

Field Test Plan for the Uranium Sequestration Pilot Test

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

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APPROVED

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Release Approval

Date

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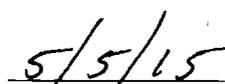
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Terms

bgs	below ground surface
CCU	Cold Creek unit
CERCLA	<i>Comprehensive Environmental Response, Compensation, and Liability Act of 1980</i>
CHPRC	CH2M HILL Plateau Remediation Company
DOE	U.S. Department of Energy
DOE-RL	DOE Richland Operations Office
DQA	data quality assessment
DTS	distributed temperature sensing
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ERT	electrical resistivity tomography
FS	feasibility study
FTP	field test plan
GPR	ground penetrating radar
IX	ion exchange
NPL	National Priorities List (40 CFR 300, Appendix B)
OU	operable unit
PNNL	Pacific Northwest National Laboratory
PVC	polyvinyl chloride
QAPjP	quality assurance project plan
RCRA	<i>Resource Conservation and Recovery Act of 1976</i>
RI	remedial investigation
SAP	sampling and analysis plan
TPA	Tri-Party Agreement
Tri-Party Agreement	<i>Hanford Federal Facility Agreement and Consent Order</i>
USPT	Uranium Sequestration Pilot Test

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1 Project Description

The U.S. Department of Energy (DOE) Hanford Site is a 1,517 km² (586 mi²) federal facility located in southeastern Washington State along the Columbia River. For administrative purposes, the Hanford Site was divided into four National Priorities List (NPL) sites (40 CFR 300, "National Oil and Hazardous Substances Pollution Contingency Plan," Appendix B, "National Priorities List") under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) in 1989, one of which is the 200 Area. In anticipation of the NPL (40 CFR 300, Appendix B) listing, DOE, the U.S. Environmental Protection Agency (EPA), and the Washington State Department of Ecology (Ecology) entered into the Tri-Party Agreement (TPA) in May 1989 (Ecology et al., 1989, *Hanford Federal Facility Agreement and Consent Order*). The TPA (Ecology et al., 1989) established a procedural framework and schedule for developing, implementing, and monitoring CERCLA response actions and *Resource Conservation and Recovery Act of 1976* (RCRA) compliance and permitting on the Hanford Site.

In March 2008, DOE/RL-2007-56, *Deep Vadose Treatability Test Plan for the Hanford Central Plateau*, was issued to meet Milestone M-015-50 of the TPA (Ecology et al., 1989). The Deep Vadose Treatability Test Plan (DOE/RL-2007-56) includes a focus on uranium sequestration as a potential remedial action. This field test plan (FTP) and its associated sampling and analysis plan (SAP) evaluate vadose zone injection of ammonia gas as a potential treatment remedy to stabilize uranium soil contamination and prevent migration to the underlying groundwater. The SAP associated with this FTP is DOE/RL-2010-88, *Sampling and Analysis Plan for the Uranium Sequestration Pilot Test*.

This FTP and associated SAP (DOE/RL-2010-88) are part of the remedial investigation (RI)/feasibility study (FS) process initiated by the original RI/FS work plan for this site (DOE/RL-91-19, *RCRA Facility Investigation/Corrective Measures Study Work Plan for the 200-UP-2 Operable Unit, Hanford Site, Richland, Washington*). The location of the test is the 216-U-8 Crib, which is included in the 200-WA-1 Operable Unit (OU). The 200-WA-1 OU, established in 2011, includes most waste sites located in the 200 West Area of the 200 Area NPL site (40 CFR 300, Appendix B).

1.1 Project Overview

Some reactive gases can induce geochemical changes in sediments that act to render contaminants, such as uranium, less mobile. A range of potential amendments was tested in the laboratory by Pacific Northwest National Laboratory (PNNL) as described in PNNL-18879, *Remediation of Uranium in the Hanford Vadose Zone Using Gas-Transported Reactants: Laboratory-Scale Experiments*. The amendments targeted oxidation-reduction reactions, pH manipulation, and phosphate addition to induce precipitation reactions that made contaminants less mobile. Based on the PNNL results, pH manipulation with ammonia gas proved to be effective in reducing the mobility of uranium and is suitable for application in the Hanford Site vadose zone (PNNL-18879; PNNL-20004, *Uranium Sequestration in the Hanford Vadose Zone using Ammonia Gas: FY 2010 Laboratory-Scale Experiments*; Szecsody et al., 2012, "Geochemical and Geophysical Changes During Ammonia Gas Treatment of Vadose Zone Sediments for Uranium Remediation"). Laboratory experiments have shown this process to be effective in many Hanford Site sediments.

This field test is being implemented to evaluate the effectiveness of injecting ammonia gas into the Hanford Site vadose zone to decrease the mobility of uranium, and other similar contaminants, to protect the underlying groundwater. Groundwater risk mitigation is derived from reducing the fraction of uranium contamination that is mobile. This process, uranium sequestration via ammonia injection, will be evaluated in a pilot test conducted at the 200-WA-1 OU, located in the 200 West Area of the

Uranium contamination is present in two distinct regions at the 216-U-8 Crib (see Figure 1-2). One region is at a relatively shallow depth of approximately 10.6 m (35 ft) below ground surface (bgs) in the coarser-grained Hanford formation. The second, deeper region is at a depth of approximately 58 m (190 ft) bgs in the tight-grained Cold Creek unit (CCU). Testing of only the shallow region in the Hanford formation is planned at this time.

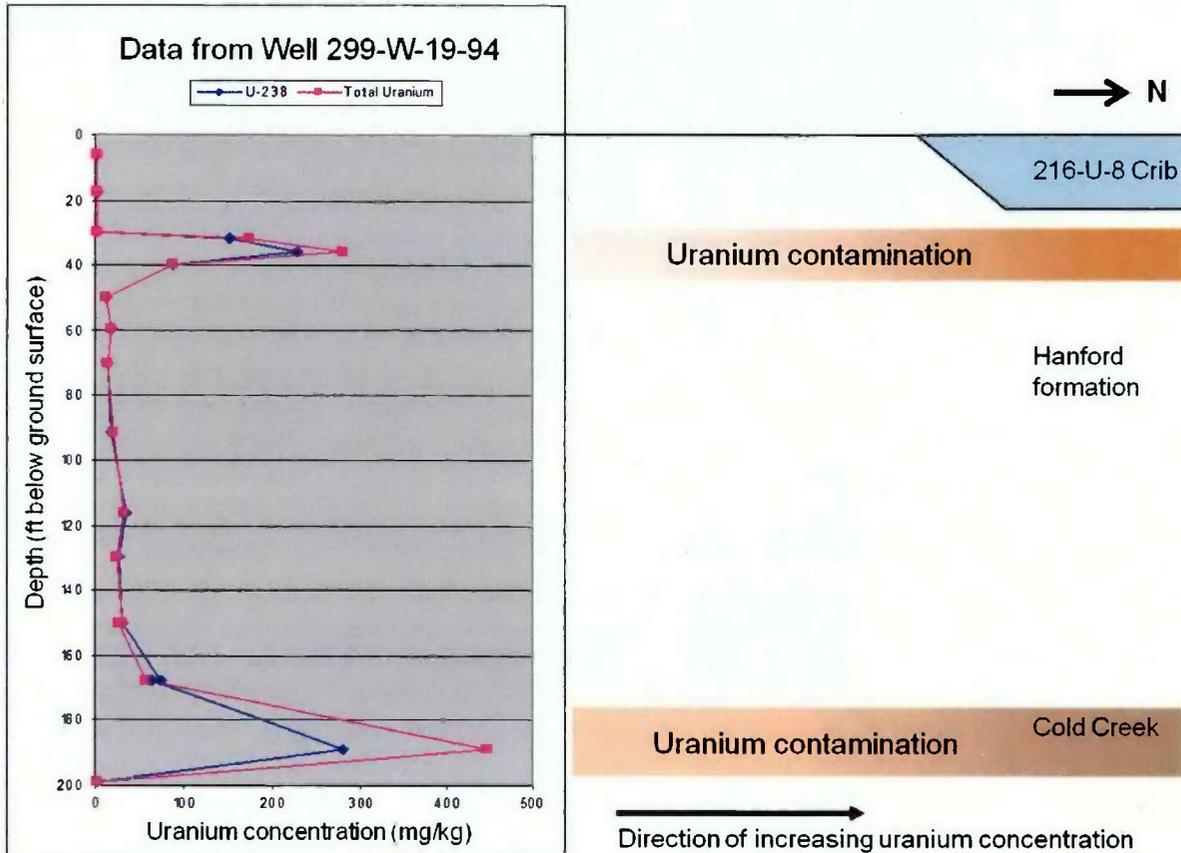


Figure 1-2. Uranium Concentrations in Sediments beneath the 216-U-8 Crib

1.2 Project Activities

This FTP describes the methodologies that will be used to evaluate uranium sequestration via ammonia injection as a potential remedy for protecting groundwater from deep vadose zone contamination. The test focus is to gather information for use in subsequent FS evaluation of this technology. The test is designed to evaluate delivery of ammonia to a targeted treatment zone and decreases in uranium mobility within the treated zone.

The first part of the test will include collecting vadose zone samples from the study area for laboratory testing. The sediments will be characterized, and the nature and levels of the contaminants will be determined. The uranium mobility results from laboratory testing of sediments from the first borehole installed at the site will be used to determine if the sediments in the study area are suitable for application of the treatment technology. If the sediments are determined to be suitable, samples of the sediments from two additional boreholes will be characterized and treated with ammonia gas to evaluate the effectiveness of the treatment.

Following determination of suitability of this region for the test, the remainder of the boreholes will be drilled, and the field application and process monitoring equipment will be installed at the test site. When all of the equipment is in place and operational, ammonia gas will be injected into the vadose zone of the study site, and field measurements will be collected to monitor the test. Finally, samples of the vadose zone sediments will be collected from the treatment zone and tested in the laboratory to characterize the post-treatment condition of the sediments and evaluate the effectiveness of the treatment.

