Department of Energy
Washington, DC 20585

May 27, 2015

Ms. Madeline Roanhorse, Director
Navajo UMTRA Program
Division of Natural Resources
PO Box 1875
Window Rock, AZ 86515

Subject: Workplan for the Uranium Biosequestration Study at the Monument Valley, Arizona, Processing Site

Dear Ms. Roanhorse:

Enclosed is the workplan for the pilot study activities planned at the Monument Valley site this year. The pilot study will be a collaborative, jointly-funded effort, between the U.S. Department of Energy, Office of Legacy Management (DOE-LM) and principal investigators for the University of Arizona (UA) Superfund Research Program (SRP). The UA SRP is funded by the National Institute of Environmental Health Sciences and focuses on the characterization and remediation of mining-impacted sites in the Southwestern United States.

The objective of the project is to investigate the feasibility and long-term efficacy of in-situ biosequestration for the remediation of uranium-contaminated groundwater at the Monument Valley site. The initial phase of the pilot study includes the installation of five alluvial monitoring wells at the Monument Valley site which started the week of May 18, 2015.

I intended to send you this report in April 2015, but it was held up due to minor corrections then inadvertently failed to be sent in a timely manner. Please call me at (970) 248-6621 if you have any questions. Please address any correspondence to:

U.S. Department of Energy
Office of Legacy Management
2597 Legacy Way
Grand Junction, CO 81503

Sincerely,

Angelita Denny
Site Manager

cc:
D. Orlando, NRC
J. Nofchissey, NN UMTRA
E Rich, NN EPA
D. Miller, SN3 (e)
File: MON 0100.02 (rc grand junction)

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PROJECT WORKPLAN

In-situ Biosequestration for Remediation of Uranium in Groundwater at the Monument Valley UMTRA Site

Prepared for:

U.S. DEPARTMENT OF ENERGY
Grand Junction Office
Grand Junction, Colorado
Re: Jody Waugh
Stoller Newport News Nuclear (SN3)

Prepared by:

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February 2015

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1. INTRODUCTION

1.1 Background

Very few alternatives to pump and treat are available for remediation of groundwater contaminant plumes containing uranium, arsenic, selenium, or similar constituents. Permeable reactive barriers (PRBs) have been demonstrated to be an effective method for treating waters containing inorganic contaminants. For example, they are a robust alternative for controlling acid rock drainage at or near the source, thereby preventing or reducing contamination of groundwater. Unfortunately, PRBs are impractical for the deep contaminant plumes common to mining sites in the western US. Monitored natural attenuation (MNA) has recently become a popular option to consider as a green, lower-cost alternative to pump and treat for inorganic-contaminated sites. However, rates of natural attenuation are insufficient to prevent migration of uranium, arsenic, selenium, or similar constituents at many mining sites, as evidenced by the very large contaminant plumes that typically develop. Methods to enhance the rates of attenuation (so-called enhanced attenuation) and improve the feasibility of MNA for inorganic contaminants are a current focus of research and development. In-situ biosequestration (Figure 1), wherein an electron donating substrate is injected to promote microbial activity and associated sequestration of contaminants (e.g., bioprecipitation, biomineralization, enhanced adsorption), is one promising enhanced-attenuation alternative for groundwater contaminant plumes containing arsenic, uranium, selenium, and similar constituents (e.g., DOE, 2003).

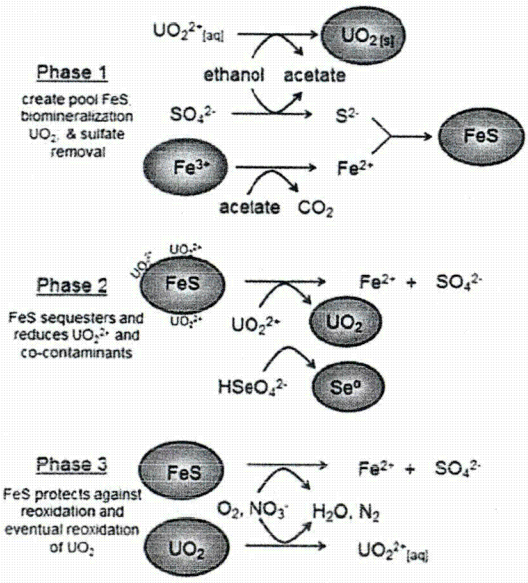

Figure 1. Critical components and uncertainties for the in-situ biosequestration approach (shaded ovals indicate insoluble minerals).

