Navajo Abandoned Uranium Mines
Eastern and Northern Regions

Final
High-Pressure Slurry Ablation Treatability Study Report

December 2023

TETRA TECH

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Final
High-Pressure Slurry Ablation Treatability Study Report

Response, Assessment, and Evaluation Services 2
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DISCLAIMER

The U.S. Environmental Protection Agency (USEPA), through its Office of Mountains, Deserts, and Plains, provided the majority of the funding for the treatability study, with USEPA Region 9 contributing approximately one-quarter of the funding. No funds from any Navajo abandoned uranium mine settlements were used in conducting this treatability study. The document was prepared by Tetra Tech, Inc. and Disa Technologies, Inc. and revised and finalized under USEPA Contract Number 68HE0923D0002; Task Order 0004. Mention of trade names or commercial products does not constitute endorsement or recommendation for use of a specific product.

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ACRONYMS AND ABBREVIATIONS

24/7	24 hours per day/7 days per week
AMICS	Automated Mineralogy Identification and Characterization System
amsl	Above mean sea level
AQMD	Air quality management district
ARAR	Applicable or relevant and appropriate requirement
AT	Amenability test
AUM	Abandoned uranium mine
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
CNT	Close nozzle test
COC	Contaminant of concern
CR-1	Church Rock 1 Mine
CR-H	OCRM high concentration
CTS	Cove Transfer Station
Disa	Disa Technologies, Inc.
EDD	Electronic data deliverable
EE/CA	Engineering evaluation/cost analysis
ET	Evapotranspiration
GIS	Geographic information system
GPM	Gallon per minute
GPS	Global positioning system
HPSA	High-pressure slurry ablation
kwh	Kilowatt hour
LCS	Laboratory control sample
LLRW	low-level radioactive waste
MCL	Maximum contaminant level
mg/kg	Milligram per kilogram
MLA	Mineral liberation analysis
MS/MSD	Matrix spike/matrix spike duplicate
NPDES	National Pollutant Discharge and Elimination System
NRC	Nuclear Regulatory Commission

ACRONYMS AND ABBREVIATIONS (CONTINUED)

OCRM	Old Church Rock Mine
OSHA	Occupational Safety and Health Act
P80	80 percent of particles passing the given sieve size
P100	100 percent of particles passing the given sieve size
Pace	Pace Analytical Services, LLC
pCi/g	Picocurie per gram
PSD	Particle size distribution
QA	Quality assurance
QAPP	Quality assurance project plan
QC	Quality control
QV-H	Quivira CR-1 high concentration
QV-M	Quivira CR-1 medium concentration
R^2	Coefficient of determination
Ra-226	Radium-226
RCRA	Resource Conservation and Recovery Act
REE	Rare earth element
RI/FS	Remedial investigation/feasibility study
RPD	Relative percent difference
SAP	Sampling and analysis plan
Scribe	Sampling and Laboratory Results Data Management Architecture
SDG	Sample delivery group
SENES	SENES Consultants Limited
SOP	Standard operating procedure
SPLP	Synthetic precipitation leaching procedure
TCLP	Toxic characteristic leaching procedure
Tetra Tech	Tetra Tech, Inc.
TOCOR	Task order contract officer representative
TPH	Ton per hour
USEPA	U.S. Environmental Protection Agency
XRD	X-ray diffraction
XRF	X-ray fluorescence

1.0 INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) tasked Tetra Tech, Inc. (Tetra Tech) to conduct a treatability study to evaluate the use of high-pressure slurry ablation (HPSA) technology as a treatment option to remove metals and radionuclides from waste rock at Navajo Abandoned Uranium Mines (AUM) sites. Tetra Tech, with USEPA's concurrence, selected Disa Technologies, Inc.'s (Disa) HPSA technology for evaluation in this treatability study. This treatability study is intended to evaluate HPSA as a treatment technology that may be used at abandoned uranium mine (AUM) sites on the Navajo Nation and on other state and federal lands.

This section provides background information about the treatability study conducted at AUM sites on the Navajo Nation, discusses the purpose of this treatability study report, and briefly describes the technology evaluated. Key contacts are listed at the end of this section for inquiries regarding additional information about the study, evaluated technology, and AUM sites at which the treatability study was conducted.

1.1 PROJECT BACKGROUND

USEPA, the Navajo Nation, states, and federal land management agencies all need better tools to manage metals and radionuclides at AUM sites. Over a 2-week period in summer 2022, USEPA evaluated the use of HPSA technology as a treatment option to remove metals and radionuclides from waste rock at three AUM sites on the Navajo Nation (see Figure 1, Figure 2, and Figure 3):

- Old Church Rock Mine (OCRM) in the Church Rock Chapter, New Mexico
- Quivira Church Rock 1 Mine (CR-1) in the Coyote Canyon Chapter, New Mexico
- Cove Transfer Station (CTS) 2 waste stockpile at the CTS Complex in the Cove Chapter, Arizona

HPSA technology uses a mechanical process (that is, without chemicals) to remove radionuclides and metals from mine waste at AUM sites. HPSA technology is designed to treat mine waste and results in two solid media outputs:

- A large volume of coarse fraction material containing sand liberated of mineralized coating
- A smaller volume of concentrated fines fraction containing the liberated radionuclides and metals

Depending on the radionuclide and metals concentrations, characteristics of the waste undergoing treatment, and future site exposure scenarios, the coarse fraction material may be clean enough to be managed on site as backfill or under a soil cover, which is a risk management decision. The treated coarse fraction also exhibits no leachability characteristics, providing added assurance of long-term groundwater and surface water protection if left on site. The concentrated fines fraction would typically be disposed of in a Resource Conservation and Recovery Act (RCRA) C disposal facility or a low-level radioactive waste (LLRW) disposal facility licensed to accept waste of this type. The concentrated fines could also be recycled at a recovery facility (when available). Process water is recycled throughout treatment with only the final amount of recycled water requiring treatment before use on site or for disposal.

USEPA collected metals and radionuclide data on feed, treated, and fine materials, documented metals and radionuclide removal, and recorded operational information pertinent to the evaluation of HPSA technology. USEPA evaluated HPSA technology based on the removal efficiencies for uranium and radium-226 (Ra-226), comparison of wastewater effluent concentrations to discharge standards, and characteristics of resulting metals- and radionuclide-laden solid wastes. A summary of the treatability study and the results of the HPSA technology evaluation are presented in Sections 2.0 through 5.0.

1.2 PURPOSE OF REPORT

This treatability study report is designed to aid decision-makers in evaluating specific technologies, specifically HPSA, for further consideration as applicable options in AUM cleanup. This report includes a comprehensive description of the HPSA treatability study and its results. It is intended for use by USEPA remedial project managers, USEPA on-scene coordinators, contractors, and other decision-makers carrying out specific removal and remedial actions. The Navajo Nation Environmental Protection Agency advocated for the evaluation of HPSA as a possible treatment technology to reduce the quantity, toxicity, and mobility of radionuclides from AUM sites on the Navajo Nation.

To encourage the use of treatment technologies, USEPA provides information regarding the applicability of a technology to specific sites and wastes. This report includes information on cost and desirable site-specific characteristics. It also discusses the advantages, disadvantages, and limitations of HPSA technology. However, a treatability study evaluates the performance of a technology in treating a specific waste matrix at a specific site. The characteristics of other wastes and other sites may differ from the characteristics at the treatability study sites. Therefore, a successful or unsuccessful treatability study of a technology at one site does not necessarily ensure or preclude its applicability at other sites. Data from the treatability study may require extrapolation for estimating the operating ranges in which HPSA technology will perform satisfactorily. Only limited conclusions can be drawn from a single treatability study. Site-specific bench-scale studies should be conducted to assess mineral characteristics and particle size distribution (PSD) and to optimize operating parameters for specific waste material.

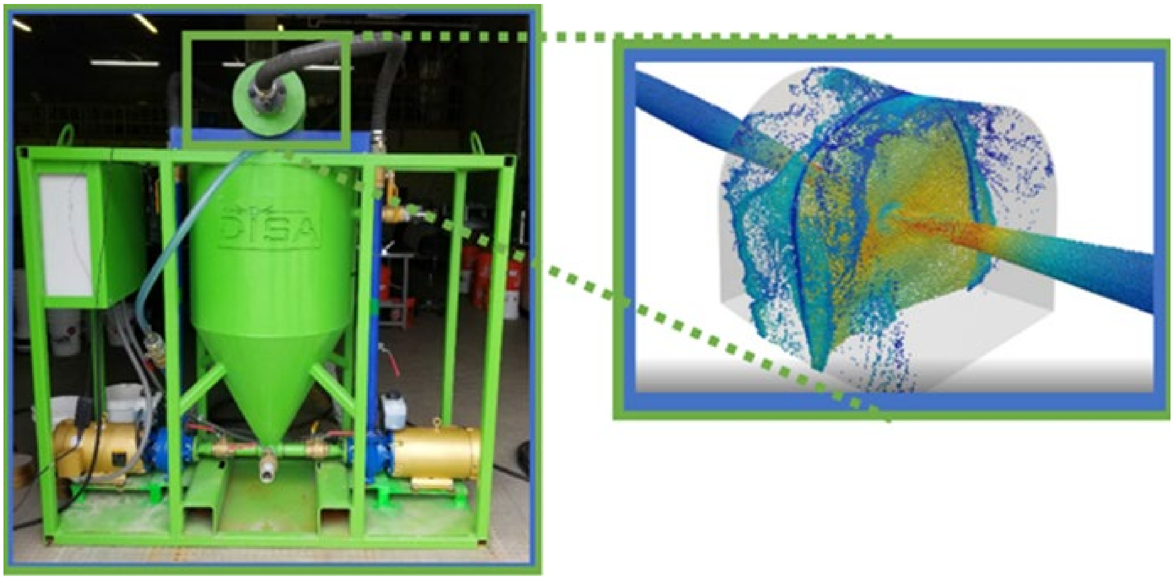
This treatability study report provides information on the application of HPSA technology at three Navajo AUM sites to reduce the concentration of metals and radionuclides in mine waste at the three AUM sites, which is a critical step in the development and commercialization of HPSA technology for use at other applicable AUM sites.

1.3 TECHNOLOGY DESCRIPTION

HPSA technology is used in minerals processing and other applications for liberating and separating mineralized deposits from host rock, whereby repeated collisions of processed solids are used to selectively fracture or liberate certain minerals in the deposit while others remain intact. HPSA technology achieves this liberation by processing solid feed material in slurry or suspension form and using high-pressure pumps to pump material through opposing nozzles contained in collision housing, creating impinging high-pressure slurry jet streams.

Since HPSA technology relies on collisions between particles with similar masses under a high-impact angle, imparting enough energy over long enough particle contact time, for particle distortion, deformation, and rebound, the technology is particularly amenable for processing co-located composite materials with the ability to fracture along discreet subfraction boundaries. During distortion and rebound, the sub-phases of the composite material particles, which have different material properties, distort and fracture disproportionately, resulting in selective liberation of the processed materials, which makes HPSA technology distinct from other minerals processing technologies (Miskovic 2019). The batch HPSA system used in this treatability study, coupled with a computational fluid dynamics-generated image depicting the basic operating principles of HPSA technology, is shown in Exhibit 1 (Weaver and Miskovic 2021).

Exhibit 1. HPSA Batch Test Unit Used for Treatability Study and Exploded Computational Fluid Dynamics Model View of Slurry Jet Stream and Particle Collision Chamber



The selective fracture of minerals contained in a composite material are governed by the mineral properties. Softer minerals fracture into smaller particles during collisions while harder minerals remain intact. Mohs hardness is a rough measure of the resistance of a smooth surface to scratching or abrasion and is expressed in terms of a scale. Where a mineral lies on the Mohs hardness scale is determined by whether its surface is scratched by a substance of known or defined hardness. The Mohs hardness of the minerals contained in a composite can typically indicate which minerals HPSA technology will selectively fracture or liberate. As such, when applied to uranium waste rock (typically, sandstone containing uranium and other minerals), HPSA technology uses the quartz (Mohs hardness of 7) in the deposit as the material's intrinsic grinding media to fracture (that is, liberate) natural uranium-bearing minerals, such as carnotite (Mohs hardness of 2), from the host quartz.

Combined with size separation at a fine particle size (typically, 270 mesh), HPSA treatment can produce a concentrates waste stream (fines containing increased concentrations of Ra-226, uranium, and other metals) and a low-concentration treated material stream (coarse fraction containing decreased Ra-226 and uranium concentrations). Figure 4 demonstrates how HPSA technology can be used to clean the surfaces of quartz host rock by removing natural uranium-containing minerals and other potential hazards. Traditional grinding technology operates on the principles of massive and indiscriminate fracture of particles for mineral liberation. HPSA technology operating principles provides an energy-efficient selective liberation system by achieving the desired particle liberation with only a few minutes of process residence time.

However, despite its novel application of energy to perform liberation, HPSA technology still follows the physical limitations of other grinding machinery in that it is most energy efficient when processing larger particles. As demonstrated on Figure 5, particles become increasingly difficult to fracture as they decrease in size (Valery and Jankovic 2002). Additionally, since the particles are transported by the slurry pumps through the nozzles at the same velocity for the entire stream, both kinetic energy and momentum of the particles are proportional to their mass. This means that collisions between larger particles will exhibit greater energy transfer between particles, resulting in greater fracture.

The particle size range for best HPSA treatment results is from 100 percent of particles passing the given sieve size (P100) of 6.35 millimeters to 80 percent of particles passing the given sieve size (P80) of greater than 100 microns. While HPSA technology typically treats these size ranges effectively, treating a heavily bimodal PSD with fines comprising a large percentage of mass can result in the collisions of the coarser particles being hindered by the presence of the fines.

Disa has experience conducting HPSA technology testing on AUM waste and other uranium mine waste in the Western United States. Disa has also completed pilot tests using larger-scale ablation-based treatment systems on non-uranium-bearing material and holds six U.S. patents and several related foreign patents for kinetic separation and HPSA technology. Disa has licensed the use of HPSA technology to a commercial vendor. No other vendors have developed ablation or HPSA technology.

When treating AUM waste, HPSA technology can concentrate more than 80 percent of the uranium in the treated material into less than 30 percent of the total treated mass (Williams 2022). In some cases, HPSA treatment combined with size separation can concentrate over 95 percent of the uranium contaminants into less than 15 percent of the total treated mass (Disa 2020). Furthermore, HPSA treatment has been shown to reduce not only the uranium concentration in the coarse fraction but also other hazards associated with the waste, such as the activity concentrations of natural uranium's radioactive progeny and leachability of other contaminants of concern (COC) as indicated on Table 1 and Table 2 (Buckingham 2022).

In addition to uranium waste rock treatment, HPSA technology can improve both efficiencies and economics in various minerals recovery applications, such as those for rare earth elements (REE), graphite, and phosphate. Using processed material as its intrinsic grinding media and with the ability of HPSA technology to improve recoveries and grades without overgrinding to the finer sizes needed for conventional comminution methods, HPSA treatment can significantly reduce costs and improve efficiencies associated with valuable mineral recovery as demonstrated by private mining client data on REEs, graphite, and phosphate. Figure 6 shows how HPSA technology was able to concentrate over 95 percent of the total REEs into the mass fraction passing a 400-mesh screen when processing samples from a U.S. REE deposit. Figure 7 shows the preservation of graphite flake size when processing graphite ore in HPSA treatment and then floating while maintaining graphite recovery and increasing grade by 20 percent compared to a conventional ball mill and flotation circuit in North America. Figure 8 shows the selective liberation of acid-consuming minerals and aluminosilicates in phosphate ore processing, which has the potential to reduce operating costs and manufacturing of products such as fertilizers.

1.4 KEY FINDINGS

This treatability study was performed on uranium mine waste at three sites on the Navajo Nation. Bulk samples were collected from locations at each site identified to represent low, medium, and high concentrations of uranium and Ra-226 for treatment with a HPSA pilot-scale test unit. Bulk material from each site was treated for 4-, 8-, and 30-minute contact times. Grab samples of treated materials were collected, separated by PSD at the Disa process laboratory, and sent to Pace Analytical Services, LLC (Pace) for chemical analysis and Eagle Engineering for qualitative mineral liberation analysis (MLA) and qualitative X-ray diffraction (XRD) analysis of mineral surfaces as shown in Exhibit 2.

This treatability study of HPSA technology, consistent with previous studies at other sites, demonstrated the following key findings:

1. HPSA technology achieved greater than 90 percent reduction in uranium and Ra-226 concentrations in the treated coarse fraction. While the HPSA technology was not able to attain conservative site-specific Navajo AUM residential cleanup goals for uranium and site-specific background levels for Ra-226, up to a 98 percent reduction in the concentration of uranium and up to a 93.5 percent reduction in the concentration of Ra-226 (see Exhibit 3, Exhibit 4, and Exhibit 5) in the coarse fraction demonstrates HPSA is a viable technology for treatment of AUM waste. These percent reduction values may meet cleanup goals, which are presented in Exhibit 6, for sites with other land uses and geologies on the Navajo Nation and at sites across the country outside of the Navajo Nation.
2. HPSA technology did not achieve conservative site-specific Navajo residential cleanup goals for uranium or background levels for Ra-226 for waste processed at OCRM and Quivira CR-1, and in only one of three waste samples at CTS 2. At CTS 2, the uranium cleanup goal of 3.2 milligrams per kilogram (mg/kg) was attained for the low-feed uranium concentration (4.5 mg/kg), but not at the medium- or high-feed uranium concentrations. A low-feed Ra-226 concentration (1.6 picocuries per gram [pCi/g]) at CTS 2 already met the cleanup goal (2.4 pCi/g). A comparison of treated coarse fraction concentrations to cleanup goals, assuming equal percentages of the high-, medium-, and low-concentration waste, is provided in Exhibit 3, Exhibit 4, and Exhibit 5 for OCRM, Quivira_CR-1, and CTS 2, respectively. While the HPSA technology did not attain the conservative site-specific Navajo AUM residential cleanup goals for OCRM and Quivira CR-1, the HPSA technology may achieve other less conservative cleanup goals on and off the Navajo Nation because of its ability to significantly reduce toxicity levels.

Examples of other less conservative cleanup goals and HPSA treatment concentrations from this study are provided in Exhibit 6.

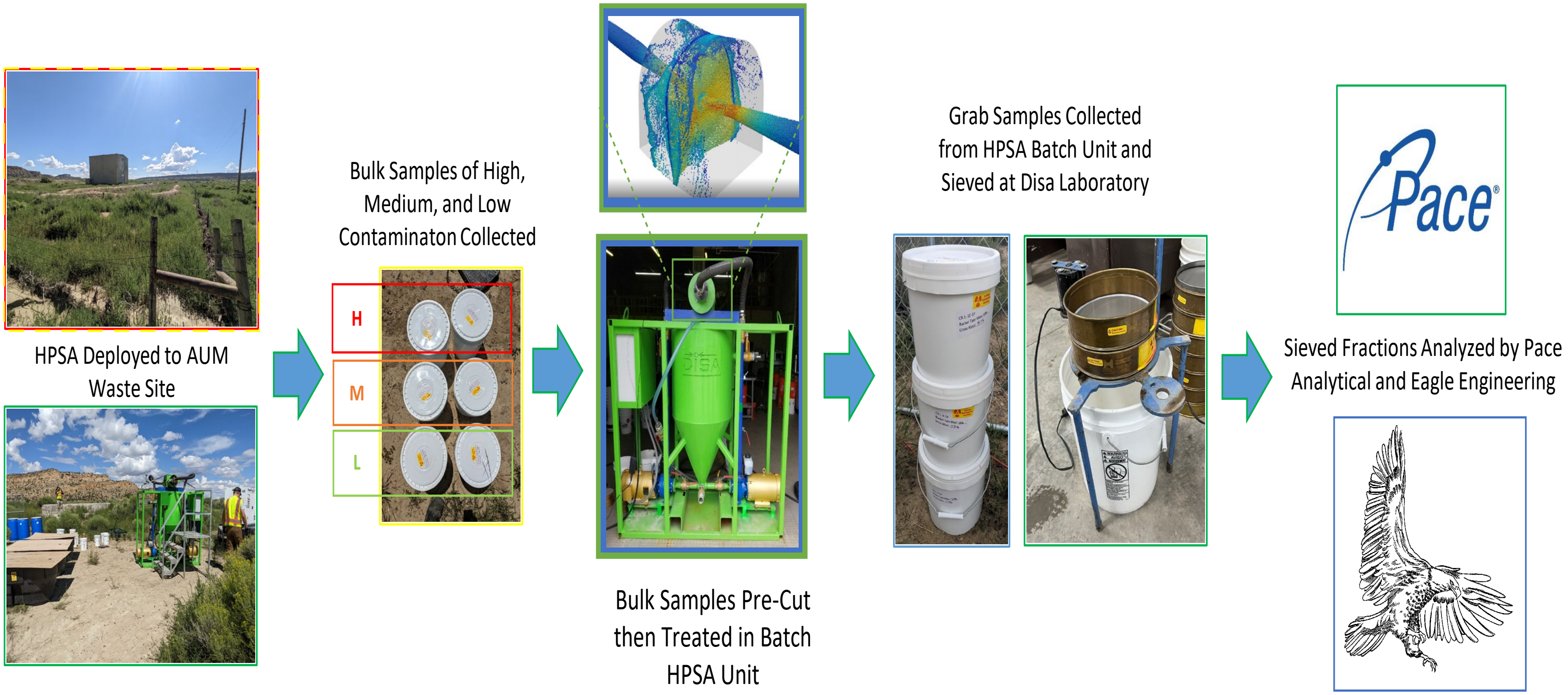
3. Treated coarse fraction does not leach metals or radionuclides above water quality standards and can be disposed of onsite without the need to cover to protect surface water or groundwater. The synthetic precipitation leaching procedure (SPLP) analysis of the feed samples indicated that uranium and Ra-226 leachability exceeded water quality standards for all three Quivira CR-1 feed samples and two OCRM feed samples. HPSA treatment reduced leachable metals and radionuclides in the treated coarse fraction by up to 96 percent over the feed material after 30 minutes of treatment (Section 2.7.3) with leachability of uranium to below detectable levels. Leachability of both uranium and Ra-226 for all CTS 2 feed samples were below water quality standards, but HPSA treatment still achieved up to 86 percent reduction in Ra-226 leachability for the treated coarse fraction compared to the feed. Based on SPLP results, the treated coarse fraction to remain on site does not leach metals or radionuclides at concentrations that could be a threat to surface water or groundwater quality; therefore, the treated coarse fraction would not require a soil cover to control residual uranium or Ra-226 leachability.
4. Treated fines fraction are not classified as a RCRA hazardous waste based on toxic characteristic leaching procedure (TCLP) results for metals; therefore, the fines need not be disposed of in a RCRA C landfill. The treated fines fraction does not exhibit a RCRA toxicity characteristic via the TCLP analysis of metals, and therefore need not be disposed in a RCRA C landfill. No TCLP analysis was performed on the feed material to the HPSA treatment process.
5. HPSA technology is most effective with coarse-grained materials. The effectiveness of HPSA technology is dependent on the PSD of the waste, where coarse-grained materials are more economically treated with short treatment durations, while increasing fines material content extends treatment durations and increases the volumes of fines that must be disposed of offsite.
6. HPSA technology operating parameters can be optimized to improve treatment and cost effectiveness. Depending on site reuse and initial concentrations, cleanup goals may be attained by adjusting operating parameters, extending treatment times, or altering the particle size separation cutoff for offsite disposal.
7. The treated coarse material may require a soil cover if cleanup goals are not met. When the risk management decision is to leave the coarse fraction on site, the treated material meeting cleanup goals can be used as backfill. Treated coarse material that does not meet cleanup goals can be placed under a soil cover to eliminate exposure pathway and achieve removal action objectives. While requiring a cover, the treatment of this material with HPSA provides assurance of significantly reduced groundwater mobility.
8. The treated fines fraction requiring offsite disposal was as low as 17 percent of the original waste volume, providing up to 83 percent reduction of the original waste volume (see Exhibit 3, Exhibit 4, and Exhibit 5). Employing HPSA technology may reduce the overall remediation time frame and costs by reducing the volume requiring offsite disposal.

9. Process water is recycled within the HPSA treatment system and is not discharged until all waste has been treated. The final volume of system charge and one system charge of rinse water (for a total of twice the system volume) would be treated before disposal on site or reuse as HPSA makeup water at another AUM site. For example, 16,500 gallons of water would be required for a 50-ton-per-hour [TPH] HPSA treatment system and 26,000 gallons for a 100-TPH HPSA treatment system), resulting in 32,000 to 54,000 gallons of treated process water requiring reuse for other purposes or disposal. This equates to 7 to 11 5,000 gallon water trucks of treated water.
10. HPSA technology requires 13 gallons per minute (GPM) of water for slurrying of material in a 50-TPH treatment system and 25 GPM for a 100-TPH treatment system. After HPSA treatment, the treated coarse fraction is rinsed with clean treated water prior to any reuse. Approximately 10 to 15 percent of rinse water is retained in the post-treatment coarse and fine fractions after filter pressing. Fortunately, the fraction of rinse water lost as moisture content in the coarse fraction is the correct amount required for placement and compaction of coarse material at the site, negating the need for any additional compaction water. Monthly water consumption is approximately 200,000 gallons per month and 384,000 gallons per month for the 50- and 100-TPH HPSA treatment systems, respectively. This equates to roughly 40 and 76 5,000 gallon water trucks monthly (2 and 4 trucks daily) for the systems, respectively.
11. HPSA technology using a 50-TPH and 100-TPH system operating 24 hours a day would cost $31.48 to $38.27, respectively per ton of waste treated. HPSA treatment, including water treatment, would result in an estimated 80 to 90 percent cost savings when compared to the cost of transporting all material for offsite disposal. However, offsite disposal of the fines fraction, which is typically 25 percent of the initial waste volume, would reduce this savings to an estimated 61 to 70 percent based on disposal at a regional uranium mill or a RCRA C or LLRW facility as described in Section 4.7.

A technology application analysis is included in Section 3.0 that evaluates the general applicability of HPSA technology to reduce concentrations of radionuclides and metals in waste rock at AUM sites.

An economic analysis performed on the results of this treatability study is included in Section 4.0 that evaluates treating AUM material using a full-scale, 50-TPH, or 100-TPH treatment system. A case study considering how HPSA treatment fits within overall AUM site cleanup, including coarse and fine material handling is include at the end of Section 4.0.

Exhibit 2. Flowsheet for the High-Pressure Slurry Ablation Treatability Study



HPSA Deployed to AUM Waste Site

Bulk Samples of High, Medium, and Low Contaminaton Collected

Bulk Samples Pre-Cut then Treated in Batch HPSA Unit

Grab Samples Collected from HPSA Batch Unit and Sieved at Disa Laboratory

Sieved Fractions Analyzed by Pace Analytical and Eagle Engineering

Notes:

AUM	Abandoned Uranium Mine
HPSA	High-Pressure Slurry Ablation

Exhibit 3. Average HPSA Performance for Treatment of Old Church Rock Mine Samples at 4, 8, and 30 Minutes of Batch Unit Residence Time

Analyte Evaluated	**Uranium (mg/kg)**			**Radium-226 (pCi/g)**		
Parameter Assessed	**4-Minute HPSA**	**8-Minute HPSA**	**30-Minute HPSA**	**4-Minute HPSA**	**8-Minute HPSA**	**30-Minute HPSA**
Feed Concentration (Average)	413			117		
Feed Concentration (Range*)	40 - 940			19.7 - 228		
Treated Coarse Fraction Concentration (Average)	25.7	20.5	**12.1**	21.8	18.4	**12.6**
Treated Coarse Fraction Concentration (Range*)	11.3 - 43.4	13.3 - 30.8	**7.8 - 27.3**	9.8 - 31.5	7.8 - 27.3	**5.7 - 18.3**
Site-Specific Cleanup Goals	3.2 (Residential)			1.6 (Background)		
Contaminant Reduction (Average)	86.2%	85.6%	**93.0%**	71.2%	76.4%	**83.3%**
Contaminant Reduction (Range*)	71.8% - 95.4%	66.9% - 96.7%	**85.7% - 98.1%**	50.5% - 86.2%	60.6% - 88.0%	**71.0% - 92.0%**

Mass Evaluation			
Parameter Assessed	**4-Minute HPSA**	**8-Minute HPSA**	**30-Minute HPSA**
Feed Material Untreated Fines** (Average)	19.7% of total mass		
Feed Material Untreated Fines ** (Range*)	16.7%-24.6% of total mass		
Final Treated and Untreated Fines Fraction (Average) - Offsite Disposal	21.8% of total mass	21.7% of total mass	25.5% of total mass
Final Treated and Untreated Fines Fraction (Range*) - Offsite Disposal	17.8% - 26.6% of total mass	18.2% - 26.1% of total mass	23.5% - 28.2% of total mass
Final Treated Coarse Fraction (Average) - Onsite Reuse	78.2% of total mass	78.3% of total mass	74.5% of total mass
Final Treated Coarse Fraction (Range*) - Onsite Reuse	73.4% - 82.2% of total mass	73.9% - 81.8% of total mass	71.8% - 76.5% of total mass

Notes:
Green shading denotes average concentrations.
Yellow shading denotes the draft site-specific Navajo cleanup goals for comparison. Draft site-specific Navajo cleanup goals are based on Removal Assessment results. A risk assessment has not been conducted at this site yet to establish final cleanup goals.
Bolded value denotes best performance metric.

*	Range of low, medium, and high concentrations
**	Feed material pre-cut at site before HPSA treatment of coarse material
HPSA	High-pressure slurry ablation
mg/kg	Milligram per kilogram
pCi/g	Picocurie per gram

Exhibit 4. Average HPSA Performance for Treatment of Quivira Church Rock 1 Mine Samples at 4, 8, and 30 Minutes of Batch Unit Residence Time

Analyte Evaluated	Uranium (mg/kg)			Radium-226 (pCi/g)		
Parameter Assessed	**4-Minute HPSA**	**8-Minute HPSA**	**30-Minute HPSA**	**4-Minute HPSA**	**8-Minute HPSA**	**30-Minute HPSA**
Feed Concentration (Average)	247			82		
Feed Concentration (Range*)	110-400			31.8-121		
Treated Coarse Fraction Concentration (Average)	19.4	17.8	**11.0**	8.5	7.3	**5.9**
Treated Coarse Fraction Concentration (Range*)	16.6 - 23.4	13.3 - 20.7	**10.3 - 12.2**	5.1 - 12.3	4.6 - 9.1	**4.0 - 7.9**
Site-Specific Cleanup Goals	3.2 (Residential)			2.0 (Background)		
Contaminant Reduction (Average)	90.4%	90.4%	**94.3%**	88.3%	89.7%	**91.5%**
Contaminant Reduction (Range*)	84.9% - 92.6%	82.3% - 94.8%	**90.6% - 96.9%**	83.9% - 91.3%	85.7% - 92.5%	**87.3% - 93.5%**

Mass Evaluation			
Parameter Assessed	**4-Minute HPSA**	**8-Minute HPSA**	**30-Minute HPSA**
Feed Material Untreated Fines** (Average)	19.1% of total mass		
Feed Material Untreated Fines ** (Range*)	18.7%-19.7% of total mass		
Final Treated and Untreated Fines Fraction (Average) - Offsite Disposal	20.3% of total mass	20.4% of total mass	23.3% of total mass
Final Treated and Untreated Fines Fraction (Range*) - Offsite Disposal	18.4% - 22.5% of total mass	19.0% - 21.6% of total mass	21.9% - 24.2% of total mass
Final Treated Coarse Fraction (Average) - Onsite Reuse	79.7% of total mass	79.6% of total mass	76.7% of total mass
Final Treated Coarse Fraction (Range*) - Onsite Reuse	77.5% - 81.6% of total mass	78.4% - 81.0% of total mass	75.8% - 78.1% of total mass

Notes:
Green shading denotes average concentrations.
Yellow shading denotes the final site-specific Navajo cleanup goals for comparison. Final cleanup goals are based on the Draft Final Engineering Evaluation/Cost Analysis as of December 2023.
Bolded value denotes best performance metric.

*	Range of low, medium, and high concentrations
**	Feed material pre-cut at site before HPSA treatment of coarse material
HPSA	High-pressure slurry ablation
mg/kg	Milligram per kilogram
pCi/g	Picocurie per gram

Exhibit 5. Average HPSA Performance for Treatment of Cove Transfer Station 2 Samples at 4, 8, and 30 Minutes of Batch Unit Residence Time

Analyte Evaluated	**Uranium (mg/kg)**			**Radium-226 (pCi/g)**		
Parameter Assessed	**4-Minute HPSA**	**8-Minute HPSA**	**30-Minute HPSA**	**4-Minute HPSA**	**8-Minute HPSA**	**30-Minute HPSA**
Feed Concentration (Average)	31.5			9.8		
Feed Concentration (Range*)	4.52 - 50			1.6 - 15		
Treated Coarse Fraction Concentration (Average)	32.2	25.0	**14.7**	6.7	5.9	**4.6**
Treated Coarse Fraction Concentration (Range*)	1.75 - 55.7	1.34 - 42.2	**0.92 - 22.9**	0.93 - 10.9	0.81 - 9.1	**0.85 - 7.0**
Site-Specific Cleanup Goals	3.2 (Residential)			2.4 (Background)		
Contaminant Reduction (Average)	17.4%	35.7%	**61.0%**	34.6%	42.8%	**51.2%**
Contaminant Reduction (Range*)	NC - 61.2%	15.5% - 70.3%	**49.2% - 79.6%**	27.1% - 41.9%	39.2% - 49.5%	**47.1% - 53.6%**

Mass Evaluation			
Parameter Assessed	**4-Minute HPSA**	**8-Minute HPSA**	**30-Minute HPSA**
Untreated >1/4-inch Fraction – Offsite Disposal ** (Average)	3.4% of total mass		
Untreated >1/4-inch Fraction – Offsite Disposal ** (Range*)	2.7-4.3% of total mass		
Final Treated Fines Fraction (Average) - Offsite Disposal	45.4% of total mass	48.0% of total mass	53.1% of total mass
Final Treated Fines Fraction (Range*) - Offsite Disposal	43.5%-47.0% of total mass	47.4%-48.6% of total mass	51.7% - 55.2% of total mass
Final Treated Coarse Fraction (Average) - Onsite Reuse	54.6% of total mass	52% of total mass	46.9% of total mass
Final Treated Coarse Fraction (Range*) - Onsite Reuse	53.0%-56.5% of total mass	51.4%-52.6% of total mass	44.8%-48.3% of total mass

Notes:
Green shading denotes average concentrations.
Yellow shading denotes the draft site-specific Navajo cleanup goals to which the data are being compared. Draft cleanup goals are based on the CTS Time-Critical Removal Action as of June 2023.
Bolded value denotes best performance metric.