The results of the test will be interpreted in terms of FS criteria, such as short-term effectiveness, implementability, long-term effectiveness, and cost. The impact to groundwater cannot be directly measured by a test of this limited aerial extent and short duration. However, information needed to conduct fate and transport modeling will be collected so that numerical models can be used to estimate how the treatment is effective for protection of groundwater.

2 Treatment Technology Description

The treatment technology being tested is geochemical manipulation via ammonia injection. Previous laboratory evaluation of gas phase technologies focused on immobilization of uranium (PNNL-18879) and recommended pursuing ammonia injection because it was best suited for field implementation and was effective in reducing uranium mobility. Additional study of the ammonia gas treatment process and large-scale application has also been conducted (PNNL-20004; Szecsody et al., 2012; PNNL-23699, *Scale-Up Information for Gas-Phase Ammonia Treatment of Uranium in the Vadose Zone at the Hanford Site Central Plateau*; Zhong et al., 2015, "Ammonia Gas Transport and Reactions in Unsaturated Sediments: Implications for Use as an Amendment to Immobilize Inorganic Contaminants").

As conceptually depicted in Figure 2-1, when ammonia gas flows into vadose zone sediments, it rapidly partitions into the pore water. A portion of the ammonia dissociates and causes the pore water pH to increase to near pH 12. Under these conditions, aluminosilicate compounds in the soil matrix dissolve in the pore water. When ammonia injection is stopped, pore water pH will decline due to buffering and the loss of ammonia. As the pH declines, the aluminosilicate ions in solution precipitate. These precipitates coat and bind much of the uranium contamination, rendering it less mobile. By reducing the fraction of uranium contamination that is mobile, its potential to contaminate groundwater is reduced.

Field implementation of the ammonia treatment technology involves injection of an ammonia gas mixture into a subsurface target zone. The ammonia partitions into the pore water and approaches a pore water concentration dependent on the concentration of ammonia in the gas phase according to its Henry's law coefficient. Because partitioning is very rapid and volatility is low, a sharp dissolution front is observed with near equilibrium ammonia gas and liquid concentrations behind the front and low concentrations elsewhere (Figure 2-2); thus, the physical properties of ammonia are favorable for controlled injection.

Ammonia treatment results in uranium surface phases being coated with or incorporated in aluminosilicates. In this process, uranium is not chemically reduced, so the oxidation state of the uranium does not affect treatment effectiveness, and the sequestration process is not readily reversible in an oxic vadose zone. Under post-treatment neutral pH conditions, precipitates formed during ammonia treatment have low solubility and would dissolve slowly over long time periods as part of natural weathering processes. Transport of uranium that is bound or coated by precipitates will be limited, thereby reducing the migration of uranium to the groundwater.

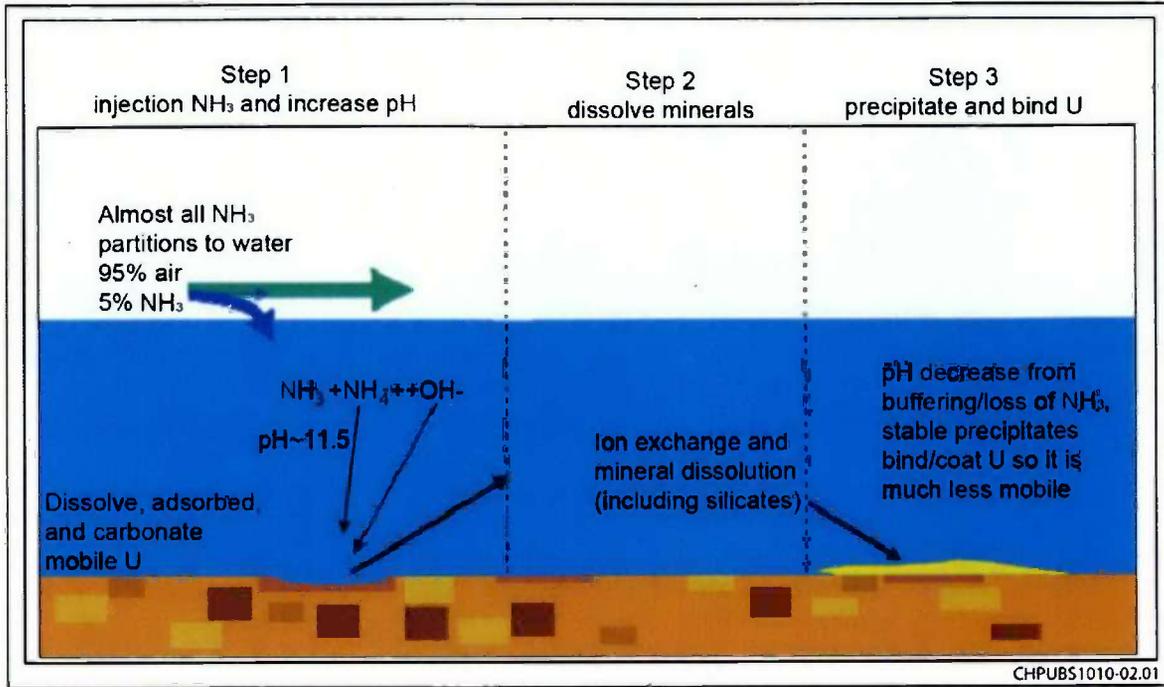


Figure 2-1. Conceptual Depiction of Ammonia Treatment Mechanism

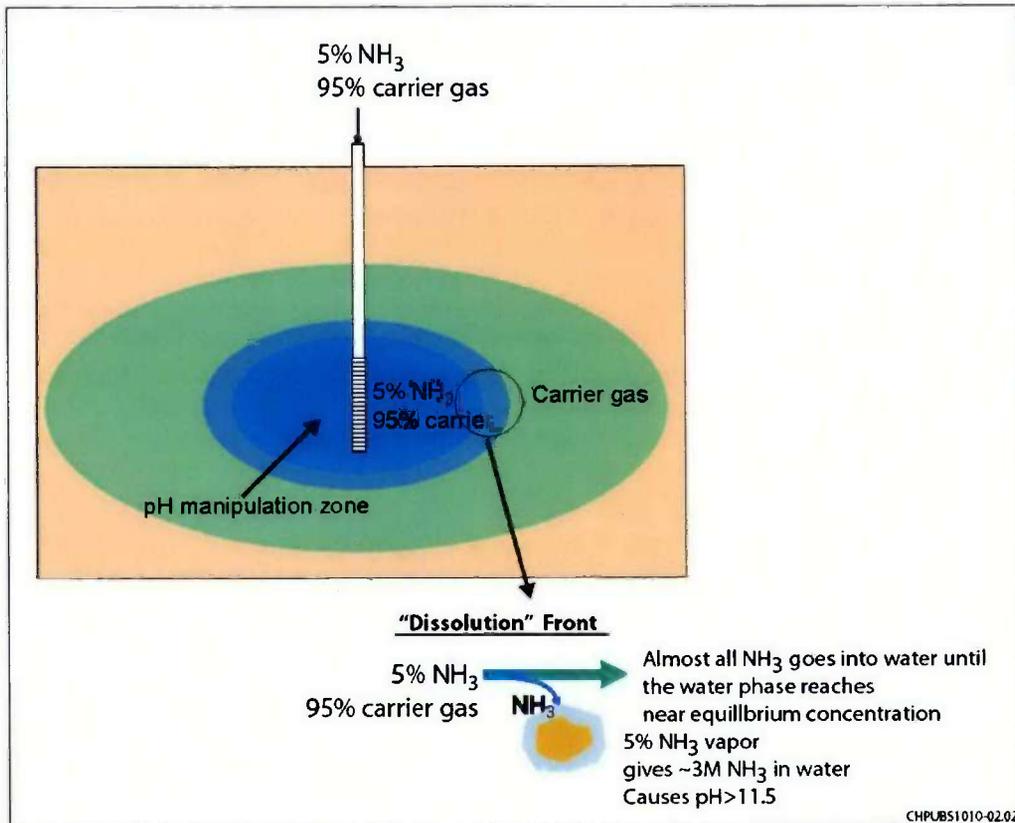


Figure 2-2. Conceptual Depiction of Ammonia Distribution in the Subsurface from an Injection Well

As with any gas phase treatment technology, uniformity of distribution in the vadose zone is impacted by many factors and may be problematic, especially in low-permeability zones. During the ammonia treatment process, the increase in pore water pH releases ions into solution where they will be in a mobile state until the pH returns to neutral, causing precipitation reactions. In most vadose zone conditions, movement of pore water is very slow, and a decrease in pH will occur before any significant movement. In other words, the reaction processes are rapid compared to potential contaminant transport.

The long-term fate of ammonia added to the subsurface to induce uranium treatment, as described in laboratory testing (PNNL-23699), is (1) volatilization and upward ammonia gas migration in the vadose zone, (2) conversion of ammonia to nitrate in the pore water, and/or (3) ammonium sorption or incorporation into aluminosilicate precipitates. To examine the relative importance of these processes, sediment dosed with 5, 0.5, or 0.05 percent ammonia gas was incubated for varying lengths of time in closed containers so that volatilization of ammonia was not possible. Sacrificial treatments were analyzed for ammonia, nitrate, and nitrite concentrations. In all treatments, no increases in nitrate or nitrite were observed over 3 months of incubation time. Total microbial populations were also measured before ammonia dosing and during incubation. With exposure to a 5 percent ammonia gas concentration, representative of the treatment zone concentration, microbial populations starting at about 1×10^7 cells/mL declined to nondetectable levels. Microbial populations exposed to 0.05 percent and 0.5 percent ammonia gas concentrations declined by orders of magnitude. The microbial populations exposed to 0.05 percent ammonia gas concentrations recovered quickly on exposure to air, whereas populations exposed to higher concentrations showed minimal recovery. These results suggest that the nitrification pathway is insignificant during ammonia injection and the subsequent precipitation phase. Longer duration fate, however, may potentially include nitrification.