In-situ biosequestration is currently under investigation for treatment of uranium-contaminated groundwater. For example, more than a decade of research has been conducted at the Department of Energy's (DOE) Old Rifle research site in Colorado. The results from this and other efforts have demonstrated that in-situ biosequestration has potential for addressing uranium-contaminated groundwater. However, the results have also revealed a set of critical issues that must be addressed for successful application. One such issue is long-term sustainability of the method. Uranium concentrations in groundwater were observed to rebound within several weeks after cessation of substrate injection, for example, at the Old Rifle test site (e.g., Williams et al., 2011). As described below, we are investigating methods for implementing biosequestration that hold promise for achieving longer-term sustainability.

1.2 Monument Valley Site

The Monument Valley site is a former uranium mining site located at Cane Valley, Arizona, 24 km south of Mexican Hat, UT (Figure 2). Uranium mining at the site occurred from 1943 to 1968. From 1964 to 1968, batch and heap leaching with sulfuric acid solution was used to process an estimated 1.1 million tons of tailings and low-grade ore at the site (DOE, 1999, 2005). The solutions used in ore processing were discharged to the "new tailings pile". A groundwater contaminant plume, approximately two km long, comprising elevated levels of nitrate and sulfate exists at the site. Concentrations are as high as 600 mg/L and 1500 mg/L for nitrate and sulfate, respectively. Concentrations of heavy metals, uranium, and arsenic are relatively low (most values < 10 µg/L) within the study area. One exception is the presence of elevated uranium (> 200 µg/L) in the alluvial and De Chelly aquifers at one location near the source area (see red circle in Figure 2).

The aquifer system that is the focus of this study resides in a north-south oriented paleovalley that is bounded by bedrock on the south and west sides as well as on the bottom. Bedrock is exposed at the southern and southwestern areas of the source zone, and it has been determined that infiltration at these areas serves as the primary source of recharge to the shallow alluvial aquifer (DOE, 1999). It is estimated that only a minor fraction of the low annual precipitation recharges the aquifer in the center of the valley (where the plume resides) due to loss from evaporation and plant uptake (DOE, 1999). Depth to groundwater is approximately 11 meters for the alluvial aquifer.

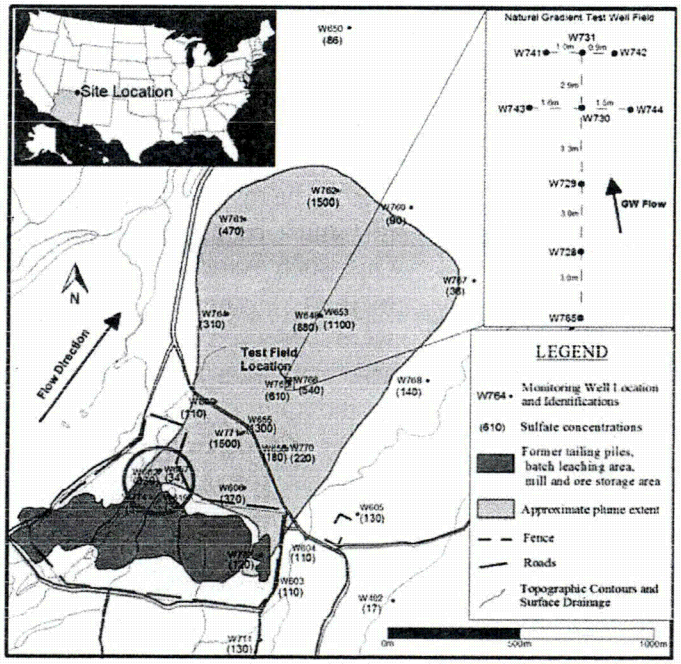

Figure 2. Map of Monument Valley Site. Local of prior pilot tests is noted in the center of the plume. The red circle denotes the area with elevated U in groundwater.

