Project Narrative File

Organization: NuFuels, Inc.

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Project Title: Laboratory-Scale In-Situ Recovery and Restoration Demonstration Using Uranium Deposit Core Materials

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Team partnership:

Team	Project Scope Split	Fed Funding Split
NuFuels, Inc.	55.3%	25%
Los Alamos National Laboratory	44.7%	75%

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PROJECT OBJECTIVES

Overview

Concerns over groundwater usage and the associated disposal of wastewater hinders the cost-effectiveness of uranium in-situ recovery (ISR) operations and restoration efforts at many legacy sites associated with DOE and DOD. Any enhancement in the efficiency of groundwater usage and cost reduction related to subsurface remediation could have a large impact on the global competitiveness of the U.S. natural resource industry at restoration strategy at numerous legacy sites. The objective of the proposed research project is to demonstrate the capacity to restore groundwater geochemical conditions to background levels at uranium recovery operations through the application of restoration strategies optimized for pore-water/flow-water mixing and exchange. This will be accomplished by laboratory-scale experiments that first maximize mixing between pore-water and flow-water and then evaluate the performance of these maxing strategies in simulated post-ISR restoration approaches, including but not limited to, 1) groundwater sweeping, 2) active treatment through reverse osmosis and recirculation operations, 3) amendment injections, and 4) natural attenuation processes. The primary focus though will be on ISR restoration technologies that would result in reduced groundwater consumption during groundwater restoration activities following uranium ISR operations, though the results are likely to aid in the reduction of water usage at other uranium recovery related groundwater restoration projects such as legacy tailings operations. This study will be performed using uranium rich core collected from multiple representative locations from Nuclear Regulatory Commission (NRC) licensed ISR uranium properties owned by NuFuels, Inc. in the Grants Uranium District of New Mexico.

Specific project objectives include:

1. Construction of a representative laboratory-scale ISR testing facility that can be used to optimize pore-water/flow-water mixing and post-ISR restoration strategies.
2. Use the ISR testing facility to test new restoration strategies aimed at reducing the volume of water required to complete restoration and optimize the long-term stability of the restored subsurface.
3. Evaluate the economic impact of the new restoration strategies on domestic uranium production

The key innovations of the proposed research include:

1. Optimization of pore-scale mixing to improve the effectiveness of sweep operations and amendment deployment.
2. Examination of the effect of acoustic stimulation on pore-scale mixing.
3. Laboratory investigation of the potential impact of natural attenuation on the fate of uranium and other trace metals.

If successful, this study will have a significant impact on reducing the cost related to ISR, reducing the amount of water used in restoration efforts, and create a pathway for more sustainable uranium recovery in the United States. Additionally, a successful demonstration of the effectiveness of the remedial approaches developed in this research could inform regulators of how to setup robust and effective monitoring programs. Although the research developed here is geared towards the uranium industry, the techniques and strategies developed would benefit many DOE and DOD as well as legacy industrial sites that would benefit from water-efficient remedial approaches.

Background

During the uranium ISR process, a leaching solution or "lixiviant" is injected into a permeable ore zone rich with uranium to solubilize and extract the uranium. The lixiviant solution often contains both an oxidant (i.e., oxygen) and a complexant (i.e., CO_3^{2-}). The oxidant is used to oxidize/dissolve U(IV) minerals (e.g., uraninite or coffinite) and the complexant is used to form soluble mobile U(VI)-carbonate complexes (e. g., $UO_2(CO_3)_3^{4-}$), which do not strongly adsorb to the subsurface matrix. The solubilized uranium is then pumped to surface treatment facilities, where it is extracted using ion-exchange resins. The water is then treated, refortified, and reinjected into the formation. This process is repeated until extracted uranium concentrations drop below economical levels. At the completion of extraction (i.e., recovery) operations, the mined ore zone is flushed with groundwater to remove residual uranium, lixiviant, and other residual trace metals. Groundwater sweeping is typically coupled with reverse osmosis treatment to remove trace metal contaminants from the flushing water. Multiple cycles of groundwater sweeping and reverse osmosis treatment are required to reduce the concentrations of uranium and other metals to acceptable levels (Davis and Curtis, 2007). The process is effective and acceptable concentrations are often initially achieved after only a few pore volumes of flushing (Borch et al. 2012). Concentrations of uranium tend to gradually rebound however, most likely due to desorption/diffusion of U(VI) complexes formed during ISR, but adsorbed to less hydrologically accessible regions of the host rock (e.g., matrix pore spaces) and therefore insufficiently flushed during the recovery or restoration phases (Catchpole and Kuchelka, 1993, Davis and Curtis, Darling 2008, 2007, Hall, 2009). This rebounding then requires further aquifer restoration using additional sweeps of reverse osmosis treated groundwater, in an asymptotic trend of diminishing returns. These additional restoration operations require large amounts of groundwater and produce large amounts of wastewater that must subsequently be disposed of. For example, a single 5-spot ISR pattern (50 feet × 50 feet) with an ore zone thickness of 12 feet, a porosity of 0.3, a horizontal dispersion factor of 1.5, and a vertical dispersion factor of 1.3, would require approximately 1.2 million gallons of water to circulate 9 pore volumes (PVs) for restoration. If reverse osmosis recovery were 80 % (i.e. 20 % of inlet water goes to the reject stream), 240,000 gallons of wastewater is produced and must subsequently be disposed of by injection into deep wells. A commercial ISR operation will consist of hundreds of these 5-spot ISR patterns, thus, the total volumes of wastewater produced can be enormous.