3 Test Objectives

The overall objectives of the uranium sequestration treatability test are listed in DOE/RL-2007-56. The original objectives have been refined based on the selected reactive gas process (ammonia treatment) and the characteristics of this process identified in laboratory investigations (PNNL-18879; PNNL-20004; Szecsody et al., 2012; PNNL-23699; Zhong et al., 2015). The refined test objectives include the following:

- Determine the design parameters for applying uranium sequestration via ammonia injection to the study area. This includes determining the operational parameters such as reactant flow rates and properties (e.g., gas composition) and identifying the target areas to achieve acceptable reduction of mobile uranium.
- Demonstrate field scale treatment for targeted areas within the vadose zone by quantifying the following:
 - Reduction of uranium mobility in the field test treatment zone compared to the reduction of uranium mobility observed in laboratory-induced treatment of site sediments with a goal of decreasing the mobile uranium fraction in the sediment by half. Extent is determined by a decrease in the amount of uranium that can be extracted using a sequential application of groundwater, an ion exchange (IX) solution, and a mild acetic acid solution as the extracting solutions.
 - Stability of sequestered uranium in terms of dissolution rate of uranium into the pore water.
- Demonstrate the ability to deploy operational equipment and instrumentation necessary to implement the treatment process on a large scale.

- Collect data to support consideration of uranium sequestration via ammonia injection as a remedy in the FS process. Although the objectives of the treatability test are focused on uranium sequestration, impacts to expected co-contaminants (technetium-99, strontium-90, and cesium-137) will also be quantified.

4 Experimental Design and Procedures

The Uranium Sequestration Pilot Test (USPT) will be conducted at the south end of the 216-U-8 Crib. The vadose zone of this site has been previously characterized, and data indicate the presence of significant levels of mobile uranium contamination. Two zones of uranium contamination have been previously identified: one relatively shallow in the Hanford formation, and another much deeper in the CCU silt layer. This treatability test will focus on the shallow region of contamination in the Hanford formation.

The treatability test design is intended to evaluate uranium sequestration via vadose zone ammonia gas injection as a potential remedy for groundwater protection. The test will consist of a single ammonia injection well screened within an interval of the vadose zone where sufficient mobile uranium contamination exists to test the technology. The target soils will be characterized prior to the test to ensure that uranium contamination is present and the conditions are suitable for the test. Ammonia gas will then be injected into the vadose zone through the well to interact with the sediment moisture to increase its pH and render it sufficiently corrosive to dissolve a fraction of the aluminosilicate minerals that are present. Ammonia gas concentrations and soil parameters (e.g., temperature and electrical conductivity) will be monitored during the test to evaluate the distribution of ammonia in the subsurface. After ammonia injection is stopped, sediment pore water pH will return to near normal, resulting in precipitation of the aluminosilicate minerals and their entrainment of a significant portion of the mobile uranium. Post-treatment soil samples will be collected and analyzed to evaluate the effectiveness of the treatment. The fundamental objectives are to evaluate this form of geochemical manipulation, as a means of slowing contaminant transport, and collect information to support inclusion of ammonia treatment as a technology in future CERCLA FSs.

4.1 Technical Basis

A series of laboratory tests have been conducted to develop and quantify how ammonia treatment of vadose zone sediments can decrease the mobility of uranium contamination. Details of these studies are contained in multiple reports and journal manuscripts (PNNL-18879; PNNL-20004; Szecsoy et al., 2012; PNNL-23699; Zhong et al., 2015). In many of these tests, a sequential extraction procedure was used to determine the amount of uranium that could be extracted from sediment by using increasingly aggressive extraction solutions. These data are interpreted in terms of uranium mobility. The first three extractions (groundwater, IX solution, and weak acetic acid) are less aggressive, and uranium extracted by these solutions is considered relatively mobile with pore water moving through the vadose zone. The next three extractions are fairly aggressive (pH 2.3 acetic acid, oxalic acid, and hot nitric acid), and uranium extracted by these solutions is considered relatively immobile and only released slowly as part of sediment weathering processes (e.g., dissolution of precipitates or minerals).

Laboratory results show that ammonia treatment results in a lower fraction of uranium removed by the three less aggressive extractions, indicating less mobile uranium. There is also a corresponding increase in the fraction of uranium removed by the three aggressive extractions, indicating more immobile uranium. There is a notable increase in the uranium fraction, which is removed by the most aggressive (nitric acid) extraction. These tests suggest that ammonia treatment is decreasing the mobility of uranium by binding or coating uranium with precipitates that do not readily release uranium to the pore water.

Laboratory evaluation and geochemical modeling has been conducted to examine these ammonia treatment mechanisms (PNNL-20004; Szecsody et al., 2012). In summary, laboratory analysis of pore water associated with treated sediment and selected mineral components expected in Hanford Site sediments shows the predicted elevated pH conditions along with significant increases in solute concentrations, including those associated with aluminosilicate and other mineral dissolution and IX processes. Solute concentrations then decline as precipitation occurs. Geochemical modeling confirms these processes. Additional details of these studies and sediment/precipitate analyses are provided in the uranium sequestration study (PNNL-20004; Szecsody et al., 2012).

Laboratory studies (PNNL-18879; PNNL-20004; Szecsody et al., 2012; PNNL-23699; Zhong et al., 2015) have also investigated factors impacting distribution of ammonia within the vadose zone. Ammonia distribution is strongly influenced by partitioning to the pore water. With a dimensionless Henry's law coefficient (equilibrium vapor concentration/aqueous concentration) of 6.58×10^{-4} , ammonia readily partitions to the aqueous phase. The partitioning process is rapid (within seconds), and associated rapid pore water pH increase initially occurs until pH 10. Partitioning is slower thereafter but still relatively rapid compared to the expected gas flow rate in the subsurface.

By assuming equilibrium partitioning, a mass balance type calculation can be used to estimate the ammonia loading needed for a targeted region of sediment at a specified water content and ammonia gas concentration (PNNL-23699; Zhong et al., 2015). Additionally, ammonia dissociation can be computed based on thermodynamic information so that the pH of the pore water can also be estimated. Table 4-1 shows the results of this analysis for a nominal Hanford formation and CCU sediment. While these estimates do not account for all of the phenomena that can occur, they capture the dominant phenomena. Laboratory testing has confirmed that these estimates are close to what is observed at the laboratory scale. These calculations will be used as a baseline to estimate operational conditions and material needs for the field test. The spreadsheet calculations are also useful for comparison to subsequent numerical simulation of the injection process.

The spreadsheet-based analysis shown in Table 4-1 provides an initial basis for the injection design based on calculations for ideal conditions and includes assumptions based on laboratory experience and professional judgment. The estimates provided in Table 4-1 will be used as guidance by the project team with the expectation that conditions may be somewhat different at the field site. These calculations assume that with anisotropy in the subsurface, the injected gas flow is expected to be more horizontal than vertical. In this case, the volume impacted by ammonia can be approximated as a cylinder with a radius of 6 m (20 ft) and with the height of the injection well (3.1 m [10 ft]) to represent the horizontal core of the injection zone. To account for some movement vertically (upward and downward), 40 percent of the volume of a sphere with a 6 m (20 ft) radius was added to the cylindrical volume. Gas advection, partitioning, and diffusion processes will control the distribution of ammonia during injection. Partitioning causes a sharp concentration front in the ammonia gas phase. This front then moves slowly compared to the carrier gas advection. The slow advective movement of ammonia and high-concentration gradient provide a large driving force and relatively long time frame for diffusion processes to occur. Laboratory intermediate-scale tests show ammonia distribution into small-scale low-permeability zones adjacent to and embedded in high-permeability zones (PNNL-20004). The diffusion rate was shown to be significant with respect to distributing ammonia to lower-permeability zones (PNNL-23699; Zhong et al., 2015). The relatively slow advective movement, rapid partitioning process, and contribution of diffusion are expected to improve the uniformity of ammonia distribution during injection and improve the chances that use of an injection only design will effectively distribute ammonia to the target treatment zone.

Table 4-1. Spreadsheet Calculations of Ammonia Loading

Parameter	Hanford Formation
Water Content (g/g)	0.04
Porosity	0.2
Particle Density (g/mL)	2.5625
Bulk Density (g/mL)	2.05
Water Volume Fraction (mL/mL)	0.082
Gas Volume Fraction (mL/mL)	0.118
Equilibrium NH ₃ Concentration	3.192
Calculated Equilibrium pH	11.88
Target Screen Interval (m)	3.1
Target Radius of Injection (m)	6
Target Treatment Volume (m ³) (cylinder + 40% of a sphere)	713
Total NH ₃ Mass (kg)	3,170
NH ₃ Mass/Pore Volume (kg)	3
Pore Volumes Needed	1,057
Total Gas Volume Needed (NH ₃ + carrier) (m ³)	88,853
Gas Flow Rate (ft ³ /min)	50
Time for NH ₃ Delivery (d)	44
NH ₃ = nitrate	

A more detailed design associated with gas flow in the vadose zone with an injection only design will be tested using numerical simulations to examine a variety of potential subsurface conditions. Unless these simulations show that an injection only design is not likely to function properly, field testing will proceed using an injection only approach. The simulation results will be used as a basis to adjust the injection design in conjunction with the field test site data collected in Phases 1 and 2 (e.g., tracer test data). Table 4-2 (Zhong et al., 2015) summarizes the relationship between ammonia concentration and pH. (Note that very little ammonia is required to cause a large pH change.)

Table 4-2. Ammonia Gas Partitioning to Water and Resulting pH

% NH ₃ (g)	NH ₃ (aqueous) Total	pH
100	15.7 mol/L	12.52
30	9.2 mol/L	12.26
10	6.3 mol/L	12.02

Table 4-2. Ammonia Gas Partitioning to Water and Resulting pH

% NH ₃ (g)	NH ₃ (aqueous) Total	pH
5	3.1 mol/L	11.87
1	0.63 mol/L	11.52
0.3	0.19 mol/L	11.26
0.1	6.3×10^{-2} mol/L	11.02
0.01	6.3×10^{-3} mol/L	10.51
10^{-3}	6.3×10^{-4} mol/L	9.99
10^{-4}	6.3×10^{-5} mol/L	9.41
10^{-5}	6.3×10^{-6} mol/L	8.69 (assumes no other aqueous ions)
10^{-6}	6.3×10^{-7} mol/L	7.78 (assumes no other aqueous ions)

NH₃ = nitrate

4.2 Experimental Design

A phased approach to the treatability test will be implemented. The following sections describe the details of the planned field and laboratory testing. Procedures for field operations will be prepared as field test instructions and will cover the activities described as follows.