*	Range of low, medium, and high concentrations
**	No pre-cut of the fines fraction at site occurred before HPSA treatment. Greater than ¼-inch material were screened out before treatment because of the presence of ore chips. Ore chips were screened out before processing because of the small amount and because screening would reduce contamination without any required HPSA treatment. Treated fines fraction and ore chips fraction were analyzed separately and not included in the estimate of contaminant reduction.
HPSA	High-pressure slurry ablation
mg/kg	Milligram per kilogram
NC	Not calculated
pCi/g	Picocurie per gram

Exhibit 6. HPSA Performance for Treatment of Three Sites Compared to National and Navajo Nation Cleanup Criteria

Analyte Evaluated	Uranium (mg/kg)			Radium-226 (pCi/g)		
Parameter Assessed	**4-Minute HPSA**	**8-Minute HPSA**	**30-Minute HPSA**	**4-Minute HPSA**	**8-Minute HPSA**	**30-Minute HPSA**
Old Church Rock Mine Treated Coarse Fraction Concentration (Range*)	11.3 - 43.4	13.3 - 30.8	7.8 - 27.3	9.8 - 31.5	7.8 - 27.3	5.7 - 18.3
Quivira Church Rock 1 Mine Treated Coarse Fraction Concentration (Range*)	16.6 - 23.4	13.3 - 20.7	10.3 - 12.2	5.1 - 12.3	4.6 - 9.1	4.0 - 7.9
Cove Transfer Station 2 Treated Coarse Fraction Concentration (Range*)	1.75 - 55.7	1.34 - 42.2	0.92 - 22.9	0.93 - 10.9	0.81 - 9.1	0.85 - 7.0
National Cleanup Criteria						
NRC Cleanup Criteria	Determined by radium-226 (5 pCi/g) benchmark dose analysis – yielding 764 mg/kg uranium above background			5 pCi/g (0-6 inches) / 15 pCi/g (> 6 inches) – above background		
USEPA RSL	16 mg/kg (residential soil)			Not promulgated		
Navajo Nation Cleanup Criteria						
Residential	3.2 mg/kg			1.5 to 6.6 pCi/g **		
Sheep Camp	8.5 mg/kg					
Open Space Uses	19 - 21 mg/kg					

Notes:

*	Range reflects low to high post-treatment concentrations
**	Values are based on background levels observed in a range of geologies in different regions of the Navajo Nation. Higher background levels are typical of geology containing uranium ore, but not the ore horizon.
HPSA	High-pressure slurry ablation
mg/kg	Milligram per kilogram
NRC	Nuclear Regulatory Commission
pCi/g	Picocurie per gram
RSL	Regional screening level
USEPA	U.S. Environmental Protection Agency

1.5 KEY CONTACTS

Key project personnel and contact information for USEPA and Tetra Tech personnel are presented in Exhibit 7.

Exhibit 7. Key Project Personnel

Role	Key Personnel	Agency/ Company	Phone Number	Email
USEPA				
USEPA TOCOR	Kenyon Larsen	USEPA Region 9	(415) 914-4213	larsen.kenyon@epa.gov
NNEPA				
NNEPA Project Manager	Warren Roan	NNEPA	(928) 871-7993	wroan@navajo-nsn.gov
Tetra Tech Team				
Program Manager	Ed Sussenguth	Tetra Tech	(510) 302-6333	ed.sussenguth@tetratech.com
Project Manager	Yohji Ono	Tetra Tech	(510) 302-6301	yohji.ono@tetratech.com
Technical Lead	Matt Udell	Tetra Tech	(916) 853-4516	matt.udell@tetratech.com
President	Greyson Buckingham	Disa	(307) 690-2508	greyson@disausa.com
Project Manager	John Lee	Disa	(307) 851-3980	john@disausa.com
Technical Lead	Andrew Halverson	Disa	(307) 871-7291	a.halverson@disausa.com
Radiation Health Physicist	Tyler Alecksen	ERG	(505) 298-4224	tyleralecksen@ergoffice.com

Notes:

Disa	Disa Technologies, Inc.
ERG	Environmental Restoration Group, Inc.
NNEPA	Navajo Nation Environmental Protection Agency
Tetra Tech	Tetra Tech, Inc.
TOCOR	Task order contract officer representative
USEPA	U.S. Environmental Protection Agency

2.0 TECHNOLOGY EFFECTIVENESS

The following sections discuss the effectiveness of the HPSA technology evaluated at the three AUM sites on the Navajo Nation. The discussion includes a background summary of the three sites; descriptions of the technology process and the evaluation approach; a summary of bench-scale, field evaluation, and process laboratory activities; and results of the technology evaluation.

2.1 BACKGROUND

The proposed sites on the Navajo Nation for conducting this treatability study were:

- CTS 2 at the CTS Complex in the Cove Chapter
- Quivira CR-1 in the Coyote Canyon Chapter
- OCRM in the Church Rock Chapter

CTS 2 is a former uranium ore transfer facility within the Northern AUM Region of the Navajo Nation that currently serves as a temporary waste stockpile site. The site has an elevation of 6,102 feet above mean sea level (amsl) and is approximately 2 miles north of CTS 1 on the northwest side of Indian Route 33 near Cove, Arizona (Figure 1). During operations from 1952 to 1968, ore from the Tronox mines in the Lukachukai Mountains, primarily the Mesa II Complex, was stockpiled at the site before being transported to a mill in Shiprock, New Mexico, for uranium recovery. The waste removed during the 2012 removal action at CTS 1 and CTS South is currently stockpiled at CTS 2. Previous CTS 2 investigation activities only involved a gamma radiation survey of the temporary waste stockpile and overall site; therefore, available metals and radionuclide characterization data were limited for the treatability study. For this treatability study, test material was collected from the CTS 2 waste stockpile. Because the stockpile at CTS 2 is the result of a removal action, it contains a mixture of waste rock and sandy clay soil.

Quivira CR-1 is within the Eastern AUM Region of the Navajo Nation on Tribal Trust Lands in McKinley County, New Mexico. The site has an elevation of 7,057 feet amsl and is approximately 12 miles north of Church Rock, New Mexico, on the north side of State Route 566 (Figure 2). The Kerr-McGee Corporation conducted exploration at Quivira CR-1 and the Quivira Church Rock 1 East Mine from the late 1960s into early 1986 (SENES Consultants Limited [SENES] 2010). Uranium ore from the mines was processed at the Quivira Mining Corporation’s Ambrosia Lake Mill approximately 50 miles to the east and north of Grants, New Mexico. Surface material exhibiting relatively high gamma radiation measurements are present in the Quivira CR-1 and Quivira Church Rock 1 East Mine waste piles. A large portion of the Quivira CR-1 waste pile has a 1-foot-thick reclamation cover, which was temporarily removed to survey and sample the waste rock layer below and then replaced during the treatability study (SENES 2011). The surface of the waste pile was surveyed to select and collect test material for this treatability study. Waste in the Quivira CR-1 waste pile contains coarse to fine grain sand left in place from underground uranium mining.

OCRM is within the Eastern AUM Region of the Navajo Nation on Tribal Trust Lands in McKinley County, New Mexico. The site has an elevation of 6,800 feet amsl and is approximately 6 miles north of Church Rock, New Mexico, on the north side of State Route 566 (Figure 3). No previous AUM investigation documents were available for OCRM. In 2019, Disa (2020) evaluated surface soil from OCRM with permission from the Navajo Nation. Surface soil exhibiting high gamma radiation measurements was present east of the former ponds near the former mine operation area in the eastern part of the site. The area where Disa had previously collected surface soil samples was surveyed to select and collect test material for this treatability study. The contaminated area Disa had labeled as OCRM sample CR-5 during the previous assessment was identified as the medium-concentration sample for testing during this study. Waste at OCRM is coarse to fine grain sand left in place from underground mining.

2.2 PROCESS DESCRIPTION

The HPSA batch test unit deployed to the field for the treatability study was used to assess both material amenability to treatment and factors required for scaled treatment of the material. This subsection discusses the design and key components of the HPSA batch test unit, the operation of the unit, and how the test unit compares to the designed continuous throughput system and the envisioned larger-scale systems. In general, the operating principles between the pilot system design and the larger-scale continuous throughput units are the same. The batch test unit informs the system residence time, which is the main scale-up factor, to determine the required collision rate of a material to achieve desired results.

2.2.1 Pilot-Scale System Design

The HPSA batch test unit (Figure 9) consists of the following major components:

1. Collision chamber placed atop the unit containing the nozzles for creation and containment of the collision region
2. Collision catch tank of 106 gallons total volume with a typical operating volume between 80 and 90 gallons of water and slurry
3. Two 1.5-inch suction by 1-inch discharge pumps for material recirculation that each feed an individual collision nozzle in the collision chamber
4. One variable frequency drive for control of motor rotation frequency and nozzle outlet velocity for each of the two 10-horsepower pump motors
5. Grab sampling point with 2-inch ball valves on the discharge of each collision pump leading to a 1-inch ball valve and hose for sampling from the unit at various times during a batch test

The test unit is designed to process up to 200 pounds of material at 80 to 90 gallons of total volume in batch form. Samples from the system are collected at multiple time intervals throughout the test to identify the required number of collisions needed for effective material treatment at larger continuous throughput scales. The test unit is designed to be modular, allowing for variation of operating ranges by switching nozzles for different collision velocities and pressures. During the field portion of the treatability study, the test unit was equipped with nozzles with a 2-inch inlet and 0.5-inch outlet to generate the pressures and velocities required. In this configuration, the test unit has a maximum particle size of ¼-inch material.

In addition to the main components of the system, the test unit is equipped with pressure sensors at the inlet of the collision nozzles for monitoring unit performance and identifying the collision velocities required for scale, as well as a Siemens Smart Access Module for real-time monitoring of power consumption via the test unit variable frequency drives. Finally, a portable doppler flow meter can be attached to the unit for further monitoring of flow rates during testing if required.

2.2.2 Pilot-Scale Unit Operations

Before operation of the HPSA batch test unit, material was collected and prepared for treatment. Material preparation involves screening the collected material through a ¼-inch screen to separate material small enough to be treated. Typically, the material retained on the ¼-inch screen is crushed using a laboratory-scale jaw crusher and then combined with the material originally passing the ¼-inch screen. At this point, a small grab sample of approximately 1,000 grams is typically subsampled from the bulk material that has been screened, crushed, and well mixed to give a baseline for comparison against the treated time samples. For representative and unbiased sampling, either the method of coning and quartering or riffle splitting is recommended.

When a test is ready to be performed, dilution water must first be added to the system and the pumps must be ramped using the variable frequency drive pump to the desired recirculation rate for collision velocities to be achieved. Collected bulk feed material is introduced into the HPSA batch test unit manually by pouring collected buckets of material into the open top of the HPSA catch tank while the unit is recirculating water. After all bulk material has been added to the system, a timer is started so that treatment effectiveness may be gauged by sampling from the grab sampling point at different time intervals.

2.2.3 Pilot-Scale Material Feed Rates and Residence Duration

Recorded residence time for each of the individual grab samples is used in combination with the recorded variables of solids mass processed, total slurry volume, and flow rate to calculate the number of probable collisions for the material to achieve the timed results. The residence time in the system is only a metric used to identify the true scale-up factor of required collisions to achieve a desired product output and does not have any bearing on the required volume of the tank to match this residence time in scaled-up HPSA units.

For instance, when treating material in the test unit using the 0.5-inch outlet nozzles used for this treatability study, the flow rate for each pump is approximately 50 GPM, resulting in a total recirculation rate of 100 GPM. Operating at a slurry volume of 85 gallons, a grab sample collected at 4 minutes of batch system treatment time would represent material having undergone the probability of four to five collision passes. From this metric, continuous throughput units are designed to meet or exceed the probability that all material has undergone four to five collisions.

Although small-scale testing to identify scale-up design factors is the main intended use for the HPSA batch test unit when operating at the maximum capacity of 200 pounds per batch for a system residence time of 4 minutes, the test unit has the potential to treat 1.5 tons of material per hour.

2.3 EVALUATION APPROACH

This subsection describes the evaluation approach, including the study objectives, treatability study overview, and sampling program as presented in the sampling and analysis plan (SAP)/quality assurance project plan (QAPP) of the ablation treatability study work plan (Tetra Tech 2022).

2.3.1 Project Objectives

The overarching objective of this treatability study was to evaluate the effectiveness of HPSA technology in removing uranium, Ra-226, and other metals from waste at AUM sites. This study is intended to support USEPA's consideration of ablation as a possible treatment technology by itself or in conjunction with other technologies as a cleanup alternative in an engineering evaluation/cost analysis (EE/CA) or remedial investigation/feasibility study (RI/FS) report. The report will provide USEPA with general considerations when conducting technology screening, cost estimating, and designing and planning for future response actions.

The following objectives were evaluated during this treatability study:

Primary Objectives

1. Can HPSA technology treat AUM waste material to achieve concentrations at or below site-specific cleanup goals?
2. What is the removal efficiency of COCs in various geologies, in various uranium mineralogies, and at various pretreatment concentrations?
3. What is the output quantity (mass) ratio of clean material (at or below site-specific cleanup goals) to dirty material (above site-specific cleanup goals)?

Secondary Objectives

1. What quantity of wastewater is generated per ton of waste material treated? How much water is consumed to treat 1 ton of waste material?
2. What are the wastewater concentrations for comparison to discharge requirements?
3. What factors (such as flow rate, volume, and time) increase or decrease the technology's effectiveness?
4. What design and operating parameters are needed to optimize technology performance?
5. What is the estimated cost of HPSA per ton of waste processed?
6. How easily can the HPSA technology be implemented at AUM sites?

Secondary Objective 5 is addressed in the Section 4.0 economic analysis, while Secondary Objective 6 is addressed in the Section 3.0 technology applications analysis.

2.3.2 Treatability Study Overview

The treatability study approach was to treat waste material typically found at AUM sites. By conducting the study at the three sites identified in Section 2.1 (OCRM, Quivira CR-1, and CTS 2) and selecting three feedstock material concentrations (low, medium, and high range) from each site, the study tested HPSA technology across a range of AUM waste materials and concentrations to evaluate the consistency of treatment performance across varying feed material. HPSA treatment times of 4, 8, and 30 minutes for each batch were also tested to evaluate optimum treatment time and contaminant reduction and identify the scale-up metric of the probable collision rate for continuous throughput full-scale HPSA units.

While HPSA technology can typically be gauged on its effectiveness in the first 4 to 8 minutes of batch unit residence time, after which diminishing returns are observable for each additional minute of treatment, a 30-minute residence time sample was collected to broaden the range of data and to better understand the optimal number of collisions required for the most effective results. From this 30-minute grab sample, further optimization on the treated sample could be performed to reduce the time to reach results seen for a 30-minute residence time.

To minimize onsite time and site disturbance, the onsite testing tasks were limited to only batch HPSA treatment of samples at each site. Onsite testing consisted of collecting bulk material feed for testing, performing batch unit treatment, and collecting grab samples for further analysis to assess the effectiveness of the HPSA technology at each of the three sites. Fraction separation of soil was not part of the field testing and, instead, was carried out in the Disa process laboratory in Casper, Wyoming, where the soil fractions were separated by wet sieving and prepared for analysis at the Pace and Eagle Engineering laboratories.

2.3.3 Sampling Program

The goals of the sampling program for this treatability study were to characterize the feed bulk material, treated soil fractions, coarse fraction, fines fraction, and process water for COCs (uranium and Ra-226), as well as document the process and effectiveness of the treatment technology. The sampling program summarized below was conducted in three phases: (1) reconnaissance survey and bench-scale study, (2) field pilot study, and (3) post-field activities.

Reconnaissance Survey and Bench-Scale Study. Before deployment of the HPSA batch test unit to the individual sites, Tetra Tech and Disa conducted a visit at each site for a reconnaissance survey using a gamma radiation detector and handheld X-ray fluorescence (XRF) instrument to identify and select areas from which to sample high-, medium-, and low-concentration uranium in contaminated material as described in the SAP/QAPP (Tetra Tech 2022). The three sample areas were marked with a global positioning system (GPS) instrument for field study deployment.

Tetra Tech and Disa collected approximately 200 pounds of surface and subsurface uranium waste material from the medium-concentration location at each site for initial bench-scale processing, fractionation, and characterization at the Disa process laboratory. This step allowed Disa to optimize the necessary parameters for HPSA system deployment and operations on site.

Feed grab and fractionation samples of the treated material were used to quantify the values of the medium-concentration material for each site (Exhibit 8). Additional details on reconnaissance survey and bench-scale study activities are presented in Section 2.4.

Exhibit 8. Sampling Summary with Deviations

Data Type	Planned Number of Samples	Actual Number of Samples	Analytes	Analytical Methods
Solid Samples				
Bench-Scale Study	3 (medium concentration during reconnaissance survey)	4 medium concentration (including duplicate)	Metals	USEPA 6010, 6020 but not 7471B (mercury) as not of concern
			Radium-226	USEPA 901.1
Field Pilot Study Bulk Feed Samples	9 bulk samples	9 bulk samples, 3 CTS 2 oversize bulk concentration, 1 OCRM high-concentration coarse fraction	Metals	USEPA 6010, 6020 but not 7471B (mercury) as not of concern
			Radium-226	USEPA 901.1
Field Pilot Study Process Soil (feed plus three time samples, seven fractions)	252 (metals only)	273 (planned number plus duplicates)	Metals	USEPA 6010, 6020 but not 7471B (mercury) as not of concern
	252 (Radium-226)	87 (composited because of insufficient volume in certain size ranges)	Radium-226	USEPA 901.1
	27 TCLP (passing 270 mesh); 27 SPLP (retained 270 mesh); 36 AMICS	29 TCLP (passing 270 mesh, 2 duplicates) 38 SPLP (bulk feed and retained 270 mesh, 2 duplicates) 36 AMICS (coarse fractions composited)	RCRA TCLP Metals; SPLP Metals and Radium-226; AMICS (MLA and XRD)	Extraction: USEPA 1311 and 1312 Leachate Analysis: USEPA 6010, 7470, 903.1; AMICS (MLA and XRD)
Water Samples				
Makeup Water (same as Field Blank, which was not collected)	4	2 (Gallup Source plus duplicate). Field Blank not collected as it is the same as Makeup Water.	Metals	USEPA 6010 and 6020
			Radium-226	Alpha Scintillation USEPA 903.1
			Radium-228	GFPC USEPA 904.0
			Total Dissolved and Suspended Solids	SM 2540
Process Water	27	35 (planned number plus 3 process water, 3 fractionation water, 1 Disa shop water, 1 duplicate)	Metals	USEPA 6020

Exhibit 8. Sampling Summary with Deviations

Data Type	Planned Number of Samples	Actual Number of Samples	Analytes	Analytical Methods
Wet Sieving Water, 0.45 Micron Filtrate	1	2 (pre- and post-filtration)	Metals	USEPA 6010 and 6020
Equipment Blanks	Minimum 1 per matrix sampling method per team per event	Vessel rinsed twice. Equipment blanks not collected because concentration in feed soils would exceed any residue by several orders of magnitude.	Metals	USEPA 6010 and 6020
			Radium-226	Alpha Scintillation USEPA 903.1
			Radium-228	GFPC USEPA 904.0

Notes:

Orange shaded text indicates a sample type or analysis was not performed during the treatability study that was included in the sampling and analysis plan (Tetra Tech 2022).

AMICS	Automated Mineral Identification and Characterization System
CR	Old Church Rock Mine
CTS	Cove Transfer Station
Disa	Disa Technologies, Inc.
GFPC	Gas flow proportional counter
MLA	Mineral liberation analysis
RCRA	Resource Conservation and Recovery Act
SM	Standard method
SPLP	Synthetic precipitation leaching procedure
TCLP	Toxic characteristic leaching procedure
Tetra Tech	Tetra Tech, Inc.
USEPA	U.S. Environmental Protection Agency
XRD	X-ray diffraction

Field Pilot Study. Following the reconnaissance survey and bench-scale study, Disa conducted an onsite demonstration of the HPSA technology using the batch test unit to treat selected uranium-contaminated materials from a high-, medium-, and low-concentration area at each site. Tetra Tech and Disa collected approximately 100 pounds of surface and subsurface uranium waste material from the low-, medium-, and high-concentration locations at each site for the field pilot study.

Mine waste collected from each site was treated using the portable HPSA batch test unit to test ablation of uranium from the test feed material. The treatability study was conducted at a single location at each site. Because of the small scale of the test, the area required to stage equipment was also small (approximately 2,100 square feet). Operation at each site was conducted over 3 to 4 days during normal daytime working hours.

Bulk feed material for HPSA batch test unit processing was collected for each test in approximately 100-pound masses (two 5-gallon buckets). This bulk feed material was screened over a ¼-inch screen (largest particle size). Materials retained on and a ¼-inch screen were weighed to the nearest 0.1 pound to calculate the material as a percentage of the total to be crushed for HPSA treatment at full scale. Disa used its laboratory-scale jaw crusher to crush oversize material to pass through a ¼-inch screen. From this combined sample of the original passing ¼-inch and crushed oversize material, a feed grab sample of approximately 1,000 grams was retrieved by coning and quartering for wet sieving and other analyses on the size fractions as a baseline to compare against the HPSA-treated material.

The bulk feed material was then loaded into the HPSA batch test unit for treatment. HPSA-treated slurry samples were retrieved in grab samples at 4-, 8-, and 30-minute timed intervals from the sample discharge ports of the HPSA batch test unit in approximately 2-gallon volumes for wet sieving at the Disa process laboratory and for metals and Ra-226 analyses at Pace. The remaining bulk material in slurry form was discharged from the HPSA batch test unit into a containment tote. Once the solids settled, water was pumped from the top of the solids into the excavated pit at the collection location for the highest contaminant concentration sample. The remaining moist solids were removed from the discharge tote with a shovel and replaced on site in the area of the highest contaminant concentration.

With three feed grades (low, medium, and high), three samples per test, and three sites, a total of 27 HPSA treated slurry samples were produced. The water phase of these samples (separated water above settled solids from slurry) was sampled and analyzed for total metals, Ra-226, radium-228, total dissolved solids, and total suspended solids. The makeup water used for the field batch test and for wet sieving at the Disa process laboratory was also analyzed for the same analytes. Exhibit 8 summarizes the laboratory analysis for makeup and process water sampling. The settled solids were sent to the Disa process laboratory for post-field wet sieving, drying, and sampling. Additional details on field pilot study activities are presented in Section 2.5.

Post-Field Activities. Disa performed wet sieve analysis on the time duration grab samples. Wet sieve screen analysis was conducted by Disa using a RO-TAP method for the sieve sizes of 25-, 50-, 100-, 140-, 200-, and 270-mesh yielding seven sample fractions per grab sample. Fine material passing the 270-mesh screen was collected in slurry form in a 5-gallon bucket under the screen and then pressure filtered at 60 pounds per square inch on 5-micron filter paper. All size fractions were dried to calculate the mass of the material in each size fraction. Treated slurry samples were subject to the same sieve classification as the time zero grab feed samples for consistency. Before performing sieve analysis on the slurry grab samples, sample volumes were weighed for a wet mass to calculate the percent solids of the sample. Additional details on post-field activities are presented in Section 2.6.

The feed and sieved samples were analyzed for metals and Ra-226, TCLP leachable metals, SPLP leachable metals and radionuclides, and filtered sieve processing water for metals, radionuclides, and solids by Pace. The feed and sieved samples were also analyzed qualitatively using the Automated Mineralogy Identification and Characterization System (AMICS) by Eagle Engineering. Exhibit 8 summarizes the laboratory analyses for post-pilot study sampling.

Sample Nomenclature. Sample nomenclature referenced in discussions of sample handling, analysis, and results in Sections 2.4 through 2.7 are identified in Exhibit 9.

Exhibit 9. Sample Identification Nomenclature Summary with Deviations

Matrix/ Data Collection Technique	Sample Number Components	Example Identification
Soil Samples		
Test Soil	Site ID. Concentration (L for low, M for medium, H for high). Treated time (0 for feed). Matrix (SL for soil). Duplicate differentiator (-01 or -02).	CR-L-0-SL-01 CTS-L-0-SL-01 QV-L-0-SL-01
Process Slurry/Soil	Site ID. Concentration (L for low, M for medium, H for high). Treated time (4, 8, or 30 for 4, 8, or 30 minutes). Matrix (SY for slurry). Duplicate differentiator (-01 or -02).	CR-L-4-SY-01 CTS-L-4-SY-01 QV-L-4-SY-01
Test Soil Fines	Site ID. Concentration (L for low, M for medium, H for high). Treated time (0 for feed). Matrix (F for fines). Consecutive numbering.	CR-L-0-F-01 QV-L-0-F-01
Water Samples		
Makeup Water	Site ID. Matrix (MU for makeup water, WT for water).	CR-MU-WT-01
Process Water	Site ID. Concentration (L for low, M for medium, H for high). Treated time (4, 8, or 30 for 4, 8, or 30 minutes). Matrix (WT for water). Duplicate differentiator (-01 or -02).	CR-L-4-WT-01 CTS-L-4-WT-01 QV-L-4-WT-01
Quality Control Samples		
Duplicate	Duplicate differentiator (-01 or-02).	CR-MU-WT-02
Equipment Blank	Site ID. EB to indicate equipment blank. Consecutive numbering. Sample date.	CR-EB-01-MMDDYY
Field Blank	Site ID. FB to indicate field blank. Consecutive numbering. Sample date.	CR-FB-01-MMDDYY

Notes:

Green shaded text indicates samples added as a deviation from the sampling and analysis plan (Tetra Tech 2022).

Orange shaded text indicates samples removed as a deviation from the sampling and analysis plan (Tetra Tech 2022).

CR	Old Church Rock Mine
CTS	Cove Transfer Station 2
QV	Quivira Church Rock 1 Mine
Tetra Tech	Tetra Tech, Inc.

2.4 RECONNAISSANCE SURVEY AND BENCH-SCALE STUDY

Before deployment of the HPSA batch test unit to the sites in August 2022, USEPA, Tetra Tech, and Disa conducted a site visit in May 2022 to each of the three sites to identify representative bulk sampling points for testing during the field study. Site evaluations began by using previous maps developed for the areas where potential high, medium, and low concentrations of uranium-contaminated soils existed. Based on the previous maps, Tetra Tech used a Ludlum Model 44-10 coupled to a Ludlum Model 2221 ratemeter to read surface gamma activity in counts per minute. Once an area had been identified by the ratemeter as a potential sampling point, Disa performed in situ XRF measurements of the soil with an Olympus Vanta Reflex V3 XRF analyzer at these locations while digging down into the soil with a shovel.

A total of 10 in situ measurements were made at each of the three identified locations of low, medium, and high uranium concentrations. These spots were marked both with stakes and a GPS so that the same locations would be sampled during the treatability study. Table 3 summarizes the recorded gamma activities, average XRF measurement, and depth excavated during the reconnaissance survey at the three sites. Figure 1, Figure 2, and Figure 3 depict the locations of the identified low, medium, and high sample points for Quivira CR-1, OCRM, and CTS 2, respectively, as identified during the reconnaissance survey.

During the reconnaissance survey, Disa also collected approximately 200 pounds (four 5-gallon buckets) of material from each of the XRF-estimated medium-concentration locations for initial treatment and fine tuning of the HPSA batch test unit before field demonstration. Samples were submitted to Pace for analyses of metals and Ra-226 (Exhibit 8). This material was returned to the site at the high-concentration location after bulk material collection and treatment had occurred for the site during the field pilot study in August 2022.

2.4.1 Previous Investigation Findings

The range of surface soil concentration for the three sites previously identified during other investigations are shown for selected analytes in Table 4. Ra-226, arsenic, molybdenum, selenium, thallium, uranium, and vanadium are common target metals at AUM sites on the Navajo Nation, but limited data were available from previous investigations that focused primarily on gamma radiation levels and corresponding Ra-226 concentrations based on correlation studies.

At CTS 2, a maximum correlated Ra-226 concentration of 76.6 pCi/g was measured on the constructed waste pile but soil samples were analyzed directly from this waste pile (Ecology and Environment, Inc. 2013). Therefore, the metals concentrations shown in Table 4 are from post-removal surface soil concentrations from CTS 1 and CTS South. At Quivira CR-1, Ra-226 soil concentrations ranged from 0.82 to 47.1 pCi/g (SENES 2011). At OCRM, only uranium and Ra-226 soil concentration data from the Disa (2020) 2019 uranium mine waste treatment study for the Navajo Nation were available and Ra-226 surface soil concentrations ranged from 10.1 to 238 pCi/g.

2.4.2 Evaluating Potential Feed Material Sources

As summarized in Table 3, the average uranium concentrations recorded during the reconnaissance survey at Quivira CR-1 ranged from 65 to 689 mg/kg with XRF measurements collected up to 3 feet below ground surface. Most XRF measurements were collected from at least 0.5 foot below ground surface. Average uranium concentrations at OCRM ranged from 171 to 1,143 mg/kg with XRF measurements up to 2 feet below ground surface. CTS 2 had a wider range of uranium concentrations compared to OCRM and Quivira CR-1. At CTS 2, separate measurements were collected for the fine red soil and the coarser material. The coarser material CTS 2 had uranium concentrations at least 100 mg/kg higher (with one rock measurement as high as 6.7 percent uranium from an in situ measurement) than the fine red soil concentration at a maximum of 62 mg/kg uranium.

From the bulk material sample collected from the medium-concentration sample point at each of the three sites, small subsamples were collected after the material was passed through the ¼-inch screen and material retained on the ¼-inch screen was subsequently crushed and recombined with the passing material. These samples were sent to Pace to assess agreement between XRF measurements and USEPA Method 6020 (Exhibit 8). Additionally, the laboratory analytical results were used to calculate if the sampled locations met the intended goals of sampling low, medium, and high concentrations of uranium at each site. Table 3 shows the fixed laboratory uranium and Ra-226 results compared with XRF analyzer and gamma activity data. The greatest difference between the recorded XRF analyzer 10-measurement average and the laboratory metals concentration was in the CTS 2 medium-concentration sample and is likely because of the presence of high-concentration ore chips in low-concentration soil, illustrating a drawback of using the XRF analyzer for in situ measurements when the material is not well homogenized (as is the case for large particles where the view of the beam emitter of the XRF analyzer is dominated by particle).

Once the feed grab samples from each site had been subsampled from the collected bulk material, wet sieving was conducted to develop a PSD. Based on the PSD results, the Quivira CR-1 and OCRM medium-concentration samples had similar particle size ranges to which HPSA technology had previously been amenable. However, a significant portion of the mass of the CTS 2 medium-concentration sample was much finer than the Quivira CR-1 and OCRM medium-concentration samples with 46 percent of the material passing the 270-mesh screen. Furthermore, 32.1 percent of the total uranium contamination was present in the retained ¼-inch fraction while making up only 8.5 percent of the total mass. Based on data showing that the oversize coarse material had, on average, higher uranium concentrations than the fine red soil, Disa deviated from the SAP/QAPP and collected and analyzed the oversize material separately from the material passing the ¼-inch screen during the field portion of the treatability study.

2.4.3 High-Pressure Slurry Ablation Bench-Scale Operations and Optimization

In past pilot tests on uranium mine waste material, the HPSA batch test unit required only a few minutes of operation to complete the treatment. However, depending on the minerals present and PSD, certain operating parameters can be adjusted on the HPSA batch test unit to reduce uranium and Ra-226 concentrations in a shorter treatment time. These variables include nozzle outlet size (by extension pressure and velocity), slurry percent solids by mass, and nozzle distance.

Because of the presence of solids in the slurry, the jets exiting the nozzles into the collision region experience a high degree of turbulence, causing jet break up and spreading of particles as the particles travel into the collision region. As a result, adjusting the spacing of the nozzles can reduce the amount of time required to achieve treatment results, as well as increase particle breakage.

Two tests were conducted on each of the materials. An amenability test (AT) was performed first without the removal of fines or adjustment of nozzle outlet distance in the collision chamber. A close nozzle test (CNT) was performed next to remove fine material before HPSA treatment and adjust nozzle outlets as close as possible to the center of the collision region. The results of the two tests look similar, but the CNT achieves slightly better results by the metric of mass found in the fines fraction. Samples from the HPSA system were subjected to the same wet sieving per Disa's RO-TAP material processing standard operating procedure (SOP) provided in

Appendix B-1C as the samples collected from the sites during the field study. Size fractions were sent to Pace and analyzed for metals (Exhibit 8). The results of the treatment for OCRM and Quivira CR-1 samples during bench-scale testing are summarized in Table 5. As shown in Table 5, calculations for the retained 270-mesh screen material uranium concentrations included the assumption that any size fraction analysis yielding a nondetect result has a concentration of 9 mg/kg uranium.