Once uranium ISR operations have been terminated, the extraction area groundwater must be returned to either 1) pre-ISR background conditions, 2) meet or exceed EPA drinking water standards, or 3) meet or exceed an alternate concentration limit agreed to by the ISR operator and the NRC or a state regulatory agency. To date, no ISR site has restored all groundwater constituents of concern to pre-operational concentrations and most receive alternate concentration limits for at least one regulated constituent (Hall 2009). In the long-term, the concentrations that rebound often require additional restoration efforts and long-term monitoring. Restoration efforts using chemical amendments such as H_2S, dithionite injections, or biostimulant injections to restore reducing conditions in the subsurface have shown limited efficacy (Power Resources Inc, 2004, Ruiz et al. 2019). The inefficiency of these remediation efforts is due, in part, to the relatively short-term nature of these efforts and the inability of the amendments applied to permeate the micro-porosity of the ore zone (Power Resources Inc, 2004, Davis and Curtis, 2007). Both the lixiviant and the restoration flushing water and amendments tend to remain in the main flow pathways and do not adequately penetrate the pore-spaces rich in uranium and other trace metals. Optimizing the hydrological and geochemical controls on pore-water/flow-water mixing and exchange to promote efficient propagation of uranium from the micro-pores and amendments to the micro-pores within the ore zone is key to developing cost-effective water usage reducing recovery and restoration strategies. Similarly, under unlined tailings impoundments at legacy uranium recovery operations, soluble U(VI) is a common element requiring groundwater remediation. Remediation strategies proposed for the stabilization of mine tailings have the same issues described above. Poor hydrological controls and lack of mixing between the amendments/recirculated water with contaminated regions of the aquifer limit the effectiveness of applied restoration approaches. The objective of this study is to determine the hydrological and geochemical parameters critical to optimizing mixing of pore-waters with waters in the dominant flow paths relevant to uranium ISR operations and post-ISR restoration for all regulated constituents. Our research approach is designed to address the challenges related to increasing uranium recovery during ISR operations and developing a cost effective restoration approach that minimizes water requirements and wastewater produced. A laboratory-scale ISR testing facility is proposed that will enable controlled experiments to be performed, specifically targeting: 1) groundwater sweeping, 2) active treatment through reverse osmosis and recirculation operations, 3) amendment injections, and 4) natural attenuation processes.

Work Plan Summary

- **Task 1.** Drilling, Core Retrieval, and Borehole Logging
- **Task 2.** Optimization of Pore-Scale Mixing
  - **Task 2.1** Microfluidic Optimization of Pore-Scale Mixing
  - **Task 2.2** Impact of Acoustic Stimulation on Pore-Scale Mixing
- **Task 3.** Construction of Laboratory-Scale ISR Testing Facility at LANL
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  - **Task 5.1** Optimization of Reverse Osmosis Sweep Efficiency
  - **Task 5.2** Reverse Osmosis with Abiotic Reduction (Dithionite)
- **Task 6.** Laboratory Evaluation of Natural Attenuation
- **Task 7.** Techno-Economic Evaluation of Remedial Strategies from Task 4 and Task 5

Detailed Work Plan

The challenges outlined in our research approach will be addressed in a series of laboratory tests that are made possible by a collaboration between NuFuels, which owns uranium properties at locations in the Grants Uranium District of New Mexico, and Los Alamos National Laboratory (LANL), whose scientists have significant interest and expertise in radionuclide geochemistry and environmental transport processes. NuFuels is interested in developing effective groundwater restoration approaches that are cost effective and are compliant with the applicable regulatory requirements in New Mexico. They are also interested in significantly reducing water usage and creating more sustainable ISR operations. LANL is interested in performing state of the art research focused specifically on addressing the needs of ISR, but more broadly in leveraging LANL's expertise and knowledge in actinide science and access to specialized facilities and equipment that is specifically designed to handle actinides to uranium help advance the science of subsurface remediation. While the research proposed here is specific ISR operation, the challenges outlined here are important to the management and cleanup of legacy sites associated with DOE and DOD.

Task 1. Drilling, Core Retrieval, and Borehole Logging

The laboratory-scale research program proposed herein will utilize uranium-bearing sandstone core and groundwater obtained from multiple representative locations in the Grants Uranium District of New Mexico owned by NuFuels and licensed by the NRC for ISR. These core materials will be obtained either from the Church Rock Section 8 uranium deposit or the Crownpoint Section 24 uranium deposit, depending on timelines and site-access logistics. At Church Rock, core would be obtained near one or more existing wells (CR4, CR5, CR6 and CR8), from the same stratigraphic horizons that these four wells are completed in. At Crownpoint, cores would be obtained near one or more existing wells (CP-2, CP-3, CP-5, CP-6, CP-7, CP-9), also from the same stratigraphic horizons that these wells are currently completed in. The existing wells will be used to provide representative groundwater from the same stratigraphic horizons as the extracted core. At both sites, the wells are spaced evenly across the uranium deposits, thus, providing representative core and groundwater from a variety of locations across the ore body. By obtaining core adjacent to the existing wells, in the same completion intervals, the same interval will be subjected to in situ column testing as was the water obtained. This will ensure that all experiments are as representative of the natural background geochemical characteristics of uranium deposits as possible.

Core drilling operations will utilize a standard 1500 or 2500 class rotary truck-mounted drill rig. The upper lithologies of each drill hole will be penetrated with standard mud rotary drilling techniques, using bentonite-based drilling fluids, with minimal additives to control swelling and spalling of the Mancos Formation. The standard rotary drill tools would be switched out for core drilling equipment (3.345 in. diameter core), or similar, prior to intersecting the target formation(s) for core collection. Drilling fluids will be thinned as practicable to prevent core damage while still maintaining drill hole wall stability. Core may be collected within both the Poison Canyon Sandstone and the Westwater Canyon Member of the Morrison Formation, which are the geologic units that host the uranium mineralization in the Churchrock district of the Grants Mineral Belt. Total vertical section cored in each drill hole will be determined by the on-site geologist, and will be based on well-defined data requirements. All drill depths and core points will be based on borehole data from the existing background wells and adjacent historical exploration holes, as well as by direct observation by NuFuels geological staff.

Every precaution will be taken to minimize oxidation of the core, by sealing core material in a nitrogen-filled vessel as soon as it is removed from the ground. Up to four core holes are planned which will be drilled as offsets to the existing background wells; all completed in the roll front mineralization in the Westwater Canyon Member of the Morrison Formation. The planned drill hole locations represent the diverse spatial, mineralogical and redox characteristics of the uranium deposits that were previously studied during background sampling associated with permitting and licensing. As such, extensive temporal water sampling results are available from the monitor wells. All of the core holes, including those intervals that will be drilled by rotary methods, will be logged (examined and geological and mineralogical characteristics recorded) by the site geologist. Following completion of the core holes, drilling fluids will be circulated to clean and stabilize the hole prior to geophysical logging, which will include prompt fission neutron (PFN), natural gamma, spontaneous potential (SP), short-normal resistivity, and a drill hole deviation survey. Once brought to the surface, cores will be cleaned, measured, protected from oxidation by sealing in airtight plastic sleeves and purging the sleeves with nitrogen. Cores will then be taken to the NuFuels Crownpoint facility for more detailed geological examination and description. After the core has been examined it will be shipped to the Los Alamos National Laboratory (LANL) ISR Testing Facility. Because the ISR and restoration simulations will utilize groundwater from the project site, groundwater will be collected from the existing monitoring wells and sent also to the LANL ISR Testing Facility.