4.2.1 Phase 1 – Site Characterization

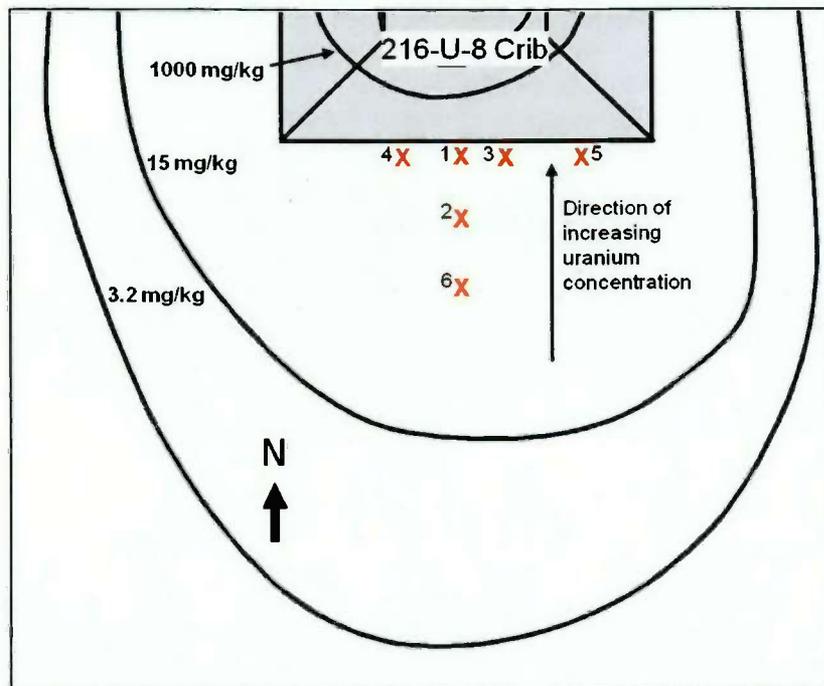
Three boreholes will be installed at the study site and sampled to characterize the vadose zone soils. The characterization data will be used for the following functions:

- Validate the test site selection.
- Obtain baseline information for site characterization.
- Determine effectiveness of ammonia on uranium present at this site.
- Select a target treatment zone.

The boreholes will be drilled to avoid potential impact to the representativeness of vadose zone soil samples; all efforts must be made to drill without the use of slurry makeup water. In the event that drilling slurry makeup water is needed, the situation must be discussed with project technical staff before proceeding.

4.2.1.1 Install, Sample, and Characterize Borehole 1

Borehole 1 will be installed at the location shown on Figure 4-1. The borehole will be drilled to a depth of approximately 24.3 m (80 ft) bgs. Soil samples will be collected continuously, initiated at approximately 9.1 m (30 ft) bgs. Sampling will be performed using a 10.2 cm (4 in.) diameter, 0.76 m (2.5 ft) long split-spoon sampler. The split-spoon samplers will be equipped with four separate nonconductive plastic liners that are each 15.2 cm (6 in.) long. Once the split-spoon liners have been appropriately labeled and documented in the field logbook, the liners will be sealed and shipped to the laboratory for analysis. Once final depth is achieved and all samples have been obtained, Borehole 1 will be geophysically logged using downhole neutron and spectral gamma technology.



Note: Uranium concentration data is from D&D-27783, 200-UW-1 Field Summary Report for Fiscal Years 2004 and 2005. Contours are the estimated uranium sediment concentrations from previous characterization in the upper 25 m (82 ft) of the vadose zone (not to scale).

Figure 4-1. Layout of Boreholes

Using the geophysical logging information, five split-spoon interval samples will be selected for characterization at the laboratory. The sampling intervals will be selected based on regions of expected uranium contamination. The five samples will be sieved to remove material greater than 4 mm in size. The less than 4 mm fraction of each sample will undergo sequential extraction to determine the pore water uranium and mobile uranium fractions. Adjacent liners from each sample interval will be analyzed for bulk conductivity and for physical and chemical properties.

Borehole 1 is anticipated to be the injection well for the test. The geophysical data will provide a vertical profile of contamination for use in selecting an appropriate target depth interval for the test. Sequential extraction analysis of the five sediment samples from the target interval will be used to evaluate the total uranium concentration and relative amount of mobile uranium present. These data will be used to evaluate the suitability of the test site and finalize the drilling targets for the subsequent boreholes. Sequential extraction analysis will require approximately 2 weeks to complete.

The following criteria will be considered to determine whether the full test system should be installed (i.e., is the site appropriate for the test) and select the borehole/well completion configurations:

- Pore water uranium concentration $>30 \mu\text{g/L}$
- Uranium mobile fraction (aqueous, sorbed, and rind carbonate) >20 percent of total
- Uranium concentration and concentration gradient with preference for a test location with uranium concentrations ranging from 10 to 1,000 mg/kg

- Thickness of uranium contamination and target depth intervals that can be effectively treated and monitored

4.2.1.2 Install, Sample, and Characterize Boreholes 2 and 3

Based on the determination that the study site is suitable for the treatability test, Boreholes 2 and 3 will be installed at the locations shown on Figure 4-1. The boreholes will be drilled to a depth based on the characterization information determined from Borehole 1. Similar to Borehole 1, soil samples will be collected continuously, initiated at approximately 9.1 m (30 ft) bgs. Sampling will be performed using a 10.2 cm (4 in.) diameter, 0.76 m (2.5 ft) long split-spoon sampler. The split-spoon samplers will be equipped with four separate nonconductive plastic liners that are each 15.2 cm (6 in.) long. Once the split-spoon liners have been appropriately labeled and documented in the field logbook, they will be sealed and shipped to the laboratory for analysis. Once final depth is achieved and all samples have been obtained, Boreholes 2 and 3 will be geophysically logged using downhole neutron and spectral gamma technology.

Using the geophysical logging information and data from Borehole 1, three to five split-spoon interval samples will be selected from each borehole for characterization at the laboratory. The sampling intervals will be selected based on regions of expected uranium contamination. These samples will be sieved to remove material greater than 4 mm in size. The less than 4 mm fraction of each sample will undergo sequential extraction to determine the pore water uranium and mobile uranium fractions. Adjacent liners from each sample interval will be analyzed for bulk conductivity and for physical and chemical properties.

4.2.1.3 Laboratory Ammonia Testing

In the final step of site characterization, a subsample of the less than 4 mm fraction from liners for each of the intervals characterized for uranium in Boreholes 1, 2, and 3 will be treated with exposure to ammonia in the laboratory and analyzed. This will include five samples from Borehole 1 and three to five samples each from Boreholes 2 and 3, obtained from the same intervals that were used for sequential extraction analysis in the previous characterization steps. After exposure to ammonia, each sample will undergo sequential extraction to determine the pore water uranium and mobile uranium fractions. Extraction data from the samples exposed to ammonia will be compared to extraction data from untreated samples of the same sampling intervals.

Data from laboratory ammonia treatment will primarily be used to evaluate the geochemical treatment and sequestration processes at the test site. Laboratory data will quantify the increase in pH due to the ammonia exposure, timescale of pH decrease and associated precipitation/sequestration processes following initial ammonia distribution, and change in uranium surface phase distribution (mobility). Laboratory-scale geophysical monitoring on selected samples will provide the geophysical signatures of pH increase and decrease necessary to interpret field-scale geophysical images in terms of spatial and temporal pH distribution. The geochemical process and timescale information from the laboratory will be the primary data used to evaluate the ammonia reaction processes for field site sediments. These data will be used to set baseline conditions for the field test.

If ammonia treatment is not successful in the laboratory, the project team will confer with the DOE Richland Operations Office (DOE-RL) and EPA to determine whether or not to continue the field test. The target for laboratory ammonia treatment is to demonstrate a decrease in the amount of uranium in the mobile fraction by at least 50 percent.

If ammonia treatment is successful, the laboratory tests will continue with sediment chemistry and leaching studies to evaluate the long-term dissolution of sequestered uranium after ammonia gas treatment. The fate of expected co-contaminants (technetium-99, strontium-90, and cesium-137) will also

be assessed in these tests. Results from these tests are anticipated to require about 6 months to 1 year to complete. During that time, Phase 2 of the test will be conducted.

4.2.2 Phase 2 – Field Site Test System

Based on the decision from Phase 1 that the study site is suitable for the treatability test, Boreholes 4, 5, and 6 will be installed at the locations shown on Figure 4-1. The boreholes will be drilled to depths based on the characterization information determined from Boreholes 1, 2, and 3. Once final depth is achieved, boreholes will be geophysically logged using downhole neutron and spectral gamma technology.

The ammonia injection well will be completed at the targeted depth interval, and distance from the crib edge will be based on the information obtained in Phase 1. The screened interval is tentatively set at 3 m (9.8 ft) for the test but will be refined based on evaluation of Phase 1 data. Conceptually, the injection well will be located at the borehole location closest to the center of the crib (Borehole 1).

The remaining boreholes (assumed to be Boreholes 2, 3, 4, 5, and 6) will be completed as instrumented monitoring locations with vertically discrete monitoring intervals. Monitoring will focus on obtaining and field analyzing gas samples, monitoring temperature at multiple depth intervals, monitoring borehole and surface electrodes for electrical resistivity tomography (ERT) surveys, collecting neutron moisture logging data, and conducting ground penetrating radar (GPR) surveys. Two sampling and instrumentation tests will be conducted, which include use of sediment coupons in Boreholes 2 and 3 (two per borehole) for field moisture measurements and installing fiber-optic distributed temperature sensing (DTS) cable in all of the boreholes for temperature monitoring. A pressure monitoring system will also be installed at the surface for each gas sampling location. Table 4-3 lists the monitoring techniques and a brief description of their function. Figures 4-2, 4-3, and 4-4 show the conceptual monitoring installation details.