Testing of CTS 2 bench-scale samples yielded less effective results with HPSA treatment because of a large portion of material in the finest material fraction. Disa performed both an AT and a CNT for the CTS 2 material. Following the AT, the 4-minute post-HPSA treated uranium concentration of 59 mg/kg showed an increase from the bulk feed concentration of 58 mg/kg uranium. With the oversize (retained on a ¼-inch screen) material in the CTS 2 medium-concentration sample with a higher uranium concentration (610 mg/kg) than the material passing a ¼-inch screen (51 mg/kg), Disa hypothesized that crushing the oversize material and combining it with the material passing the ¼-inch screen before batch treatment contributed to this increase. However, this likely reflects the fracture of albite and orthoclase, which are softer than quartz, before the fracture of carnotite at the short treatment time. Disa assumed the +25-mesh material contained most of the uranium contamination added by combining the crushed oversize with the material originally passing the ¼-inch screen and removed it before HPSA treatment for the CNT. As a result, the CNT on CTS 2 material improved the reduction of the uranium concentration from the AT with coarse fraction uranium concentrations being reduced to 30, 28, and 21 mg/kg at treatment times of 2, 4, and 15 minutes, respectively. The results of the bench-scale testing on the collected CTS-M-T buckets are summarized in Table 5.

2.4.4 Lessons Learned

Two issues arose during the bench-scale study that could be avoided if the study were repeated:

- During the bench-scale study, uranium contaminants were not homogenously distributed throughout the particle size classes with higher concentrations in material greater than ¼ inch in diameter. As a result, for the field pilot study, the material originally retained on the ¼-inch screen was removed from the bulk sample before treatment in the HPSA batch unit.
- Results from the AT and CNT for the OCRM and Quivira CR-1 bulk sample processing during the bench-scale study indicated that decreasing the distance between the nozzle outlets and removing the passing 270-mesh material by a pre-cut step before treatment in the HPSA batch unit further reduced the final concentrations of treated material. This finding resulted in making these changes to the procedures for the field pilot study for both AUM sites.

2.5 FIELD EVALUATION ACTIVITIES

The following steps were performed at each of the three sites:

1. Mobilize to the site.

2. Set up equipment and the HPSA batch test unit.
3. Locate low-, medium-, and high-concentration samples.
4. Collect and prepare material for treatment in the HPSA batch test unit.
5. Process material in the HPSA batch test unit for a 30-minute test while collecting 4-, 8-, and 30-minute treatment time samples.
6. Discharge the system and prepare and label samples for post-processing analysis.
7. Disassemble and remove equipment and clean up the work area.
8. Demobilize from the site.

2.5.1 Mobilization

Fieldwork was conducted during a single mobilization period where Disa brought the HPSA batch test unit, as well as a mobile process laboratory trailer for other required equipment, to all three sites. At least one Disa staff member was always present at the site and up to three staff were present for operation of the unit and collection of samples and other process data needed for reporting. Additionally, two Bitco (a Navajo-owned company) personnel were present during the mobilization and testing at the sites for operation of the backhoe, construction of the fence for the site activities perimeter, and operation of the generator to provide power to the test unit.

With the low-, medium-, and high-concentration sample points spread out across the sites, all bulk material samples collected from the sampling points were brought to a central location for material preparation and HPSA treatment steps. In accordance with the SAP/QAPP and because excess material (water and excess treated bulk samples) was to be returned to the site at the high-concentration point, Disa deployed the HPSA batch test unit and set up its operating perimeter around the high-concentration sample points at OCRM and Quivira CR-1. As demonstration day was to take place at CTS 2, the HPSA batch test unit and working perimeter were set up outside the fence around the site rather than at the high-concentration point. Photographs of mobilization activities are presented in Appendix A.

2.5.2 Feed Material Characterization and Makeup Water

Feed material was collected in masses of approximately 100 pounds and no more than 135 pounds at OCRM and Quivira CR-1. Photographs of bulk sample collection activities are presented in Appendix A. All material samples at OCRM were collected using shovels as the reconnaissance survey identified highly contaminated material near the surface at the sample points (Table 3). With contamination at Quivira CR-1 located further below grade than at OCRM, a backhoe was used so that samples could be collected and put into buckets with shovels.

Complications were encountered when collecting bulk samples from Quivira CR-1 during the field pilot study. First, upon arrival, the originally marked sample point for the Quivira CR-1 medium-concentration sample was flooded because of monsoon rains. As a result, a new medium sample point was selected for bulk sample collection. When performing the initial XRF screening of the collected Quivira CR-1 bulk samples after ¼-inch mesh screening, crushing, and recombination, the uranium concentration of the collected high sample was lower than recorded during the reconnaissance survey (160 to 200 mg/kg compared to the average of 689 mg/kg during the reconnaissance survey). However, some reconnaissance survey XRF measurements at the Quivira CR-1 high-concentration (QV-H) sample point read as low as 26 mg/kg uranium. Based on these data, the QV-H sample likely exhibited high-concentration intervals up to 1,649 mg/kg uranium concentration among lower concentration soil (Table 3). Once mixed through the process of digging to retrieve the samples, the bulk samples had a lower overall concentration than could be accurately approximated by the 10-measurement average of the reconnaissance survey data. To maintain the integrity of the study, the high-concentration sample originally collected was relabeled as the Quivira CR-1 medium-concentration (QV-M) sample and the backhoe was used to dig further down at the high-concentration sample point until a higher uranium concentration sample could be collected as the new high sample for testing. The new QV-H sample was observed by XRF analysis to have a concentration of 340 to 427 mg/kg uranium after ¼-inch mesh screening, oversize crushing, and homogenizing of the sample. The collected QV-M sample was placed back at the QV-M sample location.

During the reconnaissance survey, CTS 2 was characterized by high uranium concentration material greater than ¼ inch in size mixed with lower uranium concentration fines comprising the red soil matrix. As a result, three buckets of material were originally collected to have enough material for collection of a crushed oversize sample and for HPSA treatment if the pre-cut step was used (as described in Section 2.5.3, a pre-cut step was not included for CTS 2 material). Approximately 150 pounds and no more than 165 pounds were collected from each of the three sample points. As at OCRM, samples were collected using shovels to dig from surface material until the three bulk sample buckets were full. After a crushed oversize sample had been collected from each of the CTS 2 samples, one bucket of material originally passing the ¼-inch screen and the remainder of the crushed oversize material were returned to their respective sample points. The remaining mass of 100 pounds was treated in the HPSA batch test unit.

2.5.2.1 Feed Material Chemical and Mineralogical Description

Feed material or time zero samples were not only analyzed by Disa through wet sieving but also split into bulk solid analytical samples for USEPA Method 6020 metals and qualitative AMICS analyses, including qualitative XRD and MLA. Results from the bulk solids analysis of uranium and Ra-226 are summarized in the feed grade parameter in Table 6, Table 7, and Table 8. Pace performed metals and Ra-226 analyses while Eagle Engineering performed the qualitative AMICS analyses. Analysis results of the feed material at the three sites were as follows:

- CTS 2 waste material had the lowest average concentrations of uranium and Ra-226 of 31.5 mg/kg and 9.8 pCi/g, respectively. The highest and lowest concentrations of uranium were 50 mg/kg and 4.52 mg/kg, respectively, while Ra-226 ranged from 1.6 to no greater than 15 pCi/g.
- Quivira CR-1 waste material uranium concentrations ranged from 110 to 400 mg/kg with an average across the three samples points of 247 mg/kg. Ra-226 averaged 82 pCi/g and ranged from 31.8 to 121 pCi/g.
- OCRM waste material had the highest average uranium and Ra-226 concentrations of 413 mg/kg and 117 pCi/g, respectively. Uranium ranged from 40 to 940 mg/kg, and Ra-226 ranged from 19.7 to 228 pCi/g.

AMICS analysis, for the purposes of this study, was used for the qualitative assessment of the main uranium-containing minerals present and determination of which major mineral phases were associated with the uranium-containing mineral present. Based on the qualitative AMICS analysis, the main uranium-containing mineral at all three sites was carnotite ($K_2(UO_2)_2(VO_4)_2$). Low-, medium-, and high-concentration samples contained less than 0.2 percent carnotite (Mohs hardness of 2). The major mineral phases in the samples were albite ($NaAlSi_3O_8$, Mohs hardness of 6 to 6.5), orthoclase ($KAlSi_3O_8$, Mohs hardness of 6 to 6.5), and quartz (SiO_2, Mohs hardness of 7). Backscatter images produced from the qualitative AMICS analysis for the CTS 2 samples material (Figure 10) showed an array of carnotite association and encapsulation by the other minerals. In the cases of the identified low- and high-concentration samples, only one carnotite particle was found. The image of the low-concentration sample carnotite shows association of the carnotite on the surface of the orthoclase particle, which may indicate amenability to HPSA treatment, whereas the medium and high samples show encapsulation by the orthoclase, making carnotite liberation from the orthoclase without first fracturing the orthoclase more difficult. Free carnotite, carnotite associations, and carnotite encapsulations by the minerals of albite, orthoclase, and quartz were seen throughout the site samples collected from the low-, medium-, and high-concentration sample points at Quivira CR-1 (Figure 11) and OCRM (Figure 12).

While oversize (retained on a ¼-inch screen) mass was identified for all three sites (described in Section 2.4.2), the oversize material collected for CTS 2 samples was not treated with the material passing a ¼-inch screen so that it could be analyzed separately. This analysis showed that although the oversize material on average comprised less than 3.4 percent of the total mass, it had elevated concentrations of both uranium and Ra-226. While only comprising 2.7 percent of the mass, the CTS-M-0-SL-01 retained on a ¼-inch screen sample contained 24.8 percent of the total uranium (610 mg/kg) and 17.6 percent of the total Ra-226 (102 pCi/g). Similarly, the CTS-H-0-SL-01 retained on a ¼-inch screen sample comprising only 4.3 percent of the total mass contained 32.2 percent of the uranium (610 mg/kg) and 25.9 percent of the Ra-226 (129 pCi/g) when balanced across all size fractions. The CTS 2 low-concentration oversize sample did not possess elevated concentrations above the material passing a ¼-inch screen and comprised 3.2 percent of the total mass, 4.0 percent of the total uranium, and 4.5 percent of the total Ra-226. Table 6, Table 7, and Table 8 compare the total metals and Ra-226 concentrations of the low, medium, and high samples for each site to their leachable concentrations from SPLP extraction and metals and Ra-226 analyses.

In general, waste material at OCRM and Quivira CR-1 is coarser in PSD than at CTS 2, and each site has varying degrees of contamination present throughout. OCRM samples exhibited the highest concentrations of uranium and Ra-226 with Quivira CR-1 and CTS 2 samples exhibiting lower concentrations in that order. The major minerals in waste material at the sites were silicate compounds, and carnotite was the only identified uranium-containing mineral based on qualitative MLA . While material greater than ¼ inch was not analyzed at OCRM and Quivira CR-1, the retained ¼-inch material at CTS 2 had higher concentrations relative to the rest of the PSD at the site.

2.5.2.2 *Feed Material Particle Size Distribution*

As part of the testing of materials at the three sites, material was screened through a ¼-inch screen as the top size (oversize) for the HPSA batch test unit. The average oversize at CTS 2, Quivira CR-1, and OCRM comprised 3.4, 3.0, and 1.2 percent of the mass, respectively. With the collected grab samples from the field treatability study, Disa performed wet sieving using a RO-TAP setup (further described in Section 2.6.1) that developed PSDs for each of the three sites. These PSDs were graphed according to the cumulative mass percentage of the sample passing the given particle size of the sieve they were washed over during wet sieving. As shown on Figure 13, the P80s for OCRM samples were at 210, 550, and 700 microns for the low, medium, and high samples, respectively. Figure 14 shows the mass percent of the sieve sample retained on the individual sieves used for the PSD. For these samples, the mass passing the 270-mesh screen on the fractionated feed samples was less than 25 percent and averaged less than 20 percent.

Figure 15 depicts the cumulative percent passing curves for the PSDs performed on Quivira CR-1 samples and shows that the P80s for the high-, medium-, and low-feed concentrations were more closely grouped than the OCRM samples at 640, 640, and 600 microns, respectively. Figure 16 shows that the feed mass originally passing the 270-mesh screen was also more closely grouped with low-, medium-, and high-concentrations having 18.7, 19.7, and 18.9 percent fines by mass, respectively.

Figure 17 depicts the cumulative mass percent passing curves for CTS 2 feed sample PSDs. While OCRM and Quivira CR-1 samples had bimodal distributions of mass, the PSDs for CTS 2 feed samples were more heavily bimodal, passing the 270-mesh screen with 44.8, 45.0, and 48.3 percent for the low, medium, and high samples, respectively. Figure 18 shows the mass percent of the total sample retained on the individual sieves used for the PSD.

2.5.2.3 *Makeup Water*

All makeup water was collected from the same source of municipal water in Gallup, New Mexico, over the course of the 2-week study. A report of the municipal water concentrations in Gallup is provided in Appendix B-9. Water was collected for onsite use from a Gallup municipal source and transported to the site in four separate clean totes with volumes ranging from 300 to 350 gallons. When deployed at OCRM, the first site for the field study, a makeup water sample and a duplicate makeup water sample were collected and sent to Pace for analysis parameters per Exhibit 8. Because the makeup water was collected from the same source over the span of 1 week during the field study, any variance in concentrations of the makeup water at the different sites was assumed to be negligible. To analyze the accumulation of constituents in the process water during HPSA batch tests, the average between the two makeup water samples collected at OCRM was used as the baseline for all concentrations.

2.5.3 Operational Activities and Modifications

During the bench-scale study, Disa found that removing the passing 270-mesh material before treating the coarse material improved the overall efficiency of the test unit treatment by reducing the residence time needed to achieve high uranium reduction. Removal and retention of fines does not impact coarse fraction post-treatment concentrations as the fines fraction is not recombined with the coarse soil fraction in any way. Additionally, as shown on Figure 19 and Figure 20 for the larger, continuous HPSA system, removing the fines fraction before material processing through the HPSA chambers increases overall throughput.

To model this step in the continuous process and deliver the best results possible during the field demonstration, a pre-cut step was added to operations on site as a deviation from the original plan to treat all material in the system after initial size reduction of the retained ¼-inch oversize material. Based on the bench-scale study results at OCRM and Quivira CR-1, the pre-cut step was added. However, for field operations at CTS 2, the pre-cut step was not included because of a large proportion of fines at the site, as well as an effort by Disa to understand a third option that was not included in the original bench-scale sample analysis.

During bench-scale testing, the retained ¼-inch material was crushed and combined with material originally passing a ¼-inch screen. As described in Section 2.4.2, this resulted in a perceived increase in the uranium concentration for the samples. During material preparation at CTS 2, the retained ¼-inch material was separated from the passing ¼-inch material and crushed but not recombined to assess how amenable the material passing the ¼-inch screen was to HPSA treatment without added contaminant mass from the crushed oversize fraction as a comparison against the CTS 2 AT performed during the bench-scale study.

To perform this pre-cut step on site, a 12-inch-diameter, 270-mesh screen was placed over a sieve shaker designed and fabricated for screening bulk samples over the top of an open 55-gallon drum. Photographs of pre-cut sieving activities are presented in Appendix A. After the baseline grab feed sample had been collected from the homogenized bulk feed, material was scooped out of its buckets onto the top of the sieve shaker with a trowel while water was sprayed over the top of the shaking sieve. Wetted fine material passed through the 270-mesh screen into the 55-gallon drum while material retained on the 270-mesh sieve was scooped into a metal pan lined with aluminum foil. The aluminum foil served both as a method to contain waste material and as a method to dry the material for easier mass recording and loading into the system. Figure 21 shows Disa personnel performing the pre-cut step process at OCRM.

The pre-cut step with 100 pounds of bulk material typically required 2 hours to perform. As such, a whole day at OCRM and Quivira CR-1 was devoted to this process. This also allowed the material in the aluminum foil-lined pans more time to dry for a better mass approximation used in the final mass balance. For all coarse samples to be treated in the test unit except OCRM coarse feed sample CR-L-0-SL-01, a wet weight was recorded before loading the material into the HPSA batch test unit. Sample CR-L-0-SL-01 was too wet to accurately assess how much moisture content was present. For all other samples, the moisture content of the coarse material loaded into the system ranged from 12.4 to 19 percent with all Quivira CR-1 coarse feed samples having a moisture content no greater than 13 percent.

Because inclusion of the pre-cut step in the field study was a deviation from the SAP/QAPP, the fine material (passing 270-mesh screen) from the pre-cut step collected in the 55-gallon drums was added to the sample nomenclature (for example, the fine material from the pre-cut step for the OCRM bulk sample CR-L-0-SL-01 was labeled as CR-L-0-F). These fines were allowed to settle from the fractionation water for 1 day after the pre-cut step had concluded before the settled solids at the bottom of the drum were collected. During the bench-scale study, Disa observed that all fines typically required no more than 1 day to settle out. However, for all but the high-concentration OCRM sample, the fractionation water appeared visibly turbid after 1 day of settling.

The turbid fractionation water was collected into a 2-gallon bucket and labeled according to the corresponding collected fines drum with the affix of "-WT," denoting the water sample. As an example, the 2-gallon bucket for the standing water with some suspended fines for the OCRM low-concentration pre-cut sample was labeled as CR-L-0-F-WT. The volume of standing water was measured for the drums before decanting it on the high-concentration sample excavation location. After decanting, the fine sludge at the bottom of the drums was collected in totality to develop a mass balance that included suspended fines. Both the fine sludge (collected in 5-gallon buckets) and standing water samples (collected in 2-gallon buckets) were transported to the Disa process laboratory for drying. The very small mass of the dried solids was added to the pre-cut material in the mass balance.

2.5.4 Treated Material Sampling

Per standard operations of the HPSA batch test unit, treated material samples were collected in slurry form from the 1-inch grab sample port in approximately 2-gallon volumes with pre-labeled buckets that identified the site, concentration, and residence time per the sample nomenclature in Exhibit 9. Photographs of treated material sampling activities are presented in Appendix A. The 2-gallon buckets came equipped with rip tabs that provided a seal to keep material from spilling during transport. During material preparatory work at the Disa process laboratory in Casper, Wyoming, laboratory logbooks (Appendix B-7) were kept to detail when each sample's rip tab was opened on each of the 2-gallon buckets in accordance with Disa's material tracking SOP (Appendix B-1B).

Additionally, because of the deviation from the SAP/QAPP to include the pre-cut fines process before HPSA treatment, 55-gallon drums containing the settled pre-cut fines were dewatered with the fractionation water discharged onto the high-concentration location at each site while the settled solids in the bottom were retrieved in 5-gallon buckets. Some of the retrieved settled solids required only two buckets while others required more. The sample chains of custody in Appendix B-2A list the number of buckets for each pre-cut step process. These samples were collected so that a full mass balance could be performed on the pre-cut process for the passing 270-mesh material without losing any data in a bulk material preparation step.

As discussed in Section 2.5.3, settled fractionation water samples were collected from the pre-cut drums where the water could be visibly seen to have some suspended fines (all but the OCRM high-concentration [CR-H] sample). Total mass of suspended solids in the turbid water was calculated by measuring the volume of the standing water in the drum, collecting a 2-gallon bucket sample of the turbid water, and drying the sample to obtain a mass at Disa's laboratory. At no point was this turbid water filtered, negating the potential for the suspended solids in the water to have passed through a 5-micron filter paper. As shown in the mass balance documents in Appendix C, the fine suspended mass from the pre-cut step accounted for a minimal portion of the total mass at OCRM (less than 0.5 percent) whereas the fine suspended mass from the pre-cut step for Quivira CR-1 fine samples accounted for more (between 2.0 and 4.6 percent). XRF readings showed that the dried solids from the turbid water samples were similar in uranium concentration to the collected fine sludge (passing 270 mesh) from the bottom of the drums. The very small mass of the dried solids was added to the pre-cut material in the mass balance. All samples retrieved from the sites during the testing were logged in sample chains of custody provided in Appendix B-2A.

2.5.5 Process Water and Settled Material Handling

Post-process slurry at OCRM, the first site of the pilot study, was discharged following Disa's batch system operation SOP (Appendix B-1A). Per the SOP, material was discharged from the system into 150-gallon totes to allow for settling, decanting of the water onto the high-concentration point, and scraping of the settled solids back onto the high-concentration point. Photographs of settled material handling at OCRM are presented in Appendix A. However, during the demonstration at OCRM, the USEPA task order contract officer representative (TOCOR) determined that performing this extra step was not necessary and a deviation was made to discharge the post-HPSA treatment slurry into open excavation at the location of the highest concentration sample.

2.5.6 Excess Treated Material and Water Handling

During the bench-scale study, Disa kept all HPSA process water from the AT and CNT contained in 300-gallon totes. This water was subsampled and sent to Pace for analysis (Exhibit 8) to assess the process water conditions that might exist during the field study. These process water samples were found to be below discharge standards for the sanitary sewer and low enough to allow for the discharge of the process water during the field study on the high-concentration sample point. Therefore, process water was discharged along with the excess treated bulk material samples at the location of the highest concentration sample at Quivira CR-1 and CTS 2. Photographs of excess treated material and water handling activities are presented in Appendix A. No samples were collected from the settled process water or from the settled solids in the troughs at OCRM.

As CTS 2 was the last site for the study, some excess water collected from the Gallup, New Mexico, municipal source remained after the conclusion of demonstration day. This remaining water totaled approximately two totes of 300 gallons each. Because this water had not come into contact with contaminated materials at any of the three sites for the study and was presumed to contain drinking water concentrations as detailed in the Appendix B-9, the water was discharged to the ground before demobilization from CTS 2.

2.5.7 Community Demonstration Day

On August 31, 2022, USEPA and the Navajo Nation Environmental Protection Agency hosted a demonstration of the HPSA batch test unit at CTS 2. Disa and Tetra Tech presented to both Cove Chapter community members and industry and agency stakeholders on HPSA technology and conducted a live demonstration using the HPSA batch test unit. Photographs of community demonstration day activities are presented in Appendix A. A brief video about the community demonstration day is available at https://www.youtube.com/watch?v=KHnJNSN0wAo.

2.5.8 Demobilization Activities

Demobilization occurred after the community demonstration day at CTS 2 and involved transporting Disa staff, the HPSA batch test unit, and a mobile process laboratory trailer for other required equipment to Disa's facility in Casper, Wyoming. Post-treatment and water samples were also transported to the Disa facility for further sample preparation. Bitco demobilized personnel, a backhoe, temporary fencing, and a generator from CTS 2 test site.

2.5.9 Lessons Learned

Two issues arose during the field pilot study that could be avoided if the study were repeated:

- During the field pilot study, the pre-cut of fine material required the most time before processing the coarse material in the HPSA batch test unit. This was performed using a wet RO-TAP setup over a drum. A Sweco screening machine has a much larger capacity for performing this pre-cut step and could shorten the process from 2.5 hours per bulk sample (100 pounds) to 0.5 hour.
- After the pre-cut step was performed, samples dried in the sun for easier loading of the material into the HPSA batch test unit. Waiting for samples to dry before loading into the HPSA unit required a full day. Although the temperature was high enough during the field pilot study for the samples to reach 15 percent moisture content before processing the coarse fraction in the HPSA unit, alternate drying methods could shorten the drying time.

2.6 PROCESS LABORATORY ACTIVITIES

For further post-treatment material preparation, collected slurry samples from the field study were transported to the Disa process laboratory in sealed containers. Additionally, the sealed rip tabs on the 2-gallon buckets in which residence time samples were collected controlled cross-contamination between samples.

The sample chains of custody, tare masses, and gross masses were recorded for each of the slurry samples collected in the field (Appendix B-2A). Upon arrival at the Disa process laboratory, the samples were again logged by Disa personnel while still in slurry form (Appendix B-7). This logging involved checking that all samples were accounted for and no damage or cross-contamination had occurred during transportation and verifying that the gross and net masses for comparison against the sample collection in the field. Masses recorded once the material had been logged at the Disa process laboratory were noted as the “true” sample masses. Any field weight measurement error in weight measurements at the field study sites can be attributed to environmental factors such as wind that might have caused the weight scale to read less accurately. The average difference between recorded weights in the field and Disa process laboratory was less than 1.5 percent. After initial logging at the Disa process laboratory, the collected slurry grab samples underwent the following steps:

1. Separating the process water from the soil and submitting the process and fractionation water for analysis of metals and Ra-226 at Pace (Exhibit 8). Submitting makeup water to Pace for analysis of metals, Ra-226, and total dissolved and suspended solids for assessment of Secondary Objectives 1 and 2.
2. Wet sieving (sieve separation) into the size fractions of +25, +50, +100, +140, +200, +270, and -270 mesh for assessment of Primary Objectives 2 and 3.

3. Analyzing each of the size fractions using an Olympus Vanta Reflex V3 XRF analyzer for approximation of the uranium concentration to establish the correct combination of sieve-separated size fractions for the composite analyses required.
4. Splitting the size fractions into their respective analytical groups (total metals, Ra-226, TCLP metals, and SPLP metals and Ra-226 analyses) at Pace and qualitative AMICS (MLA and XRD) analysis at Eagle Engineering (Exhibit 8) for assessment of the primary objectives.
5. Shipping samples to the Pace and Eagle Engineering laboratories for analyses.

Sample mass was captured through every step of the process from initial sample collection through final post-treatment processing at Disa's laboratory. During the wet sieving process, the mass of the sample was retained on each successive screen and the sieving water passing the final screen was captured by pressure filtering. When this water was pressure filtered, water was recycled through the cake if it had suspended particles (visually cloudy) after the first pressure filtration to capture suspended mass from the sieve separation water. Further, water samples retrieved from separation of the solids and water were analyzed for total and dissolved solids to record any mass contained in the water after the solids-water separation step.

The following subsections detail general information and the reason for performing the above described tasks. For further discussion on the Disa process laboratory steps before analysis by Pace and Eagle Engineering, refer to Appendix G.

2.6.1 Wet Sieving

To assess Primary Objectives 2 and 3 by observing the shift of uranium, Ra-226, and other metals throughout different particle classes, a wet vibratory sieve method was used to fractionate the samples into their particle size classes for PSD by both mass and constituent concentration. The vibratory sieve shaker used is shown on Figure 22. Photographs of wet sieving activities are presented in Appendix A. For more information on the vibratory sieve shaker procedure, see Disa's RO-TAP material processing SOP in Appendix B-1C. Additional details of the wet sieving process performed for this study is provided in Appendix G. PSD forms are provided in Appendix B-3. City of Casper, Wyoming, potable water was used during the wet sieving process, the chemical constituents of which are presented in Appendix B-9.

Slurry samples were separated from their standing water by 5-micron pressure filtration before sieve separation for assessment of Secondary Objectives 1 and 2 whereas soil samples were sieved as received after drying for percent moisture content. After filtering through 5-micron filter paper, multiple samples were still visibly turbid, indicating a high presence of suspended solids between 5 microns and 0.45 micron in size (as shown on Figure 23 for OCRM sample CR-M-4-WT). As a result, 11 process water samples were analyzed for both total and dissolved analytes (Exhibit 8) to evaluate where process water contaminants resided for a more in-depth assessment of Secondary Objectives 1 and 2. This information on which process water contaminants reside in the suspended or dissolved fractions allows for identification of the best method to remove them from the water at greater scale. Process water contaminants suspended in the water could potentially be more easily removed through clarification while dissolved contaminants in the water would need to be removed with an adsorbent material.

2.6.2 Water Filtering, Filtrate Drying, and Combining with Fines Fractions

The water used for the wet sieving process passing the 270-mesh screen was collected in a 5-gallon bucket underneath the RO-TAP sieve setup as shown on Figure 22 and then pressure filtered over 5-micron filter paper again with the same apparatus and components as shown on Figure 24 at 60 pounds per square inch. Photographs of water filtration and dry activities are presented in Appendix A. Laboratory notes and collected data for assessment of quality control (QC) of the performance of this step are presented in Appendix G.

The pre-cut fine materials brought back from the field study in 5-gallon buckets were allowed to settle. Water was decanted from the top, and the settled material in the bottom of the buckets was dried in the oven at 105 degrees Celsius. Once the dried mass had been recorded for these pre-cut fines, the data collected in the field for the total mass of the pre-cut fines, percent moisture of the soil feed calculated at the Disa process laboratory, and recorded mass of the bulk sample collected from the field notebook (Appendix B-7) were used to calculate the mass balance for the distribution of coarse and fine material. An example mass balance sheet used to estimate the proper mixing of pre-cut fines and HPSA-generated concentrate from the wet sieving samples is shown on Figure 25 and Figure 26. For further information on the calculation of this mixing ratio, see Appendices C-4 and C-5. For Quivira CR-1 and OCRM samples, the pre-cut fines were combined with the HPSA-generated concentrate to reflect what the treated coarse and fines fractions would look like at continuous throughput scale.

All water used during fractionation was saved in clean 300-gallon totes throughout the course of processing at the Disa process laboratory. This process water was analyzed at the end of the study with results compared to the standards for Casper, Wyoming, municipal discharge and Nuclear Regulatory Commission (NRC) regulations on discharge of radionuclides to sewers as presented in Table 9 and Table 10, respectively.

2.6.3 Soil Drying, Homogenizing, and Sample Splitting

Once dry, the samples were transferred from plastic cups into plastic bags labeled according to the site, residence time, and size fractions. If samples were split into multiple PSD fractions as discussed in Section 2.6.1, the samples for the same fraction were placed in the same bag after logging (Appendix B-7). An example of how samples were split is shown on Figure 27. The sample mass logging and splitting forms are presented in Appendices B-4 and B-5. Photographs of soil drying, homogenizing, and sample splitting activities are presented in Appendix A. To reduce cross-contamination during sample splitting, the bagged samples were further split using plastic spoons and homogenized in the sample bags. The proper mass proportions were then scooped into composite sample bags. Further description of the splitting scheme is provided in Appendix G. The sample mass logging and splitting forms are presented in Appendices B-4 and B-5.

According to the SAP/QAPP (Tetra Tech 2022), all size fractions from wet sieving fractionation of the slurry samples treated by Disa were to be analyzed for both total metals and Ra-226 so that the shift of both through the size fraction over HPSA treatment time could be observed and compared to each other. However, after many of the size fraction samples had been shipped to Pace, the amount of mass for multiple fractions were insufficient to perform both metals and

Ra-226 analyses. Tetra Tech, Disa, and Pace concluded that the required 1 gram for total metals analysis should be split from the samples at Pace and the remainder of the samples should be combined into a range of fractional composites from each remaining mass for Ra-226 analysis. The USEPA TOCOR concurred with this resolution. Disa prepared a Ra-226 compositing sample list with directions for analysis and included these in chains of custody with the sample fractions. As a part of creating this Ra-226 compositing list, the error associated with the removal of mass before compositing was analyzed for each of the samples.

Appendix B-6 contains the laboratory forms used to track all material mass throughout preparation at the Disa process laboratory, as well as the project files referenced in Appendix C for all master Excel spreadsheets used to track the mass digitally.

2.6.4 X-Ray Fluorescence Analyzer Screening

Before splitting or shipment of materials to Pace for metals analysis, all fractions of each wet sieving treated sample were analyzed using the same Olympus Vanta Reflex V3 XRF used during both the reconnaissance survey and bench-scale and field pilot studies. Photographs of the XRF, stand, and sample cups are presented in Appendix A. Fractionated samples were evaluated with the XRF analyzer to calculate the appropriate compositing of fines for TCLP metals and coarse fractions for SPLP metals and Ra-226 analyses. The data were also useful in compositing size fractions where limited sample mass was available for Pace analysis. For QC measures associated with performance of the XRF, as well as the correlation of XRF results to the wet chemistry data provided by Pace, refer to Appendix G.

2.6.5 Sample Submittal and Custody for Fixed Laboratory Analysis

All soils and water samples collected were sent for fixed laboratory analyses at Pace or Eagle Engineering as specified in Exhibit 8. As discussed in Section 2.6.2, the pre-cut fines were combined with the concentrate fractions for the respective fractionation samples. All the water was separated from the slurry grab samples before submittal for analysis. Appendices B-2B and B-2C present photographs of all the samples (soil and water) with chains of custody (both shipped by Disa and received by Pace and Eagle Engineering) for each sample delivery group (SDG). For all water samples, photographs were taken of the water mass, water in the bucket, and water in the bottles for analysis.

2.6.6 Lessons Learned

Two post-treatment issues arose during the process laboratory activities that could be avoided if the study were repeated:

- Of the steps in the Disa process laboratory activities, wet RO-TAP sieving required the most time. This was partially because of the large sample masses collected and the flow of sample processing in which the entire sample was sieved. In the future, the entire sample may be washed through a passing 270-mesh sieve only to remove the fines. All material retained on the 270-mesh screen can then be dried, homogenized, and split into the proper fractions for PSD, qualitative MLA, and TCLP or SPLP. This would reduce the overall mass that needed to be sieved and allow for quicker turnaround at the processing laboratory.

- Achieving adequate subsample sizes for chemical analysis was difficult. The work plan specified conducting Ra-226 analysis for all size fraction samples. To achieve adequate volume for Ra-226 analysis, compositing was required for some size fractions. This issue is partially unavoidable because of the nature of the unknown size distributions (both feed material and post-HPSA treatment) in this study. However, if the study were repeated, PSD analysis could be conducted during the bench-scale study to better estimate the bulk sample volume needed for adequate subsample masses. Also, larger post-treatment samples could be collected from the HPSA batch unit instead of the 2-gallon volumes collected.

2.7 TECHNOLOGY EVALUATION RESULTS

This subsection discusses the treatability study results in the context of the evaluation of the primary and secondary objectives.

2.7.1 Primary Objectives

Three primary project objectives were evaluated during the treatability study as described in the following subsections.

2.7.1.1 Primary Objective 1

Primary Objective 1: Can HPSA technology treat AUM waste material to achieve concentrations at or below site-specific cleanup goals?

Cleanup goals on the Navajo Nation depend on existing and future land uses both at the AUM sites and the locations where the HPSA treated coarse fraction will be placed after treatment. In the SAP/QAPP (Tetra Tech 2022), site-specific cleanup goals were identified for CTS 2 based on the Navajo residential exposure scenario for uranium and background for Ra-226. Site-specific cleanup goals were not identified for OCRM and Quivira CR-1. Following preparation of the SAP/QAPP, the Navajo residential cleanup goal for uranium has increased while the cleanup goal for Ra-226 depends on local geology background. Further, background levels have since been developed for OCRM and Quivira CR-1.