Task 2. Optimization of Pore-Scale Mixing

One of the key deficiencies of current recovery and restoration strategies is related to incomplete mixing between the dominant recovery/restoration flow paths and the sandstone matrix pore-spaces (Power Resources Inc, 2004, Ruiz et al. 2019), which contain uranium. In fact, during the course of ISR operations, recovery/restoration flow paths tend to become more distinct, limiting the contact of injected fluids with materials within the matrix pores (Reimus et al. 2019). Prior to testing post-ISR restoration strategies on the ISR mined columns, microfluidic experiments will be used to optimize the geochemical and flow parameters that influence mixing between pore-water and flow-water. Microfluidic devices will be constructed to examine how chemical gradients and changes in the chemical properties of fluids impact mixing in sandstone pores. Novel acoustic stimulation will also be tested to examine its impact on mixing at the pore-scale. Geochemical and flow parameters optimized at the pore-scale will then be used in the column experiments.

We will focus on understanding how solution chemistry (e.g., ionic strength, pH, alkalinity, and chemical composition) of injected solutions, their injection rates, and potentially the addition of acoustic stimulation can be used to improve mixing between matrix pores and the dominant flow paths. Pore-scale mixing studies will be conducted at LANL's state of the art microfluidic laboratory. Microfluidic devices will be constructed with ore zone materials. The mineralized sandstone materials will be loaded into microfluidic devices that are sufficiently thin to approximate a 2D flow system. Mixing optimization experiments will be performed to improve mixing as a function of flow conditions and by varying the chemical composition of the injected solutions. We will use solutions amended with fluorescent dyes to facilitate visual observation of mixing and transport within the microfluidic device. Image processing will be performed using ImageJ to measure dye concentrations. Concentration profiles will be correlated with flow parameters and injected solution chemistry to gain an understanding of fluid mixing at the microscopic/pore-scale. More details on the microfluidic system can be found in previous descriptions from our team (Porter et Al. 2015). Briefly, the system consists of a microscope visualization system, injection pumps, and a software platform for image processing. The micromodels are filled with a solution simulating the pore fluids, which is displaced by the sweeping solution containing the fluorescent dye. The imaging allows the capture of mixing/displacement and preferential flow within the model. We will also examine the impact of acoustic stimulation on mixing at the pore-scale. Acoustic transducers will be mounted directly on the microfluidic device and acoustic stimulations will be applied to the micromodel. The acoustic wavelength and frequencies will be varied to assess if acoustic stimulations could be used to enhance pore-scale mixing.

Task 3. Construction of Laboratory-Scale ISR Testing Facility at LANL

A laboratory-scale ISR testing facility will be constructed by NuFuels at LANL that will simulate the subsurface conditions at approximately 450 feet of hydrostatic pressure. Experimental columns will be 6 feet in length and will be fabricated from 4-inch diameter stainless steel tubing specifically for this purpose. This testing facility will be used to simulate both the uranium recovery phase and the restoration phase under a variety of post-ISR restoration schemes. A flow diagram of the proposed column experiments is shown in Figure 1. Note that this drawing represents a single column system, which will be one of a set of four identical systems.

