making up the vadose zone include the following:

- Surface wind-deposited sand and silt deposits
- Unconsolidated sand and gravel of the Hanford formation
- Silt and carbonate-cemented layers of the Cold Creek unit
- Semi-consolidated sand and gravel of the Ringold Formation.

The stratigraphy varies significantly across the 200 Areas, as shown in the geologic cross-section in Figure 1. The physical structure and properties of the geologic framework and its principal transport pathways affect the movement and distribution of contaminants within the vadose zone [3, 5, 6]. Figure 2 illustrates some of these important features of the vadose zone in the Central Plateau.

Contaminants entered the vadose zone through a variety of liquid waste discharges, buried solid waste, and unplanned releases. The nature and extent of contamination was affected by the waste chemistry and type of release. Technetium and uranium were carried into the deep vadose zone due to their mobility and driving forces from previous releases, as well as nearby water releases and natural precipitation. Technetium and uranium are expected to continue to migrate toward the groundwater when present as a dissolved component of mobile pore fluids and driven by infiltrating water.

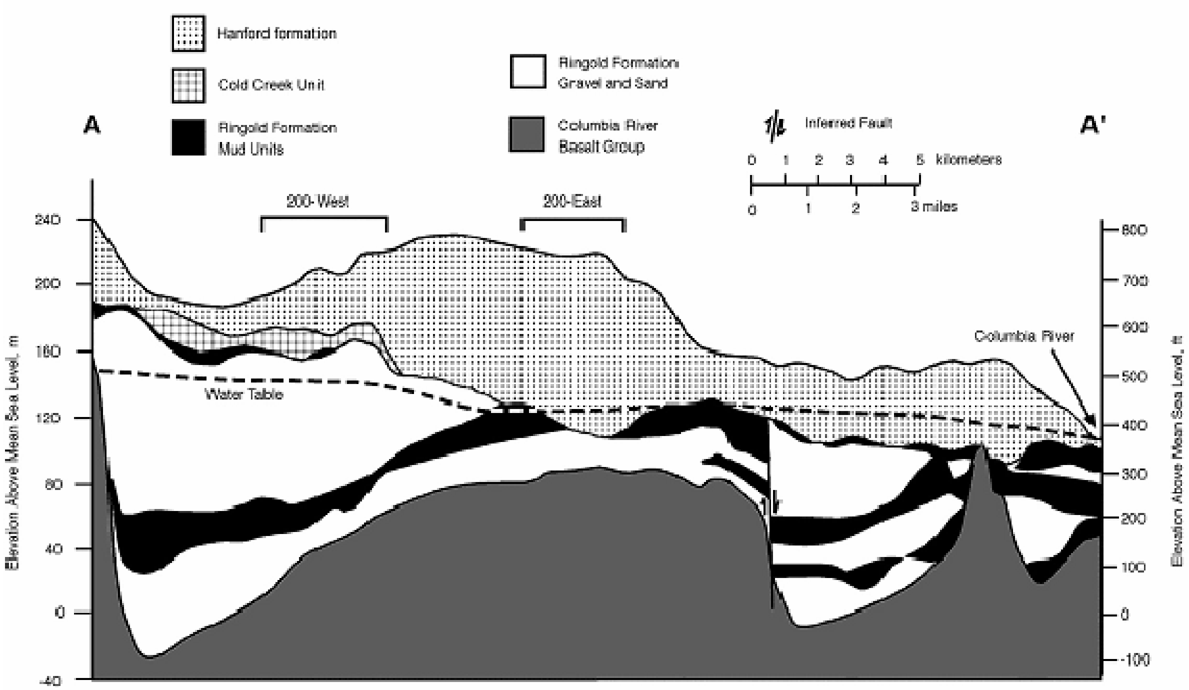

Fig. 1. Generalized West-to-East Geologic Cross-Section Through the Hanford Site. (after [4]).