Table 4-3. In Situ Monitoring Techniques

Instrument	Function	Borehole
Gas Sampler	A port for withdrawing soil gas samples.	2, 3, 4, 5, 6
Thermistor	In situ probe that measures temperature. Temperature can be a measure of when the ammonia gas front passes a location.	1, 2, 3, 4, 5, 6
Fiber-Optic DTS Cable	Temperature measurement using DTS technology. Provides temperature measurement along entire cable with a targeted spatial resolution between 25 cm (9.8 in) and 100 cm (39.4 in) and temperature accuracy comparable to thermistors.	1, 2, 3, 4, 5, 6
Resistivity Electrodes	Allows use of cross-borehole/surface electrical resistance tomography (two- or three-dimensional depiction electrical resistivity) that is related to ammonia distribution and induced reactions. These electrodes also enable collection of Spectral Induced Polarization data that may enable imaging of the dissolution/precipitation processes in the field.	1, 2, 3, 4, 5, 6
Access for Logging	A 5.1 cm (2 in.) diameter blank PVC casing will be provided, so that a neutron probe and/or GPR transmitters and receivers can be deployed.	2, 3, 4, 5, 6
Sediment Coupons	Packet of moist sediment deployed at a location such that it can be removed at selected times for analysis (pH, electrical conductivity, pore water cations/anions, uranium surface phases).	2, 3

DTS = distributed temperature sensing
GPR = ground penetrating radar
PVC = polyvinyl chloride

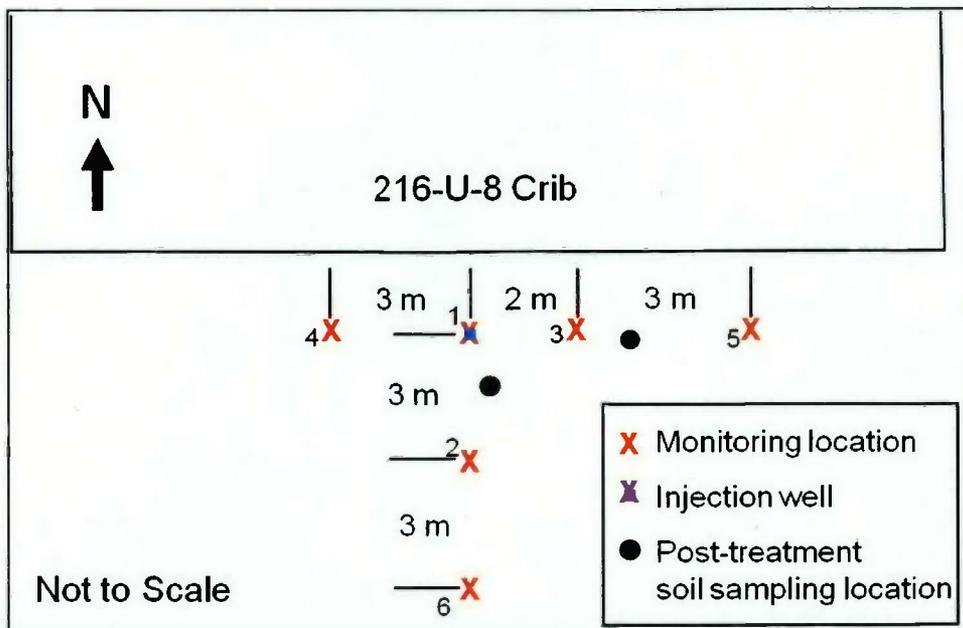


Figure 4-2. Proposed Test Layout

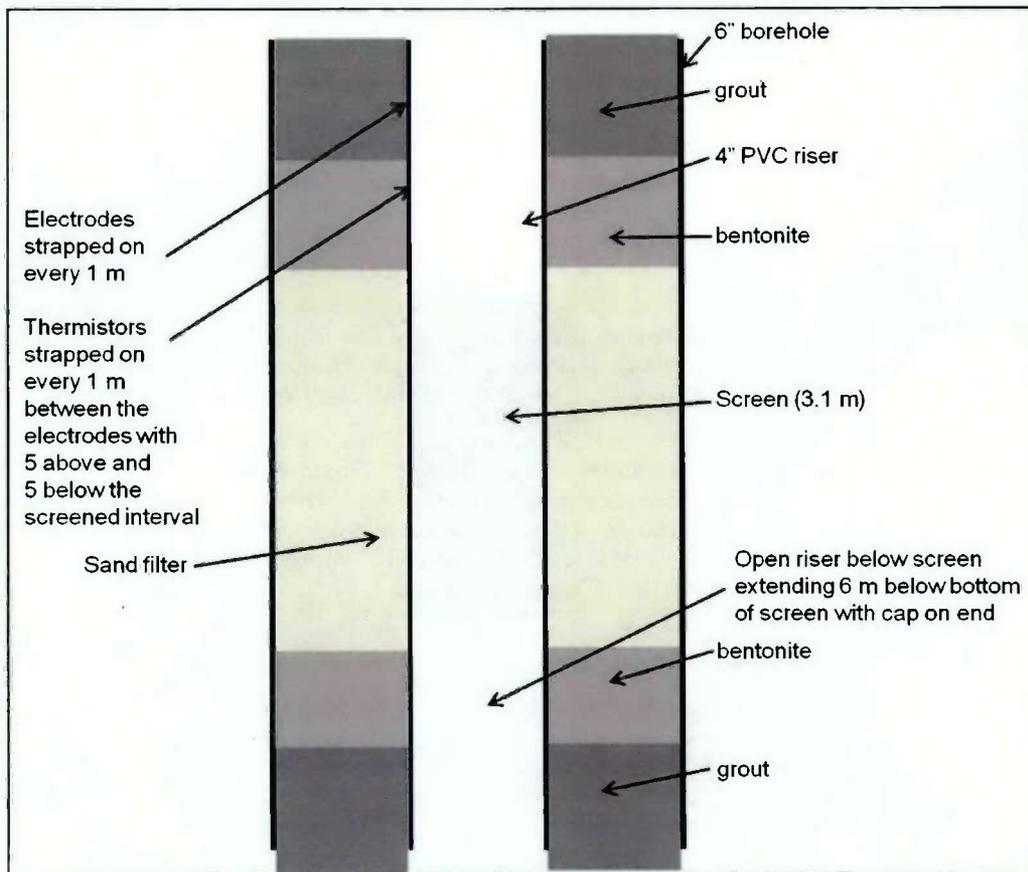
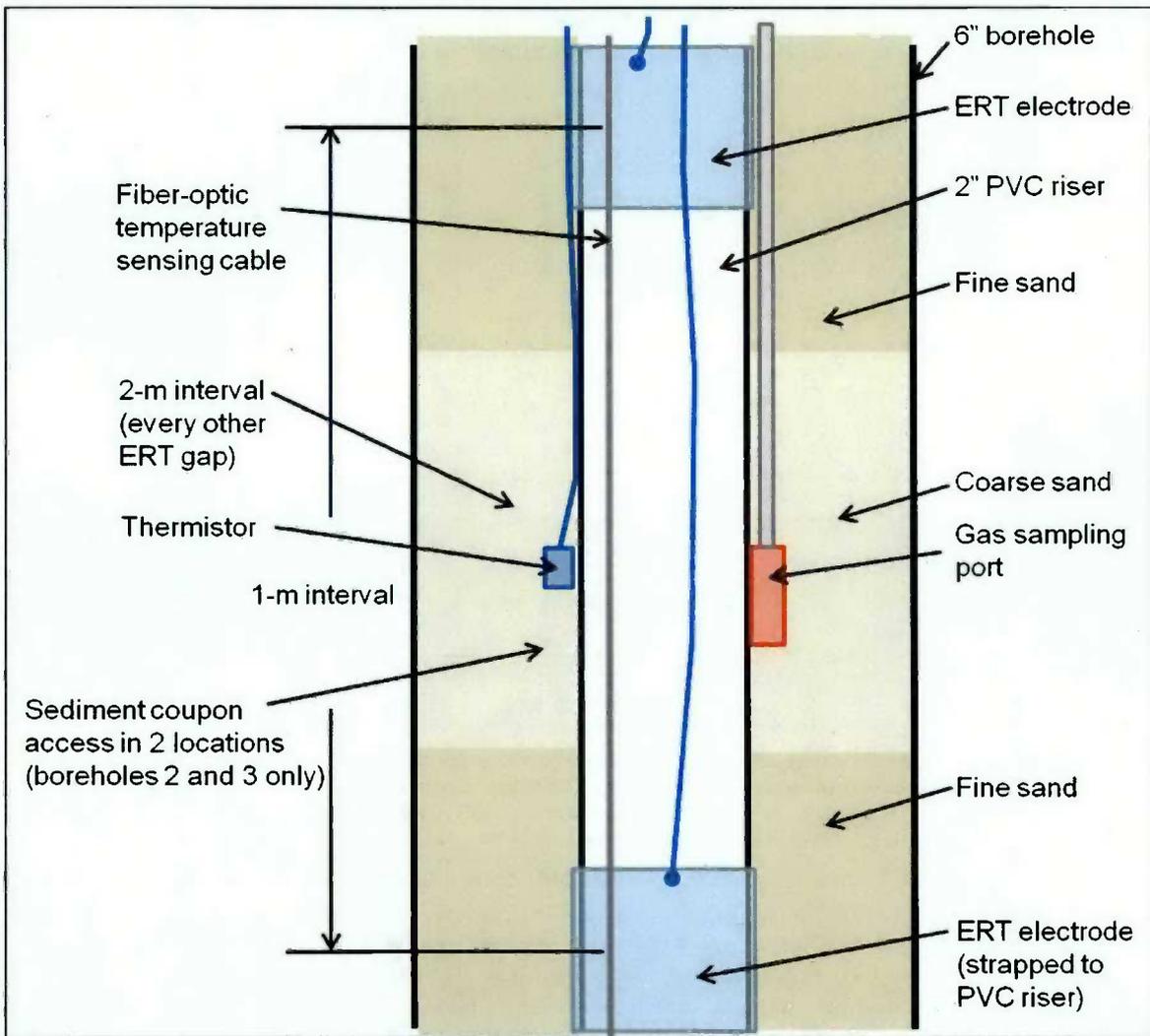
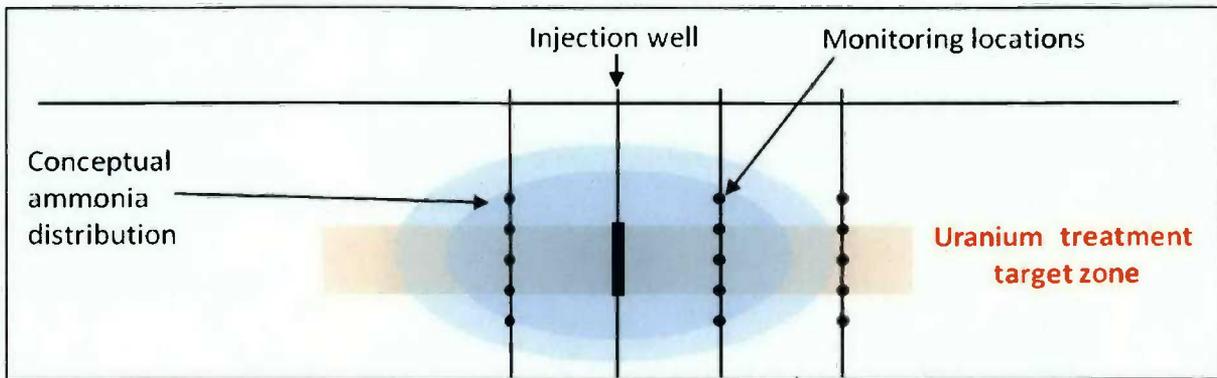