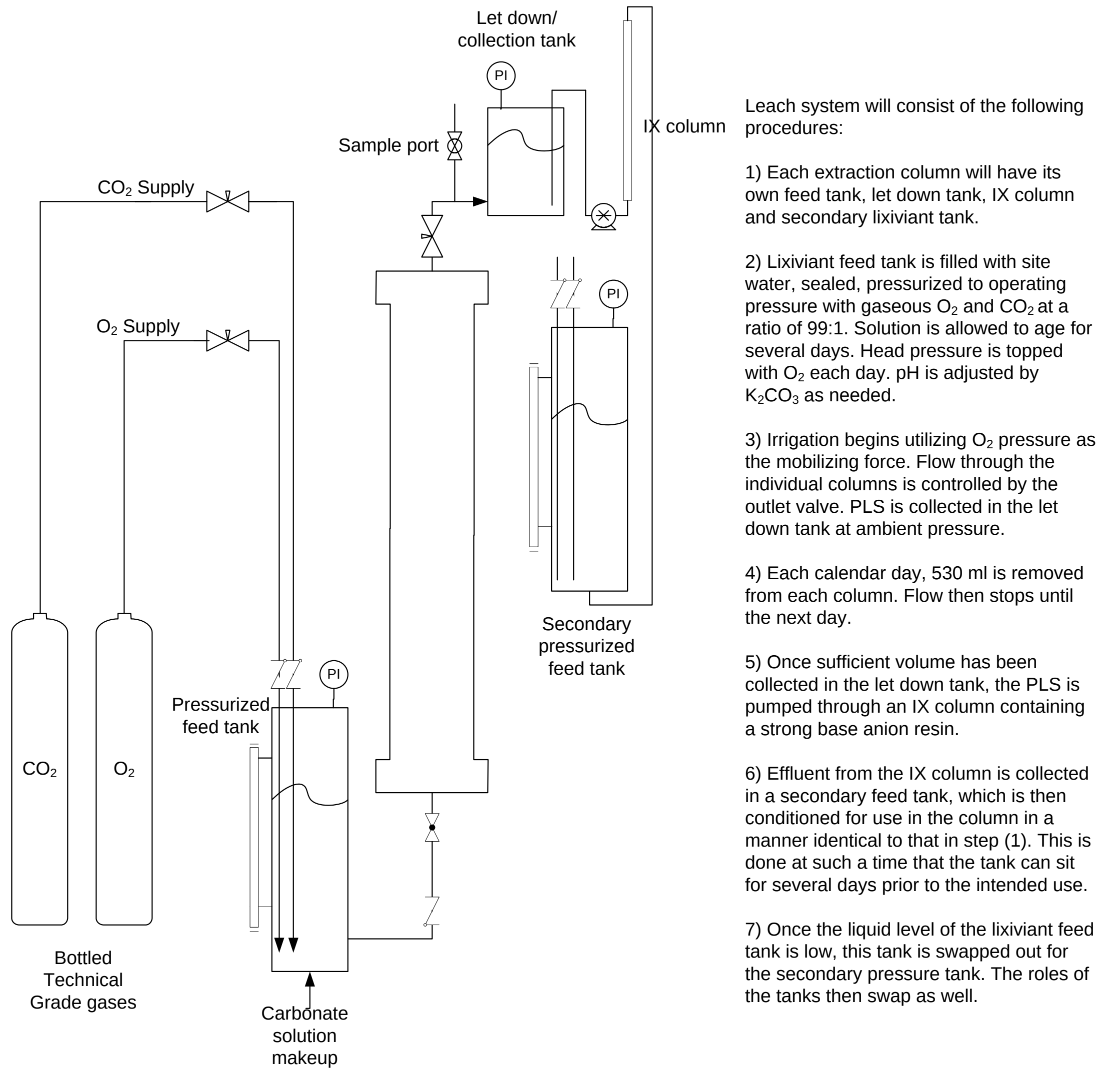

Figure 1. Pressurized column setup (one of four proposed systems shown).

The ISR testing facility will be constructed within a temperature controlled radionuclide geochemistry laboratory facility. This state of the art facility also houses all of the instrumentation necessary to measure the concentrations of constituents of interest within the eluents and monitor the progress of the simulated ISR operation and post-ISR restoration strategies.

Task 4. Simulation of ISR Process

Once transported from the field under anaerobic conditions, core samples will be crushed to 0.5" and composited under an anaerobic atmosphere. During this phase, visual observation and description of the core will be evaluated with the downhole geophysical logs and radiometric screening of the core in the lab to determine the most appropriate material for inclusion into each individual column; permeability, grain size, sorting, mineralogy, and uranium content will all be considered when selecting the most appropriate material. Once the columns have been packed with representative core materials, a uranium recovery phase of approximately 30 pore volumes (PV) of groundwater lixiviant will be passed through the packed column (i.e. the uranium recovery phase) prior to the testing of restoration schemes; the uranium solution response will dictate the exact number of PVs used. During the uranium recovery phase, gaseous oxygen and carbon dioxide will be introduced and maintained in groundwater lixiviant supply solution at sufficient concentrations to ensure oxidizing conditions and sufficient carbonate ion concentration, as well as to increase the vessel pressure to supply motive force for flow through the column. Potassium bicarbonate and/or carbonate will be added to the lixiviant make up at a concentration of 1 g/L prior to tank pressurization and to adjust the pH, as necessary. To ensure oxygen saturation under the experimental conditions, the prepared groundwater lixiviant will be allowed to sit for several days prior to using in the column experiments to allow the oxygen to reach equilibrium. The pressure will be topped off with oxygen during this period to ensure that the solution remains in equilibrium with the head space. Leached uranium concentrations will be monitored throughout the uranium recovery phase. Following the uranium recovery phase, a variety of restoration schemes will be used to determine the optimal hydrological and geochemical parameters for groundwater sweeping, active treatment through reverse osmosis and recirculation operations, amendment injections, and natural attenuation processes.

Task 5. Optimization of Post-ISR Restoration Strategies

Column experiments will be used to examine the efficiency of restoration operations using reverse osmosis water (only) and evaluate the long-term stability of the down gradient groundwater quality. In a parallel system, reverse osmosis will be coupled with chemical amendments (i.e., sodium dithionite) and compared with the reverse osmosis treatment alone. The use of acoustic stimulation at the column scale will be considered if studies at the microscopic scale show significant improvement of mixing at the pore scale. Long-term stability of the water quality of the effluents will be monitored for uranium and other trace metals of interest. The outcome of this task will be a set of data on water quality and water utilization that be used as input for the economic evaluation of the cost of post-ISR treatments. Details of the different subtasks are provided below:

Task 5.1 Optimization of Reverse Osmosis Sweep Efficiency

The optimized parameters determined from Task 3 will be applied in the ISR testing facility to start the optimization of the post-ISR restoration strategies. The first post-ISR restoration strategy will be optimized for water usage reduction will simulate recirculation with reverse osmosis treated water using the geochemical and flow parameters determined from the microfluidic studies. During this phase two parallel setups will be run simultaneously. The first setup will utilize un-optimized recirculation, similar to current ISR operations. The second setup will up-scale the optimization parameters learned in Task 2 to increase pore-water/flow-water mixing and exchange to promote efficient propagation of uranium and other trace metals from the pore-spaces. Long-term observation of water quality and water usage will be monitored for techno-economic evaluation (Task 7).

Task 5.2 Optimization of Reverse Osmosis with Abiotic Reduction (Dithionite)

Reverse osmosis treated water typically meets or exceeds drinking water standards, and during restoration activities is reinjected back into the wellfield further diluting the impacted groundwater base leaching solutions toward baseline quality. Although reverse osmosis is highly effective at removing ions that have been introduced as part of the groundwater lixiviant, it does not restore the baseline redox conditions in the formation. Therefore, additional amendments are needed to restore and stabilize the formation to pre-ISR conditions. One column will be set up to restore groundwater using reverse osmosis followed by the introduction of a chemical amendment (i.e., sodium dithionate) to push column redox conditions towards reducing. In this test, the chemical amendment will be introduced to the recirculation stream for several pore volumes. Similar to Task 5.1, optimized pore-water/flow-water mixing parameters will be used to promote efficient propagation of reductant into the matrix pore-spaces. The treated column will then be swept with untreated groundwater for performance evaluation. Water quality will be monitored before, during, and after treatments for parameters to evaluate the treatment performance, including pH, dissolved concentrations of uranium, Fe(II), $SO_4^{2-}$and HCO_3^-/CO_3^{2-}, residual remediant (i.e. dithionite), and permeability. Long-term observation of water quality and water usage will be monitored for techno-economic evaluation (Task 7).