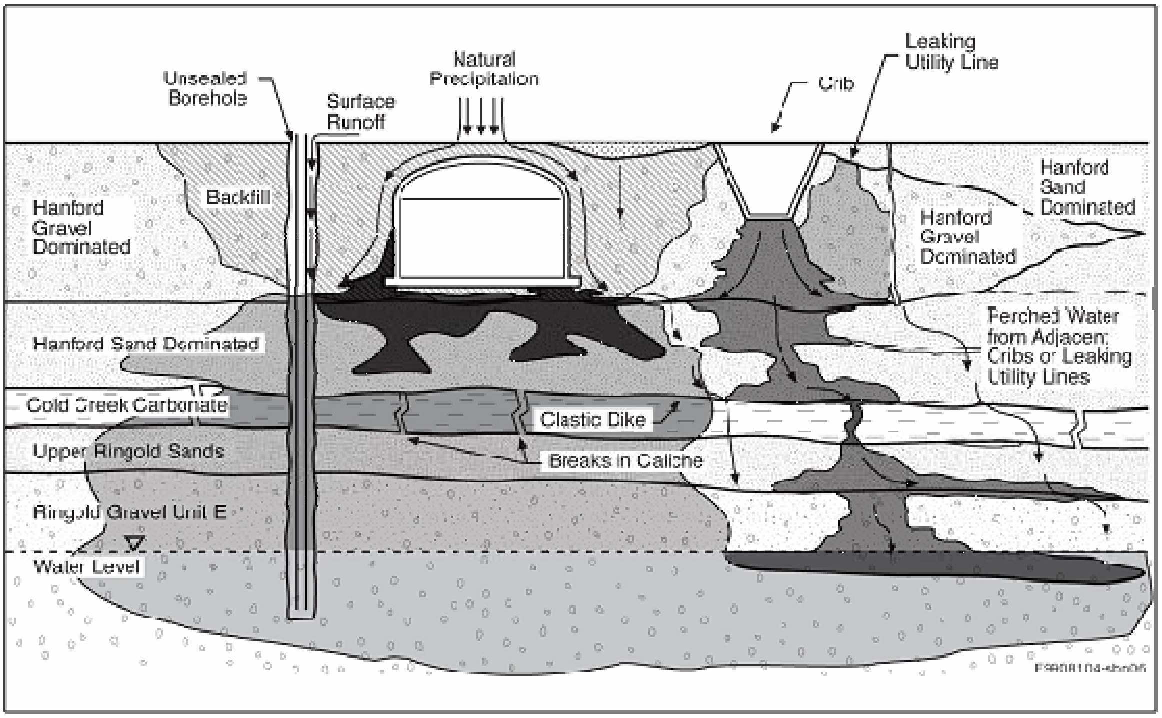

Fig. 2. General Vadose Zone Conceptual Model Concepts. (after [3]).

The long-term natural driving force for flow and transport through the vadose zone is "natural recharge," which is the fraction of the precipitation that has infiltrated below the zone of evaporation and below the influence of plant roots to eventually recharge the groundwater. Recharge rates range from <0.1 to 92 millimeters/year based on surface conditions [1].

The primary processes governing flow and transport through the vadose zone depend on the physical and chemical nature of the geologic material that makes up the vadose zone, as well as the types, amounts, and compositions of the fluids that occupy the pore spaces [7]. The natural transport of technetium and uranium can vary spatially and temporally depending on these factors and variations in geochemical conditions (e.g., oxidation-reduction potential). Remediation techniques are based on changing the subsurface conditions to either minimize the transport of technetium and uranium or to enhance their removal.

The Hanford and Ringold formations are considered the primary targets for the treatability test plan. These units comprise the bulk of the vadose zone under the Central Plateau. In the 200 East Area, the Hanford formation encompasses nearly the entire thickness of the vadose zone. In the 200 West Area, the vadose zone includes the Hanford formation, Cold Creek unit, and the Ringold Formation. The Cold Creek unit is composed of finer-grained and semi-consolidated layers that impact the flow and retention of pore fluids and contaminants. However, the Hanford and Ringold formations are the most permeable conduits for potential continued contaminant migration and are the most likely targets for deep vadose zone remediation; thus, initial treatability efforts focus on technologies appropriate for the Hanford and Ringold formations. Potential approaches to immobilize or remove contaminants in the Cold Creek unit are not specifically addressed but may be important as part of future efforts for particular waste sites.

Uncertainties Related to Deep Vadose Zone Remediation

The key uncertainties that need to be addressed can be assigned to four categories:

- Subsurface conditions. Current subsurface conditions have a significant effect on the performance of remediation technologies yet are not sufficiently defined for in situ technologies to be applied. Key elements of subsurface uncertainty include geology and distribution/connectivity of layers with contrasting properties, spatial distribution of moisture content and contaminants, and subsurface geochemistry and mineralogy. Each technology has a range of sensitivity to these uncertainties that lead to specific treatability test needs for each technology, as is reflected in the multi-phased approach planned for the treatability testing.