For comparison purposes, site-specific conservative residential cleanup goals on Navajo land were used: 3.2 mg/kg for uranium and 1.6 to 2.4 pCi/g for Ra-226. Site-specific cleanup goals were:

1. OCRM: (site-specific goals have not been established; therefore, a conservative Navajo residential exposure scenario and background were used until site-specific goals have been established)
    - 3.2 mg/kg for uranium (Navajo residential exposure scenario)
    - 1.63 pCi/g for Ra-226 (background)

2. Quivira CR-1:
    - 3.2 mg/kg for uranium (Navajo residential exposure scenario)
    - 2.0 pCi/g for Ra-226 (background)
3. CTS 2:
    - 3.2 mg/kg for uranium (Navajo residential exposure scenario)
    - 2.4 pCi/g for Ra-226 (background)

Depending on site-specific land uses other non-residential cleanup goals could be developed for AUM sites on the Navajo Nation.

HPSA technology was not able to achieve these site-specific conservative Navajo cleanup goals for uranium or Ra-226 at OCRM and Quivira sites for any feed concentration and up to 30 minutes of treatment duration. At CTS 2, the uranium cleanup goal of 3.2 mg/kg was attained for the low-feed uranium concentration (4.5 mg/kg), but not at the medium- or high-feed concentrations. A low-feed Ra-226 concentration (1.6 pCi/g) at CTS 2 already met the cleanup goal of (2.4 pCi/g). A comparison of treated coarse fraction concentrations to cleanup goals is provided in Exhibit 10, Exhibit 11, and Exhibit 12 for OCRM, Quivira CR-1, and CTS 2, respectively.

While the HPSA technology was not able to attain site-specific conservative residential Navajo AUM cleanup goals, up to a 98 percent reduction in the concentration of uranium and Ra-226 in the coarse fraction (retained on 270 mesh) demonstrates HPSA is a viable technology for treatment of the AUM waste. These percent reduction values may meet cleanup goals for sites with other land uses and geologies on the Navajo Nation and at sites outside of the Navajo Nation (see Exhibit 6). The USEPA regional screening level for uranium at sites off the Navajo Nation, while not a site-specific cleanup goal for this study, is 16 mg/kg. NRC has promulgated cleanup goals for Ra-226 of 5 pCi/g plus background in surface soils and 15 pCi/g plus background in subsurface soils (>6 inches below ground surface) for sites off the Navajo Nation.

To better attain cleanup goals, certain operating parameters can be adjusted on the HPSA unit to reduce uranium and Ra-226 concentrations more effectively. These parameters include nozzle outlet size (by extension pressure and velocity), slurry percent solids by mass, and nozzle distance and extending treatment duration. Also, for feed material with a large amount of fines, a pre-cut step can be utilized to focus treatment on the coarse fraction; however, this pre-cut step increases the volume of fines requiring offsite disposal.

Exhibit 10. HPSA-Treated Old Church Rock Mine Samples Summary

Parameter	4-Minute HPSA		8-Minute HPSA		30-Minute HPSA	
Low-Concentration	**Uranium (mg/kg)**	**Radium-226 (pCi/g)**	**Uranium (mg/kg)**	**Radium-226 (pCi/g)**	**Uranium (mg/kg)**	**Radium-226 (pCi/g)**
Feed Concentration	40	19.7	40	19.7	40	19.7
Coarse Fraction Concentration	11.3	9.8	13.3	7.8	**5.74**	**5.72**
Fines Fraction Concentration	160	73.3	150	63.1	140	62.6
Site-Specific Cleanup Goals	3.2	1.63	3.2	1.63	3.2	1.63
Contaminant Reduction	71.8%	50.5%	66.9%	60.6%	**85.7%**	**71.0%**
Contaminant Recovery in Fines	83.7%	73.1%	80.0%	74.2%	90.6%	81.1%
Treated Mass to Fines Fraction	26.6%		26.1%		28.2%	
Medium-Concentration	**4-Minute HPSA**		**8-Minute HPSA**		**30-Minute HPSA**	
Feed Concentration	260	104	260	104	260	104
Coarse Fraction Concentration	22.4	24.1	17.6	20.0	**12.7**	**13.7**
Fines Fraction Concentration	1,050	407	1,010	366	860	358
Site-Specific Cleanup Goals	3.2	1.63	3.2	1.63	3.2	1.63
Contaminant Reduction	91.4%	76.8%	93.2%	80.7%	**95.1%**	**86.9%**
Contaminant Recovery in Fines	92.6%	82.0%	93.8%	82.8%	95.7%	89.6%
Treated Mass to Fines Fraction	21.2%		20.9%		24.7%	
High-Concentration	**4-Minute HPSA**		**8-Minute HPSA**		**30-Minute HPSA**	
Feed Concentration	940	228	940	228	940	228
Coarse Fraction Concentration	43.4	31.5	30.8	27.3	**17.7**	**18.3**
Fines Fraction Concentration	4,380	1,200	4,210	1,140	3,320	1,010
Site-Specific Cleanup Goals	3.2	1.63	3.2	1.63	3.2	1.63
Contaminant Reduction	95.4%	86.2%	96.7%	88.0%	**98.1%**	**92.0%**
Contaminant Recovery in Fines	95.6%	89.2%	96.8%	90.3%	98.3%	94.4%
Treated Mass to Fines Fraction	17.8%		18.2%		23.5%	

Notes:

Green shading denotes average concentrations.

Yellow shading denotes the draft site-specific Navajo cleanup goals to which the data are being compared and are based on Removal Assessment results. A risk assessment has not been conducted at this site yet to establish final cleanup goals.

Bolded value denotes best performance metric.

HPSA	High-pressure slurry ablation	mg/kg	Milligram per kilogram	pCi/g	Picocurie per gram

Exhibit 11. HPSA-Treated Quivira Church Rock 1 Mine Samples Summary

Parameter	4-Minute HPSA		8-Minute HPSA		30-Minute HPSA	
Low-Concentration	**Uranium (mg/kg)**	**Radium-226 (pCi/g)**	**Uranium (mg/kg)**	**Radium-226 (pCi/g)**	**Uranium (mg/kg)**	**Radium-226 (pCi/g)**
Feed Concentration	110	31.8	110	31.8	110	31.8
Coarse Fraction Concentration	16.6	5.1	19.5	4.6	**10.4**	**4.0**
Fines Fraction Concentration	230	112	230	120	210	95.5
Site-Specific Cleanup Goals	3.2	2.0	3.2	2.0	3.2	2.0
Contaminant Reduction	84.9%	83.9%	82.3%	85.7%	**90.6%**	**87.3%**
Contaminant Recovery in Fines	80.1%	86.4%	76.5%	87.9%	86.6%	88.3%
Treated Mass to Fines Fraction	22.5%		21.6%		24.2%	
Medium-Concentration	**4-Minute HPSA**		**8-Minute HPSA**		**30-Minute HPSA**	
Feed Concentration	230	91.9	230	91.9	230	91.9
Coarse Fraction Concentration	18.2	8.0	13.3	8.2	**10.3**	**5.7**
Fines Fraction Concentration	770	372	710	357	640	328
Site-Specific Cleanup Goals	3.2	2.0	3.2	2.0	3.2	2.0
Contaminant Reduction	92.1%	91.3%	94.2%	91.0%	**95.5%**	**93.8%**
Contaminant Recovery in Fines	91.4%	92.1%	93.2%	91.8%	95.1%	94.7%
Treated Mass to Fines Fraction	20.0%		20.6%		23.8%	
High-Concentration	**4-Minute HPSA**		**8-Minute HPSA**		**30-Minute HPSA**	
Feed Concentration	400	121	400	121	400	121
Coarse Fraction Concentration	23.4	12.3	20.7	9.1	**12.2**	**7.9**
Fines Fraction Concentration	1,310	547	1,170	510	1,090	493
Site-Specific Cleanup Goals	3.2	2.0	3.2	2.0	3.2	2.0
Contaminant Reduction	94.1%	89.8%	94.8%	92.5%	**96.9%**	**93.5%**
Contaminant Recovery in Fines	92.6%	90.9%	93.0%	92.9%	96.2%	94.6%
Treated Mass to Fines Fraction	18.4%		19.0%		21.9%	

Notes:

Green shading denotes average concentrations.

Yellow shading denotes the final site-specific Navajo cleanup goals to which the data are being compared and are based on the Draft Final Engineering Evaluation/Cost Analysis as of December 2023.

Bolded value denotes best performance metric,

HPSA	High-pressure slurry ablation	mg/kg	Milligram per kilogram	pCi/g	Picocurie per gram

Exhibit 12. HPSA-Treated Cover Transfer Station 2 Samples Summary

Parameter	**4-Minute HPSA**		**8-Minute HPSA**		**30-Minute HPSA**	
Low-Concentration	**Uranium (mg/kg)**	**Radium-226 (pCi/g)**	**Uranium (mg/kg)**	**Radium-226 (pCi/g)**	**Uranium (mg/kg)**	**Radium-226 (pCi/g)**
Feed Concentration	4.52	1.6	4.52	1.6	4.52	1.6
Coarse Fraction Concentration	1.8	0.9	1.3	0.8	**0.9**	**0.8**
Fines Fraction Concentration	4.14	2.9	3.675	2.75	4.22	2.9
Site-Specific Cleanup Goals	3.2	2.4	3.2	2.4	3.2	2.4
Contaminant Reduction	61.2%	41.9%	70.3%	49.5%	**79.6%**	**47.1%**
Contaminant Recovery in Fines	65.8%	71.8%	73.5%	77.5%	85.9%	82.0%
Treated Mass to Fines Fraction	44.9%		50.3%		57.0%	
Medium-Concentration	**4-Minute HPSA**		**8-Minute HPSA**		**30-Minute HPSA**	
Feed Concentration	40	12.7	40	12.7	40	12.7
Coarse Fraction Concentration	39.0	8.3	31.5	7.7	**20.3**	**6.0**
Fines Fraction Concentration	60	23.4	70	21.8	70	22.4
Site-Specific Cleanup Goals	3.2	2.4	3.2	2.4	3.2	2.4
Contaminant Reduction	2.5%	34.7%	21.2%	39.7%	**49.2%**	**53.0%**
Contaminant Recovery in Fines	57.6%	71.4%	68.3%	73.4%	78.4%	79.8%
Treated Mass to Fines Fraction	46.9%		49.2%		51.3%	
High-Concentration	**4-Minute HPSA**		**8-Minute HPSA**		**30-Minute HPSA**	
Feed Concentration	50	15	50	15	50	15
Coarse Fraction Concentration	55.7	10.9	42.2	9.1	**22.9**	**7.0**
Fines Fraction Concentration	70	26.75	80	26.2	80	23.1
Site-Specific Cleanup Goals	3.2	2.4	3.2	2.4	3.2	2.4
Contaminant Reduction	None	27.1%	15.5%	39.2%	**54.3%**	**53.6%**
Contaminant Recovery in Fines	54.9%	70.3%	64.8%	73.6%	80.2%	79.4%
Treated Mass to Fines Fraction	49.2%		49.3%		53.7%	

Notes:
Green shading denotes average concentrations.
Yellow shading denotes the draft site-specific Navajo cleanup goals to which the data are being compared and are based on the CTS Time-Critical Removal Action as of June 2023.
Bolded value denotes best performance metric.

HPSA	High-pressure slurry ablation	mg/kg	Milligram per kilogram	pCi/g	Picocurie per gram

In the past, optimization of the HPSA system has shown that results can be improved via methods described in both Section 1.3 and elaborated in Section 3.3. However, with HPSA treatment already achieving up to 98 percent reduction of contaminants in the coarse fraction, optimization will likely only reduce contamination by a small margin. As an example, in order for HPSA treatment of high concentration OCRM feed containing 940 mg/kg uranium and 228 pCi/g Ra-226, to achieve the site-specific Navajo cleanup goals of 3.2 mg/kg uranium and 1.63 pCi/g Ra-226, HPSA would have to reduce uranium and Ra-226 concentrations by 99.7 percent and 99.3 percent, respectively. Attempting to achieve this reduction through changing operational variables of the HPSA system would likely cause additional fines generation and a greater mass of fines fraction requiring offsite disposal. As such, assessment of the effectiveness of HPSA treatment is a tradeoff between the final concentrations attained and the increased cost posed by transportation and disposal of additional fines fraction material. Overall, the treated mass remaining on site would still be substantially lower than without HPSA treatment.

2.7.1.2 Primary Objective 2

Primary Objective 2: What is the removal efficiency of COCs in various geologies, in various uranium mineralogies, and at various pretreatment concentrations?

Removal efficiencies for both uranium and Ra-226 increased as the feed concentration increased across all residence times. However, when confining analysis to what concentration the treated samples attained, the lowest concentration feed samples resulted in the lowest treated concentration. For both OCRM and Quivira CR-1, higher concentration feed samples were more amenable to treatment by HPSA in terms of the percentage reduction of uranium and Ra-226 in the coarse fraction and the percentage recovery of uranium and Ra-226 to the fines fraction. Exhibit 10, Exhibit 11, and Exhibit 12 summarize removal efficiencies for the coarse fraction at OCRM, Quivira CR-1, and CTS 2, respectively.

Because of the closely grouped PSDs of the Quivira CR-1 feed samples, treated Ra-226 concentrations for Quivira CR-1 samples had less variation from high to low-feed concentrations. Although less amenable to HPSA treatment because of the large percentage of fines in the feed samples, the CTS 2 samples showed closely grouped treated Ra-226 concentrations. By contrast, the PSDs of the OCRM feed samples had a broader range of contaminant mass distributions contributing to larger variations between the treated concentrations of Ra-226. For all sample ranges and sites, standard deviations between the treated concentrations from the feed concentration ranges decreased as treatment time increased.

The main factor contributing to the amenability of OCRM and Quivira CR-1, associated with ore-bearing sandstone formations, was the PSD of the feed samples. As described in Section 1.3, HPSA treatment has been observed to be more amenable with coarser feed material. In theory, this is because of higher energy required to fracture smaller particles in addition to larger, more massive particles possessing higher kinetic energy and momentum when traveling the same velocity in the nozzle jet stream as smaller particles.

For CTS 2 samples, the large percentage of fines in the PSD from Chinle Formation clays did not allow for a pre-cut step (removing of fines would have not provided a sufficient quantity of feed material and material for size fraction sampling). Therefore, the large percentage of fines increases the probability of collisions with finer material even if larger particles are present in the sample. As such, less momentum and kinetic energy is transferred between the colliding particles and the potential for fracture of the uranium coating on the larger particles is reduced. While the effectiveness of the HPSA technology was impeded by the large presence of fines in the feed material at CTS 2, results show that collisions were able to liberate some of the uranium-bearing minerals from the coarser fractions into the fines fractions.

With the low-feed concentrations of uranium present in the CTS 2 samples, identification of carnotite particles was difficult with AMICS. However, as the qualitative AMICS images show on Figure 10, one carnotite particle was found to coat the quartz grain while the other carnotite particles were found encapsulated by albite and orthoclase. While not as soft as carnotite, albite and orthoclase are still softer than the main intrinsic grinding media of the material (quartz). The quartz likely required more collisions to fracture the orthoclase and albite before the carnotite could be liberated and may explain the perceived increase in concentration of the coarse fraction for the 4-minute samples before reduction after longer treatment time.

From a qualitative perspective, the AMICS images presented on Figure 11 and Figure 12 show the encapsulation of carnotite by albite and orthoclase for the Quivira CR-1 and OCRM samples, respectively, and would need to be fractured before the carnotite could be accessed. The large mass percentage of coarse particle sizes of the Quivira CR-1 and OCRM samples, possessing higher kinetic energy and momentum, resulted in high enough energy transfer between particles to fracture these encapsulations and the encapsulated carnotite with fewer total collisions.

2.7.1.3 Primary Objective 3

Primary Objective 3: What is the output quantity (mass) ratio of clean material (at or below site-specific cleanup goals) to dirty material (above site-specific cleanup goals)?

Site-specific conservative Navajo residential cleanup goals were not attained at the three AUM sites; however, based on the optimal 30-minute treatment duration for the three sites (Exhibit 10, Exhibit 11, and Exhibit 12), the coarse and fine material percentages were calculated for all three AUM sites as follows:

- Coarse fraction percentage ranged from 71.8 to 76.5 and fines fraction percentage ranged from 23.5 to 28.2 at OCRM. Compared to original waste mass volume the ratio of clean coarse material to fine concentrates is 2.5:1 to 3.3:1.
- Coarse fraction percentage ranged from 75.8 to 78.1 and fines fraction percentage ranged from 21.9 to 24.2 at Quivira CR-1. Compared to original waste mass volume the ratio of clean coarse material to fine concentrates is 3.1:1 to 3.6:1.
- Coarse fraction percentage ranged from 44.8 to 48.3 and fines fraction percentage ranged from 51.7 to 55.20 at CTS 2. Compared to original waste mass volume the ratio of clean coarse material to greater than ¼-inch material and fine concentrates is 0.81:1 to 0.93:1.

Using average values for coarse and fines fractions for every 1 ton of waste rock treated at OCRM and Quivira CR-1, 0.74 to 0.76 ton of coarse material could be managed on site with a soil cover, and 0.23 to 0.25 ton of fine materials would require transport and offsite recycling at a recovery facility (when available) or disposal at a RCRA C or LLRW facility. For CTS 2, 0.47 ton of coarse material could be managed on site with a soil cover and 0.53 ton of fine materials would require transport and offsite disposal. Using average values, a 3.2:1 ratio of coarse to fine materials was calculated for OCRM and Quivira CR-1 and 0.88:1 coarse to fine ratio for CTS 2.

The ratio between coarse and fine particles also impacts contaminant reduction in the coarse fraction. As the particle size approaches the typical cut point of 53 microns, the uranium concentrations increase relative to the fractions above. For example, the size fractions of +25, +50, +100, and +140 mesh for the Quivira CR-1 sample QV-H-8-SY all had concentrations of 20 mg/kg uranium (Exhibit 11). The size fractions of +200 and +270 mesh had uranium concentrations of 30 and 50 mg/kg uranium, respectively, contributing to an overall coarse fraction concentration of 20.7 mg/kg uranium. By selecting a cut point of 140 mesh to separate the coarse fraction from the concentrated fines fraction, the treated coarse fraction concentration would be reduced to 20 mg/kg uranium with an increase of 3.6 percent of the total mass to be transported off site. The same holds for the selection of a smaller size for the cut point between the coarse fraction and the concentrated fines fraction. Although not analyzed for the purposes of this study, a screen used to classify the post-treatment material at 400 mesh may decrease the mass to be transported off site by 1 or 2 percent but may also increase the contaminant concentration in the material by 1 or 2 percent. This cut point can be selected depending on the feed material characteristics and project economics for each site.

The mass ratio of treated soil to the concentrated fines material to be transported off site is dependent on PSD, mineralogy, and feed concentration. By performing the treatability study at three different sites, three different particle size ranges were observed. OCRM feed samples contained 17 to 25 percent of the material mass in the passing 270-mesh fraction (Figure 14). Depending on the final fine material cutoff point, starting concentration, and treatment time, 2.55 to 4.62 times as much treated coarse material can be obtained than fine material. Quivira CR-1 feed samples were similar in PSD to OCRM in that the passing 270-mesh mass ranged from 18 to 20 percent (Figure 16). Also, depending on the final fine material cutoff point, starting concentration, and treatment time 3.13:1 to 4.43:1 as much treated coarse material can be obtained than fine material. CTS 2 feed samples were much different in PSD and contained 46 to 51 percent of the material mass passing 270-mesh (Figure 18). As a result, the ratio of coarse material obtained to fine material is very low (0.81:1 to 0.93:1) in comparison to other two sites.

2.7.2 Secondary Objectives

Six secondary project objectives were evaluated during the treatability study as described in the following subsections.

2.7.2.1 Secondary Objective 1

Secondary Objective 1: What quantity of wastewater is generated per ton of waste material treated? How much water is consumed to treat 1 ton of waste material?

Process water is recycled within the HPSA treatment system and is not discharged until all waste has been treated, leaving recycle water and rinse water that must be drained from the treatment system screens, HPSA tanks, pumps, transfer lines, and clarifiers. Therefore, the quantity of wastewater generated does not correlate with the tonnage of waste treated. A conservative estimate of the quantity of wastewater is approximately twice the system charge or 33,000 gallons for a 50-TPH system and 52,000 gallons for a 100-TPH system. This water may either be treated to the required discharge levels for the specific site or contained and transported for reuse at the next site where HSPA treatment is required. Water does not need to be cleaned for the system to operate, because HPSA is strictly a physical rather than chemical process and only requires water for transport of the material through the HPSA treatment system.

For the purposes of the field study, the HPSA batch test unit was run at a solids percent mass of no greater than 20 percent and no less than 10 percent. However, the solids percent by mass will increase for the technology at scale to increase throughput, particle collision frequency, and system efficiency. Since the HPSA batch test unit has a dedicated pump to each nozzle, performing field tests at this solids percent by mass kept the unit from clogging and allowed tests to be effectively performed. At scale, multiple nozzles per pump would be used to keep the process going if one nozzle set did clog. As such, 50- or 100-TPH units are designed to process material at greater than 30 percent solids by mass (water to solids ratio greater than 2.33:1) and would reduce the water requirement.

At full scale, water is continually recycled through the HPSA system through use of dewatering equipment such as centrifuges or filter presses, but some continuous makeup water is needed as water is lost because 10 to 15 percent moisture is retained in the treated coarse fraction and fines fraction. The treated coarse fraction is rinsed with treated water prior to dewatering. Continuous makeup water was calculated at 13 GPM for the 50-TPH system and 25 GPM for the 100-TPH system. This equates to 15.6 gallons/ton treated for a 50-TPH system and 15.0 gallons/ton treated for a 100-TPH system. This assumes an initial one-time 50-TPH system charge is 16,500 gallons and 100-TPH system charge is 26,000 gallons before continuous treatment.

Once the HPSA system is charged, if units are operating in the two-shift scenario, makeup water totals 200,000 gallons per month and 384,000 gallons per month for the 50- and 100-TPH systems, respectively, and equates to roughly 40 and 76 water trucks monthly (2 and 4 trucks daily) for the systems, respectively.

2.7.2.2 Secondary Objective 2

Primary Objective 2: What are the wastewater concentrations for comparison to discharge requirements?

Process water samples collected after 5-micron pressure filtration (Figure 28) were analyzed for total metals and total and dissolved Ra-226 (0.45-micron filtration). Process water contains multiple metals and Ra-226 concentrations exceeding the lower of USEPA maximum contaminant level (MCL) or Navajo Nation surface water quality standards at all three sites (Table 11). Therefore, process wastewater requires treatment prior to recycle and discharge and must be included as part of the HPSA operations.

While HPSA technology does not need clean water to operate, water treatment will be included in the full-scale treatment of AUM sites to keep process water from contaminating the coarse fraction. Treated water will be used to feed the spray bars on the vibrating screens depicted on Figure 29 and Figure 30, rinsing the coarse soil fraction, before filter pressing.

Before the field study, Disa tested various water treatment methods. Multiple technologies from electrocoagulation to absorption media were tested with varying results. During the bench-scale study, water used for the HPSA batch test unit and wet sieving was saved in a 300-gallon tote to be used for testing a filtration system using a zeolite-based media with activated surfaces. The setup block flow diagram and a photograph of the treatment setup are shown on Figure 28.

The media column was 1.31 gallons in volume and operated at a scaled flow rate of 0.1 GPM to reflect a 100-TPH full-scale system operating with makeup water flow of 25 GPM with the media inside the HPSA system. Post-treatment water samples were sent to Pace for total uranium and total Ra-226 analyses. Results of this treatment as presented in Exhibit 13 show that the media column was able to reduce uranium and Ra-226 concentrations below USEPA MCLs.

Exhibit 13. Results for Media Column Treatment of Process Water

Analyte		Total Uranium (mg/L)	Total Radium-226 (pCi/L)
Inlet Concentrations	Average	1.59	28.0
	High	2.81	37.4
	Low	1.05	17.2
Treated Concentrations	Composite	0.007	0.5
	High	0.025	1.2
	Low	0.003	0.3
Water Quality Standard		0.03	5

Notes:
Yellow shading denotes the water quality standards to which the data are being compared.

mg/L	Milligram per liter
pCi/L	Picocurie per liter

As a deviation from the SAP/QAPP, a breakdown of suspended versus dissolved metals and suspended versus dissolved Ra-226 was included in the process water analysis to assess the need for clarification prior to wastewater treatment. While an average of 85.6 percent of uranium contained in the water was dissolved and not contained in the suspended solids, an average of 71.7 percent of the Ra-226 was suspended for the process water samples retrieved from the OCRM and Quivira CR-1 samples, respectively. By analyzing the wastewater for both the suspended and dissolved metals, Disa can model clarifier tank processes to facilitate suspended material removal in the coarse and fines fraction filter presses at scale. Furthermore, the addition of a clarifier will prevent the media column from being overloaded by the presence of high suspended constituents, allowing for greater removal of the dissolved uranium and Ra-226 during operations on site.

To determine a correlation between feed uranium and Ra-226 concentrations and resultant process water concentrations after treatment, process water data were compared to SPLP extract data. While the data show that feed samples with higher leachability of uranium and Ra-226 typically result in higher concentrations in the process water, graphed data do not exhibit a strong linear correlation (Figure 31) with a uranium leachability coefficient of determination (R^2) of 0.4571 and a Ra-226 leachability R^2 of 0.7493.

To further assess if any correlation exists between the SPLP metals and Ra-226 content of the feed material and the HPSA process water, the measurements of percent solids for each slurry sample was scaled to the dilution ratio of the SPLP metals and Ra-226 content and the results were plotted (Figure 32). This scaling of the SPLP metals and Ra-226 results based on the dilution ratio gave a stronger correlation between the uranium results but a weaker correlation between the Ra-226 results for R^2 of 0.5626 and 0.5388 for the analytes, respectively. However, as shown on Figure 33, this correlation improves when removing the dataset for OCRM CR-M-WT samples, which may have been outliers. In future treatment operations at scale, the relationship between the feed material concentrations and characteristics, HPSA unit operations, and the resultant water concentrations should be studied further to develop a more accurate understanding of the relationship between site characteristics, HPSA processing, and resultant process water concentrations of constituents.

2.7.2.3 Secondary Objective 3

Primary Objective 3: What factors (such as flow rate, volume, and time) increase or decrease the technology's effectiveness?

The data indicate most of the liberation of the mineral patina coating is performed within the first 4 to 8 minutes of HPSA treatment time. The percent reduction of the treated coarse fraction and the final treated result follow a trend of diminishing returns as the collisions continue. As such, most scale-up designs are based on the results received from time samples taken in the 4- to 8-minute window, corresponding to between 4 and 10 probable collisions for the material. Flow rate and volume were not varied through the course of this treatability study, but variations in the operating flow rate, and, by extension, nozzle exit velocity by Disa on other projects, have been shown to increase particle breakage. Similar to the variation of the size separation point as discussed in Section 2.7.1.3 (Primary Objective 3), greater particle breakage may be desirable if the goal is to reduce the contaminant concentration further. However, this will increase the ratio of the fine material to the coarse material that remains once treatment is finished. Before deployment of the HPSA batch unit, site characterization data should be reviewed, a reconnaissance survey should be conducted, and a bench-scale study should be performed to better understand the optimal process variables.

2.7.2.4 Secondary Objective 4

Primary Objective 4: What design and operating parameters are needed to optimize the technology performance?

As described in Sections 1.3 and 2.4, HPSA technology has multiple variables that can be used to optimize and further improve performance when treating AUM material. To further improve the performance of the HPSA system to treat the material below the site-specific cleanup goals, HPSA operators may make modifications to the processing velocity or the collision chamber by varying the nozzle type or the number of nozzles per chamber. With the results of treatment on both OCRM and Quivira CR-1 achieving greater than 80 percent reduction and up to 98 percent reduction of uranium and Ra-226 concentrations, marginal improvements may be made by further optimizing the HPSA technology.

Results from CTS 2 revealed certain limitations of the HPSA technology when treating samples with a significant percentage of fines (greater than 40 percent). Step improvements of treatment results may be made with changes in the process flow (such as screen sizing, treatment of only fractions containing contamination) for HPSA treatment. Material passing the 270-mesh screen in the feed material at CTS 2 had uranium concentrations of 3.06, 50, and 50 mg/kg for the low-, medium-, and high-concentration samples, respectively. This material, while not as effectively treated by HPSA, may be treated via other means, disposed of offsite, or potentially deemed a low enough concentration to remain on site. The HPSA technology can instead focus on the highly contaminated coarse fraction. While all size fractions of the CTS-L-0-SL-01 sample had a uranium concentration of 2.9 mg/kg, the concentrations of the retained ¼-inch, +25-mesh, and +50-mesh fractions of the CTS-M-0-SL-01 and CTS-H-0-SL-01 samples had uranium concentrations of 610 mg/kg. Although the retained ¼-inch material only comprised 4.3 percent of the entire mass for the CTS-H-0-SL-01 sample, it contained 32.2 percent of the entire uranium mass for the sample. For the CTS-M-0-SL-01 retained ¼-inch material, 24.8 percent of the total uranium mass was contained in 2.7 percent of the sample mass.

As discussed in Section 2.4.2, HPSA treatment of high concentrations at Quivira CR-1 and OCRM demonstrates the ability of the technology to substantially reduce uranium and Ra-226 concentrations provided that the bulk of the material are coarser particles. Because of these material characteristics, HPSA technology would be most effective at the site if only the material between ¼ inch and 270 mesh was treated and the highly concentrated material greater than ¼ inch was either crushed and treated or combined with the HPSA-produced concentrate fraction as for offsite disposal.

2.7.2.5 Secondary Objective 5

Primary Objective 5: What is the estimated cost of HPSA per ton of waste processed?

The initial fixed project costs for the HPSA treatment technology are $137,500 for the 50-TPH system and $212,500 for the 100-TPH system. Fixed costs consist of site preparation, permitting, mobilization, and installation and setup of the HPSA skids. Variable costs to operate the HPSA system range from $31 to $51 per ton treated. The variable costs consist of consumables and rentals, labor, water purchase and delivery, water treatment, analytical services, maintenance, and indirect costs. Bringing multiple HPSA units to a site and operating them in parallel will significantly reduce the time required to treat contaminated material and incur the same additional cost for each additional unit. Variable costs per ton would remain the same with multiple units.

Treating 10,000 tons of material with a 50-TPH treatment unit operating with two shifts per day for 20 days per month would cost $64.80 per ton. Economy of scale is observed using the same work schedule when treating 100,000 tons of material with a 100-TPH treatment unit at a cost $45.15 per ton and treating 1,000,000 tons of material with a 100-TPH treatment unit at a cost $43.32 per ton.

A complete economic analysis that addresses this secondary objective is presented in Section 4.0.

2.7.2.6 Secondary Objective 6

Primary Objective 6: How easily can the HPSA technology be implemented at AUM sites?

A complete technology applications analysis that addresses this secondary objective is presented in Section 3.0. The information presented can be used to support screening of the HPSA technology and consideration of the technology as an alternative to be evaluated in EE/CA and RI/FS reports.

2.7.3 Evaluation of Solids Handling and Disposal

Depending on the radionuclide and metals concentrations, characteristics of the waste undergoing treatment, and future site exposure scenarios, the coarse fraction material may be clean enough to be managed on site as backfill or under a soil cover, which is a risk management decision. The fines fraction would be disposed of offsite at a RCRA C or LLRW facility licensed to accept radioactive materials. Based on TCLP results for the concentrates at each of the three sites (Table 12, Table 13, and Table 14), the metals in the fines fraction are below RCRA toxicity limits, therefore, the fines fraction need not be disposed of at a RCRA C landfill. The RCRA toxicity characteristic evaluation only looks at metals. Radiological receiving limits depend on the disposal facility license. The fines concentrate resulting from treatment of the OCRM high concentration waste contained up to 1,200 pCi/g Ra-226, while the fines concentrate from treating Quivira high concentration waste contained up to 547 pCi/g Ra-226. CTS 2 fines concentrate contained only 27 pCi/g Ra-226. Based on the Ra-226 concentrations in fines fraction from medium and high concentration feed samples at OCRM and Quivira CR-1, these fines fraction materials may require disposal at a LLRW facility such as Waste Control Specialists in Andrews, Texas. Alternatively, when a uranium processing facility returns to operation in compliance with the USEPA Off-Site Rule, then these fines fraction materials may be processed for uranium content.

To assess the need for a soil cover over the coarse fraction, if unable to attain site-specific cleanup goals, SPLP metals and Ra-226 results were compared to the lower of the USEPA MCLs or the most conservative Navajo Nation surface water quality criteria (Exhibit 14, Exhibit 15, and Exhibit 16). The 30-minute HPSA treatment time produced the greatest reduction in leachability of the uranium and Ra-226. Leachable Ra-226 exceeded the USEPA MCL in post-treatment coarse fraction samples at OCRM for only the high-concentration feed material after 30 minutes of treatment but did not exceed the MCL after 30 minutes of treatment for any of the coarse fraction samples from Quivira CR-1 and CTS 2. Leachable uranium did not exceed the USEPA MCL in post-treatment coarse fraction samples after 30 minutes of treatment at any site. HPSA treatment reduced the leachable uranium and Ra-226 concentrations by up to 96.2 percent and 93.3 percent, respectively. Because the leachable Ra-226 concentration from high-concentration feed materials at OCRM was well above the median and average feed Ra-226 concentrations at the site, Ra-226 in a bulk sample is not expected pose a threat to groundwater or surface water quality at OCRM. Therefore, a cover would not be required to control leachability of remaining metals and Ra-226 in the coarse fraction if it were to remain on site.

Water used during HPSA treatment with contaminant concentrations above surface discharge levels will be treated by a method Disa has explored for water treatment (zeolite activated media) (see Section 2.7.2.2, Secondary Objective 2). While the adsorbent material has not been tested by TCLP to assess RCRA metals toxicity, the adsorbent or sludge is anticipated to be disposed of at a RCRA C or LLRW facility or recycled at a recovery facility (when available) along with HPSA treatment fines because of radionuclides concentrating in the material.