Task 6. Laboratory Evaluation of Natural Attenuation

Following the restoration schemes described in Tasks 5.1 and 5.2, native groundwater will be passed through the restored core columns and into core obtained from outside of the formation downstream from the projected ISR wellfield area. This will simulate groundwater flow from upstream of the produced wellfield formation, through the ISR produces wellfield formation, and to un-affected native subsurface downstream from the produced ISR wellfield area. We will monitor the ability of the unaltered core to attenuate the transport of uranium and other trace metals of interest. Tracers will be used to characterize the hydrological properties of the column at the start and towards the end of the run. Meanwhile, flow and transport modeling of the restoration kinetics and natural attenuation will be undertaken using a reactive transport model (e.g. PHREEQC or PFLOTRAN). Following these experiments, the material used in the natural attenuation columns will be dissected and characterized by XRD, XRF, and SEM to determine the location of sorbed/reduced uranium. Results of the natural attenuation evaluation will be incorporated into the techno-economic evaluation (Task 7).

Task 7. Techno-Economic Evaluation of Remedial Strategies from Task 5 and Task 6

A techno-economic evaluation of the optimization of ISR and restoration activities (Task 4 and 5, respectively) and natural attenuation (Task 5) will be conducted to evaluate the potential economic performance of optimizing the ISR parameters and post-ISR restoration schemes, as well as more fully understanding the role of natural attenuation. Only through a complete understanding of the geochemical reaction kinetics relevant to all of the constituents of concern can the various phases of ISR restoration be optimized to reduce water usage, reduce the need for reverse osmosis treatment, and maximize amendment effectiveness, thereby reducing costs whilst ensuring the long-term stability of the subsurface and compliance with 10 CFR Part 40 Appendix A Criterion 5B(5).

MERIT REVIEW CRITERION AND OTHER SELECTION FACTORS DISCUSSION

Criterion 1 –Technical Expertise for Developing Water Treatment Technologies

Current ISR practices, which recirculate reverse osmosis treated water to perform sweeping operations intended to bring uranium and other contaminants of interest to levels that satisfy regulators, are a highly water intensive process. For example, The Uranium Producers of America provided a detailed analysis of water consumption at the COGEMA H-1 Extension restoration project in Texas (Uranium Producers of America, 2015). COGEMA projected that after restoration was completed and most groundwater parameters had been successfully restored to acceptable levels, an additional 210 million gallons of water would be required to be treated and recirculated to achieve restoration of uranium from 1.13 mg/L to 0.4 mg/L (a 0.73 mg/L decrease). These are likely conservative estimates because uranium concentration reduction per pore volume diminishes as the concentrations are lowered. This is not unique to the COGEMA, as similar analyses are presented for numerous ISR restoration projects presented in Exhibit 9 of the referenced Uranium Producers of America Comments. When viewing the restoration results and graphics in the referenced Exhibit 9, it appears that restoration is generally completed to regulatory standards for most common ions after about 3 pore volumes of flow, but the restoration of uranium to background levels often requires nine or more pore volumes. To put this in perspective, the potential water usage and cost savings if treatment was reduced from 9 PV to 3 PV for the Crownpoint Uranium Project (CUP) are shown in Table 1, based on the volume requirements for Church Rock 8, Church Rock 17, Crownpoint, and Unit 1 sections.

Table 1. Potential water usage and cost savings if treatment was reduced from 9 to 3 PV based on volumes requirement for Church Rock 8, Church Rock 17, Crownpoint and Unit 1.

	Church Rock 8	Church Rock 17	Crown point	Unit 1	CUP TOTAL
Pore Volume (PV) (gal)	148,000,000	79,000,000	234,000,000	174,000,000	635,000,000
Water Usage and Cost Under NRC Approved 9 PV Treatment Scenario					
Treatment Volume (gal)	1,332,000,000	711,000,000	2,106,000,000	1,566,000,000	5,715,000,000
Disposed Volume (gal)	266,000,000	142,000,000	421,000,000	313,000,000	1,143,000,000
Financial Security Requirement	$ 7,200,000	$ 4,700,000	$ 12,400,000	$ 9,800,000	$ 34,100,000
Water Usage and Cost Under Conceptual 3 PV Treatment Scenario					
Treatment Volume (gal)	444,000,000	237,000,000	702,000,000	522,000,000	1,905,000,000
Disposed Volume (gal)	89,000,000	47,000,000	140,000,000	104,000,000	381,000,000
Estimated Financial Security Requirement	$ 2,400,000	$ 1,600,000	$ 4,100,000	$ 3,300,000	$ 11,400,000
Estimated Water and Cost Savings Under 3 PV Treatment Volume Scenario					

The data in the table contrasts water usage and potential saving in water usage and wastewater generated between two scenarios requiring the usage of 9 PVs (approved by the NRC) and a conceptual 3 PV scenario. For the four mine units presented, a data supported demonstration that an optimized 3 PVs would sufficient to attain all regulatory requirements would result in the preservation of hundreds of millions of gallons of water and several millions of dollars in overall operating cost. Our proposed research is aimed directly at this problem. Our team brings proven experience in operating ISR facilities at a production scale with NuFuels. Mark Pelizza and Mersch Ward from NuFuels, Inc. have the field experience in ISR restoration and knowledge of water needs and regulations related to ISR. Access to NuFuels properties gives our team a unique ability to do testing at an NRC licensed ISR project, which is the only one in New Mexico. Access to NuFuels extensive resource database of thousands of exploration drill holes provides unique knowledge of the uranium deposits. New Mexico has historically been the largest uranium producing state, but ISR development has stalled due to a lack of restoration technology that can ensure compliance with New Mexico's post-ISR uranium in groundwater standard of background or 0.03 mg/L, whichever is higher. The LANL team is composed of Nathan Conroy, a junior staff scientist with a background in geochemistry and actinide speciation; Hakim Boukhalfa, a senior staff scientist specializing in actinide behavior in the environment; and Paul Reimus a former senior staff scientist with extensive experience in post-ISR restoration and remediation applications. The LANL team has an extensive experience in sorption/desorption studies and developing field remedial applications. The LANL team has designed and executed several filed scale projects designed to remediate subsurface contaminant including two pilot

projects in Los Alamos and one in Wyoming. The Los Alamos projects involved the deployment of dithionate and molasses amendments in two injections wells to treat Chromium (VI) contamination(Reimus et al. 2018, Ding et al. 2018, Telfeyan et al. 2021)
and testing of molasses-amended natural media. They also have experience characterizing natural attenuation and deployment of amendments at ISR filed sites (Harris et al. 2018, Dangelmayr et al. 2018, Reimus et al. 2019).