1.3 Results of Prior Pilot Tests

Dr. Brusseau and co-workers have conducted pilot-scale field tests at the Monument Valley site to investigate the feasibility and sustainability of in-situ bioremediation to treat groundwater contaminated by nitrate and sulfate. The field tests were supplemented by bench-scale tests, stable-isotope analysis, and mathematical modeling. The results of site characterization activities conducted prior to the test indicated slow rates of denitrification and the absence of measurable bacterial sulfate reduction. The injection of an electron donor induced denitrification and bacterial sulfate reduction, as confirmed by exponential decreases of nitrate and sulfate concentrations in concert with changes in oxidation-reduction potential, redox species, alkalinity, production of hydrogen sulfide, and fractionation of δ^{15}N-nitrate and δ^{34}S-sulfate.

The induction of reducing conditions caused a significant decrease in the concentration of uranium in groundwater (Figure 3), demonstrating feasibility of in-situ biosequestration at this site. Of great significance, the three-day, single injection of electron donor produced reducing conditions that were sustained for approximately three years. This is an order of magnitude longer than observed at the Old Rifle site. Delineating the potential cause(s) of this sustained biosequestration condition at Monument Valley will be a focus of the proposed project.

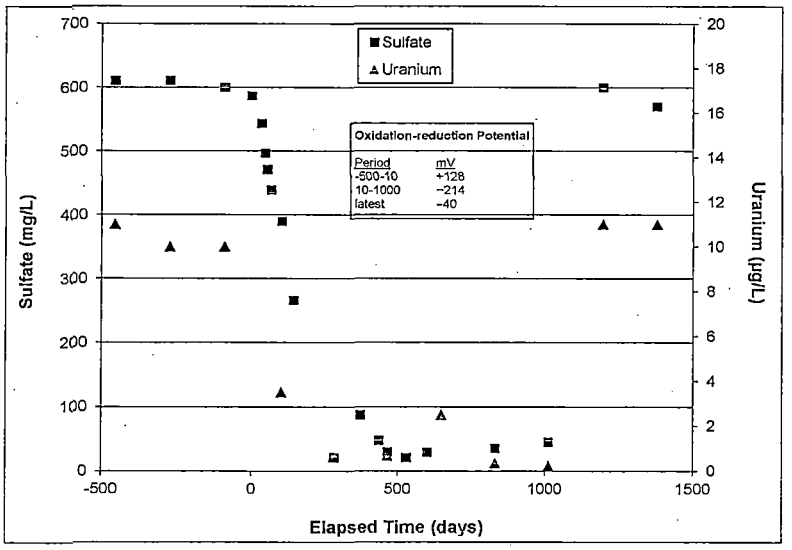

Figure 3. Results of a five year study investigating the impact of electron-donor injection on in-situ groundwater remediation. Time zero corresponds to a single, three-day injection of 5% ethanol solution into a single well. The equivalent of ~10 pore volumes of groundwater have been displaced since the injection.

1.4 Objective of Pilot Project

The objective of the project is to investigate the feasibility and long-term efficacy of in-situ biosequestration for remediation of uranium-contaminated groundwater at the Monument Valley Site. The proposed project would comprise a collaborative, jointly-funded effort. The project team from the UA (Brusseau, Field, Chorover, Maier) are principal investigators for the University of Arizona Superfund Research Program (SRP), funded by the National Institute of Environmental Health Sciences. The focus of the UA SRP is the characterization and remediation of mining-impacted sites in the Southwest US. This project provides personnel funding for Dr. Brusseau and his students.