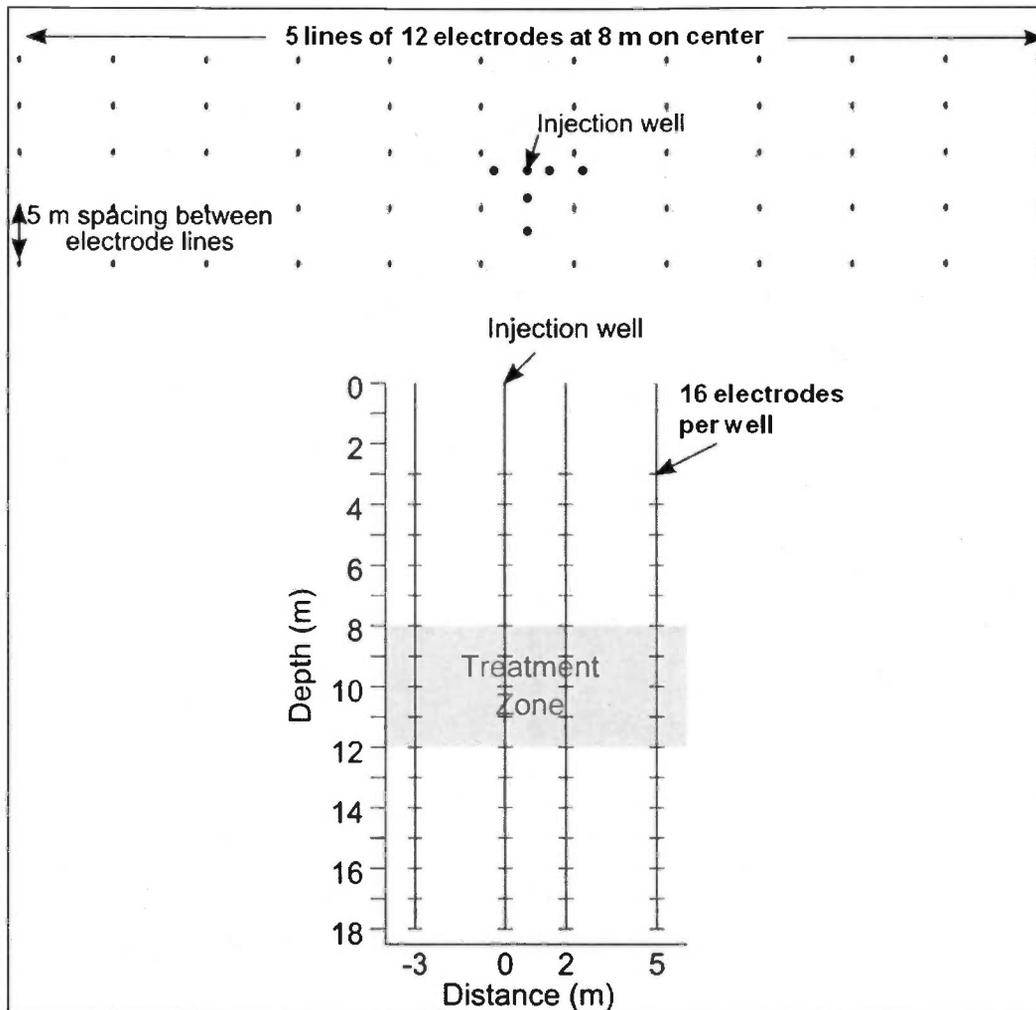
Figure 4-3. Proposed Injection Well Completion Configuration



Note: The upper diagram shows a conceptual cross section of the layout, and the lower diagram is a conceptual layout for a segment of the instrumented borehole.

Figure 4-4. Proposed Borehole Instrumentation Layout

ERT electrodes will be installed in both a surface array and within the boreholes, including the injection well. Figure 4-5 shows the conceptual layout of the electrodes. Specific electrode placement will be adjusted based on data collected in Phase 1.



Note: The upper diagram shows the surface electrode layout. Surface electrodes will be driven into the ground to less than a foot in depth and will be completed subgrade. The lower diagram shows the distribution of electrodes in the boreholes. The actual depths of the borehole electrodes will be based on the depth and thickness of the targeted treatment zone. Borehole electrode spacing will be approximately every 1 m (3.3 ft).

Figure 4-5. Proposed Electrical Resistivity Tomography Electrode Layout

Once the injection well and monitoring systems are in place, the instrumentation will be tested and monitored until conditions have equilibrated in the subsurface. After the period of equilibration, the following readiness tests will be conducted to ensure the equipment is operating as expected (results from the readiness tests will also be used to further characterize the pretreatment conditions):

- Conduct a gas injection test to determine the three-dimensional injected gas flow pattern. Pressure response will be measured during the test for use in estimating the bulk air permeability (EM 1110-1-4001, Soil Vapor Extraction and Bioventing).

- Conduct ammonia gas simulations, as needed, using geologic and tracer data to predict the field injection test results.
- Conduct a baseline ERT survey, neutron moisture log, and GPR survey analysis of the target test zones.

4.2.3 Phase 3 – Conduct Field Test

Pending successful site characterization and installation of the injection well and monitoring system, the next step is to conduct the field test. Permeability and tracer gas testing will provide baseline information about injected gas flow in the treatment zone. Ammonia distribution during injection operations will be evaluated based on ammonia gas concentrations at the gas sampling locations, ERT, and in situ temperature data at discrete locations. Because the partitioning of ammonia is rapid, the observed ammonia gas concentrations can be used to estimate the associated pore water ammonia concentrations using Henry's law. These spatial concentration data and the injection volume will provide information to assess the success of ammonia distribution to obtain the targeted treatment conditions (e.g., pore water ammonia concentration and associated pH values) within the test zone.

Figure 4-2 shows the conceptual layout for the field test with an injection well and monitoring borehole characterization locations. The target radius of ammonia injection is 6 m (20 ft). Field testing includes injecting ammonia and collecting sediment samples to evaluate uranium sequestration effectiveness. Soil gas sampling ports, in situ instruments, and ERT will be used to monitor ammonia injection and reaction processes. Details of time frames and locations for ammonia injection and monitoring may be modified, as needed, based on the results of Phases 1 and 2. The elements of the field testing are described in the following sections.

4.2.3.1 Ammonia Injection

Ammonia and carrier gas will be supplied using a system that can regulate for injection at a specified rate. The injection lines will be installed to deliver gas into the injection well with use of a packer or other sealing device, so that the gas must exit via the well screen. The injection gas pressure will be slightly above atmospheric to support ammonia distribution in the subsurface.

The gas will be injected at a nominal flow rate of 1.4 m³/min (50 ft³/min), pending results of the gas injection test and further design analyses. The injection process will be monitored for operational parameters, including injected volume, flow rate, temperature, ammonia content, tracer concentrations, and pressure. Subsurface monitoring will include the items discussed in the following sections.

Ammonia injection will be terminated by the Project Manager, in consultation with the project technical team, based on professional judgment and examination of the following data that are lines of evidence that sufficient ammonia has been injected into the subsurface to meet project objectives:

- Measurements of the mass of ammonia injected and total volume of injected mixed gas where approximately 3,170 kg (6,989 lb) of ammonia and 88,850 m³ (116,211 yd³) of mixed gas (about 43 days at 1.4 m³/min [50 ft³/min]) would be sufficient for a 6 m (20 ft) radial distribution from the injection well in a homogeneous subsurface with a moisture content of 4 wt% and predominantly horizontal gas flow (Table 4-1)
- Indications by temperature, ERT, and/or gas sampling that ammonia gas has passed the radial distance of Boreholes 2, 3, and 4
- Indications by temperature, ERT, and/or gas sampling that ammonia gas is near the radial distance of Boreholes 5 and 6

4.2.3.2 Ammonia Distribution Monitoring

Primary ammonia distribution monitoring will be achieved through collection and field analysis of gas samples at sampling ports located at different radial and vertical positions with respect to the injection well. Because the gas phase and pore water phase ammonia concentrations are expected to be directly related, ammonia gas phase concentration can be a primary indicator of ammonia distribution to the pore water. Based on laboratory experiments, ammonia partitions rapidly to the pore water such that a relatively sharp front will develop between the zone where ammonia has partitioned into the pore water to the target concentration compared to locations beyond this front. Within this treated zone, the gas phase ammonia concentration will be near the injected concentration. Outside the treated zone, the gas phase ammonia concentration will be substantially lower. The frequency of soil gas sampling during injection will be determined based on the site characterization data collected in Phases 1 and 2. ERT will also be used to monitor ammonia injection based on the change in pore water resistivity caused by ammonia partitioning into the pore water. Using both borehole and surface electrodes, ERT is intended to provide detailed ammonia distribution in cross sections between the monitoring boreholes and a less resolved three-dimensional image of ammonia distribution. In situ temperature monitoring will also be used as an indicator for when the ammonia partitioning front passes a monitoring location. At the end of ammonia injection, a neutron moisture and GPR survey will be conducted. The neutron moisture data will be used to evaluate the extent of desiccation that may occur near the injection well and to assess potential moisture changes induced by ammonia partitioning into the pore water. The GPR survey will provide a mapping of changes in pore water ionic strength to augment the ERT data and will also help quantify the small desiccation zone expected near the injection well.