- Remediation rates. The physical and geochemical kinetics for each candidate technology will differ not only due to the technologies themselves, but also due to the particular environmental conditions (e.g., permeability and geochemistry) posed by individual waste sites.

- Long-term effectiveness. Technologies based on immobilizing the contamination (i.e., versus removing or destroying it) will need to remain effective over long time periods due to the longevity of technetium and uranium (t½ for Tc-99 = 2.13 X 105 years; t½ for U-238 = 4.47 X 109 years). Components of this type of uncertainty include the longevity and long-term impact of (1) fluid addition and removal on contaminant and moisture movement, (2) geochemical conditions induced by technologies, (3) physical changes induced by technologies, and (4) potential unintended impacts of technologies. The long-term effectiveness of the technologies is also impacted by the environmental conditions during treatment. Thus, remediation technologies must allow for potential natural- or human-induced future changes in the environment that are outside the typical seasonal variations, as well as the uncertainty in the way the technologies will perform under these potential extreme conditions.

- Technology implementation. Application of *in situ* technologies in the deep vadose zone will require subsurface access and consideration of surface infrastructure. Currently, existing data has been used to develop conceptual field designs for the candidate *in situ* technologies. Key design factors such as well spacing, flow rates, and reagent quantities are still uncertain.

The treatability test approach was developed to include activities that identify uncertainties and estimate their impact on implementing the technology in the initial phase of testing. Subsequent treatability activities include laboratory and field testing to provide additional data needed to address these uncertainties so the technologies can be effectively evaluated for potential use for the Hanford Site's target problems.

EVALUATION OF TECHNOLOGIES FOR TREATABILITY TESTING

Previous studies were used as the starting point for evaluating technologies for treatability testing to address contamination in the deep vadose zone [8, 9]. Surface barriers are recognized as potential key components of an approach for the vadose zone in all of these studies.

Identification of Candidate Technologies

In all of the previous studies, technologies requiring the addition of significant amounts of water to the vadose zone were less preferred for two reasons: (1) the potential for inducing uncontrolled migration of contaminants, and (2) the difficulties in controlling the way added water moves through the vadose zone. With the exception of the soil-flushing technology, the preference for technologies that do not require adding significant amounts of water was a prime criterion for selecting technologies for treatability testing.

Several of the studies examined excavation-based technologies, as well as those that may be applicable to some limited extent in the vadose zone. For instance, deep excavation (e.g., excavation with the use of caissons) may be suitable if a plume of limited area and depth were identified. However, the intent of this treatability test plan is to consider in situ technologies that do not have depth limitations. The exception to this bias is the inclusion of surface barriers. Surface barriers are a baseline technology likely important to future remediation efforts in the 200 Areas. Although barriers are applied at the surface, the impact of the barrier reaches down into the vadose zone and is, therefore, considered a potentially important component of addressing the deep vadose zone either alone or in conjunction with *in situ* technologies [10].

There are ongoing efforts at Hanford to examine remediation technologies, including studies of uranium at the groundwater/vadose zone interface and groundwater in the shallower Hanford 300 Areas. The DOE's Office of Engineering and Technology has also undertaken several projects relevant to remediating radionuclides in the deep vadose zone. These efforts may potentially be relevant to the Hanford 200 Areas and, thus, will be incorporated into the ongoing development and demonstration efforts.

The leading candidate technologies are listed below with a brief description of the technology and reference to the specific previous study that identified the technology.

- Desiccation [8, 9]. Desiccation involves drying a targeted portion of the vadose zone by injecting dry air into wells and extracting moisture. Because desiccation removes water already in the vadose zone, it reduces the amount of pore fluid available to support downward transport of contaminants in the deep vadose zone, impedes water movement, and augments the effectiveness of controlling the infiltration of surface water (e.g., surface barriers).

- *In situ* gaseous reduction (ISGR). A reducing gas (e.g., hydrogen sulfide) can be used to either directly change the valence of some contaminants to make them less soluble or to reduce sediment-associated iron, which in turn can reduce contaminants.

- Multi-step geochemical manipulation [8, 9]. The use of geochemical manipulation (termed "perturbation geochemistry" [8]) is in the developmental stage. The technique involves introducing gases to the vadose zone that induce reduction-oxidation and/or pH changes and create conditions for precipitation of minerals (e.g., carbonates) with co-precipitation of contaminants. The co-precipitated contaminants are then less available for migration.