Criterion 2 – Proposed Scope of Work

The research proposed aims at addressing deficiencies in current ISR remediation operations that result in excessive water usage. Specifically, the research proposed here is designed to improve mixing at the pore scale, improve sweep efficiency, and reduce water requirements. The proposed research also aims at introducing chemical amendments to restore the reductive nature of wellfields following ISR operations. More importantly, the proposed research will demonstrate a complementary approach that utilizes optimized pump and teat operations with chemical amendments and a demonstration that natural attenuation has the capacity to achieve the required reduction of uranium and other contaminants concentrations to within required standards. We will obtain fresh core material and groundwater from Grants Uranium District of New Mexico owned by NuFuels that NRC licensed for ISR. The core material will be preserved in the field to preserve the geochemical conditions of the subsurface at the ISR wellfield units. This task will be performed by NuFuels and will provide the LANL team with core material to use in the laboratory scale ISR facility that will be built at LANL. The facility will be used to create a laboratory setup that will be used to simulate different restoration scenarios and collect data on water usage and water quality to perform viable evaluation and optimization of water treatment options. If successful, the team will be able to demonstrate a viable path to reduction of the water pore volumes required to satisfy complete site restoration. As demonstrated in Table 1, a reduction of water requirements from 9 PVs to 3 PVs could save hundreds of millions gallons of water. The proposed work brings together two teams with complimentary expertise. The NuFuels team has the required experience running industrial facilities and managing operations at ISR sites, and the LANL team that has extensive experience with actinide sorption, aqueous actinide geochemistry, and amendment deployment for remedial applications (including actual deployment of amendments at ISR facilities and chromium contaminated sites). The LANL team also maintains access to facilities and equipment and procedures that are specifically designed to work with complex environmental and radioactive materials.

Criterion 3 - Applicant Team Capabilities and Experience, Including Management Capability

Mark Pelizza is a Project Manager NuFuels Inc. He has significant experience in the uranium industry, including:

- Decades of experience in regulatory affairs and managing successful commercial ISR groundwater restoration activities.
- Success ISR commercial projects with multiple mine units each in Texas and one pilot project in Wyoming.

- Was responsible for licensing the Crownpoint Uranium Project, the location that will be used to obtain the core materials.

Nathan Conroy is a Scientist at LANL specializing in radionuclide geochemistry. He has significant experience in:

- Fate and transport of radionuclides in the environment.
- Laboratory experiments of radionuclides under simulated environmental conditions.
- Biogenic and abiotic reduction of uranium.
- Geochemical thermodynamic and transport modeling.

Hakim Boukhalfa is a Scientist at LANL and is Team Leader of the Radionuclide Geochemistry Team. He has significant experience in:

- Actinide behavior in the environment.
- Biogenic and abiotic reduction of uranium.
- Actinide sorption behavior.
- Tracer work at an ISR operations in Wyoming.

Paul Reimus is a former senior Scientist at LANL working as a consultant specializes in hydrology, radionuclide geochemistry. He has significant experience in:

- Repository science
- Science of tracers and subsurface hydrology interrogation
- Actinide behavior in the environment.
- Biogenic and abiotic reduction of uranium.
- Actinide sorption behavior.
- Hands on experience in developing as deployment of pilot scale amendments at various sites including ISR operations in Wyoming.

Mark Pelizza is on the "front lines" of the ISR uranium industry. He was responsible for obtaining licensing permissions for the Crownpoint Uranium Project and has successfully managed commercial ISR projects in multiple states (including NRC agreement states). Any improvement in the efficiency (both in terms of water usage and cost-effectiveness) of ISR technologies is of utmost importance to Mark and his industry.

RELEVANCE AND OUTCOMES/IMPACTS

The proposed project will provide the parameters necessary to improve uranium ISR extraction efficiency and reduce restoration cost and water usage through process optimizations. The optimization effort will include improving mixing and flow control, more efficient groundwater/amendment sweeping, and evaluation of the role of natural attenuation. These issues are also important for ISR operations. Improving the sweep efficiency is likely to have a large impact on improving extraction of uranium resources, thereby increasing process efficiency and reducing water usage and wastewater production. In the near-term, the laboratory-scale ISR testing facility developed as part of this work will provide a representative “testing ground” to evaluate the use of reverse osmosis, amendment injections, and natural attenuation to restore ISR sites following uranium recovery as well as evaluate the efficacy of enhanced pore-water/flow-water mixing and exchange strategies to be scaled up to commercial ISR operations. Ultimately, the goal of the proposed research project is to demonstrate the capacity to restore groundwater geochemical conditions to background levels at uranium ISR operations through the application of restoration strategies optimized for pore-water/flow-water mixing and exchange and the purposeful utilization of natural attenuation processes. Once the efficacy of the science has been demonstrated, a techno-economic evaluation will be conducted to evaluate the potential economic performance of the optimized recovery/restoration strategies. Long-term these optimization strategies will improve uranium ISR extraction efficiency, reduce restoration water usage and wastewater production and increase the cost competitiveness of the United States uranium industry. The knowledge developed through the proposed research will also benefit remedial efforts at sites managed by DOE and DOD and other legacy industrial sites. The data generated though this study would also be very informative to regulators. The proposed natural attenuation studies will be very informative and could help regulators evaluate/consider the incorporation of natural attenuation and log-term monitoring in the impact of ISR operations on the general environment near ISR sites.

ROLES OF PARTICIPANTS AND KEY PERSONNEL

Mark Pelizza (PI) will be responsible for:

- Project scheduling
- Coordination of field activities (Task 1)
- Techno-economic evaluation (Task 7)
- Conducting monthly project meetings
- Project quarterly progress reports and the final project report

Nathan Conroy (Co-PI) will be responsible for:

- Coordination of all LANL activities
- Oversee construction of ISR Testing Facility at LANL
- Supervise laboratory work performed at LANL (Tasks 2 – 6)
- Supervision of postdoctoral student(s)
- LANL budget allocations
- LANL quarterly progress reports and the final project report

Hakim Boukhalfa (Co-I) will be responsible for:

- Laboratory examination of natural attenuation (Task 6)

FACILITIES AND OTHER RESOURCES

NuFuels Facilities and Resources: NuFuels, Inc. owns the Crownpoint Uranium Project (CUP) which is an undeveloped NRC licensed ISR uranium project that is licensed for production of up to 3 million pounds of U_3O_8 production per year. NuFuels, Inc. will make available two CUP mineralized uranium properties for core material extraction; the Church Rock property and the Crownpoint property. NuFuels, Inc. will also support the proposed project with the office/shop space that is adjacent to the Crownpoint property. This finished space will be important to the team for: general office work, preliminary analysis of the core material, packaging of the core material, and the general logistics to allow the field work to flow smoothly.