We posit that the feasibility and effectiveness of in-situ biosequestration are site dependent, influenced by specific conditions and properties of the site. The unique properties of subsurface environments in the southwest US require focused investigation to evaluate the potential effectiveness of in-situ biosequestration for sites in this region. The project is designed to address several critical questions affecting the effectiveness of the in-situ biosequestration method for the Monument Valley site. These include:

(1) What are the mechanisms that account for the long-term sustainability of reducing conditions (years) after a short addition of electron donor (days);
(2) Can naturally occurring sediment-associated iron be used to form iron sulfides if sulfate reducing bacteria are stimulated at the site;
(3) What are the dominant mechanisms of U sequestration? Is the direct reductive biomineralization of U(VI) to UO_2 predominant? Or is the adsorption and chemical reduction of U(VI) by iron-sulfide precipitates more important?
(4) The nature and long-term stability of the sequestered phases;
(5) The impact of electron donor injection on microbial community structure and diversity (the environmental microbiome), which will help begin to elucidate the role of the microbial community in biosequestration;
(6) Can co-contaminants at the site (As, Se, etc) be sequestered by iron sulfides;
(7) Does biomass produced from the cell yield of denitrifying and sulfate-reducing organisms contribute to a long term slow release supply of electron-donating substrate.
(8) Optimal strategies for field-scale implementation, including selection of cost-effective electron-donor amendments.

This project will investigate and answer these questions. In so doing, we will advance the understanding of biogeochemical processes and their impact on the transport and natural attenuation of uranium and similar constituents in groundwater at the site. The project outcomes will also contribute to our broader understanding of Uranium in-situ biosequestration given that the biogeochemical conditions present at the site differ from those present at the prior DOE sites at which U sequestration has been tested.

2. PILOT TEST PLAN

We propose to conduct a pilot study within the area marked with the red circle shown in Figure 2- the location with elevated uranium in groundwater. The field test will be conducted using the methods we have developed for the prior pilot tests conducted at the site (Borden et al., 2012), informed and enhanced by the outcomes of the U-sequestration research conducted at DOE test sites such as Rifle and Oak Ridge. Groundwater samples will be collected periodically before, during, and after the test. In addition, boreholes will be drilled before, during, and after the test to collect sediment samples. The groundwater and sediment samples will be analyzed for geochemical, isotopic, and microbial composition. This will provide information to delineate the formation of reducing conditions, the activity of the microbial community, tracking of sulfur cycling, and the properties of sequestered phases. In addition, the use of isotopic analysis will assist in accounting for the impacts of hydrological factors such as mixing and dilution. Complementary microcosm experiments will be conducted in the laboratory to test hypotheses and characterize specific processes.

2.1 Pilot Test Design

The pilot test will comprise a several-day injection of electron donor solution, and attendant monitoring before, during, and after the test. This test will require the drilling of two to four new monitoring wells placed in the vicinity of the injection point. The specific well to be used for the injection point will be selected in consultation with DOE Contractor personnel. Each monitoring well will be completed and sampled prior to the test to have background field parameters and concentration data available. The injection will occur at a constant low flow rate to minimally perturb the gradient and pore-water velocity (~0.3 meter/day). A projected injection volume of 30,000 L is estimated to flush half the volume of the well grid and achieve complete breakthrough 6 meters from the injection well. The solution will be 0.5% ethyl-alcohol with potassium bromide (KBr) concentrations of 100 mg/L. Once the 30,000 L pulse injection is completed, the solution will be allowed to transport under natural-gradient conditions. Each monitoring well will be sampled to observe breakthrough of tracers and monitor changes in constituents.

2.1.1 Drilling and Monitor Well Installation

Drilling and monitor-well installation will be conducted by DOE Contractor personnel. The rig and methods used for drilling will be selected to allow the aseptic collection of undisturbed sediment cores during drilling of the boreholes. An additional borehole will be drilled after the test to allow collection of sediment samples.