- Nanoparticles [9]. Nanoscale-sized particles are also under development. The nanoparticles have surface-chemistry properties and large surface areas purposely designed to sequester selected metals and radionuclides.

- Grout injection [9]. Grout injection addresses subsurface contaminants by injecting a grout or binding agent into the subsurface to physically or chemically bind or encapsulate contaminants. There are multiple types of grout/binding material and emplacement techniques that have been developed and demonstrated.

- Electrokinetics [9]. Electrokinetic remediation is a process in which a low-voltage, direct-current (DC) electric field is applied across a volume of contaminated soil between electrodes inserted into the soil. Under the influence of a DC field, contaminants can be moved toward an electrode and then recovered.

- Monitored natural attenuation (MNA). The U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response (through Directive 9200.4-17P [11]) recognizes that natural attenuation processes may limit the migration of contaminants through the subsurface and constitute all or part of a remedy.

- Soil flushing [9]. Soil flushing operates through the addition of water, and an appropriate agent if necessary, to mobilize contaminants and "flush" them out of the vadose zone and into the groundwater where they are subsequently captured by a pump-and-treat system.

- Surface barriers [8, 9, 10]. Reduction of surface water infiltration by surface barriers reduces the hydraulic driving force for contaminant migration. The Hanford Prototype Barrier was installed in 1995 and a significant amount of monitoring data has been generated. A polyurea barrier is planned at the 241-T-106 site, and the impact of surface barriers has also been simulated in several modeling studies.

Technology Evaluation

Technologies based on gas-phase advection/delivery may be preferred for vadose zone treatment at Hanford for several reasons: (1) the depth and areal extent of vadose zone contamination, (2) the relatively high permeability material and low moisture content associated with a large portion of the vadose zone (especially the Hanford formation), and (3) the risk that any water added may unintentionally move contaminants into the groundwater. Four of the candidate technologies use, or can use, gas-phase advection/delivery as the mechanism for implementation: desiccation, ISGR, multi-step geochemical manipulation, and nanoparticles. The applicability of each of the potential technologies is discussed briefly below.

- Desiccation. Desiccation retards the movement of contaminants by physically removing water from the subsurface. While the concept of removing water from the vadose zone is promising, there are uncertainties with desiccation related to specific aspects of implementation and long-term effectiveness, as described in more detail by the vadose zone technical team [8]. In spite of these uncertainties, desiccation was recommended by the technical team as a technology that should be considered for field testing and has been included in the treatability test plan.

- *In situ* gaseous reduction (ISGR). The ISGR technology has been successfully demonstrated for remediating chromium in the shallow vadose zone. Technetium and uranium can be reduced and precipitated through ISGR, although the stability of the resulting precipitate is uncertain. Because ISGR has the potential to immobilize the contaminant and has been demonstrated at the field scale for similar applications, it has been included in the treatability test plan.

- Multi-step geochemical manipulation. Geochemical manipulation, as employed by ISGR, could be enhanced to provide more stable precipitates. While this multi-step process is still conceptual, it builds on the successful development and demonstration of ISGR and provides a potential for more effective immobilization of contaminants such as technetium and uranium. This approach has also been included in the treatability test plan.

- Nanoparticles. Distribution of nanoparticles in the deep vadose zone is still in the conceptual phase and is potentially problematic at Hanford. This technology has not been included in the treatability test plan but could be considered for future efforts.

- Grouting technologies. Grout injection technologies using multiple types of material have been applied and are currently being tested at other sites for *in situ* stabilization of contaminants. Likewise, more standard grouting techniques may also be useful for selected applications. There are significant uncertainties with use of grouting for in situ contaminant stabilization, especially for the deep vadose zone, as discussed by the vadose zone technical team [8]. However, because grouting technologies have the potential for use as part of a remedy for the deep vadose zone, further efforts to evaluate the performance of grouting technologies are included in the treatability test plan.

- Electrokinetics. Electrokinetics has been applied at other sites for moving contaminants to a target zone where they can be extracted by other means. Electrokinetics was eliminated in previous evaluations and by the vadose zone technical team [8] because it is not effective in dry soil and its implementation will likely be poor for a thick vadose zone and the target contaminants. Key problems included uncertainty of unintended consequences induced by concentrating contaminants and water in a small area of the vadose zone, a relatively small zone of influence for the electrodes, and limited applicability to fine-grained layers with relatively high moisture content. Because of these significant potential problems, electrokinetics is not included for treatability testing. However, electrokinetics could be considered for specific applications as part of other efforts. For instance, electrokinetics may be considered for application in the Cold Creek unit.