4.2.3.3 Reaction Monitoring

Natural buffering will reduce the pH over time after the ammonia injection is completed. Results from laboratory ammonia treatment and monitoring will be used to estimate the time required for uranium treatment. In situ ERT monitoring will be continued after the ammonia injection where resistivity changes are correlated with pore water precipitation reactions as a field indicator of the reaction process. Based on these ERT data and the laboratory study estimate, an appropriate time for post-treatment sampling will be determined.

4.2.4 Phase 4 – Post-treatment Characterization

In the final phase of the treatability test, post-treatment sediment samples will be collected from the treatment area and used to evaluate treatment effectiveness. Post-treatment sediment samples, obtained from two boreholes drilled after the treatment test, will be paired with pre-treatment sample locations. Post-treatment field test sediments will be analyzed using the same type of sequential extraction and leaching studies conducted on the laboratory-treated sediments. The data will be used to assess whether the reaction processes and associated uranium sequestration expected, based on the laboratory tests, were induced in the field test. The time frame for collection of post-treatment samples will be based on the observed geochemical process time frame in the laboratory. ERT will also provide supporting data to monitor the treatment process during the field test. Once the test is deemed complete and ready for post-treatment boreholes, a final round of gas samples and sensor and ERT data will be collected. Neutron moisture logging and GPR surveys will be conducted to evaluate changes in moisture and pore water ionic strength distribution after the ammonia injection period.

Two post-treatment boreholes will be installed at the locations shown on Figure 4-1. The boreholes will be drilled to a depth selected based on the test system boreholes (Boreholes 1, 2, and 3) and data from the field test. Similar to the pretreatment boreholes, soil samples will be collected continuously, initiated at approximately 9.1 m (30 ft) bgs. Sampling will be performed using a 10.2 cm (4 in.) diameter, 0.76 m (2.5 ft) long split-spoon sampler. The split-spoon samplers will be equipped with four separate

nonconductive plastic liners that are each 15.2 cm (6 in.) long. Once the split-spoon liners have been appropriately labeled and documented in the field logbook, they will be sealed and shipped to the laboratory for analysis. Once final depth is achieved and all samples have been obtained, the post-treatment boreholes will be geophysically logged using downhole neutron and spectral gamma technology.

Split-spoon interval samples will be selected from each borehole for characterization at the laboratory. The intervals will be paired vertically with samples collected in the pre-treatment boreholes. These samples will be sieved to remove material greater than 4 mm in size. The less than 4 mm fraction of each sample will undergo sequential extraction to determine the pore water uranium and mobile uranium fractions and assess any impact to co-contaminant mobility. Selected subsamples of the less than 4 mm fraction of the liners will be used for soil column leaching tests to compare with the previous leaching study results of pre-treatment and laboratory ammonia treatment samples. Adjacent liners from each sample interval will be analyzed for bulk conductivity and for physical and chemical properties.

Data from laboratory tests on the post-treatment sediment samples will be compared to the data from pre-treatment samples collected from the same vertical strata to assess uranium sequestration effectiveness and any impact to co-contaminant mobility. Additionally, data from the post-treatment sediment samples will be compared to data from the laboratory-treated samples to verify that the treatment observed in the field at these locations is within the range of treatment effectiveness observed in the laboratory-treated samples.

4.2.5 Description of Laboratory Tests

The following sections describe the general types of laboratory tests that will be conducted to support the treatability test.

4.2.5.1 Sequential Extractions

As described in this FTP and by PNNL-18879 and PNNL-20004, sequential extractions are a baseline measurement used to evaluate uranium mobility. The sequential extraction approach described in PNNL-18879 and PNNL-20004 will be modified to support the goals of this treatability test. These modifications are needed to address potential long-term release of uranium from sediments (addition of long-term IX extraction), eliminate the oxalate extraction because it did not provide significant value for interpreting the effectiveness of ammonia treatment, and provide a better comparison to methods used for evaluating sorbed uranium by others (e.g., PNNL-17031, *A Site-Wide Perspective on Uranium Geochemistry at the Hanford Site*). The revised extraction solutions are as follows:

- Synthetic groundwater (1 hr) (PNNL-20004)
- 0.5 molar magnesium nitrate solution for IX (1 hr) (PNNL-20004)
- Carbonate solution for IX (1,000 hr) (PNNL-17031)
- pH 5 sodium-acetate (1 hr) (PNNL-20004)
- pH 2.3 acetic acid (1 wk) (PNNL-20004)
- 8 molar nitric acid at 95°C (2 hr) (PNNL-20004)

Sequential extraction analysis will be performed on untreated samples collected during Phase 1, laboratory-treated samples collected during Phase 1, and samples exposed to ammonia treatment in the field during Phase 4. Replicates will be used to quantify variability in the analysis.

4.2.5.2 Leaching Tests

Sequential extractions evaluate uranium mobility based on an interpretation of how the extraction relates to uranium transfer into the pore water. Saturated soil column leaching tests provide a measure of uranium mobility based on contact with water over time. Soil column leaching tests will be conducted on a subset of the samples analyzed by sequential extraction, ensuring that the samples have been held a suitable length of time for ammonia sequestration. These tests will provide uranium mobility information that can be analyzed both in terms of a comparison to the sequential extractions and an estimate of uranium transport parameters. For example, the data may support use of a combined surface complexation and kinetic dissolution model of uranium release into the water. While these experiments are conducted under saturated conditions, the kinetic parameters can be translated to unsaturated flow conditions. Leaching tests will be performed on untreated samples collected during Phase 1, laboratory-treated samples collected during Phase 1, and samples exposed to ammonia treatment in the field during Phase 4.

A laboratory test instruction will be prepared to guide the soil column tests. In summary and subject to update in the test instruction, sediment from the liners selected for leaching tests will be emptied and sieved to remove particles greater than 4 mm. Sieved material will be packed into nominally 2.5 cm (1 in.) diameter by 15.2 cm (6 in.) long soil columns. High-performance liquid chromatography pumps will be used to inject simulated groundwater upward through the column with a residence time of about 4 to 10 hours. Effluent will be collected using a fraction collector, and selected time interval samples will be analyzed for uranium, bromide, and pH. At selected times, flow will be stopped for 16 to 100s of hours to allow kinetically controlled processes and reactions to reach equilibrium. The difference in uranium concentrations before and after the stop flow events will be used to calculate a rate of uranium release from the sediment. The pH will be measured with a microelectrode (Accumet 13-602-292) with 3-point calibration before measurements and calibration check after measurements. The bromide tracer will be used to evaluate flow conditions in the column based on the breakthrough pattern of bromide concentrations in the column effluent. Bromide will be measured with an ion-specific electrode (Accumet 13-620-525), with 9-point calibration before each experiment and calibration check after measurements.

4.2.5.3 Sediment Analysis

Sediment analyses will be applied to help interpret uranium data and the results of ammonia treatment. Basic physical property and chemistry analyses will be conducted, as described in the SAP (DOE/RL-2010-88).

5 Equipment and Materials

The equipment and instrumentation described in this chapter are proposed to conduct the uranium sequestration field test. The final equipment selection and sizing will be conducted, based on the results of Phase 1. Any changes will be noted in the project documentation.

5.1 Test Equipment

The test system will mix ammonia and nitrogen gas to achieve the desired injection parameters. Tracer gas cylinders can be connected to this system, as needed. Appropriate mass flow/pressure regulators will be used to provide, maintain, and measure the desired flow rate. The injection lines will deliver the ammonia gas mixture to the well screen interval, which is sealed from the surface using an inflatable ammonia resistant packer or other method of sealing the well.

The soil gas sampling system will consist of a positive displacement pump to withdraw soil gas from the in situ sample ports into a canister or bag. The gas sampling system can also be used to monitor oxygen as

a “negative” tracer for the injected gas during initial operations by connecting an oxygen sensor at the surface. The gas sample ports will also include a pressure sensor located at the surface.

5.2 Instrumentation

This section describes the borehole instruments selected for use in the field test. In situ instrumentation will include thermistors and ERT electrodes. Pressure and temperature will be collected with a data logger. The ERT system will be configured with the capability to collect and log data automatically. Geophysical surveys will also be conducted in the test wells using a neutron moisture probe and cross-hole GPR.

5.2.1 Thermistor

A thermistor is a resistor that is typically made from a ceramic or polymer. Its resistance varies with temperature. Thermistors generally operate over a small temperature range but achieve a high-precision temperature measurement. The planned temperature sensors are encapsulated negative temperature coefficient thermistors. A fifth-order polynomial will be used for determining temperature from the resistance measurement. This approach has been tested on several hundred thermistors of this type that were carefully calibrated in a precision water bath spanning the 0 to 40°C (0 to 104°F) temperature range. By fitting a fifth order polynomial to all sensors, accuracies greater than 0.07°C for more than 99 percent of thermistors were obtained.

5.2.2 Fiber-Optic Distributed Temperature Sensing

DTS is a technique for measuring the temperature along an optical fiber. Light transmission and scattering properties of the optical fiber depend on temperature and are exploited to provide a nearly continuous temperature profile. Spatial resolutions of 100 cm (39.4 in) or less and a temperature resolution of 0.01°C are possible using DTS.