Upon conclusion of this treatability study, all solid samples of solids processed by Disa and sent to Pace and Eagle Engineering for analysis will be returned to Disa and then to their respective sites. Requests for unused samples to be returned to Disa are shown on all chains of custody in Appendix B-2B. Based on the analytical results of the fractionation water used in wet sieving at the Disa process laboratory, the water is below the concentration limits for all pollutants per the Casper, Wyoming, municipal code and NRC regulations on radionuclides. As such, the water will be discharged into the Disa process laboratory sanitary sewer.

Exhibit 14. Reduction in SPLP Extract Concentrations of Uranium and Radium-226 for Old Church Rock Mine Coarse Fraction Samples Compared to Feed Material

Parameter	Low Concentration		Medium Concentration		High Concentration	
	Uranium (mg/L)	Radium-226 (pCi/L)	Uranium (mg/L)	Radium-226 (pCi/L)	Uranium (mg/L)	Radium-226 (pCi/L)
Feed Material Leachability	< 0.0241	3	**0.23**	**25.4**	**0.22**	**83.6**
4-Minute HPSA Leachability	< 0.0241	1.5	< 0.0241	**5.9**	**0.06**	**12.7**
4-Minute Percent Reduction	--	50.0%	89.5%	76.8%	72.7%	84.8%
8-Minute HPSA Leachability	< 0.0241	1.4	< 0.0241	**5.3**	**0.032**	**10.65**
8-Minute Percent Reduction	--	53.3%	89.5%	79.1%	85.7%	87.3%
30-Minute HPSA Leachability	< 0.0241	0.8	< 0.0241	3.7	< 0.0241	**5.6**
30-Minute Percent Reduction	--	73.3%	89.5%	85.4%	89.0%	93.3%
Water Quality Standard	0.03	5	0.03	5	0.03	5

Notes:
A “<” symbol indicates a nondetect result less than the corresponding method detection limit.
A “--“ symbol indicates that a value could not be calculated for nondetect results.
Green shading denotes average concentrations.
Yellow shading denotes the water quality standards to which the leachability data are being compared.
Bolded values indicate an exceedance.

HPSA	High-pressure slurry ablation
mg/L	Milligram per liter
pCi/L	Picocurie per liter
SPLP	Synthetic precipitation leaching procedure

Exhibit 15. Reduction in SPLP Extract Concentrations of Uranium and Radium-226 for Quivira Church Rock 1 Coarse Fraction Samples Compared to Feed Material

Parameter	Low Concentration		Medium Concentration		High Concentration	
	Uranium (mg/L)	Radium-226 (pCi/L)	Uranium (mg/L)	Radium-226 (pCi/L)	Uranium (mg/L)	Radium-226 (pCi/L)
Feed Material Leachability	**0.26**	**10.6**	**0.63**	**30.9**	**0.38**	**42.9**
4-Minute HPSA Leachability	< 0.0241	2.8	0.029	**5.9**	< 0.0241	**7.8**
4-Minute Percent Reduction	90.7%	73.6%	95.4%	80.9%	93.7%	81.8%
8-minute HPSA Leachability	< 0.0241	3.3	< 0.0241	4.7	< 0.0241	**5.8**
8-Minute Percent Reduction	90.7%	68.9%	96.2%	84.8%	93.7%	86.5%
30-Minute HPSA Leachability	< 0.0241	1.4	< 0.0241	2.4	< 0.0241	4.3
30-minute Percent Reduction	90.7%	86.8%	96.2%	92.2%	93.7%	90.0%
Water Quality Standard	0.03	5	0.03	5	0.03	5

Notes:
A "<" symbol indicates a nondetect result less than the corresponding method detection limit.
Green shading denotes average concentrations.
Yellow shading denotes the water quality standards to which the leachability data are being compared.
Bolded values indicate an exceedance.

HPSA	High-pressure slurry ablation
mg/L	Milligram per liter
pCi/L	Picocurie per liter
SPLP	Synthetic precipitation leaching procedure

Exhibit 16. Reduction in SPLP Extract Concentrations of Uranium and Radium-226 for Cove Transfer Station 2 Coarse Fraction Samples Compared to Feed Material

Parameter	Low Concentration		Medium Concentration		High Concentration	
	Uranium (mg/L)	Radium-226 (pCi/L)	Uranium (mg/L)	Radium-226 (pCi/L)	Uranium (mg/L)	Radium-226 (pCi/L)
Feed Material Leachability	< 0.0241	4.3	< 0.0241	2.5	< 0.0241	2.3
4-Minute HPSA Leachability	< 0.0241	0.7	< 0.0241	1.3	< 0.0241	2.1
4-minute Percent Reduction	--	83.7%	--	48.0%	--	8.7%
8-Minute HPSA Leachability	< 0.0241	0.6	< 0.0241	1.3	< 0.0241	1.2
8-Minute Percent Reduction	--	86.0%	--	48.0%	--	47.8%
30-Minute HPSA Leachability	< 0.0241	0.6	< 0.0241	0.6	< 0.0241	0.6
30-Minute Percent Reduction	--	86.0%	--	76.0%	--	73.9%
Water Quality Standard	0.03	5	0.03	5	0.03	5

Notes:
A “<” symbol indicates a nondetect result less than the corresponding method detection limit.
A “--“ symbol indicates that a value could not be calculated for nondetect results.
Green shading denotes average concentrations.
Yellow shading denotes the water quality standards to which the leachability data are being compared.
Bolded values indicate an exceedance.

HPSA	High-pressure slurry ablation
mg/L	Milligram per liter
pCi/L	Picocurie per liter
SPLP	Synthetic precipitation leaching procedure

3.0 TECHNOLOGY APPLICATIONS ANALYSIS

This section describes the general applicability of the HPSA technology to reduce the concentration of radionuclides and metals in waste rock at AUM sites. The analysis is based on the results from and observations made during the HPSA treatability study.

3.1 KEY FEATURES

HPSA technology uses a mechanical process (that is, without chemicals) to remove radionuclides and metals from mine waste at AUM sites. The technology liberates and separates mineralized deposits from host rock whereby repeated collisions of processed solids is used to selectively fracture or liberate certain minerals in the deposit while others remain intact. HPSA treatment achieves this liberation by processing solid feed material in slurry or suspension form and using high-pressure pumps to pump material through opposing nozzles contained in collision housing to create impinging high-pressure slurry jet streams. Further description of the technology is provided in Section 1.3 with design and operations in Section 2.0.

HPSA technology is designed to treat mine waste resulting in two solid media outputs:

- A large volume of coarse fraction material containing sand liberated of mineralized coating (coarse fraction now cleaned containing up to 98 percent lower radionuclide concentrations)
- A smaller volume of concentrated fines fraction containing the liberated radionuclides and metals (representing less than 20 to 25 percent of the original untreated mass)

Depending on the radionuclide and metals concentrations, characteristics of the waste undergoing treatment, and future site exposure scenarios, the coarse fraction material may be clean enough to be managed on site as backfill or under a soil cover, which is a risk management decision. The concentrated fines fraction would typically be recycled at a recovery facility (when available) or disposed of in a RCRA C or LLRW disposal facility licensed to accept radioactive materials. Process water is recycled throughout treatment with only the final amount of recycled water requiring treatment before use on site or for disposal.

3.2 APPLICABLE WASTES

HPSA technology is particularly effective for coarse to fine grain sands encountered in waste rock from Navajo AUM sites where uranium minerals typically occur as surface coatings on the sand grains. Overall, the HPSA technology is particularly amenable for liberation of mineral coatings from the surface of sand grains and is less effective at liberation of minerals within the crystalline structure of sand grains.

The size range for best HPSA treatment results is from P100 of 6.35 millimeters to P80 of greater than 100 microns. While HPSA technology typically treats these size ranges effectively, treating a heavily bimodal PSD with fines comprising a large percentage of mass can result in the collisions of the coarser particles being hindered by the presence of the fines. Long treatment times are required to liberate minerals from finer grain silts and clays because of the additional increase in particle count and collisions required, resulting in an increase in materials handling and offsite disposal costs. As the HPSA process is strictly mechanical and relies on size separation for coarse and fine fraction generation, the concentrated fines fraction to be disposed of is heavily influenced by the original fines fraction in the feed sample.

As detailed in Section 1.3 mineral hardness can be a good indicator of the amenability of the waste rock to HPSA treatment. HPSA treatment is particularly effective when the base mineral hardness is greater than the hardness of the targeted mineral. In the case of AUM sites, the base mineral is typically quartz (Mohs hardness of 7) and the target uranium mineral carnotite (Mohs hardness of 2). Even if the base mineral were orthoclase or albite (both Mohs hardness of 6), the difference in hardness between the base mineral and the target mineral would still be enough to results in efficient treatment. Base and target mineral hardness would have to be verified prior to treatment at other sites.

3.3 FACTORS AFFECTING PERFORMANCE

Several factors were observed to influence the performance of the HPSA treatment system demonstrated at the three Navajo AUM sites. These factors can be grouped into three categories: (1) waste material characteristics, (2) operating parameters, and (3) system design. The HPSA treatment system is capable of treating a broad range of metals and radionuclides primarily associated with surface mineral coatings on a sand matrix.

The main waste material characteristics that influence HPSA performance are:

- Excessive quantities of fine material (passing 270 mesh) requiring a pre-cut step to remove fines before HPSA treatment to reduce contact time
- PSD
- Physical position of the mineral to be ablated where surface coatings are readily treated and interstitial minerals require fracturing
- Mineral and matrix hardness
- Quantity of oversize material requiring screening and crushing to attain a passing ¼-inch particle size

HPSA operating parameters that influence HPSA performance are:

- Collision variables such as nozzle outlet size, nozzle spacing, number of collision nozzles, and solids percent by mass of the slurry can be adjusted to optimize the concentration of solids in the collision region. Increasing concentration of solids in the collision region will increase the fracture of particles but will likely contribute to a higher fines fraction requiring offsite disposal.
- Particle size classification within the HPSA system can be used to selectively focus treatment on the coarser particle sizes to achieve cleanup goals.
- Jet velocity (not adjusted for the purposes of this study) would additionally increase particle fracture to help achieve low cleanup goals.

- Treatment of recycle water to reduce carryover of soluble metals and radionuclides in the HPSA system and would reduce metals and radionuclides concentrations in the treated coarse fraction.

System design parameters that could improve HPSA performance are:

- Application of heat tape and heat trace to wet screen spray bars, unmixed tanks, and low velocity water lines where cold weather conditions persist for several months.
- Design of dust suppression controls for dry screening and crushing and enclosures to protect against operational delays at sites with heavy snow and extreme cold.
- Design of HPSA systems with multiple collision chambers per collision pump to help avoid any down time associated with clogged nozzles or collision chamber/nozzle service required for worn components.

3.4 TECHNOLOGY LIMITATIONS

The primary limitations of HPSA technology are the difficulty of mineral liberation from inside the crystalline matrix rather than from surficial coatings on the crystalline matrix, the longer treatment time required to economically liberate minerals from feed material with silt or clay matrix, and minerals with a higher Mohs hardness with respect to the crystalline matrix. For this study, qualitative AMICS (MLA and XRD) was sufficient to identify carnotite coatings on the sample matrix. In the future, quantitative AMICS (including MLA and XRD) should be considered as a part of bench-scale testing as an additional line of evidence to support assessing the suitability of the technology for a site. AMICS pricing under this study was $350 per sample.

All other limitations are operational issues related to available space to handle material stockpiles and operate a treatment system, winter weather conditions, available water for processing waste, handling and disposal of treated coarse and fine materials, and licensing and permitting of the HPSA technology when treating AUM waste rock. A discussion of each issue follows:

- The HPSA technology is scalable at 5-, 50-, and 100-TPH treatment units, and all components are skid mounted to allow flexibility in equipment delivery to and set up at a site. For the 5-TPH system and ancillary stockpile management, approximately 0.25 acre is required for operations; 50- and 100-TPH systems would require 3 and 4 acres, respectively.
- Freezing weather conditions are a concern any time water is introduced into a unit operation. Because of the vigorous mixing of the waste slurry, particle collisions, and clarifier stirring, most freezing concerns are associated with water used in pre-cut and ablated fines screening processes and water treatment and recycling. Heat tape or trace is typically used to address these concerns; however, if necessary, screening and water treatment steps can be conducted within an enclosure.
- Water consumption is a concern on the Navajo Nation and requires import of water from nearby cities or pumping of deep groundwater. The HPSA technology requires slurrying of material for primary and secondary screening and HPSA processing. Approximately

13 GPM of water is required for a 50-TPH system and 25 GPM for a 100-TPH system. The treated coarse fraction is rinsed with treated water prior to dewatering. An estimated 10 to 15 percent of water is lost to the coarse and fines fraction after filter pressing. Fortunately, the percent lost to the coarse fraction would have been needed for placement and compaction at the site. The percent lost to the fines fraction would marginally increase the tonnage of waste being disposed of offsite. Monthly water consumption is approximately 200,000 gallons per month and 384,000 gallons per month for the 50- and 100-TPH systems, respectively. This equates to roughly 40 and 76 water trucks monthly (2 and 4 trucks daily) for the systems, respectively.

- Licensing and permitting of the HPSA technology to treat AUM waste rock may be considered milling under current NRC regulations. Disa is working with NRC to relax the milling interpretation for uranium waste remediation technologies and is discussed further in Section 3.8.
- Handling and disposal of fines from AUM waste rock requires consideration of the loss of the Bevill exemption because of the waste rock processing and generation of a fines fraction. Offsite disposal of waste is, therefore, subject to RCRA or NRC requirements. Waste would be disposed of at a RCRA C facility in a state with a radiological license or an LLRW facility or recycled at a recovery facility (when available); disposal is discussed further in Section 3.7.

3.5 RANGE OF SUITABLE SITE CHARACTERISTICS

This subsection describes the site characteristics necessary for successful application of the HPSA technology.

3.5.1 Staging Area and Support Facilities

For 5-TPH HPSA treatment systems such as those used at small remote sites with limited space, minimal staging areas and support facilities are necessary for continuous operation of the treatment system. Space is required for the daily working waste rock, coarse fraction, and fines fraction stockpiles; daily makeup water storage tank; and a small staging area for storage of daily consumable materials and supplies; portable toilets and handwash and eyewash stations; and power-generating equipment.

An offsite staging area can be used for a field trailer, a Connex to be used for spare parts and equipment that are not weather resistant, fuel for generators, bulk makeup water storage, portable toilets and handwash and eyewash stations, and power-generating equipment. The onsite staging and storage area for a 5-TPH HPSA treatment system would require less than 0.25 acre and be located adjacent to the treatment system while the offsite staging and storage area would be approximately 0.25 acre.

For a 50-TPH or 100-TPH HPSA treatment system, all staging areas and support facilities would be located on site with the skid-mounted treatment system. The stockpile staging area would scale with the increase in daily HPSA system throughput. The additional staging and support area would be approximately 0.5 acre.

3.5.2 Treatment System Space Requirements

To conduct 5-TPH HPSA treatment, the skid-mounted grizzly and screen for oversize and pre-cut material, HPSA treatment tank and collision unit, screen for post-processed fines, clarifier, and filter press would require approximately 2,500 square feet. A 50-TPH HPSA system would use the same equipment; however, the number of unit operation skids would increase to meet the additional treatment rate and require approximately 6,000 square feet. Similarly, the number of unit operation skids for a 100-TPH HPSA system would increase based on increased treatment rate and require approximately 12,000 square feet. Additional space for waste rock, coarse, and fines fraction daily stockpiles and support facilities are discussed in Section 3.5.1.

3.5.3 Climate

Operation of the HPSA treatment system could be affected by freezing temperatures. In areas where freezing temperatures are normal throughout the winter months, such as on the Navajo Nation, freezing of unit operations using water is of concern. HPSA treatment tanks and clarifier tanks are well mixed and are not a freezing concern. However, wet screening operations may be impacted by freezing nozzles and process water treatment processes and water transfer lines may be impacted if water is not kept moving. These concerns can be addressed by insulation, heat tape, and unit operation enclosure.

The remoteness of AUM sites on the Navajo Nation can also create logistical challenges in maintaining operation of the HPSA treatment system. At lower elevations, winter storms would only temporarily limit access and operations. However, if operations are considered at higher elevations, a winter snow pack from November through May can limit site access and a good access road and snow clearing would be required.

Consumable materials, water filtration media, daily makeup water, and diesel fuel (to power a generator) must be transported to and stored in bulk at the site or lower elevation staging area during the summer and fall. Spare equipment susceptible to freezing damage must be staged at or nearby the site. Waste rock must be stockpiled nearby, and coarse and fine materials must be removed daily where space is limited. Planning is essential to maintain supplies of consumable materials and replacement equipment at remote high elevation sites.

3.5.4 Utilities

The main utility requirement for the HPSA treatment system is electricity, which is used to operate screens, mixers, pressure pumps, water recirculation pumps, solids transfer pumps, the filter press, and site work and support facility lighting. The HPSA treatment system requires approximately 10 to 15 kilowatt hour (kwh) per ton of electricity for continuous operation for a 5-TPH system, 5 to 8 kwh per ton for a 50-TPH system, and 3 to 5 kwh per ton for a 100-TPH system. Power would be provided by a 500-kilowatt diesel generator for the 50-TPH system and two 500-kilowatt generators for the 100-TPH system. Diesel fuel for the generator would be stored in a working day tank and bulk storage 1,000-gallon above ground tank. Satellite phone service may also be required because of the remoteness of many of the AUM sites.

3.6 PERSONNEL REQUIREMENTS

For the 50- and 100-TPH HPSA treatment systems, Disa estimates that four to five local laborers and one onsite project engineer will be needed for the entire onsite operation. Laborers will be responsible for handling waste from a daily working waste stockpile, operating the HPSA treatment system, handling and separating coarse and fine materials into separate daily stockpiles, and checking that the HPSA process is running as intended. During each 8-hour shift, the operators will be responsible for taking grab and field screen samples of feed, concentrated fine material, and treated coarse material. In addition, at least once per shift, an onsite project engineer will send treated material to a third-party laboratory for analytical confirmation.

Economies of scale and shift work have a significant impact on project economics. Typical shifts are 8 hours per day and 5 days per week. If the site location and local community member input allow for two 8-hour shifts or even 24 hours per day/7 days per week (24/7) work, the treatment cost per ton can be reduced. If the HPSA system can be run for multiple shifts, the time spent starting up and shutting down the system can be avoided and the fixed operating costs can be spread over a larger volume of material treated.

Personnel would also be required with support from the construction contractor to deliver water and waste rock for processing and to remove the coarse and fines fractions from the HPSA treatment system on a daily basis. The construction contractor would also be required to place coarse material on site and transport and dispose of fine materials off site. These long-term material handling activities are outside the scope of the HPSA treatment process.

3.7 MATERIALS HANDLING REQUIREMENTS

The HPSA treatment process produces two process residuals: a coarse fraction and a fines fraction. At Quivira CR-1 and OCRM, the HPSA treatment coarse fraction ranged from 74.5 to 79.7 percent of initial waste mass and the fines fraction ranged from 20.3 to 25.5 percent of initial waste mass. At CTS 2, the coarse fraction was much lower (46 to 53 percent) because of the large amount of clay in the soils, yielding a fines fraction of 47 to 54 percent of the initial mass. During full-scale operations, unrecycled process water would be generated after all HPSA treatment is completed, process and clarifier tanks are emptied and rinsed, and pumps and lines are rinsed. The water would require treatment before discharge on site.

The fines fraction produced by the HPSA treatment system was evaluated for the RCRA toxicity characteristic by TCLP extraction and analysis of RCRA 8 metals list while the coarse fraction was evaluated for chemical leachability to surface water and groundwater by SPLP and analysis of metals and radionuclides. To assess if the fines fraction was a RCRA hazardous waste by toxicity characteristic, TCLP leachate results were compared to TCLP limits (Table 12, Table 13, and Table 14). The fines fraction samples were found to not be RCRA hazardous waste and would not need to be disposed of at a RCRA C landfill. To assess the need for a cover over the coarse fraction, SPLP metals and Ra-226 results were compared to the lower of the USEPA MCLs or most conservative Navajo Nation surface water quality criteria (Exhibit 14, Exhibit 15, and Exhibit 16). Leachable Ra-226 exceeded the USEPA MCL in post-treatment coarse fraction samples at OCRM for the high-concentration feed material after 30 minutes of treatment but did not exceed the USEPA MCL after 30 minutes of treatment for any of the feed material from

Quivira CR-1 and CTS 2. No leachable metals exceeded water quality criteria. Because the leachable Ra-226 concentration from high-concentration feed materials at OCRM was well above the median and average Ra-226 concentrations at OCRM, Ra-226 would not pose a threat to groundwater or surface water quality at OCRM.

3.8 PERMITTING AND LICENSING

Actions taken on site during a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) cleanup action must comply only with the substantive portion of a given regulation. Onsite activities need not comply with administrative requirements such as obtaining a permit, record keeping, or reporting. Actions taken off site must comply with both the substantive and administrative requirements of applicable laws and regulations. All actions taken at the three Navajo AUMs were on site; therefore, permits were not obtained. Permits that may be required for offsite actions or actions at non-CERCLA sites include a permit to operate a hazardous waste treatment system, a National Pollutant Discharge and Elimination System (NPDES) permit for effluent discharge, an NPDES permit for discharge of storm water during construction and HPSA treatment activities, and an operations permit from a local air quality management district (AQMD) for activities generating particulate emissions. Permits from state and tribal agencies may also be required for grading, construction, and operational activities; transport of oversized equipment on local roads; and transport of hazardous materials on local roads.

Radioactive materials were handled during the treatability study, the following subsections identify quantities of material handled and the status of commercial radioactive material handling and licensing currently required for HPSA system operation.

3.8.1 Treatability Study Radioactive Material Handling

No permits or licenses were required for conducting this treatability study. NRC regulates the possession, use, and transfer of radioactive material, including uranium-containing mine waste. The activities and quantities proposed under this treatability study met the requirements for general license under 10 *Code of Federal Regulations* (CFR) 40.22, “Small Quantities of Source Material.”

With different masses collected for this treatability study at each site at different uranium concentrations, the total possession of uranium at each site was as follows:

- **OCRM:** At the low-, medium-, and high-concentration sample points, bulk samples were collected in masses of 96.2, 112.6, and 120.0 pounds, respectively, for a total of 328.8 pounds treated. At varying uranium concentrations of 40, 260, and 940 mg/kg, the total uranium possession for onsite operations at OCRM was less than 0.15 pound.
- **Quivira CR-1:** At the low-, medium-, and high-concentration sample points, bulk samples were collected in masses of 115.0, 108.0, and 133.4 pounds, respectively, for a total of 356.4 pounds treated. At varying uranium concentrations of 110, 230, and 400 mg/kg, the total uranium possession for onsite operations at Quivira CR-1 was less than 0.10 pound.

- **CTS 2:** At the low-, medium-, and high-concentration sample points, bulk samples were collected in masses of 164.8, 149.0, and 156.8 pounds, respectively, for a total of 470.6 pounds collected (only two thirds of the mass was treated using the HPSA batch test unit in the field). At varying uranium concentrations of 4.52, 40, and 50 mg/kg, the total uranium possession for onsite operations at CTS 2 was less than 0.015 pound.

Based on these data, the allowable possession of source material was not exceeded at any one time for the duration of the treatability study. This quantity is well below the general license limit of 3.3 pounds of uranium (dispersible form) at any one time and 15.4 pounds of uranium in any one calendar year (10 CFR 40.22(a)(1)).

3.8.2 Commercial Material Handling and Licensing

For HPSA commercial operations, USEPA has jurisdiction over CERCLA sites. As the AUM sites on the Navajo Nation fall under CERCLA authority, USEPA is responsible for the actions that occur at these sites. While USEPA works with NRC to verify that substantive requirements are met for each site, no NRC license is required for a CERCLA action on site.

On August 1, 2022, Disa submitted a license application for its HPSA technology to NRC. Disa is currently working with NRC to secure a performance-based, multisite radioactive materials license for HPSA commercial operations. Disa contends that its proposed activities are not uranium milling, and, thus, Disa's application did not seek a license under 10 CFR Part 40, Appendix A, which pertains to uranium milling. In its application, Disa (2022) sought a multisite license to use its HPSA technology to treat uranium mine waste rock piles that are scattered across the Western United States.

The source material license sought by Disa would allow Disa to mobilize its temporary HPSA equipment to an AUM site, treat the waste rock or other contaminated materials, transport isolated source material off site for disposal, produce a coarse fraction of material for reuse at the site, and demobilize the equipment for use at other sites.

3.9 COMMUNITY ACCEPTANCE

Community acceptance for the HPSA treatment system operated at the three AUM sites on the Navajo Nation is very positive. The local communities were provided fact sheets about the HPSA treatability study and invited to a demonstration day at CTS 2 in Cove, Arizona. A video recorded during the demonstration is available here: https://www.youtube.com/watch?v=KHnJNSN0wAo. Continued community involvement and regulatory agency support will be necessary for evaluating and implementing treatment technologies on the Navajo Nation.

Feedback from the Navajo community regarding HPSA treatment of waste rock is generally viewed as a good alternative to disposing of waste on or off site as no other treatment options are currently being evaluated in EE/CAs on the Navajo Nation. The community has expressed interest to date in the removal of the metals and radionuclides from material to remain on site. HPSA treatment can meet cleanup goals for unrestricted use where initial metals and radionuclide concentrations are relatively low; however, it may not meet cleanup goals for unrestricted use at sites with higher initial metals and radionuclide concentrations. Therefore, if the coarse fraction with concentrations above cleanup goals remains on site, it may need to be covered to reduce direct exposure.

Operation of the HPSA treatment system presents minimal risk to the public since all system components and treatment operations occur within a contained site. Hauling of the fines fraction off site for disposal would pose a risk to the community because of the number of trucks passing through the community during and following treatment. However, compared to hauling 100 percent of the waste rock offsite for disposal, this option would require up to 83 percent fewer number of trucks passing through the community. Hazardous chemicals used to support the HPSA treatment system include diesel fuel for generator power, unless grid power is available, and construction equipment. U.S. and Navajo Department of Transportation regulations will be followed during fuel delivery to minimize potential impacts to the public. During HPSA treatment system operation, the equipment used to move stockpiled material to and from the treatment system and the diesel generator used to power the treatment system would create the most noise and air emissions at the site. Dust emissions would be controlled through water controls and enclosures as necessary.

3.10 AVAILABILITY, ADAPTABILITY, AND TRANSPORTABILITY OF EQUIPMENT

The components of the HPSA treatment system are generally available, but the design of the collision chamber and nozzles is proprietary. Disa can offer turnkey HPSA systems, licensing, and operational training to vendors or could operate the HPSA technology. Systems can be constructed within a 1-month period provided major components are available from standard suppliers. System process components include (1) grizzly, crusher, pre-cut screen, HPSA tanks and collision chambers, post-treatment screen, clarifiers, and filter presses, (2) pumps and transfer lines, and (3) ion exchange for recycle water treatment. The HPSA treatment system components are skid mounted for ease of mobilization and to minimize the onsite footprint. Front-end loaders for moving feed material from daily working stockpiles to the HPSA treatment system and coarse and fine materials from the HPSA treatment system will also be required.

System components are available from numerous suppliers throughout the country, but the design and operational knowledge relies on Disa for implementation. The system is also scalable and currently designed for 5-, 50-, and 100-TPH HPSA treatment systems.

Transport of the HPSA treatment system skids and loader to a site may require handling as oversize or wide loads depending on U.S. and Navajo Department of Transportation limits. Additional consideration should be given to the stability of mine access roads, bridge clearances, and load limits for large shipments. The maximum skid length is 25 feet; therefore, truck and trailer kingpin limits would not be a concern for most access roads. Process consumables, such as generator and earthmoving equipment fuel, are considered hazardous materials and will require stable site access roads for delivery. For difficult access sites, a separate staging area can be set up for bulk storage and material can be transferred to the site for daily use.

3.11 ABILITY TO ATTAIN APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

Under CERCLA, remedial actions conducted at Superfund sites must comply with federal and state (if more stringent) environmental laws that are determined to be applicable or relevant and appropriate. Applicable or relevant and appropriate requirements (ARAR) are determined on a site-specific basis. If the law is not applicable, the determination must be made whether the law is relevant and appropriate. Actions taken on site during a CERCLA cleanup action must comply only with the substantive portion of a given ARAR. Onsite activities need not comply with administrative requirements, such as obtaining a permit, record keeping, or reporting. Actions conducted off site must comply with both the substantive and administrative requirements of applicable laws and regulations. Onsite remedial actions, such as HPSA treatment of AUM waste rock on the Navajo Nation, must comply with federal and more stringent Navajo Nation ARARs.

The following subsections discuss and analyze specific environmental regulations pertinent to the operation of the HPSA treatment system, including handling, transport, and disposal of both hazardous and nonhazardous treatment residuals. A complete evaluation of ARARs would be required on a site-specific basis in an EE/CA or FS report.

3.11.1 Comprehensive Environmental Response, Compensation, and Liability Act

CERCLA of 1980 authorizes the federal government to respond to releases or potential releases of any hazardous substance into the environment, as well as to releases of pollutants or contaminants, that may present an imminent or significant danger to public health and welfare or to the environment. The 1986 Superfund Amendments and Reauthorization Act amendment to CERCLA directed USEPA to:

- Use remedial alternatives that permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances, pollutants, or contaminants
- Select remedial actions that protect human health and the environment, are cost effective, and involve permanent solutions and alternative treatment or resource recovery technologies to the maximum extent possible
- Avoid offsite transport and disposal of untreated hazardous substances or contaminated materials when practicable treatment technologies exist (Section 121[b])

In general, two types of responses are possible under CERCLA: removal and remedial actions. Removal actions are quick actions conducted in response to an immediate threat caused by the release of a hazardous substance. Remedial actions involve the permanent reduction of the toxicity, mobility, and volume of hazardous substances or pollutants. The HPSA treatment technology evaluated at the three Navajo AUM sites fall under the purview of CERCLA; the HPSA treatment system is operated on site and concentrates metals and radionuclides in a smaller volume of fines material through ablating uranium minerals from waste rock material. A large volume of coarse fraction remains after HPSA treatment with reduced toxicity and leachability (mobility). The HPSA technology is protective of human health and the environment, cost effective, and permanent.

3.11.2 Resource Conservation and Recovery Act

Subtitle C of RCRA contains requirements for the generation, transport, treatment, storage, and disposal of hazardous waste, most of which are applicable to CERCLA actions. However, mining wastes are generally not subject to regulation under RCRA (see the Bevill Amendment at Section 3001(a)(3)(A)(ii)) unless the waste is disposed of offsite. For HPSA treatment residuals determined to be RCRA hazardous, substantive and administrative RCRA requirements must be addressed if the wastes are shipped off site for disposal. If treatment residuals remain on site, the substantive requirements of state and tribal disposal and siting laws may be relevant and appropriate. Criteria for identifying RCRA characteristic and listed hazardous wastes are included in 40 CFR Part 261, Subparts C and D. Other applicable RCRA requirements include hazardous waste manifesting for offsite disposal and time limits on accumulating wastes. Radioactive material licensing for the offsite disposal facility would also be required to receive concentrated uranium and radionuclide wastes.

Coarse fraction residuals generated from the HPSA treatment system have been determined to be nonhazardous wastes and do not leach metals or radionuclides above the lower of the USEPA MCLs or minimum Navajo Nation water quality criteria. Nonhazardous waste residuals are either stored or disposed of on site. Additional considerations, such as an evapotranspiration (ET) cap to address potential leachability of residual materials and exposure to residual concentrations of metals or radionuclides, should be evaluated based on site-specific cleanup goals and receiving water criteria.

3.11.3 Clean Air Act

The Clean Air Act establishes national primary and secondary ambient air quality standards for sulfur oxides, particulate matter, carbon monoxide, ozone, nitrogen dioxide, and lead. It also limits the emission of 189 listed hazardous pollutants. States are responsible for enforcing the Clean Air Act. To assist in this, air quality control regions were established. Allowable emission limits are determined by the air quality control region and AQMD subunits. The emission limits are established based on attainment of national ambient air quality standards.

The Clean Air Act requires that treatment facilities comply with primary and secondary ambient air quality standards. Emissions resulting from solids handling during the construction and operation of the HPSA treatment system may need to meet air quality standards. For example, emissions from generators and dust generated during earthwork and residual solids handling may be regulated by a local AQMD. No air permits are required for the HPSA treatment system operated at Navajo AUM sites; however, dust emissions would be limited by maintaining soil moisture during construction and system operation.

3.11.4 Clean Water Act

The objective of the Clean Water Act is to restore and maintain the chemical, physical, and biological integrity of the nation’s waters by establishing federal, state, and tribal discharge standards. If treated water is discharged to surface water bodies or publicly owned treatment works, Clean Water Act regulations will apply. A facility discharging water to a navigable waterway must apply for an NPDES discharge permit, which is designed as an enforcement tool with the ultimate goal of achieving ambient water quality standards. Discharges to publicly owned treatment works also must comply with general pretreatment regulations outlined in 40 CFR Part 403, as well as other applicable state and local administrative and substantive requirements.

An NPDES discharge permit is not required under CERCLA although the substantive requirements of the Clean Water Act are met. Safe Drinking Water Act discharge standards are discussed in Section 3.11.5.

3.11.5 Safe Drinking Water Act

The Safe Drinking Water Act of 1974 and the Safe Drinking Water Amendments of 1986 require USEPA to establish regulations to protect human health from contaminants in drinking water. The law authorizes national drinking water standards and a joint federal-state system for ensuring compliance with these standards. The National Primary Drinking Water Standards are found at 40 CFR Parts 141 through 149. These standards are expressed as MCLs and MCL goals. Under CERCLA (Section 121(d)(2)(A)(ii)), remedial actions are required to meet MCLs and MCL goals when relevant and appropriate. State and tribal drinking water requirements may also be more stringent than federal standards.

Effluent from the HPSA treatment system would typically occur after all waste treatment is completed and tanks, clarifiers, transfer lines, and pumps are rinsed and drained. Before discharge, effluent would be treated to remove metals and radionuclides to below the more restrictive of the USEPA MCLs or the minimum Navajo Nation surface water standards.