- Monitored natural attenuation (MNA). While there is not a specific evaluation of MNA underway at Hanford, there are ongoing field monitoring, characterization, laboratory, and modeling activities that are providing information to understand and predict the fate and transport of contaminants through the vadose zone and groundwater. These efforts are, by nature, site-specific and are not explicitly included as part of this treatability test plan.

- Soil flushing. There are significant uncertainties for using soil flushing in the deep vadose zone related to controlling the flow paths for the added water and effectively capturing the contaminants flushed into the groundwater. However, this technology provides a potential mechanism for removing contaminants from the subsurface. Efforts are needed to determine if soil flushing can be applied in a way that minimizes these uncertainties. Thus, soil flushing has been included in the treatability test plan.

- Surface barriers. Surface barriers are a baseline technology for near-surface contamination, and previous technology screening studies identified surface barriers as a promising technology for the deep vadose zone. Installation of a surface barrier specifically for the deep vadose zone testing is envisioned as beyond the scope of this treatability test plan. However, there are three surface barrier applications at Hanford with ongoing or planned monitoring that will provide useful data. These barriers include the Hanford Prototype Barrier constructed over the 216-B-57 Crib, the polyurea barrier at the 241-T-106 site, and the surface barriers planned for the 216-U-1 Operable Unit.

Based on the previous discussion, six technologies were selected for treatability testing:

- Desiccation
- ISGR
- Multi-step geochemical manipulation
- Grouting technologies
- Soil flushing
- Surface barriers.

TREATABILITY TEST APPROACH

A multi-element approach to the treatability test strategy was selected because candidate technologies are at different stages of development, and there are several categories of remediation approaches that require somewhat different types of assessment. Further, selecting an appropriate field testing site is linked to the needs for demonstrating a specific technology, the risks associated with the field demonstration, and the relevance to the specific problems associated with high-priority target sites. The approach involves the elements discussed in the following subsections.

Conduct Laboratory Work and Modeling

These efforts are designed to refine the scientific and technical information for the selected technologies through laboratory evaluations, modeling, and field measurements. The results will feed into a re-evaluation of the technologies for deep vadose zone application and will provide the basis for selecting appropriate technologies to move into the field-testing effort (described below). Based on the results of previous efforts, gas-phase technologies (i.e., desiccation, ISGR, and multi-step geochemical manipulation) are a key focus in this first stage of evaluation.

Assessment of the candidate gas-phase technologies will consider the results of previous studies and existing vadose zone property data, laboratory assessment of technical uncertainties as identified by the vadose zone technical team [8], and modeling to evaluate conceptual implementation strategies. This assessment will be used to determine the effectiveness, implementability, and cost of candidate technologies and to select the most appropriate technologies for initial field testing. If modeling and laboratory data indicate that the risk of unintended consequences for a technology application is high, initial field treatability testing will be conducted at a clean site. If the risk of unintended consequences is deemed low, field treatability testing will be conducted at a contaminated site.

These efforts will focus on technetium and will support a feasibility study for the 200-BC-1 Operable Unit, which is due in April 2010. Long-term efforts related to technetium will also be initiated and carried forward to support the 200-BC-1 remedial design and other remedy selection and implementation activities, as appropriate. Additional efforts for gas-phase technologies will include assessment for application to uranium sites targeted at the potential for conducting a field test in the Central Plateau in fiscal year 2010. Long-term efforts related to uranium will also be initiated and carried forward to support feasibility study and remedial design activities at operable units, as appropriate.

Select Technology for Field Demonstration/Treatability Testing

The initial focus for field testing will be on gas-phase technologies for technetium to support the 200-BC-1 feasibility study, which makes the 200-BC-1 Operable Unit a leading candidate as a field test site. However, this and other candidate sites will be evaluated using the information compiled during the laboratory and modeling phase of the treatability test strategy and from site characterizations to determine the best field testing site. The first decision involves evaluating whether or not the technology is ready for testing at a contaminated site. This determination will be based primarily on assessing the risk of unintended consequences at the candidate contaminated test sites. An uncontaminated site may be selected for initial testing if the risks at a contaminated site are deemed unacceptable. If a contaminated site is deemed appropriate, the candidate sites will be compared with respect to the contaminant distribution, knowledge of relevant subsurface properties, administrative burdens, available infrastructure, and the amount of characterization data available. The most appropriate test site will be selected based on these criteria and the usefulness of the anticipated data for supporting the 200-BC-1 feasibility study.