2.1.2 Electron-donor Solution and Nonreactive Tracer Solution

Denatured ethyl-alcohol (100%) will be added to local groundwater collected from the site. Approximately 150 liters of ethyl-alcohol will be mixed in a sealed bladder to avoid aeration and changes to in situ redox conditions. When mixed at the proper flow rate, the injection solution will be a 0.5% ethanol mix. This low ethanol percent will provide adequate carbon to facilitate microbial activity and not pose toxicity issues.

Bromide will be used as the nonreactive tracer due to its naturally low background concentrations. Potassium bromide salt will be mixed in a concentrated solution to ensure the salt is fully dissolved. This solution will be mixed with the ethanol solution external to the sealed bladder during injection using an in-line hydromixer. The ethanol-bromide solution will be injected at a constant rate during the test. Samples will be collected for bromide analysis in the field using a Hach spectrophotometer and post-test at the University of Arizona. Assessment of bromide will be used to determine field-scale transport processes and used in comparison to ethanol concentrations to evaluate ethanol usage in enhancing microbial activity.

2.1.3 Injection System

The system will be a direct-inject system drawing water from a local well. A submersible pump will be lowered into a near-by well and pumped at a constant flow rate (~4 L/min), monitored with an in-line flow meter. Flow from the extraction well will be directed to a manifold system to be mixed with the solution from the bladder. Flow rates from the bladder will be monitored to ensure the final concentrations entering the aquifer are 0.5% ethanol and 100 mg/L bromide. The combined flow rate from the extraction line and the bladder will be held at a constant rate and monitored with an in-line flow meter. A sampling port will be included in the manifold line to monitor concentrations of ethanol and bromide entering the system. Separate gas powered generators will be required to operate the submersible and peristaltic pumps. The

injection of the ethanol solution is expected to take 3-6 days, not including monitoring time. Any waste generated from the investigation will be collected, contained, and properly disposed of by on-site personnel.

2.2 Monitoring Program

2.2.1 Water Levels and Sample Collection

Field monitoring will begin upon installation and completion of the new monitoring wells. Water levels will be measured using an electric sounder tape with every sampling event before the test and throughout the injection period. Monitoring water levels will characterize pre-injection flow conditions and establish the impact of the injection on gradient, pore-water velocity, and overall transport within the system. Groundwater samples will be collected from a series of wells throughout the site to monitor changes in water quality parameters such as pH, dissolved oxygen, redox potential, electrical conductivity, and temperature, as well as relevant constituents (nitrogen species, sulfur species, U, metals, cations/anions). Prior to sampling, each well will be purged following the standard one to three well volumes (dependent on well diameter and depth) or until field parameters stabilize. Samples will be collected using well specific bladder pumps. Isotope samples ($\delta^{15}N$, $\delta^{18}O$, and $\delta^{34}S$) will also be collected, but at a less frequent interval. Each sample will be subject to standard filtration, preservation, refrigeration, and storage procedures as needed.

2.2.2 Injection Test and Post-Injection Monitoring Plan

Groundwater samples will be collected from each monitoring well within the grid at a four hour interval through the duration of the injection. Once the injection is complete, bromide concentrations measured in the field will dictate the frequency of sampling. The frequency of sampling will be reduced in the weeks and months following the test. Post-injection sampling is expected for at least six months after the completion of the injection. In addition, site-wide sampling will occur in wells up-gradient and downgradient to observe changes in major constituent concentrations, major anions and cations, and stable-isotope compositions.

2.2.3 Sediment Analysis

Sediment samples will be collected from cores collected before, during, and after the injection. Various analyses if these samples will be used to characterize native mineral geochemical composition, to collect samples for determining microbial community composition, and to monitor changes in sediment phases during remediation tests. Integration of these data with aqueous-phase data will provide a comprehensive characterization of conditions and the impacts of perturbations to the system.