Los Alamos National Laboratory Facilities and Resources: The Los Alamos laboratory team possesses many facilities with established work authorizations for the safe and secure handling of radioactive materials. Critical to the work proposed here is the ability to construct the benchtop ISR facility, and operate the leaching optimization and related analytical characterizations required to optimize ISR and restoration efforts. The benchtop ISR facility will be housed in a dedicated laboratory room within the radiological controlled are of the laboratory operated by the participating team. Analytical instruments needed to support the execution of the ISR optimization and restoration efforts available for the project include fraction collectors, pumps, HR-ICP-MS and ICP-MS/OES, , ion chromatograph, HPLC and many other capabilities. The team has additional laboratory space dedicated to performing anaerobic experimentation with a controlled atmosphere glovebox for core manipulation, sampling, and mounting samples for various analytical procedures. The LANL team has also a state of the art microfluidics laboratory used to study phenomena at the pore scale. The LANL team has also access to material characterization techniques such as SEM, XRD and TEM available through LANL's Material Science and Technology (MST) Division and Chemistry Division. The Analytical Actinide Chemistry (C-AAC) group at LANL maintains two separate analytical laboratories for qualitative and quantitative measurements of radionuclides in a variety of sample matrices.

EQUIPMENT

The NuFuels Inc. team has extensive experience working with drilling subcontractors that specialize in drilling boreholes for uranium ISR activities. Core drilling operations will utilize a standard 1500 or 2500 class rotary drill rig mounted on a three axle, rubber tired truck. Support equipment will include a drill shack, backhoe, drill pipe trailer, and two pickup trucks for drill crew and geologists.

The Los Alamos team has all the necessary equipment required to execute the proposed work. The list of general laboratory equipment needed to operate columns such as pumps, fraction collectors and analytical equipment needed to perform the necessary analytical characterization such: HPLC, automated titrators, KPA, HR-ICP-MS and ICP-MS/OES, ion chromatograph, and many other capabilities. The Los Alamos team has anaerobic glove boxes with a controlled atmosphere for sample preparation. A select list of specific equipment relevant to this project include:

<u>Agilent 7700 ICP-MS</u>

- Measures trace metal concentrations in lixiviant and eluents.
- Readily available.

<u>Dionex DX-600 Ion Chromatograph (IC)</u>

- Measures trace ion concentrations in lixiviant and eluents.
- Readily available.

<u>Chemchek Instruments Kinetic Phosphorescence Analyzer (KPA)</u>

- Measures trace U(VI) in water.
- Readily available.

<u>HPLC</u>

- Separates, identifies, and quantifies components of liquid mixtures.
- Readily available.

<u>Titrator</u>

- Measures carbonate concertation and buffering capacity of lixiviant and eluents.
- Readily available.

<u>XRD</u>

- Used for phase identification of crystalline materials (minerals).
- Readily available.

<u>XRF</u>

- Used for quantitative analysis of metal constituent of mineral phases.
- Available for Routine usage.

STATEMENT OF PROJECT OBJECTIVES
LABORATORY-SCALE IN-SITU RECOVERY AND RESTORATION DEMONSTRATION USING URANIUM DEPOSIT CORE MATERIALS

A. OBJECTIVES

The aim of the proposed laboratory-scale research program is to demonstrate the capacity to restore groundwater geochemical conditions in-situ to background levels at uranium recovery operations through the application of optimized restoration strategies. This will be accomplished by laboratory-scale experiments that evaluate the performance of simulated post in-situ recovery (ISR) restoration strategies, including but not limited to, 1) groundwater sweeping, 2) active treatment through reverse osmosis and recirculation operations, 3) amendment injections, and 4) natural attenuation processes. The primary focus though will be on ISR restoration technologies that would result in reduced groundwater consumption during groundwater restoration activities at ISR operations, the results are likely to aid in the reduction of water usage at other uranium recovery related groundwater restoration projects such as legacy tailings operations. This study will be performed using uranium rich core collected from multiple representative locations from Nuclear Regulatory Commission (NRC) licensed ISR uranium properties owned by NuFuels, Inc. in the Grants Uranium District of New Mexico.

B. SCOPE OF WORK

The scope of work outlined in this proposal is designed to demonstrate the capacity of an optimized groundwater restoration strategy that relies on active sweep operations using reverse osmosis treatment, injection of amendments, and natural attenuation to restore groundwater geochemical conditions in-situ to background levels at uranium recovery operations. The proposed work is a collaborative effort between NuFuels and a geochemistry team from LANL. NuFuels has extensive expertise in ISR and own uranium properties in locations in the Grants Uranium District of New Mexico. NuFuels is interested in developing effective groundwater restoration approaches that are cost effective and are compliant with the applicable regulatory requirement in NM. They are also interested in significantly reducing water usage and creating sustainable ISR operations in NM. LANL is interested in performing state of the art research focused on addressing the needs of ISR but more broadly in leveraging LANL's expertise and knowledge in actinides science and access to specialized facilities and equipment that is specifically designed to handle actinides to help advance the science of subsurface remediation. The approach developed by the proposing team is designed to specifically address the following challenges related to developing a cost effect restoration approach to ISR sites: (1) construct a laboratory based ISR plant that can be used to optimize ISR leaching, (2) Optimize mixing in the pore space to maximize effective sweep operation and amendment deployment, (3) compare the effectiveness of reverse osmosis as a sole subsurface treatment, (4) determine the effectiveness of deploying chemical treatments to restore native reducing conditions, (5) examine the impact of natural attenuation on water quality, and (6) perform an economic evaluation of the cost of the different treatment options examined in this study.