Field testing at a uranium-contaminated site is also a near-term objective for the treatability test plan. The evaluation process will be the same as described above for the technetium field testing site, also with a focus on gas-phase technologies. The final criterion, however, will be evaluation of the usefulness of the anticipated data for supporting operable units with uranium contamination.

Field Treatability Testing

Field testing is anticipated for gas-phase technologies to address technetium and uranium contamination. The objectives of the field testing will include an evaluation of technology implementation and short-term effectiveness so data can be collected within a timeframe to support consideration of the technology in near-term feasibility study efforts. These field test objectives will also include collection of data that support evaluation of related technologies. For instance, if desiccation is field tested, data relevant to distribution of other gases will be collected to support improved assessments of all gas-phase technologies. The field test objectives will also include monitoring of parameters that are indicative of long-term effectiveness and continued monitoring of these parameters over suitable time periods. While these data may not be available to support near-term feasibility studies, the data will be targeted at supporting later feasibility studies, remedial design, and other remedy selection efforts.

Field efforts to evaluate the effect of surface barriers on the deep vadose zone are also anticipated. These efforts will be conducted in conjunction with existing and planned surface barriers at the Hanford Site. A specific field testing and analysis plan will be developed for this effort.

Field testing of the other deep vadose zone technologies is not initially planned as part of this treatability test plan. However, the need for field testing these technologies will be re-evaluated using the laboratory and modeling information collected during the initial phase of the treatability test strategy.

TREATABILITY TEST PERFORMANCE EVALUATION

Results from the treatability tests will be evaluated in a report that discusses the modeling, laboratory data, and field work. This report will document the tasks performed and the data produced during the course of testing, will interpret the data, will evaluate the results against the objectives of the test, and will provide information to be used in remediation decision processes, including design and implementation of a larger-scale test or deployment of the remediation technology. The pertinent design information will include a detailed evaluation of testing costs and how these should be considered for full-scale technology implementation.

An essential element of a thorough treatability test analysis is verifying the technology's effectiveness. A number of indirect measurements can be made to evaluate effectiveness, but only direct physical measurements can be used for verification. Because the schedule for the initial treatability test has been optimized to provide information to the 200-BC-1 feasibility study, verification information will likely not be available for that phase of the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* process. Appropriate physical samples of the deep vadose zone at the field test site(s) will be collected after the treatability test, and the resulting data will be included in the evaluation report.

SUMMARY

A treatability test plan has been prepared to address technologies potentially viable for remediating portions of the deep vadose zone beneath the Central Plateau on DOE's Hanford Site. Contamination deep in the vadose zone, which extends to a depth of up to 100 meters (328 feet) and has the potential to contaminate groundwater in the future, lies beyond the reach of conventional surface excavation technologies.

Site characterization has identified a large number of radiological and hazardous chemical contaminants deep in the vadose zone. This treatability plan focuses on two contaminants – uranium and technetium. These elements are long-lived, and in several locations have reached the aquifer and already contaminated the groundwater. There are also a number of locations where significant inventories of these contaminants have been detected deep in the vadose zone but apparently have not yet reached the groundwater.

Most of the remediation techniques considered involve removing water from the vadose zone or changing the subsurface conditions to either minimize the transport of technetium and uranium or to enhance their removal. Previous studies have found that technologies requiring the addition of significant amounts of water to the vadose zone were less preferred and that excavation-based technologies had limited applicability. Thus, the intent of this treatability test plan was to consider *in situ* technologies that do not have depth limitations. Surface barriers are a baseline technology likely important to future remediation efforts in the Central Plateau and are considered a potentially important component of addressing the deep vadose zone, either alone or in conjunction with *in situ* technologies.

The following six technologies were selected for treatability testing:

- Desiccation
- ISGR
- Multi-step geochemical manipulation
- Grouting technologies
- Soil flushing
- Surface barriers.

A multi-element approach to the treatability test strategy was selected because candidate technologies are at different stages of development, and several categories of remediation approaches require somewhat different types of assessment. Furthermore, selecting an appropriate site for doing field tests is linked to the needs for demonstrating a specific technology, the risks associated with the field demonstration, and the relevance to the specific problems associated with high-priority target sites. The treatability test strategy is to first conduct laboratory work and modeling, then select specific technologies for field demonstration/treatability testing, perform treatability tests in the field, and evaluate the performance of those tests.

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