3.11.6 Occupational Safety and Health Act

CERCLA remedial actions and RCRA corrective actions must be conducted in accordance with Occupational Safety and Health Administration (OSHA) requirements detailed in 29 CFR Parts 1900 through 1926, and especially in Part 1910.120, which provides for the health and safety of workers at hazardous waste sites. Onsite construction at Superfund or RCRA corrective action sites must be conducted in accordance with 29 CFR Part 1926, which describes safety and health regulations for construction sites. State OSHA requirements, which may be significantly stricter than federal standards, also must be met. Workers involved with the construction and operation of the HPSA treatment system are required to have completed an OSHA training course and be familiar with OSHA requirements relevant to hazardous waste sites. Workers on hazardous waste sites must also be enrolled in a medical monitoring program.

Minimum personal protective equipment for workers at NAUM sites include gloves, a hard hat, steel-toe boots, Tyvek coveralls, and respirators where dust controls are not protective. Noise levels are generally not high except during earthwork activities, which involve the operation of heavy equipment. During these earthmoving and HPSA treatment system operations, noise levels must be monitored to ensure that workers are not exposed to noise levels above a time-weighted average of 85 decibels over an 8-hour day. If noise levels exceed this limit, workers are required to wear hearing protection.

3.11.7 State and Tribal Requirements

State and Navajo Nation regulatory agencies may require permits before operation of a HPSA treatment system. Most permits will be issued by an authorized state or tribal agency. An air permit from the local AQMD may be required if air emissions in excess of regulatory standards are anticipated. State and tribal agencies will have direct regulatory responsibility for all environmental concerns. If a removal or remedial action occurs at a Superfund site, federal agencies, primarily USEPA, will provide regulatory oversight. If offsite disposal of waste is required, the waste must be taken to the disposal facility by a licensed transporter.

3.12 TECHNOLOGY APPLICABILITY TO OTHER SITES

HPSA treatment of waste rock at the three NAUM sites was evaluated for applicability to other NAUM sites based on the nine criteria used for decision making in the Superfund feasibility study process. The nine criteria and the results of the evaluation are summarized in Table 15.

4.0 ECONOMIC ANALYSIS

This section presents an economic analysis of HPSA technology for full-scale treatment of waste rock on AUM sites across the Navajo Nation.

4.1 INTRODUCTION

The information, calculations, and assumptions for the economic analysis of HPSA technology for treatment on AUM sites on the Navajo Nation was derived from (1) historical observations and a pilot testing run on AUM material from privately-owned sites, (2) data collected from the field portion of this treatability study at the three selected sites on the Navajo Nation, and (3) market research of both historical and current pricing for equipment rentals available in the fourth quarter of 2022.

HPSA treatment operations are broken down into the following 13 cost elements and are assumed to be applicable to similar AUM sites on the Navajo Nation.

1. Site preparation
2. Permitting and regulatory requirements
3. Mobilization to site
4. Installation and setup
5. Equipment rentals
6. Fuel Consumption
7. Labor
8. Water
9. Water treatment
10. Analytical services
11. Maintenance
12. Indirect costs
13. Demobilization

For purposes of this economic analysis, 50- and 100-TPH commercial units were considered. Because of the significant economic impact of multishift operations, a two-shift (two 8-hour shifts with crews operating for a total of 16 hours per day) and a 24/7 scenario are assumed for both the 50- and 100-TPH scales.

As discussed in Sections 2.3.2 and 4.2.1, the treatment times of 4, 8, and 30 minutes sampled for the purpose of this study were used to indicate the amenability of material to the HPSA process over time. Based on the results from this treatability study, Disa has used the lessons learned and data to scale up the HPSA technology to operate at the parameters required for 50 and 100 TPH throughputs. Disa plans to use the optimal operating parameters from each site, typically 30 minutes of processing, to achieve the lowest levels of chemical concentrations in the treated coarse fraction. The results from the various time samples from this treatability study will not significantly alter the assumptions of the economic model. Instead, they will influence the design for the 50 and 100 TPH units.

4.2 FULL-SCALE DESIGN, MOBILIZATION, AND OPERATIONS

The continuous 5-TPH HPSA unit under development (Figure 19) and future full-scale 50- and 100-TPH HPSA unit designs (Figure 32 and Figure 33) rely on the same concept of high pressure and high velocity to ablate or clean the uranium minerals from the surface of the sand grains. The main basis of design for larger units is the probability of particle collisions for all material contained in the control volume. While this probability of collisions in the test unit is gauged through treatment time, recirculation flow rate, and total volume of slurry in the system, the collision probability for continuous units is designed based on a ratio of the recirculation through collision chambers inside the HPSA control volume relative to the input of slurry feed and product draw off.

Continuous and commercial-scale HPSA units exhibit profound economies of scale when compared to the HPSA batch test unit. Although continuous amperage data and power consumption data can be recorded for the test unit, this power consumption per ton of material should drop significantly with scale. The test unit uses two individual pumps to feed a single collision chamber, limiting throughput and efficiency. In future scale-up efforts, continuous throughput units will be designed with multiple chambers per collision pump, allowing for higher recirculation to draw off rates without requiring increased velocity, pressure, and, by extension, power consumption because of the high pressures needed for higher flow through a constricted orifice.

4.2.1 Full-Scale Design and Mobilization Requirements

The full-scale system incorporates the same process used to validate the HPSA batch test unit during this treatability study. The steps in the full-scale process flow are described below. Referenced tank and equipment numbers can be found on Figure 32.

Initial Screening and Crushing. The first step for the process involves collecting the feed material with a front-end loader and running it through a screen or crusher. The cut point in the screens are generally ¼ inch. Any material over ¼ inch is considered “oversize” and flows to the crusher. After crushing to 100 percent passing ¼ inch screen, the material is recombined and ready to be fed to the HPSA system.

Slurry and Pre-Cutting. After initial screening and crushing, material proceeds up a conveyor and is mixed with water in a tank (TK-01) to create slurry. The targeted slurry density for full-scale treatment is expected to be 35 to 45 percent solids by mass. Once the slurry is created, the material is pumped to the first wet vibratory screen (SC-01), where the fines are pre-cut. The targeted cut point is expected to be 270 mesh but can vary based on mineral characteristics and PSD. The fines are then sent to the dewatering clarifier (CL-01). The purpose of pre-cutting the material at the front of the process is to increase throughput and capacity of the system as a small portion of the overall mass is already considered “fine.”

HPSA Treatment. Oversize material from the previous screen is then pumped to the HPSA unit. The HPSA chambers (HPSA-01, HPSA-02, and HPSA-03) treat the material until the targeted liberation is achieved. Through the intense particle-to-particle collisions, the material has the opportunity and probability to reside in the tanks until the liberation target has been achieved through optimizing the recirculation rate to material draw off ratio. This design allows the operator to leave material in the HPSA recirculation tanks (process control volume) longer if needed or move material through faster. This is dependent on the unique mineral characteristics and PSD at each site.

Secondary Screening. Post-HPSA treatment, the material is pumped to the secondary and final screen (SC-02). Because of the intense particle-to-particle-collisions in the previous step, the liberated uranium is now much finer than the coarse sand particles. The material is screened, and the generated fines are sent to the same dewatering clarifier (CL-01) as the initial pre-cut fines. This combination of pre-cut and post-processed fines make up the concentrated fine fraction waste.

Dewatering. Dewatering is an important part of the design as it is paramount to recover and recycle as much water as possible. By recycling water, less makeup water is required. For dewatering, filter presses are the primary option, but dewatering centrifuges are also an option (depending on cleanup goals and required throughput). The concentrated fines fraction are settled in the clarifier (CL-01) and then pumped to the "product" dewatering filter (FT-02). Once dewatered, this water is treated and recycled back into the HPSA process and the filter cake is ready to be transported off site. The coarse fraction from the final screen (SC-02) is dewatered in the "reject" dewatering filter (FT-01). Again, this water is treated and sent back into the process for reuse.

Water Treatment. As described in Section 2.7.2.2 (Secondary Objective 2), Disa plans to use a water treatment unit for full-scale systems that is engineered into the process flow as a slip stream from the process water tank, treating the water used for the spray bars on the first (SC-01) and secondary (SC-02) wet vibratory screens to ensure that any accumulation of uranium or Ra-226 mass in the process water does not reach levels that may impact the coarse fraction in residual moisture content. While concentrations of uranium and Ra-226 in the process water are dependent on material characteristics, treatment at larger scales will yield further insight into the accumulation of contaminants in the water throughout the process, as well as the proper frequency of water treatment. If concentrations of uranium and Ra-226 are not enough to significantly impact the coarse fraction, water treatment may be performed on the system charge volume of the water that remains at the conclusion of shifts or at the end of operations at a treatment site.

Mobilization Requirements. Disa engineered its commercial skids to be mobile and easily deployable to sites across the Navajo Nation. Smaller, more remote sites will be addressed using small skids that can easily traverse narrow roads or difficult terrain. For medium to large sites, skids are still mobile but will be brought in on larger trucks. See Figure 33 for a screenshot of the current computer-aided design model for a commercial-scaled HPSA unit with associated equipment. Individual skids will be connected by piping and hoses on site to form the entire process flow as explained above. Depending on site work area and access, volume, and cleanup goals, building a much larger regional treatment systems is also an option. This could be assessed based on transportation distances and material characteristics that may make treating several sites together at one local HPSA processing site more economic and efficient.

4.2.2 Full-Scale Operations

As described in Section 4.2.1, Disa’s commercial skids are mobile and easily deployable. Before the skids arrive on site, another contractor will be responsible for setting up the basic infrastructure, such as roads, and preparing the site. A flat, compact area will be identified and prepared for the arrival of the HPSA system. The estimated total footprint or operating area to place the HPSA system and all associated equipment is roughly 300 by 600 feet for both the 50- and 100-TPH systems. This working area does not include the feed stockpile for treatment and should be as close as possible to the waste rock source. Front-end loaders will be used to unload the skids from the trucks and place them in their respective locations for treatment.

Once the skids are placed, pumps and piping will be connected and the initial water can be charged in the system, making the system ready for shakedown. This consists of running the unit with just water to check that all processes and equipment are operating as intended. Once deemed ready, the system can receive waste rock for treatment.

The full-scale design presented in Section 4.2.1 describes the operation of HPSA technology. The equipment needed for treatment include:

- Vibrating grizzly feeder to break apart large chunks of dirt and screen out boulders before initial screening and crushing
- Screening system to screen material to less than ¼ inch and send larger material to the crusher
- Crusher to crush material and rocks over ¼ inch diameter to less than ¼ inch diameter for recombination with material already pass a ¼ inch screen
- Conveyors to feed the HPSA system and strategically move material to specific locations on the site
- Loaders to both feed the HPSA system and move the treated coarse and fine materials after dewatering
- HPSA skids to support the HPSA system that include tanks, agitators, pumps, and wet vibratory screens
- Filter presses (or alternately, centrifuges) to dewater the treated coarse and fine materials and recover as much water as possible to be recycled as process water
- Diesel generator to power the operation
- Air compressor to run certain pumps and filter presses in the process

Disa estimates that four to five laborers will be needed for the entire onsite operation. Laborers will be responsible for operating the equipment listed above and checking that the HPSA process is running as intended. During each 8-hour shift, the team operating will be responsible for taking grab samples of feed, concentrated fine materials, and treated coarse material to run analysis and check quality assurance (QA) and QC procedures on site. Disa recommends using an Olympus Vanta Reflex V3 XRF analyzer or similar to check that targeted levels of reduction are met. In addition, at least once per shift, an onsite project engineer will send treated material to a third-party laboratory for analytical confirmation.

Economies of scale and shift work have a significant impact on project economics. Typical shifts are 8 hours per day and 5 days per week. If the site location and local community member input allow for two 8-hour shifts or even 24/7 work, the treatment cost per ton can be reduced. If the HPSA system can be run for multiple shifts, the time spent starting up and shutting down the system can be avoided and the fixed operating costs can be spread over a larger volume of material treated.

4.3 COST SUMMARY

The initial fixed project costs for the HPSA treatment technology are $137,500 for the 50-TPH system and $212,500 for the 100-TPH system. Fixed costs consist of site preparation, permitting, mobilization, and installation and setup of HPSA skids. Site preparation assumes that basic infrastructure such as roads, a level and compact working surface, and stockpiles for HPSA treatment are in place before the HPSA skids arrive. For Disa's portion of site preparation, this includes placing the skids; fencing the working area; installing all electrical, lines, hoses, and equipment; and running a shakedown to check that the system is operating as intended. Permitting and licensing would be on an as-needed basis and is further discussed in Section 3.8. Mobilization consists of trucks bringing the skids in on trailers and placing the skids on the sites.

Variable costs to operate the HPSA system range from $31 to $51 per ton treated. The variable costs consist of consumables and rentals, labor, water purchase and delivery, water treatment, analytical services, maintenance, and indirect costs.

The total costs for the HPSA treatment of 10,000, 100,000, and 1 million tons using 50- and 100-TPH units are summarized in Exhibit 17, Exhibit 18, and Exhibit 19. Bringing multiple units to a site and operating them in parallel significantly reduces the time required to treat waste rock and incurs the same additional cost for each additional unit. Variable costs per ton would remain the same with multiple units. An example of this concept can be seen in Exhibit 20 for one or more 100-TPH units operating 24/7 at a 1,000,000-ton site.

Exhibit 17. Summary of Total Costs and Variable Costs for Each Size HPSA System to Treat 10,000 Tons

Description	50-TPH Treatment Capacity		100-TPH Treatment Capacity	
Operations Time Frame	2 shifts for 20 days per month	24 hours per day, 7 days a week	2 shifts for 20 days per month	24 hours per day, 7 days a week
Treatment Duration for One Unit	1 Month	Less than 1 Month	Less than 1 Month	Less than 1 Month
Total Fixed Project Costs	$137,500	$137,500	$212,500	$212,500
Total Variable Costs	$510,500	$382,700	$430,200	$314,800
Variable Costs per 10,000 Tons Treated	$51.05	$38.27	$43.02	$31.48
Total Project Costs	**$648,000**	**$520,200**	**$642,700**	**$527,300**

Notes:

HPSA	High-pressure slurry ablation
TPH	Ton per hour

Exhibit 18. Summary of Total Costs and Variable Costs for Each Size HPSA System to Treat 100,000 Tons

Description	50-TPH Treatment Capacity		100-TPH Treatment Capacity	
Operations Time Frame	2 shifts for 20 days per month	24 hours per day, 7 days a week	2 shifts for 20 days per month	24 hours per day, 7 days a week
Treatment Duration for One Unit	9 Months	4 Months	5 Months	2 Months
Total Fixed Project Costs	$137,500	$137,500	$212,500	$212,500
Total Variable Costs	$5,105,000	$3,827,000	$4,302,000	$3,148,000
Variable Costs per 100,000 Tons Treated	$51.05	$38.27	$43.02	$31.48
Total Project Costs	**$5,242,500**	**$3,964,500**	**$4,514,500**	**$3,360,500**

Notes:

HPSA	High-pressure slurry ablation
TPH	Ton per hour

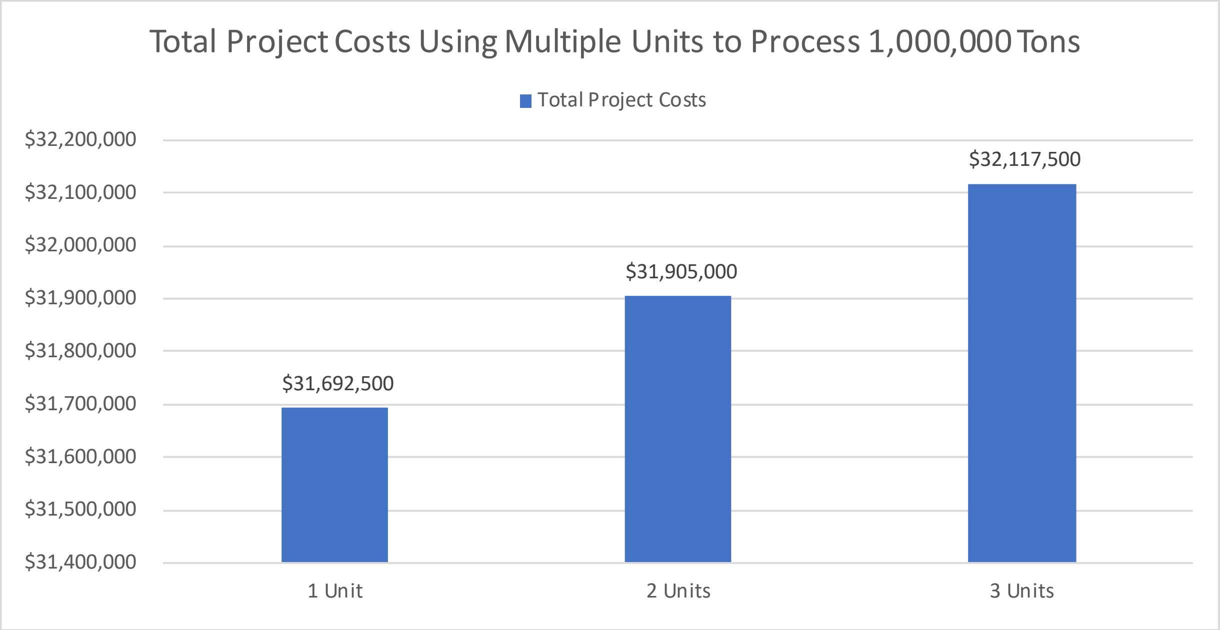
Exhibit 19. Summary of Total Costs and Variable Costs for Each Size HPSA System to Treat 1 Million Tons

Description	50-TPH Treatment Capacity		100-TPH Treatment Capacity	
Operations Time Frame	2 shifts for 20 days per month	24 hours per day, 7 days a week	2 shifts for 20 days per month	24 hours per day, 7 days a week
Treatment Duration for One Unit (month)	87 Months	39 Months	44 Months	20 Months
Total Fixed Project Costs	$137,500	$137,500	$212,500	$212,500
Total Variable Costs	$51,050,000	$38,270,000	$43,020,000	$31,480,000
Variable Costs per 1,000,000 Tons Treated	$51.05	$38.27	$43.02	$31.48
Total Project Costs	**$51,187,500**	**$38,407,500**	**$43,322,500**	**$31,692,500**

Notes:

HPSA	High-pressure slurry ablation
TPH	Ton per hour

Exhibit 20. Summary of Total Costs Using Multiple HPSA Systems to Treat 1 Million Tons



	1 Unit	2 Units	3 Units
Fixed Project Costs	$212,500	$425,000	$637,500
Variable Costs Per Ton	$31.48	$31.48	$31.48
Total Project Cost	$31,692,500	$31,905,000	$32,117,500
Months to Process	**20**	**10**	**7**

4.4 FACTORS AFFECTING COST ELEMENTS

Several factors affect the cost of treating AUM material with HPSA technology. The most significant factors include the scale of the HPSA unit, number of shifts operated per day, and number of working days per month. For purposes of this economic analysis, 50- and 100-TPH units are considered and analyzed. As unit size increases, the variable cost per ton decreases. The trade off with systems of 100 TPH and larger is decreased mobility to remote sites. A future consideration includes building larger, regional treatment facilities or linking multiple 50- and 100-TPH units together.

The number of shifts worked per day and working days per month significantly impact the variable cost per ton. Equipment rentals are one of the highest variable costs and because this cost is fixed monthly, the more hours worked per day and per month, the lower the variable cost will be per ton. Two scenarios are considered in this analysis for the 50- and 100-TPH systems. The first scenario assumes operating 20 working days per month with two 8-hour shifts, and the second scenario assumes operating 24/7 for 365 days per year.

4.5 ASSUMPTIONS

The following assumptions were used in the development of this economic analysis:

- Another contractor will prepare roads, infrastructure, and the pad where the units will be placed. Furthermore, the contractor will have a minimum of 2,500 tons material stockpiled nearby ready to be treated.
- Post-HPSA treatment, another contractor will handle the treated coarse and fine materials.
- Feed material from the site has 10 percent moisture content.
- Makeup water is 13 GPM for the 50-TPH system and 25 GPM for the 100-TPH system.
- The 50- and 100-TPH systems throughputs are engineered around the predetermined batch test unit treatment time necessary to achieve the desired level of contaminant reduction.
- Shift length is 8 hours per day not including travel to and from the sites. If the system is operating 24/7, shifts are still 8 hours long with crews on rotation.
- Working days are 20 days per month and 365 days per year for the 24/7 scenario.
- HPSA treatment use is 80 percent with 20 percent downtime per shift for startup, shutdown, and other unforeseen issues that arise while operating.
- All equipment other than HPSA skids is rented from local sources to reduce mobilization costs.
- Electricity is provided on site by generator. One 500-kilowatt generator will be used for the 50-TPH system, and two 500-kilowatt generators will be used for the 100-TPH system. Equipment on site will be self-powered or powered by generator.

- Water is purchased locally at $10 per 1,000 gallons, and 5,000 gallons is provided in each delivery at roughly $200 per delivery.
- Diesel is purchased locally at $6 per gallon, and 2,500 gallons is provided in each delivery at roughly $200 per delivery.
- Laborers are hired locally and paid at or above the prevailing wage for the region. Four laborers are needed for the 50-TPH system, and five laborers are needed for the 100-TPH system. One project engineer is always on site.
- Lodging and meals are paid per Government Services Administration rates for the area.
- Water treatment is $500 per day for the 50-TPH system and $1,000 per day for the 100-TPH system.
- Maintenance and parts costs are included based on past operational experience.
- Spot checks of pretreatment material, fines fraction, and post-treatment filter cake is completed with a handheld XRF instrument. Nine grab samples are taken per shift.
- Grab samples of post-treatment filter cake are sent to a third-party verified laboratory for analysis of metals and Ra-226. One sample is taken per shift.
- Once a site is remediated, the HPSA system is disassembled and demobilized. Another contractor will clean up the pad and area used for operations.

4.6 COST ELEMENTS

In the following subsections, each of the 13 cost elements identified in Section 4.1 are defined and the associated costs for each scale of unit are presented. The first four cost elements discussed comprise the total fixed project costs that are estimated in Exhibit 17, Exhibit 18, and Exhibit 19.

4.6.1 Site Preparation

Site preparation for each treatment system addresses system design, health and safety plan compliance, construction management for prepping the site for deployment, and up-front project management. This is a fixed project cost. Once the site is prepped for Disa by another contractor, Disa mobilizes the appropriate treatment units and associated equipment for set up and connections. Site preparation for the 50- and 100-TPH systems total $20,000 and $25,000, respectively.

4.6.2 Permitting and Regulatory Requirements

Permitting and regulatory costs may vary on whether treatment occurs at a CERCLA-lead site or a local authority-lead site. This is a fixed project cost. Permitting and regulatory requirements is estimated at $10,000 per site, which includes a regulatory consultant checking that all applicable laws and regulations are properly followed.

4.6.3 Mobilization to Site

HPSA skids are mobilized on large semi-trailers and brought to the sites. The units are modular and, once placed, connected for treatment. Associated equipment rentals are sourced and rented locally to reduce mobilization costs. This cost element is the highest for the fixed project costs for each site. Mobilization for the 50- and 100-TPH systems totals $40,000 and $60,000, respectively. Mobilization to the site is expected to take 1 week.

4.6.4 Installation and Setup

Installation and setup include the labor to physically place the skids and associated equipment; run all electrical lines, hoses, and connections; fence the area for security; and check initial system startup and shakedown so that the system is optimized to meet the site-specific cleanup goals. Installation and setup occur at the beginning of each project to check that the system is optimized as outlined in the planning phase and no problems exist. This is the last cost element for the fixed project costs. For the 50- and 100-TPH systems, this cost totals $27,500 and $57,500, respectively. This portion of the project is expected to take 1 to 2 weeks but may require more depending on the work area, access, or site features.

4.6.5 Equipment Rentals

Equipment for each system are assumed to be rented locally and mobilized to the site. All equipment is self-powered or runs off a diesel generator located on site. Equipment fuel consumption is estimated based on equipment sizes and included in the cost estimate. Equipment rentals are a monthly cost, so the more tons treated per month, the lower the variable cost per ton. The variable costs are highly sensitive to both the scale and number of shifts for treatment. Exhibit 21 lists all equipment rentals for the HPSA treatment process and the cost per month for the 50- and 100-TPH systems based on historical quotes for equipment in the area.

Exhibit 21. Summary of the Equipment Rentals for the HPSA Treatment Process

Equipment	50 TPH (per month)	100 TPH (per month)
Vibrating Grizzly Feeder	$3,000	$5,000
Pre-Screen with Conveyor	$3,000	$5,000
Crusher	$20,000	$40,000
Discharge Conveyor	$2,500	$5,000
Feed Loader	$7,500	$12,500
Product Loader	$7,500	$12,500
HPSA Skids with Tanks, Agitators, Pumps, Wet Vibratory Screens, Sensors, and Electrical	$125,000	$215,000
Concentrated Fines Fraction Dewatering	$25,000	$50,000
Coarse Fraction Dewatering	$25,000	$50,000
Generator	$15,000	$30,000
Air Compressor	$7,500	$10,000

Notes:

HPSA	High-pressure slurry ablation
TPH	Ton per hour

4.6.6 Fuel Consumption

All equipment on site will be self-powered or powered by generator. Four major items will consume fuel: the loaders, generator, air compressor, and crusher. Fuel consumption is estimated at 55 gallons per hour and 90 gallons per hour for the 50- and 100-TPH systems, respectively. Fuel will be delivered to the site and stored in contained fuel tanks to fuel the equipment daily. Fuel costs are estimated at $330 per hour and $540 per hour for the 50- and 100-TPH systems, respectively.

4.6.7 Labor

Labor costs for each HPSA system include the field personnel necessary to operate the system and address day-to-day maintenance issues. Labor associated with mobilization, installation, and setup are included in Sections 4.6.3 and 4.6.4. Labor is a variable cost. For the 50- and 100-TPH systems, four laborers and five laborers are required, respectively. One full-time project engineer is also required on site.

Laborers are hired local to the Navajo Nation. These field personnel operate the loaders and associated equipment, ensure optimal operations of the HPSA system, and handle all day-to-day tasks and issues. Field personnel are estimated at $40 per hour, which includes hourly wage, payroll taxes, and fringe benefits.

The project engineer on site oversees the operation and is responsible for engineering oversight, unit optimization, analytical grab sampling, administrative support, and checking that equipment is safely operated. The project engineer is estimated at $100 per hour, which includes hourly wage, payroll taxes, and fringe benefits.

4.6.8 Water

Water is not expected to be readily available at sites on the Navajo Nation and will be delivered by tanker truck. Water is a variable cost. Water is purchased locally at $10 per 1,000 gallons, and 5,000 gallons is provided in each delivery at roughly $200 per delivery

Water is continually recycled through the HPSA system, but some makeup water is needed as water is lost because of evaporation and moisture in the treated coarse and fine materials. The treated coarse fraction is rinsed with treated water prior to dewatering. Dewatering technologies, such as filter presses, are used to remove as much water as possible, but 10 to 15 percent of moisture is lost in the filter cakes. Makeup water is calculated at 13 GPM for the 50-TPH system and 25 GPM for the 100-TPH system. If units are operating in the two-shift scenario, makeup water totals 200,000 gallons per month and 384,000 gallons per month for the 50- and 100-TPH systems, respectively, and equates to roughly 40 and 76 water trucks monthly (2 and 4 trucks daily) for the systems, respectively.

4.6.9 Water Treatment

Water treatment is engineered into the process as a slip stream from the process water tank so that any accumulation of uranium or Ra-226 in the process water does not reach levels that may impact the coarse fraction through moisture content. Water treatment is a variable cost. Water treatment has been repeatedly tested and is projected to have a minimal impact on project economics. Water treatment is estimated at $500 per day and $1,000 per day for the 50- and 100-TPH systems, respectively.

4.6.10 Analytical Services

During each shift, the onsite project engineer is responsible for taking grab samples of feed, fines fraction, and treated coarse material to run analysis and check QA/QC procedures on site. Analytical services are a variable cost. Disa recommends an Olympus Vanta Reflex V3 or similar XRF analyzer to check pretreatment, coarse and fines fraction filter cake material concentrations and that targeted levels of reduction are met. In addition, at least once per shift, the onsite project engineer is responsible for collecting a grab sample of post-treatment filter cake and sending samples to a third-party laboratory for analytical confirmation of metals and Ra-226 concentrations. This totals nine XRF grab samples and one grab confirmation sample per shift sent to a laboratory. XRF grab samples are calculated at $25 per sample, and the composite sample for metals and Ra-226 is calculated at $150 per sample.

4.6.11 Maintenance

Maintenance costs include regular equipment replacement because of wear and tear. Maintenance of equipment is a variable cost. Equipment is expected to require replacement items and serviceable parts as outlined in operating manuals. Vendors for equipment rentals are expected to service and maintain their equipment in the field. For the HPSA skids, the main items requiring maintenance and replacement include internal components of the high-pressure pumps, discharge hoses, and nozzles. Based on historical industry observations, maintenance costs are estimated at $2 to $3 per ton for the 50- and 100-TPH systems, respectively.

4.6.12 Indirect Costs

Indirect costs are variable and include all unforeseen items in the above cost elements, general overhead and personnel not related to fieldwork, and the cost of advancing and improving HPSA technology and treatment systems. Indirect costs are roughly $5 per ton for both the 50- and 100-TPH systems.

4.6.13 Demobilization

Demobilization includes labor to clean, disassemble, and prepare components at the end of project. Demobilization includes checking that all equipment and items on site are decontaminated before leaving. This is a fixed project cost including transportation from the site. Similar to mobilization, the units will be transported with semi-trailers. Rental equipment will be transported back to the renting agency that is local to the project. Demobilization for the 50- and 100-TPH systems totals $40,000 and $60,000, respectively. Demobilization from the site is expected to take 1 to 2 weeks.

4.7 CASE STUDY OF APPLICATION OF HIGH-PRESSURE SLURRY ABLATION TECHNOLOGY AT A NAVAJO ABANDONED URANIUM MINE SITE

To evaluate how HPSA technology fits into the overall cleanup at a site, two scenarios were envisioned depending on whether the coarse material remaining on site is consolidated in one location and capped or used as unrestricted backfill. Exhibit 22, Exhibit 23, and Exhibit 24identify all costs for cleanup at a Navajo AUM site, including applying HPSA technology. Exhibit 22 assumes that the coarse material not meeting site-specific cleanup goals will be placed under an ET cap on site and the concentrated fines fraction will be disposed of at the Clean Harbors RCRA C facility in Deer Trail, Colorado. Depending on radiological receiving limits, the concentrated fines fraction may require disposal at Waste Control Specialists in Andrews, Texas. The haul distances are similar; however, the disposal costs are approximately 40 percent higher than at the Clean Harbors RCRA C facility. Exhibit 23 assumes that the coarse material will meet site-specific cleanup goals and be used for unrestricted backfill on site and the concentrated fines fraction will be disposed of at the Clean Harbors RCRA C facility while Exhibit 24 assumes that the concentrate fraction will be recycled at a regional uranium mill (when available).

For cost estimation purposes, 23.3 percent of the overall mass is assumed to comprise the concentrated fines fraction that would be taken to Clean Harbors RCRA C facility or a regional uranium mill. Also, for the HPSA treatment cost per ton, two 100-TPH units are assumed to be deployed and operated using two shifts for 20 working days per month, resulting in a 2-year treatment duration. The overall project duration ranges from 48 to 52 months with waste excavation and handling, HPSA treatment, concentrated fines fraction offsite disposal, and onsite backfill or ET cap construction taken into account. Exhibit 26 shows the comparison of the HPSA case studies to other alternatives being considered for Navajo AUM sites.

Exhibit 22. HPSA Case Study at a Navajo AUM Site with Treated Material Placed under an ET Cap on Site and Fines Disposed of at the Clean Harbors RCRA C Facility

Cost Component	Cost Rollup
Estimated Excavated Surface Area (Acres)	58
Estimated Excavated Volume (Bank Cubic Yards)	993,700
Direct Capital Costs	
Field Overhead and Oversight	$8,212,000
General Site Work	$104,000
Earthwork including ET Cap on Top of Treated Material	$22,380,000
HPSA Treatment (2 x 100-TPH Units)	$67,462,900
Onsite Hauling and Consolidation of Treated Coarse Fraction (972,500 LCY)	$15,974,600
Offsite Transportation and Disposal of Fines Material (250,000 LCY) at the Clean Harbors RCRA C Facility in Deer Trail, Colorado	$71,250,000
Subtotal Direct Capital Costs	**$185,384,000**
Indirect Capital Costs	$18,259,000
Total Capital Costs including 15% Contingency	**$234,189,000**
Maintenance Costs	
Present Worth of 100 Years of Maintenance at a Discount Rate of 7%	$772,600
Contingency Allowance (25%)	$193,100
Total Present Worth Maintenance Cost	**$965,700**
Total Cost	**$235,154,700**

Notes:

Green shading denotes the portion of the case study impacted by HPSA and coarse and fine material disposal.

ET	Evapotranspiration
HPSA	High-pressure slurry ablation
LCY	Loose cubic yard
RCRA	Resource Conservation and Recovery Act
TPH	Ton per hour

Exhibit 23. HPSA Case Study at a Navajo AUM Site with Treated Material Used for Backfill on Site and Fines Disposed of at the Clean Harbors RCRA C Facility

Cost Component	Cost Rollup
Estimated Excavated Surface Area (Acres)	58
Estimated Excavated Volume (Bank Cubic Yards)	993,700
Direct Capital Costs	
Field Overhead and Oversight	$7,877,000
General Site Work	$104,000
Earthwork including Backfill of Treated Material	$16,826,000
HPSA Treatment (2 x 100-TPH Units)	$67,462,900
Onsite Hauling and Use of Coarse Fraction as Unrestricted Backfill (972,500 LCY)	$7,073,900
Offsite Transportation and Disposal of Fines Material (250,000 LCY) at the Clean Harbors RCRA C facility in Deer Trail, Colorado	$71,250,000
Subtotal Direct Capital Costs	**$170,594,000**
Indirect Capital Costs	$16,172,000
Total Capital Costs including 15% Contingency	**$214,781,000**
Maintenance Costs	
Present Worth of 30 Years of Maintenance at a Discount Rate of 7%	$671,900
Contingency Allowance (25%)	$168,000
Total Present Worth Maintenance Cost	**$839,900**
Total Cost	**$215,620,900**

Notes:

Green shading denotes the portion of the case study impacted by HPSA and coarse and fine material disposal.