C. TASKS TO BE PERFORMED

Task 1. Drilling, Core Retrieval, and Borehole Logging
Task 2. Optimization of Pore-Scale Mixing

Task 2.1 Microfluidic Optimization of Pore-Scale Mixing
Task 2.2 Impact of Acoustic Stimulation on Pore-Scale Mixing
Task 3. Construction of Laboratory-Scale ISR Testing Facility at LANL
Task 4. Optimization of ISR Process Parameters.
Task 5. Optimization of Post-ISR Restoration Strategies
Task 5.1 Optimization of Reverse Osmosis Sweep Efficiency
Task 5.2 Reverse Osmosis with Abiotic Reduction (Dithionite)
Task 6. Laboratory Evaluation of Natural Attenuation
Task 7. Techno-Economic Evaluation of Remedial Strategies from Task 4 and Task 5

D. DELIVERABLES

The proposing team will communicate its progress through periodic updates to the program and will prepare a final report summarizing the work performed. Periodic reports will include:

1. Summary report describing drilling operations and core description
2. Report describing the construction and operation of the bench scale ISR facility constructed at LANL.
3. Summary report describing restoration strategies investigated
4. Summary report on natural attenuation
5. Summary report describing the techno-economic studies
6. Final report describing the findings from the project

REFERENCES

Borch T., Roche N., Johnson T.E., Determination of contaminant levels and remediation efficacy in groundwater at a former in situ recovery uranium mine, J. Environ. Monit., 14 (7) (2012), pp. 1814-1823

Catchpole G., Kuchelka R., Groundwater restoration of uranium ISL mines in the United States: paper 10, Proceedings workshop on uranium production environmental restoration: an exchange between the United States and Germany, NM1993, IAEA, International Nuclear Information System, Albuquerque (16-20 Aug 1993), p. 9

Darling B.K., Report on Findings Related to the Restoration of Groundwater at In-situ Uranium Mines in South Texas, Southwest Groundwater Consulting, LLC, Houston, TX (2008)

Dangelmayr, Martin A. ; Reimus, Paul William ; Clay, James T. ; Chamberlain, Kevin R. Evidence of natural uranium reduction and retardation during a cross-hole study at an in-situ recovery mine, Environmental Science & Technology, LA-UR-18-25101 ; 2018-06-11

Davis J.A., Curtis G.P., Consideration of Geochemical Issues in Groundwater Restoration at Uranium In-situ Leach Mining Facilities U.S. Nuclear Regulatory Commission. Division of Fuel, Engineering, and Radiological Research & U.S. Geological Survey (2007)NUREG/CR-6870

Ding, Mei ; Musa, dea ; Harris, Rose ; Rearick, Michael ; Perkin, George ; et al. Characterizing Natural Attenuation of Cr(VI) in a Chromium Plume at Los Alamos National laboratory, WM2018 ; 2018-03-18 - 2018-03-22 ; phoenix, Arizona, United States, LA-UR-18-22355 ; 2018-03-20

Hall M. Susan, Groundwater Restoration at Uranium In-Situ RecoveryMines, South Texas Coastal Plain, in abstracts with programs,Global Uranium Symposium U2009, CMA, DREGS, CRMC HealthPhysics Society, Society of Economic Geologists, Society of MiningEngineers, Wyoming Mining Association Joint Meeting, Keystone, CO, May 9–13, 2009.

Harris, Rose Janina ; Reimus, Paul William ; Clay, James , Use of Sodium Dithionite for Groundwater Restoration Following Uranium In-Situ Recovery at the Smith Ranch Highland Site in Wyoming, Goldschmidt ; 2018-08-12 - 2018-08-17 ; Boston, Massachusetts, United States, LA-UR-18-22587 ; 2018-03-26

Porter, Mark L. and Jiménez-Martínez, Joaquín and Martinez, Ricardo and McCulloch, Quinn and Carey, J. William and Viswanathan, Hari S., Geo-material microfluidics at reservoir conditions for subsurface energy resource applications", Lab Chip,2015, V(15), 15, 4044-4053

Power Resources Inc.Smith Ranch–Highland Uranium Project, A-wellfield Groundwater Restoration Information, Glenrock, Wyoming (2004)

Ruiz Omar, Thomson Bruce, Cerrato José M., Lucia Rodriguez-Freire, Groundwater restoration following in-situ recovery (ISR) mining of uranium, Applied Geochemistry, Volume 109, 2019, 104418, ISSN 0883-2927

Reimus Paul W., Clay James T., Harris Rose, Chamberlain Kevin, Jemison Noah, Ware S. Doug, and Dangelmayr Martin, Evaluation of Sodium Dithionite and Sodium Acetate as Reductive Amendments for Groundwater Restoration at Uranium In-Situ Recovery Facilities, with Emphasis on Sodium Dithionite. Los Alamos National Laboratory, LA-UR-19-28684.

Reimus, Paul William ; Boukhalfa, Hakim ; Migdissov, Artaches ; Telfeyan, Katherine Christina ; Martinez, Bennie ; et al. Laboratory and Field Investigations of In-Situ Remediation of Cr(VI) in the LANL Regional Aquifer, Prepared for : 2018 Waste Management Symposia ; 2018-03-18 - 2018-03-22 ; Phoenix, Arizona, United States, LA-UR-18-21965 ; 2018-03-09

Reimus, Paul W. ; Dangelmayr, Martin A. ; Clay, James T. ; Chamberlain, Kevin R. Uranium Natural Attenuation Downgradient of an in Situ Recovery Mine Inferred from a Cross Hole Field Test. Published as: ENVIRONMENTAL SCIENCE & TECHNOLOGY ; Vol.53, iss.13, p.7483-7493, JUL 2 2019.

Telfeyan, Katherine Christina; Reimus, Paul William ; Migdissov, Artaches, Mechanism and suitability of sodium dithionite treatment of Cr(VI) groundwater plumes, Journal of Environmental Chemical Engineering Volume 9, Issue 1, February 2021, 104913.

Uranium Producers of America (UPA). 2015. Uranium Producers of America Comments on Docket ID Number EPAHQ-OAR-2012-0788; FRL-9909-20-OAR RIN 2060-AP43 Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings Proposed Rule Federal Register / Volume 80, Number 16 / Monday, January 26, 2015 / Proposed Rules.