5.2.3 Electrical Resistivity Tomography

ERT is a geophysical technique for imaging subsurface structures from electrical resistivity measurements made at the surface and electrodes installed in the boreholes. Ammonia treatment will cause an increase in pore water conductivity, which will be measured by a change in electrical resistance. Because electrical resistance imaging can be applied as a tomographic technique, it can provide a two- or three-dimensional image of the ammonia-treated zone, based on the change in pore water conductivity. ERT can also monitor the decline in conductivity when precipitates form during pH neutralization. Laboratory soil columns were used to monitor the change in bulk sediment electrical resistivity during and after ammonia treatment (PNNL-23699). These data demonstrated that ERT is expected to have a sufficient response in the field to provide information about ammonia distribution and the progress of the reaction processes. ERT is also sensitive to large changes in moisture content and, as demonstrated previously at the desiccation field test, can provide information on the size and location of the desiccated zone expected near the injection well.

5.2.4 Sediment Coupons

Sediment coupons may be deployed as a test for this type of monitoring technique. The concept of sediment coupons is to use sediment extracted during drilling to prepare packets (coupons) of sieved sediment that can be deployed within a well where it will be exposed to the ammonia gas. Coupons can be removed at selected times during the treatment process and sediment analyses applied to evaluate reaction processes. In this way, the coupon acts as a surrogate of sediment samples but can be retrieved more readily than obtaining standard soil samples.

5.2.5 Geophysical Surveys

Neutron moisture logging provides a vertical profile of data that can be interpreted in terms of vertical moisture content variation in the sediment within about 0.5 m (1.6 ft) of the access well. Injection of ammonia in anhydrous nitrogen gas will cause a small zone of desiccation near the injection well, and neutron moisture logging will help evaluate the extent of this zone. Partitioning of relatively high ammonia concentrations into the pore water will slightly increase the volume of the pore water and increase the volumetric hydrogen concentration. This effect may be measureable by the neutron moisture probe.

Radar energy propagation in soil is affected by pore water electrical conductivity. GPR is sensitive to large changes in moisture content and, as demonstrated in a previous the desiccation field test, can provide information on the size and location of the desiccated zone expected near the injection well. For the field test, cross-hole GPR will be deployed to develop two- or three-dimensional images that depict changes in the ionic strength of the pore water between the baseline survey and the survey between the boreholes after ammonia injection. Absolute and relative changes in the volumetric moisture content can also be obtained using GPR.

6 Sampling and Analysis

Sampling and analysis details are provided in the SAP (DOE/RL-2010-88), which summarizes the data quality objectives process that was completed to define the data collection design for the test. The SAP (DOE/RL-2010-88) also contains the quality assurance project plan (QAPjP) for the document. The QAPjP provides information on the levels of quality assurance/quality control that will be applied to the test. The primary data acquisition tasks for the test are drilling boreholes and collecting representative soil samples for laboratory analysis. Data management requirements are also contained in the SAP (DOE/RL-2010-88).

7 Data Management

Data resulting from implementation of the SAP (DOE/RL-2010-88) will be managed and stored in accordance with applicable programmatic requirements governing data management procedures. Planning for sample collection and analysis will be performed in accordance with the programmatic requirements governing fixed laboratory sample collection activities, as discussed in the sampling teams' procedures. Information on applicable programmatic requirements and procedures is contained in the SAP (DOE/RL-2010-88).

A project-specific database will be developed and maintained to collect, organize, store, verify/validate, and manage analytical laboratory data and field measurements for environmental samples. The data will be stored in electronic files or spreadsheets, and paper copies will be maintained in the project files. A project data custodian will be designated to control and maintain the data.

The Technical Lead, in conjunction with the Project Manager, is responsible for ensuring that the analytical data are appropriately reviewed, managed, and stored in accordance with applicable programmatic requirements governing data management procedures. Pertinent analytical data collected in the laboratory will also be recorded in the Hanford Environmental Information System.

8 Data Analysis and Interpretation

Evaluation of the uranium sequestration test will include interpretation of (1) ammonia distribution in the subsurface, (2) treatment effectiveness, and (3) operational performance with respect to supporting

evaluation of the technology using the CERCLA FS criteria. Descriptions of these elements of the evaluation are provided in the following sections.

8.1 Ammonia Distribution in the Subsurface

Ammonia concentration arrival curves at each of the radial and vertical sampling locations will be used to interpret the three-dimensional ammonia distribution at the end of the injection period. Arrival curves will also be used to evaluate the rate of ammonia transport along pathways to each sampling port, and this information will be compared and correlated to the interpreted distribution of sediment physical properties and moisture content. Arrival curves for ammonia will be compared to arrival curves for a conservative tracer to evaluate the transport attenuation due to ammonia partitioning into pore water along the flow path. Use of the ammonia as a "partitioning tracer" will provide an estimate of moisture content along the flow path.

ERT will be used to map the ammonia distribution in two- and three-dimensional inversions of the data. Temperature sensor data will be used to map the arrival of ammonia based on the increase in temperature that occurs during ammonia partitioning to the pore water.

8.2 Treatment Effectiveness

Geochemical reactions induced by ammonia and associated sequestration of uranium will be quantified to evaluate treatment effectiveness for laboratory ammonia-treated sediment samples and then confirmed from post-field treatment samples collected from zones where ammonia was shown to be effectively delivered in the field test. Effectiveness will be quantified using the following methods.

Data from sequential extractions of sediments that were exposed to ammonia will be compared to similar data from pre-treatment sediment conditions. For the Phase 1 laboratory samples, there will be a minimum of 11 samples subjected to pre-treatment analysis and laboratory ammonia treatment. For the Phase 4 post-treatment samples from the field, these analyses will be conducted on paired location pre- and post-test samples from two locations with five depths per location for a total of 10 paired data points for the comparison of pre- and post-test field results. Results will be evaluated in terms of changes in the fractional quantity of uranium within each sequential extraction "bin" to evaluate whether the treatment has reduced the amount of uranium in bins associated with relatively mobile uranium and increased the amount in bins that represent relatively immobile uranium. Statistical comparison of mean concentrations in each bin will be conducted.

The stability of sequestered uranium will be evaluated using laboratory soil column leaching experiments for six samples: two pre-treatment sediments, two post-laboratory treatment sediments, and two field treated sediments. These tests will quantify uranium release over time when treated sediments are exposed to simulated infiltration water. Leaching methods will be conducted for sediments that were exposed to ammonia and pre-treatment sediment conditions for comparison of the cumulative mass of uranium released over time in the leaching.

A selected subset of laboratory and field post-treated sediments will be examined to evaluate the type of precipitates that are formed. Geochemical modeling and databases will be used to evaluate the expected weathering and dissolution rates from the precipitates that are formed to aid interpretation of the data collected on field-treated sediments. Geochemical information along with sediment characterization collected for the field test site will be used to estimate fate and transport parameters for pre- and post-treatment conditions.

8.3 Operational Performance

The key factor in operational performance is the ability to distribute ammonia effectively to the target treatment zone. Tracking of aboveground operational parameters will provide information on the conditions necessary to maintain injection of the ammonia gas mixture. Tracer gas distribution and ammonia gas distribution from subsurface monitoring will provide data on the ability to distribute ammonia to a targeted treatment zone. Information on required equipment and operations will be compiled to assess short-term effectiveness, implementability, and cost.

9 Health and Safety

Health and safety requirements will be contained in a health and safety plan specifically created for this task. Air monitoring will be conducted in accordance with the radiological monitoring plan prepared for this study. Both the health and safety plan and air monitoring plans will be issued separately before field work is initiated.

10 Waste Management

Waste generated from sampling activities will be managed in accordance with an approved waste control plan. The waste control plan establishes the requirements for management and disposal of generated waste. Investigation-derived waste from these sampling activities will be handled as CERCLA waste. Unused samples will be archived for potential later analysis. Laboratory waste will be dispositioned in accordance with the laboratory contract and agreements concerning return to the Hanford Site. In accordance with 40 CFR 300.440, "National Oil and Hazardous Substances Pollution Contingency Plan," "Procedures for Planning and Implementing Off-Site Response Actions," approval from the Task Lead is required before unused samples or wastes are returned from offsite laboratories.

11 Community Relations

This treatability test is part of the RI/FS process that was initiated by the original RI/FS work plan for this site (DOE/RL-91-19). The RI/FS process includes communication between DOE-RL, state and federal regulators, and stakeholders. At the request of DOE or EPA, the project manager or principle investigator will be available to present information on the planning, progress, and results of the treatability study to interested parties.

12 Reports

At the end of the project, a final project report will be prepared summarizing the data and results of the test. Also a data quality assessment (DQA) report will be prepared to evaluate whether the type, quality, and quantity of data that were collected met the intent of the data quality objective prepared for this treatability test. After completion of the DQA report, a treatability test report summarizing the results of the test will be published.

13 Schedule

Table 13-1 shows the project schedule and the schedule drivers.

Table 13-1. Project Schedule

Activity	Due Date	Driver
Initiate USPT Site Characterization	April 2015	Project goal
Initiate USPT Injection Test	October 2015	Project goal
Complete USPT	February 2016	Project goal

USPT = Uranium Sequestration Pilot Test

14 Management and Staffing

DOE-RL is responsible for completing this treatability test. The test will be managed by CH2M HILL Plateau Remediation Company (CHPRC) Soil and Groundwater Remediation Project personnel. Staffing will include personnel from CHPRC, other Hanford Site contractors, and subcontractors as specified by the CHPRC Project Manager. The CHPRC Project Manager will ensure that the personnel selected are qualified to perform all activities in accordance with the requirements specified in this test plan. Specific staffing plans are specified in work planning documents or subcontracts prepared on a task-specific basis.

15 Budget

This treatability test will be conducted by CHPRC, as directed by DOE-RL. CHPRC project management has prepared detailed cost estimates for the work required to complete this treatability test. Overall cost of the project is approximately \$5.6 million, broken down as shown in Table 15-1.

Table 15-1. Overall Cost of Treatability Test Project

Work Step	Cost
Regulatory documents	\$150,000
Lab tests, modeling support, and instrument development	\$1,050,000
Analyze characterization samples	\$500,000
Drill/install injection well/monitoring boreholes	\$1,500,000
Design/procure/fabricate/install test equipment	\$525,000
Perform/monitor test	\$1,350,000
Post-test confirmation testing	\$500,000
Reporting	\$50,000
Project Total	\$5,625,000

16 References

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