AUM	Abandoned uranium mine
HPSA	High-pressure slurry ablation
LCY	Loose cubic yard
RCRA	Resource Conservation and Recovery Act
TPH	Ton per hour

Exhibit 24. HPSA Case Study at a Navajo AUM Site with Treated Material Used for Backfill on Site and Concentrates Disposed of at Regional Uranium Mill

Cost Component	Cost Rollup
Estimated Excavated Surface Area (Acres)	58
Estimated Excavated Volume (Bank Cubic Yards)	993,700
Direct Capital Costs	
Field Overhead and Oversight	$7,877,000
General Site Work	$104,000
Earthwork including Backfill of Treated Material	$16,826,000
HPSA Treatment (2 x 100-TPH Units)	$67,462,900
Onsite Hauling and Use of Coarse Fraction as Unrestricted Backfill (972,500 LCY)	$7,073,900
Offsite Transportation and Disposal of Concentrated Material (250,000 LCY) at the Regional Uranium Mill *	35,250,000
Subtotal Direct Capital Costs	**$134,594,000**
Indirect Capital Costs	$12,212,000
Total Capital Costs including 15% Contingency	**$168,827,000**
Maintenance Costs	
Present Worth of 30 Years of Maintenance at a Discount Rate of 7%	$671,900
Contingency Allowance (25%)	$168,000
Total Present Worth Maintenance Cost	**$839,900**
Total Cost	**$169,666,900**

Notes:

Green shading denotes the portion of the case study impacted by HPSA and coarse and fine material disposal.

*	Disposal costs at a regional uranium mill was quoted at $81 per cubic yard for waste rock; however, concentrates from HPSA treatment would yield an economically recoverable quantity of uranium and reduce milling and disposal costs. Therefore, mill disposal costs are conservative and actual fees quoted may be much lower.
AUM	Abandoned uranium mine
HPSA	High-pressure slurry ablation
LCY	Loose cubic yard
RCRA	Resource Conservation and Recovery Act
TPH	Ton per hour

Exhibit 25. HPSA Case Study Compared to Other Alternatives at a Navajo AUM Site

Alternative	Capital Cost	Onsite Maintenance Present Value 7% Discount Rate	Total Present Value Cost
No Action	$0	$0	$0
Consolidate and Cap All Waste on Site	$65.3 million	$0.97 million (100 years)	$66.3 million
HPSA Treatment, Coarse Fraction Used for Backfill on Site, and Offsite Disposal of Concentrates at a Regional Uranium Mill**	$168.8 million	$0.84 million (30 years)	$169.7 million
Disposal of All Mine Waste off Site at the Red Rock Disposal Facility*	$181.5 million	$0.73 million (30 years)	$182.2 million
HPSA Treatment, Coarse Fraction Used for Backfill on Site, and Offsite Disposal of Fines at the Clean Harbors RCRA C facility in Deer Trail, Colorado	$214.8 million	$0.84 million (30 years)	$215.6 million
HPSA Treatment, Cap Coarse Fraction on Site, and Offsite Disposal of Fines at the Clean Harbors RCRA C facility in Deer Trail, Colorado	$234.2 million	$0.96 million (100 years)	$235.2 million
Disposal of All Mine Waste off Site at the Clean Harbors RCRA C facility in Deer Trail, Colorado	$555.6 million	$0.50 million (30 years)	$556.1 million

Notes:

Green shading denotes the portion of the case study impacted by HPSA and coarse and fine material disposal.

*	The Red Rock disposal facility is under consideration to accept waste from Quivira mines and is meant to show a local disposal concept rather than at the regional Clean Harbors RCRA C facility in Deer Trail, Colorado. Hauling and disposal costs are estimated at $12.90 LCY and $82.50 LCY, respectively.
**	Disposal costs at a regional uranium mill was quoted at $81 per cubic yard for waste rock; however, concentrates from HPSA treatment would yield an economically recoverable quantity of uranium and reduce milling and disposal costs. Therefore, mill disposal costs are conservative and actual fees quoted may be much lower.
AUM	Abandoned uranium mine
HPSA	High-pressure slurry ablation
LCY	Loose cubic yard
RCRA	Resource Conservation and Recovery Act

5.0 DATA QUALITY REVIEW

This section summarizes deviations from the SAP/QAPP (Tetra Tech 2022) and evaluates data quality and precision, accuracy, representativeness, comparability, and completeness criteria to assess data usability.

5.1 DYNAMIC PLANNING CHANGES AND DEVIATIONS FROM THE SAMPLING AND ANALYSIS PLAN/QUALITY ASSURANCE PROJECT PLAN

This section presents the dynamic planning changes during field activities and the deviations from the SAP/QAPP during processing at Disa laboratory.

5.1.1 Dynamic Planning Changes During Field Activities

While the work plan provided a detailed outline of the activities to be performed at the sites, such plans must be adapted to field conditions once field work is under way. As such, reconnaissance conducted at each of the sites before field deployment identified modifications to HPSA treatment strategies subsequently approved by the USEPA TOCOR. Resulting modifications are listed below with explanations and references to relevant sections for details:

- Before deployment of the HPSA batch test unit for the field study, the USEPA TOCOR agreed that no equipment blank was needed for treating low-, medium-, and high-concentration bulk samples at the sites because any material remaining in the HPSA batch test unit after performance of the two rinses between tests was assumed a low concentration that would not affect the results of treating the subsequent high-concentration bulk sample. To further alleviate any concerns of cross-contamination between bulk sample treatment in the absence of an equipment blank, bulk samples were processed in the HPSA batch test unit in the order of low to high uranium concentration.
- The QV-M sample point identified during the reconnaissance survey was flooded by monsoon rains during the field portion of the treatability study. Additionally, initial samples collected from the QV-H sample point had low XRF uranium concentration measurements when first collected in the field. As a result, both QV-M and QV-H samples were collected from the same location with the QV-H sample collected at a greater depth as described in Section 2.5.2.
- For operations at OCRM and Quivira CR-1, a pre-cut step was added and approved by the USEPA TOCOR to remove the passing 270-mesh material before HPSA treatment to improve the uranium and Ra-226 removal efficiencies based on a particle size distribution analysis during the reconnaissance study. The passing 270-mesh material not treated in the HPSA batch test unit was collected and subsampled for combination with the HPSA slurry sample passing 270 mesh in proper mass-balanced proportions for analysis by Pace as described in Section 2.4.2.
- During the reconnaissance portion of the treatability study, Disa determined material greater than ¼ inch at CTS 2 contained ore chips with elevated concentrations of uranium relative to the rest of the mass. When deployed for the field study, instead of combining the crushed ¼-inch material with the material originally passing the ¼-inch mesh during

the initial material screening, the crushed ¼-inch material was subsampled for analysis to better understand the distribution of contamination at the site as described in Section 2.4.2. This deviation was discussed with and approved by the USEPA TOCOR before deployment. With the goal of concentrating as much uranium contamination into as little mass as possible for cleanup, screening material at ¼ inch and deeming +¼-inch material as waste before treatment of -¼-inch material with HPSA achieves this in an upfront step.

- After the conclusion of HPSA treatment of the OCRM bulk samples, excess material was discharged into a trough and allowed to settle before discharging onto the high-concentration sample point. No sample was collected from the settled water as originally planned. For testing at Quivira CR-1 and CTS 2, the USEPA TOCOR did not require soil settling as all the process water and soil would both end up on the high-concentration point. The process water and bulk treated samples were discharged onto the high-concentration point without settling as described in Section 2.5.6.

5.1.2 Deviations from the Sampling and Analysis Plan/Quality Assurance Project Plan

Deviations were made to the post-field study sample preparation steps for handling of the material at the Disa process laboratory after discussion with Tetra Tech and concurrence with the USEPA TOCOR. Figure 34 details the originally planned handling of the material with blue indicating samples and green indicating actions. In comparison, Figure 35, Figure 36, and Figure 37 and Appendices C-1, C-2, and C-3 detail the actual handling of the material with actions deviating from the SAP/QAPP (Tetra Tech 2022) denoted in orange and newly generated samples not originally included in the SAP/QAPP denoted in yellow for the CR-H sample. Deviations from planning fixed laboratory analyses are documented in Exhibit 8.

A bulleted list of the deviations relevant to sample processing at the Disa process laboratory, as well as the relevant sections in this report where the deviation is discussed, are identified below:

- To better understand the mass distribution of suspended fines between 5 microns and 0.45 microns, process water samples were separated from the soil using Disa process laboratory pressure filters. Mass retained on the 5-micron filter paper from process water separation and the corresponding water sample solids filtered on 0.45-micron filter paper were recombined with the remaining soil in the slurry sample to be included in the PSD as described in Section 2.6.1.
- For a total of 10 samples, total and dissolved fraction for both metals and Ra-226 were performed as opposed to the originally planned analysis of total sample only. These analyses were performed to evaluate the constituents present in the visibly turbid water (Figure 23, for example) and assess how to treat the water in a full-scale HPSA system.
- Instead of using a riffle splitter to prepare sample volumes for analyses of total metals, Ra-226, qualitative AMICS, and SPLP analysis of Ra-226 and uranium, samples were homogenized in bags and split sampled by spooning or pouring into their respective sample bags in the proper mass proportions. As described in Section 2.6.3, this method was used to avoid cross-contamination between sample size fractions to minimize sample loss for limited sample sizes for some fractions.

- While the SAP/QAPP called for Ra-226 analysis of all size fractions from wet sieving-generated samples, multiple size fractions were present with mass less than the 50-gram minimum required to perform the analysis. As a result, compositing of size fractions was required to obtain enough sample mass to perform the analysis as described in Section 2.6.3.

5.2 SUMMARY OF DATA EVALUATION AND PRECISION, ACCURACY, REPRESENTATIVENESS, COMPARABILITY, AND COMPLETENESS CRITERIA EVALUATION

This subsection summarizes QA/QC procedures, data management, data validation, data quality assessment, and data usability. QA and QC were priorities throughout all data acquisition and analysis tasks completed during this treatability study. QA/QC procedures were implemented to both minimize and evaluate potential sources of inaccuracy during sample collection and analysis. QA/QC procedures were designed to conform to the “National Functional Guidelines for Inorganic Superfund Methods Data Review” (USEPA 2017), as well as the *Multi-Agency Radiation Survey and Site Investigation Manual* (USEPA 2000) and *Multi-Agency Radiological Laboratory Analytical Protocols Manual* (USEPA 2004).

5.2.1 QUALITY ASSURANCE AND QUALITY CONTROL PROCEDURES

QA/QC procedures were implemented throughout data acquisition and analysis tasks completed during this treatability study. All project soil and water analytical and QA/QC results are in Appendix E, and the data validation reports are in Appendix F. Radiological laboratory analytical reports and electronic data deliverables (EDD) underwent complete third-party data validation by Validata Chemical Services, Inc. Inorganic laboratory analytical reports and EDDs underwent a cursory review by a Tetra Tech chemist at the direction of the USEPA TOCOR. Tetra Tech also conducted an inspection of material handling, wet sieving, and sampling procedures at the Disa process laboratory in Casper, Wyoming (Appendix D). All QA/QC results, both field and laboratory, met the performance criteria specified in the SAP/QAPP (Tetra Tech 2022).

5.2.2 DATA MANAGEMENT

All field samples and associated information (such as sample date, time, sample type, and analytical analysis) were loaded into the project Sampling and Laboratory Results Data Management Architecture (Scribe) database. The Scribe database, published under USEPA Region 9 to Scribe.net, provides a method for storing and sharing Scribe projects. During the project, the database was published when any additions or modifications to the data occurred.

In addition to field data, laboratory analytical results were loaded into the database in the project-specific EDD format. Validated data were entered into validation-specific fields so that original laboratory data remained intact. XRF field and process laboratory and field gamma scanning data, provided in Appendix C, were reviewed by field task leaders and Tetra Tech and Disa managers. XRF and gamma survey data were not loaded into the project database as the data were used for screening purposes and not to meet project objectives. Geospatial data, including gamma data, were downloaded from GPS and tablet instruments daily and evaluated for any errors using geographic information system (GIS) software. Geospatial data were input into the geodatabase for use in the GIS.

An extensive set of Scribe auditor rules was developed for data integrity and completeness in the Scribe project. This custom rule set checked for valid values, blanks and nulls, missing records, and other project-specific criteria. The set of Scribe auditor rules was run before publication to Scribe. Any auditor issues were addressed before publication or as soon as practicable.

5.2.3 DATA VALIDATION

All samples analyzed for inorganic chemicals and radiological analysis were sent to Pace in Sheridan, Wyoming. All radiological results were validated by third-party contractor Validata Chemical Services, Inc. in Duluth, Georgia, and all third-party data validation reports were reviewed by a Tetra Tech chemist. Data validation results are presented in 14 data validation reports that validate laboratory results from 14 paired metals and radiological laboratory reports. Metals data did not undergo a third-party review because of budget constraints. Radiological data validation reports are organized by SDG in Appendix F. Laboratory reports and EDDs are in Appendix E.

Ninety percent of all radiological samples were validated according to Stage 2B validation methodology, and 10 percent of all samples were validated according to Stage 4 validation methodology, which builds on the Stage 2B methodology. Descriptions of these validation methodologies are in the SAP/QAPP (Tetra Tech 2022).

5.2.4 DATA QUALITY ASSESSMENT

Precision, accuracy, representativeness, completeness, and comparability parameters were reviewed to validate all analytical data. A discussion of overall quality of the analytical data, including precision, accuracy, representativeness, completeness, and comparability parameters, as established by the data validation is provided below. A cursory review of metals data is included with the following discussion while a complete evaluation of radiological data quality is provided in data validation reports in Appendix F.

Precision. Precision is a measure of reproducibility of an experimental value without regard to the true or reference value. The primary indicators of site data precision are relative percent differences (RPD) between results from pairs of field and field duplicate samples and laboratory and laboratory duplicate samples. For this treatability study, one or more metals sample results in 6 of 14 SDGs were qualified for at least one precision-related QC issue. No radiological sample results were qualified because of precision issues. Within each SDG, only a subset of metals results was qualified. Most of the precision-related QC issues involved RPD exceedances in results for a minority of metals analytes (typically one but as many as four of the 24 metals analytes). RPDs outside the guidance for duplicate pairs were noted in the laboratory reports for inorganics. No metals or radiological data were rejected because of laboratory or field precision violations. The data underwent the documented data validation process, and, overall, precisions of results were found acceptable.

Accuracy. Accuracy assesses the proximity of an experimental value to the true or reference value. The primary accuracy indicators are matrix spike/matrix spike duplicate (MS/MSD) and laboratory control sample (LCS) spike percent recoveries, as well as ion chromatography results for metals analyses and tracer/chemical yield for radiological analyses. Among all metals and radiological data from this treatability study, one or more sample results from 13 of 14 SDGs were qualified as estimated. Within each SDG, only a subset of metals and radiological results was qualified. Most of these qualifications were MS/MSD exceedances that may have affected only the sample spiked for the MS/MSD. One radiological SDG was qualified because of duplicate precision issues. No metals or radiological data were rejected because of accuracy violations.

A subset of accuracy is bias, which assesses the direction (high or low) an experimental value may deviate from the true reference value. In addition to MS/MSD, LCS, and tracer/chemical yield percent recoveries, primary indicators of bias are method and preparation, field blanks, and sample density for radiological analyses. Among all analytical data from this treatability study, one or more sample results from 3 of 14 radiological SDGs were qualified as estimated because of blank contamination and affected only a subset of the samples within the affected SDGs. No data were rejected because of bias violations. The data underwent the documented data validation process, and, overall, accuracy of the results was found acceptable.

Representativeness. Representativeness refers to how closely sample data reflect true environmental conditions. Determinants of representativeness include sampling locations, frequency, collection procedures, and possible compromises to sample integrity (such as cross-contamination) that can occur during collection, transport, and analysis. Selection of representative samples is important to obtain samples that accurately reflect treatment conditions. Correct sample collection, transport, and analytical procedures are important so that samples closely resemble the medium sampled and to minimize cross-contamination.

Sampling locations, frequencies, and collection protocols for the treatability study were described in the SAP/QAPP (Tetra Tech 2022). These protocols followed standard accepted methods of sample characterization and were approved by USEPA. This treatability study followed the sampling program outlined in the SAP/QAPP except for the deviations discussed in Section 5.1. Thus, the sampling program for this treatability study met all relevant requirements for data representativeness with respect to accepted sampling approaches, existing guidance, and regulatory compliance.

Completeness. Completeness is defined as the percentage corresponding to the ratio of the number of valid results to the total number of results obtained. Valid data are those identified as acceptable or qualified as estimated during the data validation process. Data qualified as rejected are considered unusable and not valid. The assessment of completeness involved comparison of the number results acceptable and qualified as estimated to the total number of results.

As specified in the SAP/QAPP, the project completeness goal for the treatability study was 90 percent. No rejected results were identified during reviews by Validata Chemical Services, Inc. or the Tetra Tech chemist. Based on an evaluation of the data collected and analyzed and other documentation, completeness for the project was greater than 100 percent. Deviations from the SAP/QAPP because of unplanned changes in system operation or sampling preparation procedures did not impact the validity of the data. Instead, the unplanned changes provided an opportunity to evaluate different modes of system operation and to reduce sampling error and cross-contamination.

Comparability. Comparability is a qualitative assessment of how well one dataset compares with another. The important determinants of comparability include uniformity of sampling activities, analytical procedures, data reporting, and data validation. A high degree of analytical comparability results from appropriate applications of USEPA protocol, establishment and application of appropriate and well-documented analytical protocols and methods, use of approved laboratories, and implementation of the standardized process of data review and validation.

Holding Time. One objective of data validation was to assess the validity of the chemical dataset based on compliance with holding time requirements. Technical holding times are defined as the maximum time allowable between sample collection and, as applicable, sample extraction, preparation, and analysis. Samples from two laboratory reports (S2209244 and S2210480) (less than 2 percent of all paired SDGs) had holding time violations. Four samples were water samples for total suspended solids and total dissolved solids for 5-micron filtered water samples for OCRM low and medium sample concentrations. One sample was a fines fraction sample from a CTS 2 low sample concentration submitted for TCLP metals analysis. The data were qualified as estimate and not used to evaluate project primary objectives.

Conclusions. Although some qualifiers were added to the data, a final review of the dataset against the USEPA data quality parameters indicated that the data are of high overall quality. The data meet all precision, accuracy, representativeness, completeness, and comparability requirements specified in USEPA (2002) guidance for QAPPs and are useable for this technology evaluation. The overall assessment of the sampling program, QA/QC data, data review, and data validation results indicates that the data are of acceptable precision, accuracy, representativeness, completeness, and comparability. Supporting data validation reports are provided in Appendix F. Chain-of-custody forms were used to track possession of samples from field collection to the analytical laboratory. Completed chain-of-custody forms are in Appendix B-2B.

5.2.5 EVALUATION OF DISA QUALITY CONTROL PROCEDURES, ERRORS, AND POTENTIAL IMPACTS ON DATA USABILITY

Minimization of errors is built into Disa’s QC procedures, as outlined in Appendix B SOPs, to ensure quality of data resulting from sample preparation work performed. Performance of wet sieving, pressure filtration, and sample splitting preparation steps at Disa’s laboratory were tracked via the forms in Appendix B. Through application of SOPs, Disa identified sample preparation errors and has assessed how these errors may have influenced data usability.

5.2.5.1 Disa Technologies, Inc. Quality Control Procedures

A summary of Disa’s QC procedures to ensure quality data during sample preparation work, including wet sieving, pressure filtration, and sample splitting, is described below.

Wet Sieving. Wet sieving involves the use of sieves to separate material of certain particle size to establish fractionation by mass and gradation of constituents. The wet sieving process is described in Section 2.6.1. Since sieves were reused between samples, the sieves were cleaned according to Disa's RO-TAP material processing SOP (Appendix B-1C) using both a soap and water scrub and an ultrasonic sieve cleaner. To further minimize cross-contamination, slurry samples were wet sieved in order from low to high concentrations. Time zero feed samples were wet sieved after the timed slurry grab samples so that the coarser particle fractions in the feed material likely to possess higher contaminant concentrations would not cross-contaminate the timed coarser particle fractions if errors in the cleaning procedure were made. The sieves used for wet sieving underwent deep cleaning between sample sites by repeating with the standard cleaning procedure.

While Disa made efforts to retain as much wet sieved material as possible for analysis, a small portion of mass is always lost to the sieves during the cleaning process between wet sieve steps. Based on Disa's previous experience with wet sieving samples, material loss is less than 1 percent of the processed mass. However, because of the samples containing moisture content after solids-water separation, the percentage of material lost in the slurry samples could not be calculated; therefore, dry feed PSD sample masses were compared to the summation of dried masses retained on the size fractions post-wet sieving. For all feed samples, the difference between these masses was found to average less than 0.8 percent with the highest difference in mass for the CTS-L-0-SL-01 sample PSD at 1.6 percent. For the PSDs performed on the slurry samples, a similar amount of mass can be assumed to be lost during the wet sieving process as during the sieve cleaning process.

A comparison between the mass-balanced average uranium and Ra-226 concentrations of the feed PSD samples and the bulk analytical samples was not found to follow a trend with the mass lost from the performance of wet sieving (Table 16). Negative differences in the table indicate that the mass-balanced PSD average concentration of the constituent was less than the bulk analytical sample while positive differences in the table indicate that the mass-balanced average concentration was higher. This can be seen to follow no trend with the samples regardless of site or concentration even when analyzed by the average of the absolute differences (Table 17). Therefore, the mass loss from the wet sieving process can be assumed minimal and the resultant error in the analytical results can be assumed random.

Per Disa's sampling after RO-TAP processing SOP (Appendix B-1D) for performance of wet sieving, solids settled at the bottom of the collected grab sample buckets were split into approximately equal masses less than 500 grams to avoid overloading the screens during wet sieving. Because the samples were moist, this sample splitting was performed using the spray head hose to divide the settled solids into the PSDs. Figure 38 shows an example of the OCRM CR-H-4-SY sample with two remaining PSDs to be performed. The standard deviation of sample splits for each of the three sites is shown in Table 18. The higher standard deviation of sample PSD splits and total PSDs with masses greater than 500 grams for the CTS 2 samples is likely because of the method used to split the samples from the buckets. Because CTS 2 sample PSDs have a high presence of fines, splitting the CTS 2 samples by spraying water disproportionately removes the easily suspended fine material into the conducted first PSD of the splits.

Pressure Filtering. Pressure filtration rather than decanting of water represents a deviation from the SAP/QAPP (Tetra Tech 2022). The pressure filtration process is described in Section 2.6.2. The pressure filter tubes and filter cloths were cleaned between each sample using soap and water because the tube and cloth were the most likely locations for contaminant buildup. Between sample sites (that is, between filtering of OCRM and Quivira CR-1 samples), the entire pressure filter apparatus, as depicted on Figure 24 including the steel tube, filter cloth, bottom mesh, pressure filter base, pressure filter gasket, and effluent water tube, was cleaned with soap and water. The effluent water tubing was cleaned by scrubbing the base with soap, replacing the gasket and steel tube, filling the steel tube with clean water, and pressure filtering the water at 60 pounds per square inch until no bubbles remained in the effluent water.

Sample Splitting. With the inclusion of size fraction compositing for Ra-226 samples as described in Section 2.6.3, some error propagation was introduced into the analysis by first splitting the required 1 gram out of the fraction and then compositing the remaining sample. As a result, some size fractions for the samples were either under- or overrepresented in the composite, especially for the coarse fraction samples from CTS 2 sample PSDs present in much lower masses than for OCRM and Quivira CR-1 samples. Even with the low mass coarse fractions of CTS 2 samples, the greatest difference between the composite sample and the true mass from the originally performed PSD was 1.7 percent. Sample splitting at the Disa process laboratory, with the exception of the errors mentioned, introduced less error because splits typically varied no more than 1 gram from the goal mass and the samples were split into equal proportions as detailed in the SAP/QAPP.

5.2.5.2 Errors in Performance of Standard Operating Procedures and Potential Effects on Data Usability

Of the more than 354 samples generated at the sample preparation steps at the Disa process laboratory, only four sample preparation errors with the potential to affect analytical results occurred for an error rate of less than 1.1 percent. Still, because the data analyses follow the same trends throughout samples with the potential to be affected by errors and those unaffected by errors, the effects of these errors can be assumed minimal. These errors were as follows:

- During solids-water separation of OCRM sample CR-L-4-SY, 300 milliliters of clean shop water was inadvertently added to the pressure filter tube. With a recorded water sample mass after filtration of 13.8 pounds roughly equivalent to 6.3 liters of volume, this errant dilution is likely to have diluted the concentration of the analyzed constituents by 4.8 percent.
- Because of a logging error for the OCRM sample CR-M-8-SY +50-mesh sample, the fractions were split incorrectly into their respective analytical subsamples for SPLP extraction, metals, and Ra-226 analyses, impacting the results of the SPLP analysis. With this splitting error, the +50-mesh fraction was underrepresented in the composite mass by 2.9 percent in comparison to a true composite. With the uranium concentration of 10 mg/kg for the OCRM CR-M-8-SY +50 sample, underrepresentation of this size fraction contributed to an increase in the uranium concentration of the composite by 0.15 mg/kg from the true composite. This is likely to have increased the SPLP leachate analysis result for the uranium concentration.

- Noted originally as a possible logging error during sample splitting, the Quivira CR-1 QV-H-8-SY +140-mesh and QV-H-8-SY +200-mesh samples were found to be lower and higher by approximately 7 grams from their actual recorded masses. This was likely because a misplaced XRF puck from the QV-H-8-SY +140-mesh sample was placed into the QV-H-8-SY +200-mesh sample after XRF screening of the fractions. Relative to the mass of the original PSD fractions, this would result in a difference of 6.5 percent in mass to the +140-mesh fraction and 11.5 percent in mass to the +200-mesh fraction. This error is likely to have no effect on metals analyses of the QV-H-8-SY +140-mesh and QV-H-8-SY +200-mesh samples, where uranium mass is only 0.4 percent and 0.3 percent of the total sample mass, respectively. Similarly, no effect is expected for the QV-H-8-SY +25- and +270-mesh SPLP composite samples and Ra-226 analysis of the QV-H-4-SY +100- and +270-mesh composite samples.
- A leak from the pressure filter was observed during the solids-water separation of the CTS-L-30-SY sample, contributing to a difference between the theoretical mass of the CTS-L-30-WT sample to the actual recorded mass of 7.4 pounds (45.6 percent). While the water was likely homogeneous and the water mass lost during this separation likely had the same concentration of constituents, this leak has the potential to affect the results of the analyzed CTS-L-30-WT sample. With the average wet mass retained on the filter paper during solids-water separation at 8.21 grams for all CTS 2 slurry samples and the wet mass retained on the filter paper for CTS-L-30-SY separation recorded at 7.86 grams, no mass was estimated to be lost from this leak. Even if the amount of mass lost was the difference between the recorded wet mass and the average wet mass for the sample group, this mass loss would only make up 0.05 percent of the total sample. Any mass lost from the leak would be likely to decrease both the fines fraction uranium and Ra-226 concentrations of the CTS-L-30-SY and CTS-L-30-WT samples.

6.0 TECHNOLOGY STATUS

HPSA technology demonstrated by Disa is proprietary, but the HPSA treatment system can be purchased from Disa and operated under a license by another vendor. Further, only the core treatment components, such as the HPSA treatment tanks, collision chambers, nozzles, and high velocity slurry pumps, are proprietary. Support equipment, such as screens, clarifiers, and filter presses, can be purchased from Disa or separately from other vendors.

HPSA technology has been demonstrated at bench and pilot scales under this treatability study, for the Navajo Nation Environmental Protection Agency under a separate study, and at approximately 10 private client uranium waste rock piles throughout the Western U.S. The technology has also been demonstrated at full-scale continuous flow to concentrate hematite from ore at an iron mine. Disa operated a 5- to 10-TPH full-scale continuous flow system to remove coatings from green filter sand at a private client site in Colorado in the Fall of 2023. Disa is currently operating a 5- to 10-TPH full-scale continuous flow system installed at a phosphate mill.

HPSA technology is scalable to 50- and 100-TPH systems by simply requiring larger screens and pumps, additional HPSA treatment tanks and collision chambers, and additional clarifiers and filter press capacity at each step. The HPSA treatment system is undergoing continuous refinement and optimization by better understanding the relationship between batch and continuous flow systems, using multiple chambers per pump to allow higher material throughput for the same nozzle sizes and collision velocities, and improving particle size classification inside of the HPSA treatment tank.

Because of the promise of the HPSA treatment of waste rock at the three Navajo AUM sites, Disa is working with NRC to include remediation technologies under the source material rather than the mill licensing process currently envisioned by NRC regulations. Application of HPSA technology to other AUM and metals-impacted sites would typically require bulk sampling of site-specific material to understand mineralogy, PSD, and chemical makeup and a bench-scale study using site-specific materials at Disa’s facilities to optimize nozzle and velocity parameters, fines settling rates, and filter press time and residual moisture content.