Specifically, sediment samples will be analyzed by x-ray diffraction (XRD) to characterize mineral composition. Samples will also be subjected to acid-digestion extraction treatment to characterize metal/metalloid content. Finally, selected samples will be analyzed using synchrotron x-ray absorption (XRA) techniques to delineate the formation of sequestered mineral constituents (Root et al., 2013; Hayes et al., 2014). Uranium speciation (oxidation state and bonding environment) will be determined using XANES and EXAFS analysis. Sulfur and iron oxidation states will be determined using NEXAFS and XANES, respectively.

2.2.4 Chemical Analysis

Samples will be transported to the University of Arizona for laboratory analysis. Ethanol will be determined using gas chromatography (flame ionization detection). Anionic nitrogen species and major anions will be analyzed using EPA 300.0 standard method or ion chromatography. Ammonium and hydrogen sulfide concentrations will be measured using a Hach colorimetric spectrophotometric analysis. Major cations will be analyzed by inductively coupled plasma mass spectroscopy (ICP-MS). Isotope analysis will be conducted at the University of Arizona Isotope Lab and the Waterloo University Isotope Lab (Carroll et al., 2009).

2.2.5 Microbial Activity Sample Collection and Analysis

The primary goal of microbial studies at Monument Valley is to directly characterize the presence and abundance of microbial species known to be capable of nitrate, sulfate, and iron reduction activity, and to monitor changes in their populations as a function of the ethanol injection. This will be accomplished by using iTag sequencing of prokaryotic 16S rRNA amplicons (Valentin-Vargas, 2013). Media for the analyses will be obtained from groundwater samples collected from selected monitoring wells in the study area, as well as sediment samples collected from boreholes. Groundwater samples will be filtered to collect the microbial matter for DNA extraction. DNA will be extracted from the filtered samples and from sediment samples using standard kits (e.g., Neilson et al., 2012). The PCR amplification, purification and iTag sequencing will be performed following protocols described by Caporaso et al. (2011, 2012). Samples for these analyses will be collected before, during, and after the ethanol injection.

2.3 Data Analysis

The data collected during the enhanced-remediation pilot test will be used to evaluate the effectiveness of sequestration for reducing uranium concentrations in groundwater. Groundwater elevation monitoring will be used to observe any changes in direction and magnitude of the natural gradient before, during, and after the test. Nitrogen and sulfur speciation, major cations and anions, and isotope data will be collected through all stages of the pilot-test (for both groundwater and sediment) to determine denitrification and sulfate-reduction rates and provide comparison to results obtained from the prior pilot tests. Ethanol and bromide concentrations will be compiled to evaluate mass loss of ethanol due to increased microbial activity and transport behavior through the subsurface. Microbial analyses will provide information on gene expression and population dynamics and noticeable changes from the introduction of ethanol to the system. Advanced characterization of sediment samples will provide direct determination of the processes involved in uranium sequestration.

2.4 Bench-scale Investigation of Electron Donors

A set of bench-scale experiments will be conducted to evaluate the effectiveness of selected electron donors for U sequestration, using sediment and groundwater collected from the site. This work will be conducted at the UA, and UA personnel will follow all of the UA specific health and safety and environmental management procedures. As reviewed by Barlett et al. (2012), several compounds have been used to promote U reduction, including acetate, lactate, ethanol, methanol, glucose, formate, benzoate, pyruvate, fumarate, and hydrogen. In addition, Barlett et al. compared the effectiveness of more complex amendments, emulsified vegetable oil (EVO) and hydrogen release compound (HRC), to simpler ones (acetate and lactate). We will

test methanol and glucose as representatives of simple amendments. We will test EVO and HRC as representative of more complex amendments that are anticipated to provide a more controlled, slower release of donor. We will test molasses and corn syrup as representatives of inexpensive commercially available materials. We will test glycerol, a waste product of bio-diesel, as a representative of a waste-product material. Finally, we will test the impact of microbial biomass carbon, under the hypothesis that microbial die-off of populations enhanced by reduction of elevated nitrate present in groundwater at the site may serve as a long-term source of donor. Ethanol will be used as the control amendment given its use in prior pilot tests at the site.

Column experiments will be conducted using methods we have employed previously (Bodour et al., 2003; Wang et al., 2005; Brusseau et al., 2006), adapted for the specific application of U reduction (Luna-Velasco et al., 2010; Tapia-Rodriguez et al., 2011). Concentrations of U and electron-donor in the column effluent will be monitored. At the end of the experiments, the columns will be disassembled and the sediment will be analyzed. The presence of microbial populations will be characterized using the methods described in section 2.2.5.

2.5 Complementary Process-investigation Bench Study

Microcosm studies will be conducted to verify under controlled conditions that the processes in Figure 1 are occurring. This work will be conducted at the UA, and UA personnel will follow all of the UA specific health and safety and environmental management procedures. Both sediment and groundwater collected from wells in the field site will be used as microbial inoculum for the bench study. Microcosm studies will be carried out in 160 mL sealed serum flasks with 100 mL of liquid medium and 60 mL of headspace. In anaerobic incubations the headspace will be flushed with 80% He and 20% CO_2. Defined mineral medium used in previously published paper (Tapia-Rodriguez et al. 2010) from our laboratory will be used. The media will subsequently be adjusted to a pH value of 7.0, and then provided with $NaHCO_3$ to a final concentration of 35 mM, $NaHCO_3$ will serve to buffer pH as well as a ligand for complexing U(VI), representing the natural complexed state of uranium in the groundwater.

2.5.1 Biomineralization of uranium (Phase I)

Microcosms will be spiked with U(VI) (0.4 mM) with and without ethanol 10 mM. Heat-sterilized controls will be used to verify conversion is due to microbial activity. The loss of soluble U(VI) will be monitored by measuring soluble U via ICP as evidence for the formation of U(IV). Insoluble U(IV) will be confirmed by XRD analysis. The conversion of ethanol to acetate and subsequent conversion of acetate will be monitored by GC-FID.

Cell biomass formed from the metabolism of ethanol can also serve as an electron donor to drive U(VI) reduction. To test this possibility, ethanol will first be used for denitrification to produce cells and these cells will be recovered and washed and then be used as slow release electron donor for U(VI) reduction.

2.5.2 Sulfate and Fe reduction, and precipitation of sediment iron as iron sulfides (Phase I)

Microcosms inoculated with sediment will be spiked with SO_4^{2-} (2.0 mM) with and without ethanol 10 mM. The loss of soluble SO_4^{2-} will be monitored by IC measurments as evidence for the formation sulfate reduction. Sulfide formation by colorimetric method will also be measured to confirm sulfate reduction. Extractable iron (sequence of water, ammonium acetate and ammonium oxalate) will be monitored by measuring Fe via ICP. The loss of

extractable iron in parallel with sulfate reduction will be used as evidence of iron sulfide formation. Changes in Fe speciation will be monitored with colorimetric methods (o-phenanthroline). Evidence of FeS containing minerals such as mackinawite, greigite and pyrite will be confirmed by XRD. The ability of the sediment to reduce Fe(III) will be monitored using acetate and ethanol as electron donors (10 mM) to study the conversion of ferrihydrite to ferrous iron. Heat killed controls will be used to confirm biological nature of reactions. The conversion of ethanol and acetate will be monitored as described above.

2.5.3 Sequestration of U(VI) by iron sulfides (Phase 2)

The pool of iron sulfide minerals generated in Phase 1 can potentially have a role in sequestering soluble U(VI). To test this hypothesis, amorphous FeS will be synthesized by reaction of NaS_2 and rinsing the precipitate first with water then followed by rinses with ethanol, and drying the pellet (from ethanol rinses) with a stream of N_2. Likewise biogenic FeS will be produced during simultaneous sulfate reduction and ferrihydrite reduction using inoculum form the phase 1 sulfate reduction experiments. Synthetic and biogenic FeS will then be incubated anaerobically with U(VI) (0.4 mM) and the loss of U(VI) will be monitored over time. A sequential extraction methodology (water, 1 M $NaHCO_3$, followed by 1 M HNO_3) will be utilized to distinguish between adsorbed U(VI) and insolubilized U(IV) phases formed by the chemical reduction of U(VI) (Tapia-Rodriguez et al. 2010). Also the solid phase can be probed with XRD to determine their mineralogy. U(IV) minerals such as uraninite (UO_2) or mixed valent minerals (e.g. U_3O_8) are anticipated to form.

2.5.4 Reoxidation of sequestered uranium (Phase 3)

Reduced uranium minerals such as uraninite can be subject to chemical and biological reoxidation, potentially releasing dissolved U(VI). The pool of FeS formed during Phase 1 can serve as a reservoir of reducing equivalents that can protect against reoxidation if groundwater becomes more oxic due to dissolved oxygen and/or nitrates. Thus reduced minerals formed in Phase 1 and Phase 2 microcosms will be purposefully subjected to O_2 and NO_3^- to study the kinetics of the U(IV) oxidation back to dissolved U(VI) as measured by ICP. Additionally the release of Fe^{2+} and SO_4^{2-} will be measured by IC to study the oxidation of FeS.

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4. HEALTH & SAFETY

a. U of A personnel will follow all of the U of A specific health and safety and environmental management procedures for field work and lab work. A copy of U of A health and safety procedures will be provided to the DOE Contractor contact.
b. DOE Contractor and U of A contacts will develop a project activity evaluation (PAE) based on DOE Contractor requirements before any work begins.
c. All required permits for core drilling, well installations, and ethanol injection will be obtained by DOE Contractor before any work begins.
d. DOE Contractor will provide safety with a pre-job briefing and a plan of the day/plan of the week reviews for specific work being done that day.
e. Expected Site hours: expected hours in the field at the Monument Valley site for UA employees are 80 hours each for 3 employees. The hours for each employee spent at the field site will be tracked and recorded using form LMS 2146, to be provide by the DOE Contractor contact.

5. TASKS AND BUDGET

The component tasks for the project, and estimated costs, are presented in the table below.

Task	Timeframe	Performer	Cost	Leveraging by UA
Well installation [2-4]	Before injection	DOE Contractor	?	NA[1]
Core collection [3]	Before, during, after inj	DOE Contractor	?	NA
Groundwater sampling before/during test	Before/during injection	UA	1200	50% Reduction in cost
Groundwater sampling after test	After injection	Contractor /UA	?	NA
On-site chemical analyses	During injection	UA	1000	50% Reduction in cost
Major cations analyses	Before, during, after inj	UA	6000	50% Reduction in cost
Major anions analyses	Before, during, after inj	UA	6000	90% Reduction in cost
Metals/metalloids analyses	Before, during, after inj	UA	8000	90% Reduction in cost
Isotope analyses	Before, during, after inj	UA	7500	90% Reduction in cost
Extraction treatments for sediment	Before, during, after inj	UA	4000	50% Reduction in cost
XRD analysis of sediment	Before, during, after inj	UA	2000	75% Reduction in cost
XRA analysis of sediment	Before, during, after inj	UA	7600	75% Reduction in cost
Genomic microbial analysis	Before, during, after inj	UA	10000	50% Reduction in cost
Travel to site	Before, during, after inj	UA	3000	NA
Bench Electron-donor Analyses	During	UA	30000	50% Reduction in cost
Bench Process-investigation Analyses	During	UA	30000	75% Reduction in cost
Total Direct Cost [excluding Contractor costs]			116,300	
Service fee charge- UA (9%)			10,467	
TOTAL COSTS [excluding Contractor costs]			**126,767**	***Note that salary costs for UA personnel are covered by UA SRP as additional leveraging**

[1]NA = not applicable