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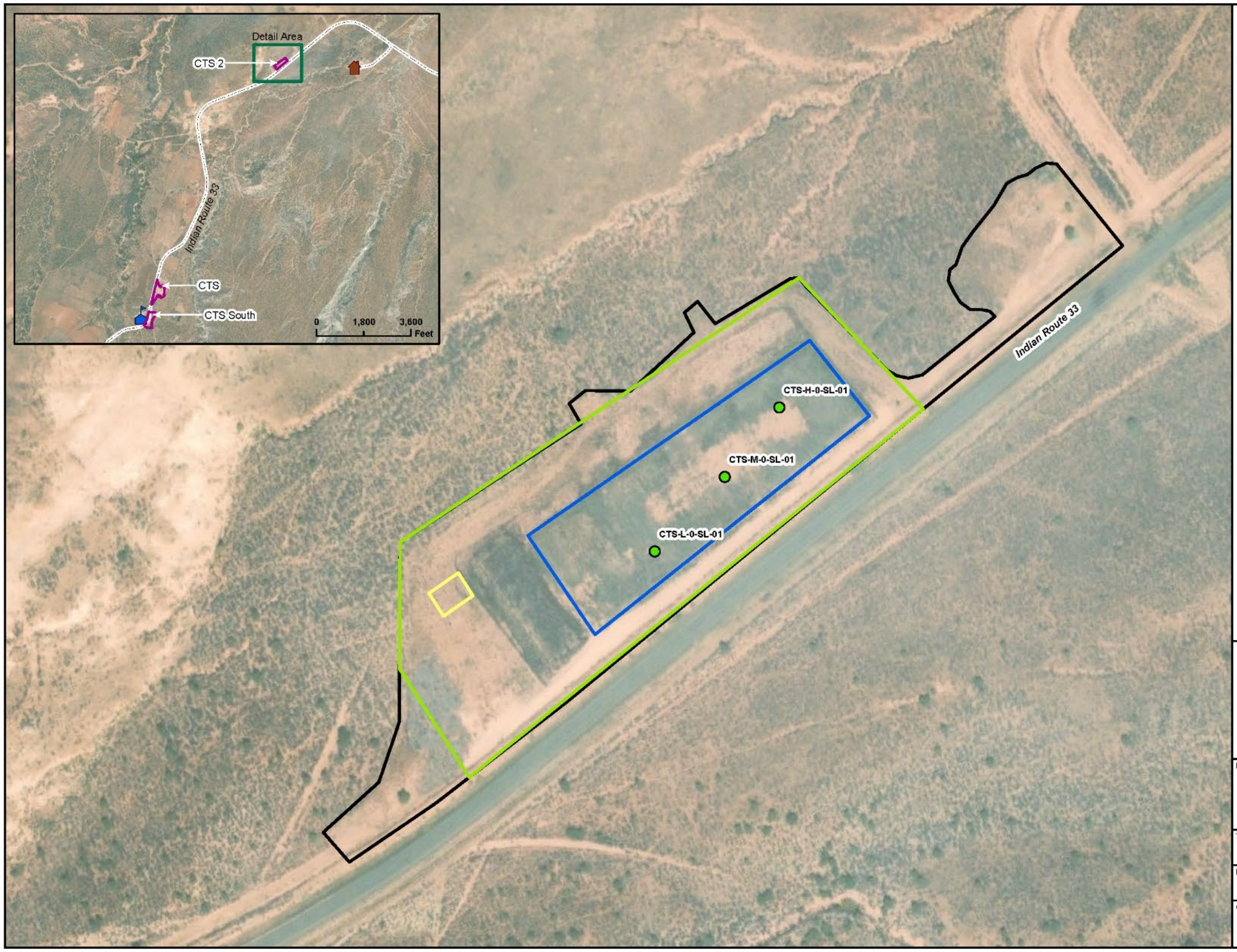
FIGURES



● Soil Sample Location for Feed Soils
▭ Field Demonstration Area
▭ Field Study Area
▭ Site Boundary
▭ Existing Stockpile and Field Survey Area (TCRA Waste from CTS, CTS 2, and CTS South)
▭ AUM-Related Site
Cove Day School
Cove Chapter House

Notes:

AUM	Abandoned uranium mine
CTS	Cove Transfer Station
TCRA	Time-critical removal action

1 inch = 140 feet

1:1,680

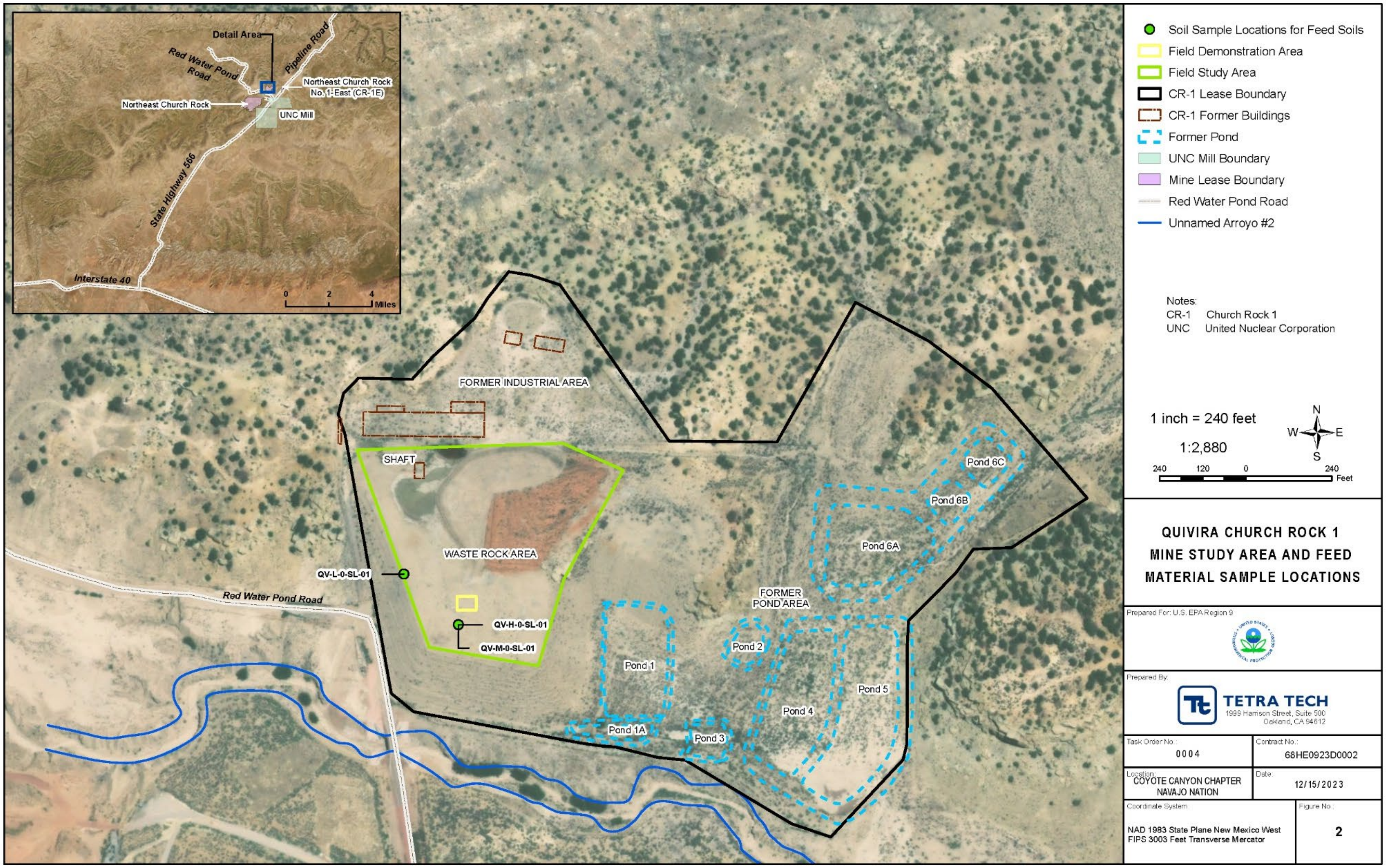
0 70 140 280 Feet

N W E S

COVE TRANSFER STATION 2
STUDY AREA AND FEED MATERIAL
SAMPLE LOCATIONS

Prepared For: U.S. EPA Region 9	Prepared By: TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612
Task Order No.: 0004	Contract No.: 68HE0923D0002
Location: COVE CHAPTER NAVAJO NATION	Date: 12/15/2023
Coordinate System: NAD 1983 State Plane Arizona East FIPS 0201 Feet Transverse Mercator	Figure No.: 1

Figure 1. Cove Transfer Station 2 Study Area and Feed Material Sample Locations



Notes:
CR-1 Church Rock 1
UNC United Nuclear Corporation

QUIVIRA CHURCH ROCK 1
MINE STUDY AREA AND FEED
MATERIAL SAMPLE LOCATIONS

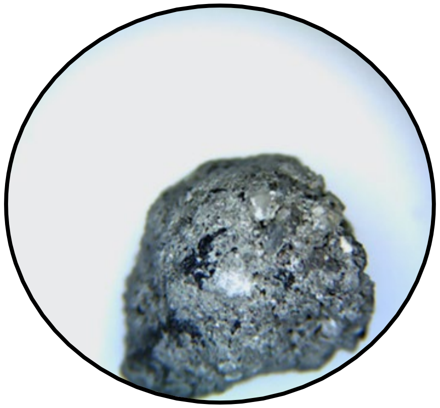
Prepared For: U.S. EPA Region 9

Prepared By:
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

Task Order No.: 0004
Contract No.: 68HE0923D0002
Location: COYOTE CANYON CHAPTER NAVAJO NATION
Date: 12/15/2023
Coordinate System: NAD 1983 State Plane New Mexico West FIPS 3003 Feet Transverse Mercator
Figure No.: 2

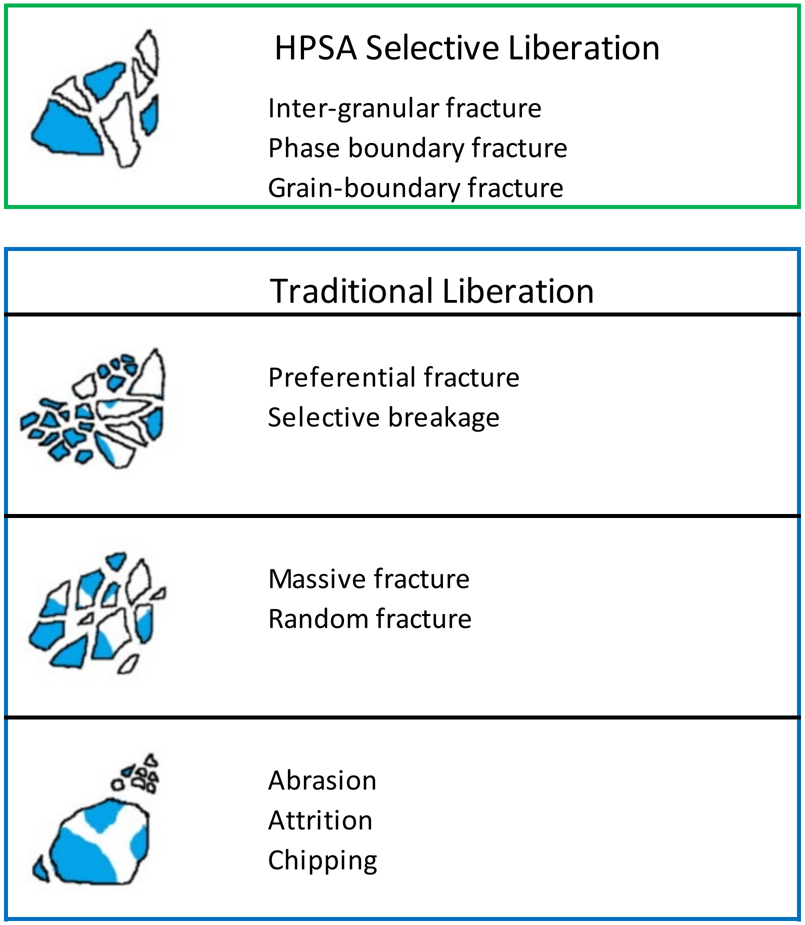
Figure 2. Quivira Church Rock 1 Mine Study Area and Feed Material Sample Locations

Figure 3. Old Church Rock Mine Study Area and Feed Material Sample Locations



Pre-HPSA Treatment

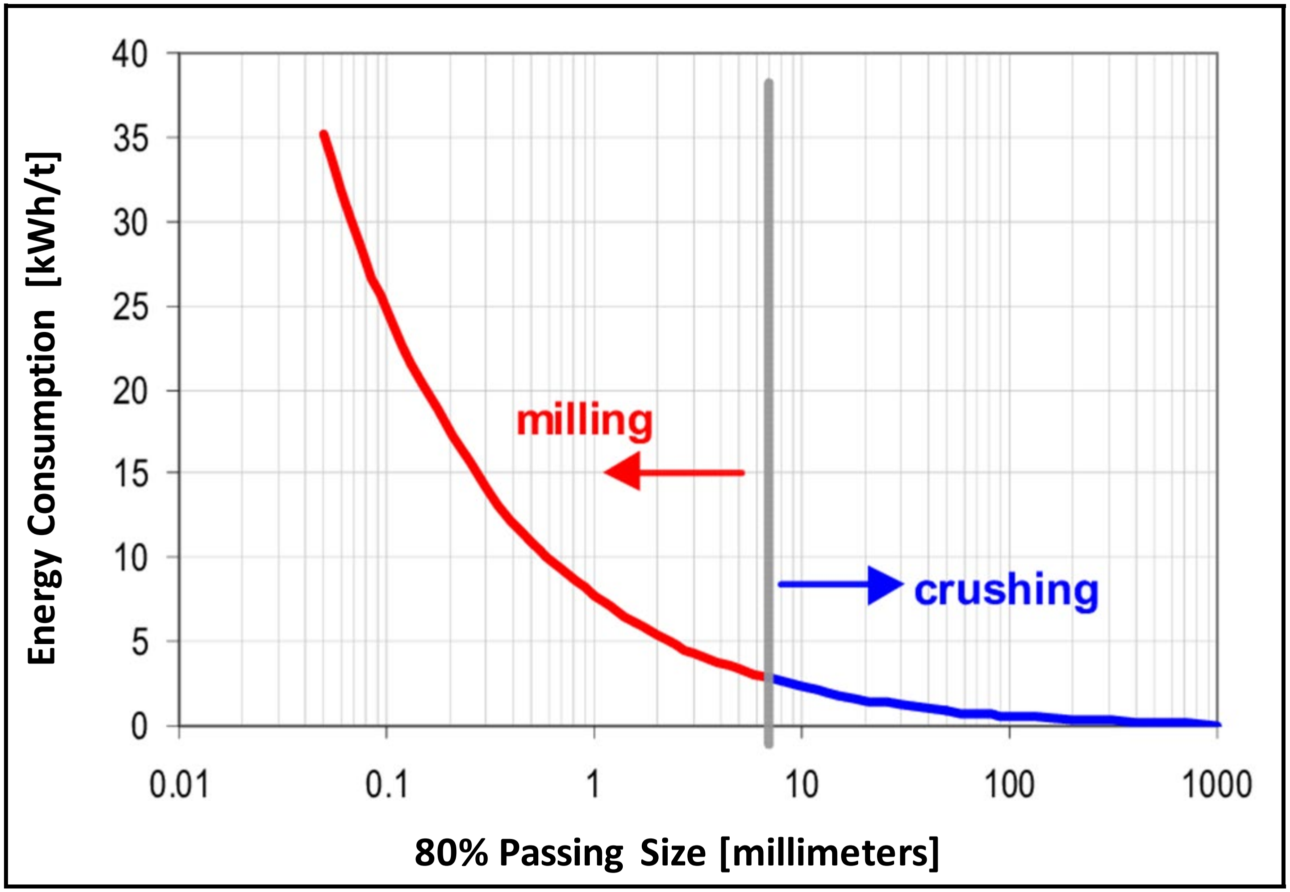
Post-HPSA Treatment



Notes:

HPSA High-Pressure Slurry Ablation

Figure 4. Quartz Grain with Uranium Association Pre- and Post-HPSA with Graphic Illustration of Selective Liberation Performed by HPSA

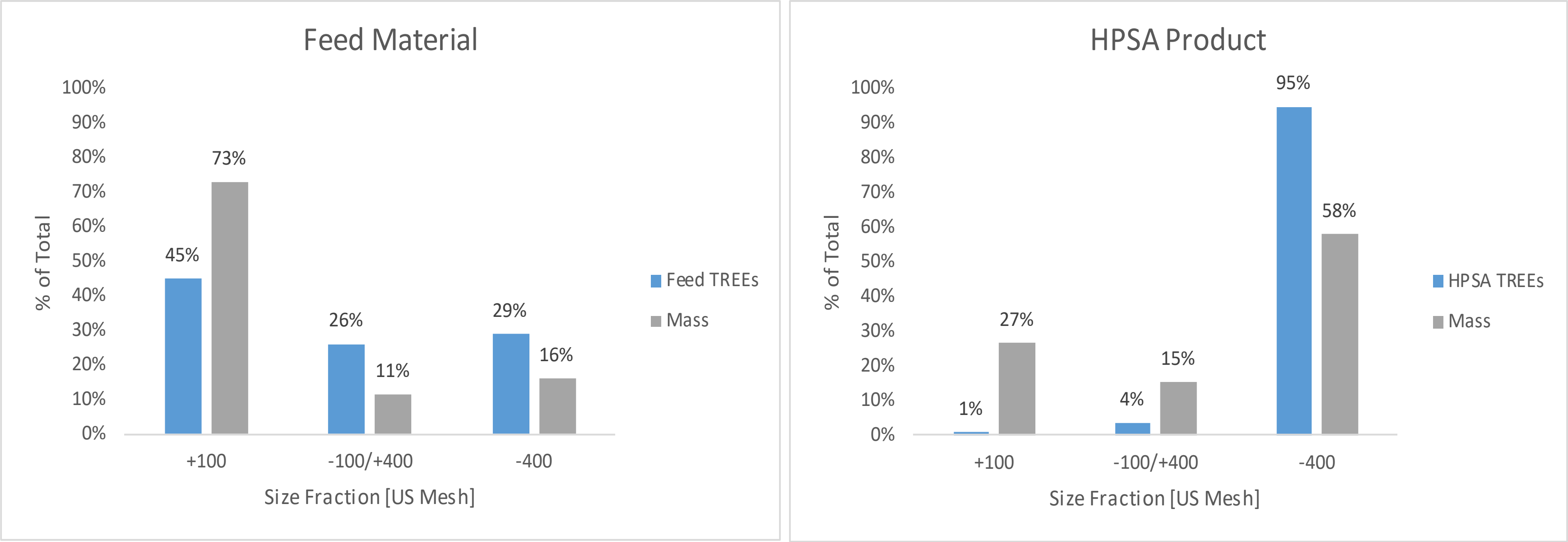


Notes:

Source: (Valery and Jankovic 2002)

kWh/t kilowatt hour per ton

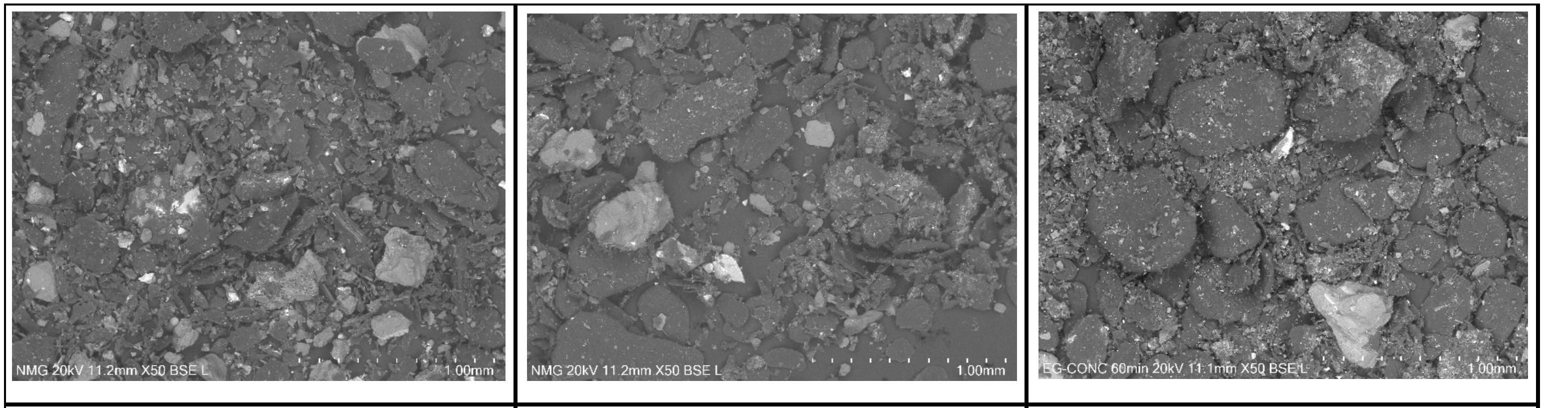
Figure 5. Increase in Energy Consumption to Further Reduce Particle Size with Decreasing Particle Size



Notes:

HPSA	High-Pressure Slurry Ablation
TREEs	Total Rare Earth Elements

Figure 6. Total Rare Earth Element Gradation of Pre-HPSA and Post-HPSA Treatment



Traditional Ball Mill Concentrate at 55% Graphite and 96% Recovery

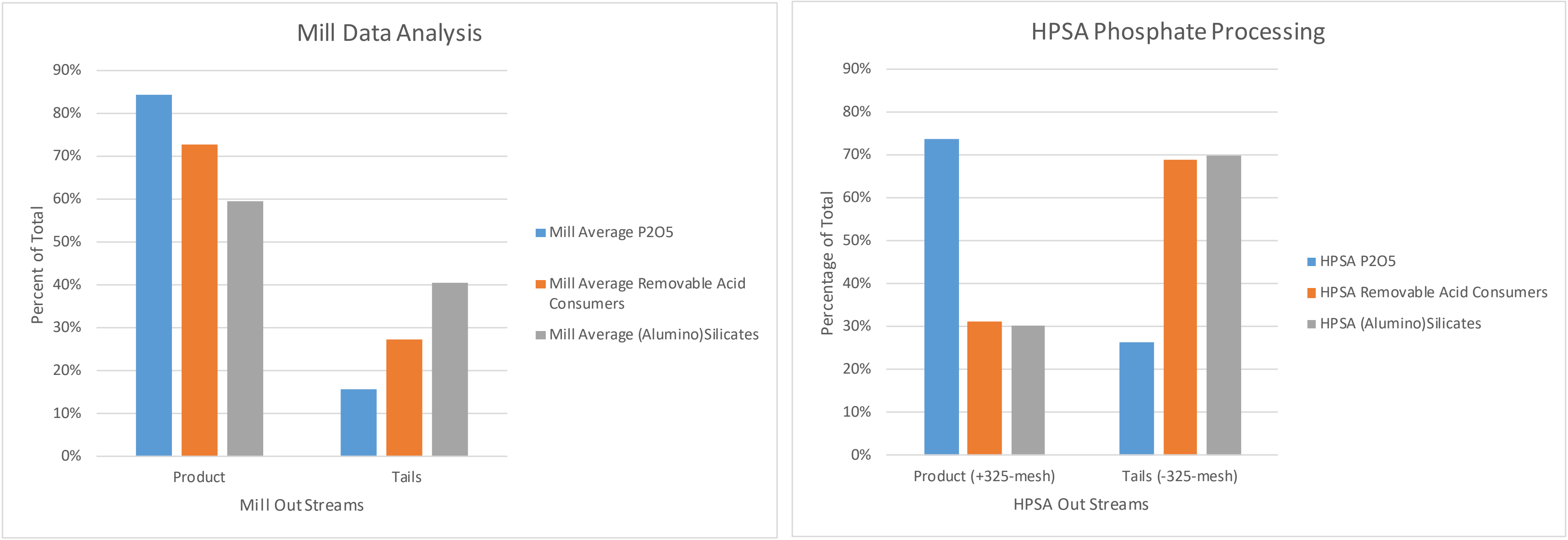
HPSA Test 1 Concentrate at 74% Graphite and 94% Recovery

HPSA Test 2 Concentrate at 80% Graphite and 96% Recovery

Notes:

HPSA High-Pressure Slurry Ablation

Figure 7. Scanning Electron Microscope Images of HPSA Graphite Concentrate Compared to Conventional Ball Mill Flotation Circuit



Notes:

P2O5	phosphate content

Figure 8. Comparison of Phosphate Mill Gangue Processing to HPSA Gangue Removal

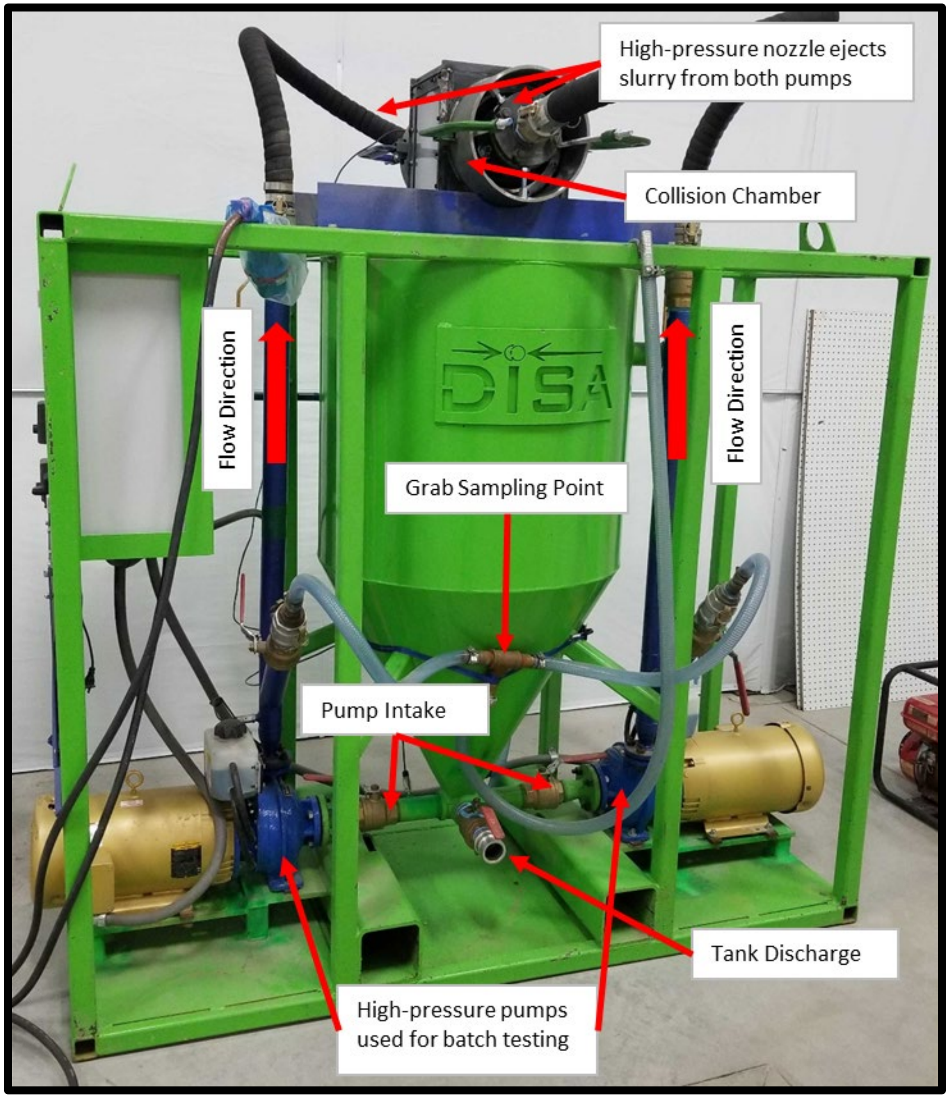
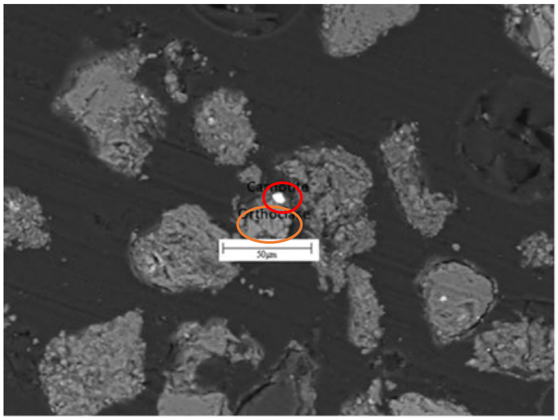
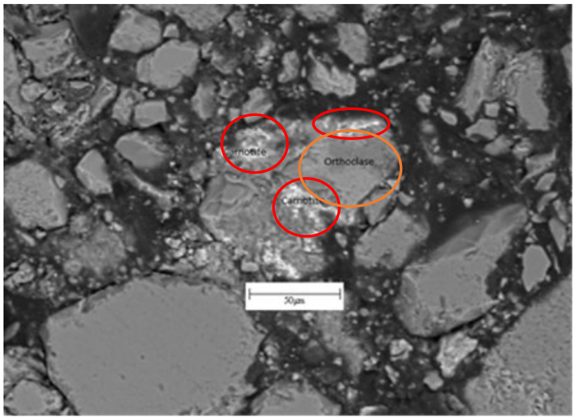
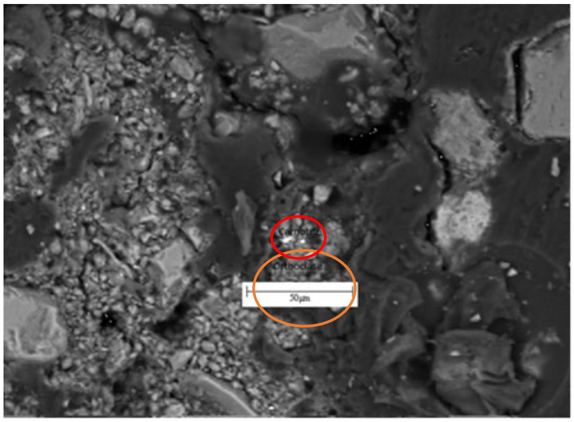


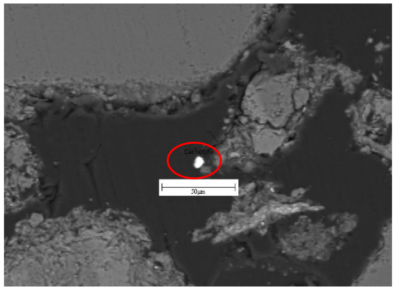
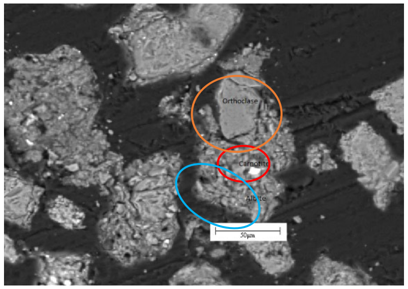
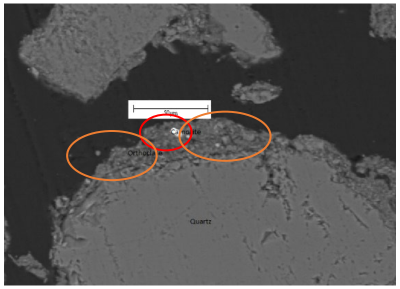
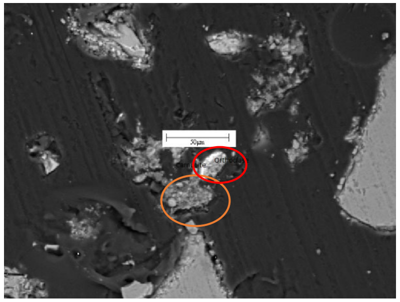
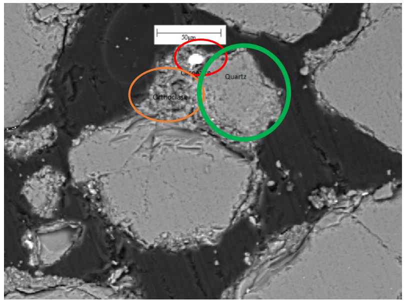
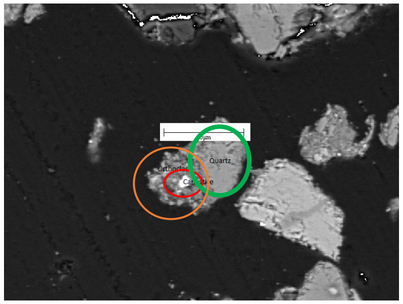
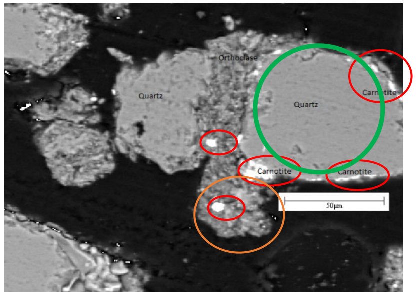
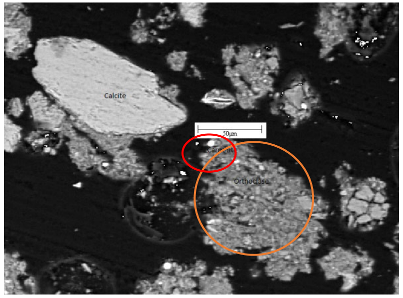
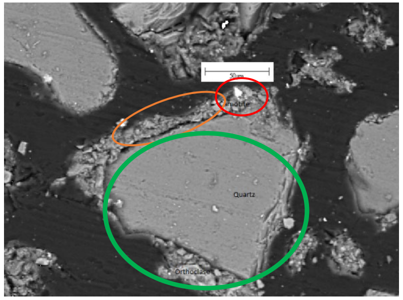
Figure 9. Disa HPSA Batch Test Unit Process Components and Sampling Points

Sample ID	Automated Mineralogy Identification and Characterization System Images
CTS-L-0-SL-01* (Low Concentration)	 Carnotite Particle (Red) Associated with Orthoclase Particle (Orange)
CTS-M-0-SL-01* (Medium Concentration)	 Carnotite Particles (Red) Rimmed Around Orthoclase Particle (Orange)
CTS-H-0-SL-01* (High Concentration)	 Carnotite Particles (Red) Associated with Orthoclase Particle (Orange)

Notes:

* Refer to Sample Nomenclature in Section 2.3.3

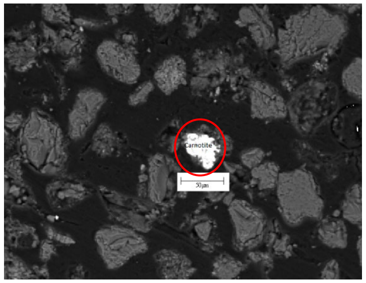
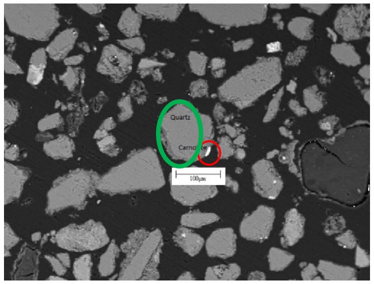
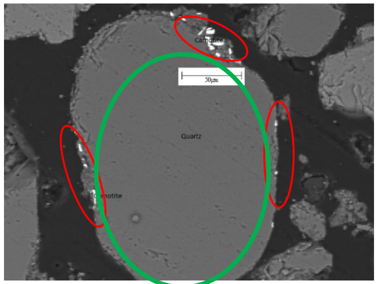
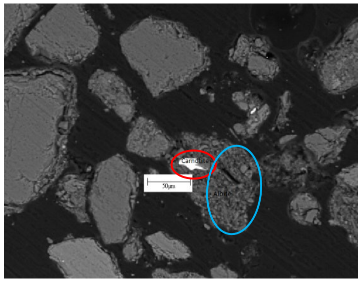
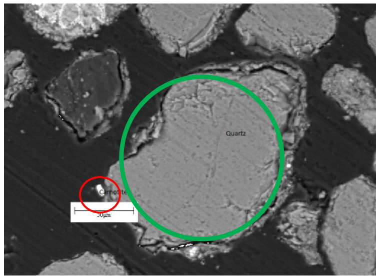
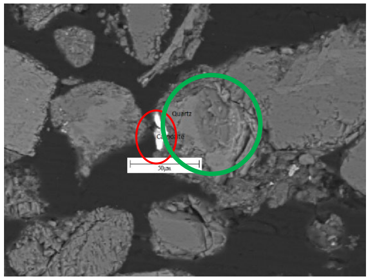
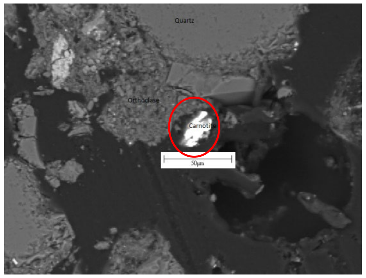
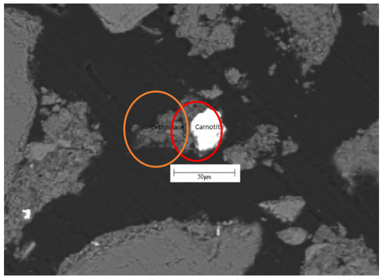
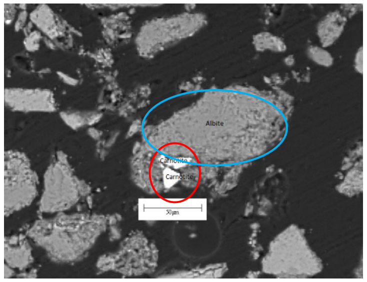
Figure 10. Cove Transfer Station 2 Site Feed Sample AMICS Images Grouped by Associated Samples

Sample ID	Automated Mineralogy Identification and Characterization System Images		
QV-L-0-SL-01* (Low Concentration)	 Free Carnotite (red)	 Carnotite (red) Encapsulated by Orthoclase (orange) and Albite (blue)	 Carnotite (red) Encapsulation by Quartz (green) and Orthoclase (orange)
QV-M-0-SL-01* (Medium Concentration)	 Carnotite (red) Associated with Orthoclase (orange)	 Carnotite (red) Encapsulated by Orthoclase (orange) and Quartz (green)	 Carnotite (red) Encapsulation by Quartz (green) and Orthoclase (orange)
QV-H-0-SL-01* (High Concentration)	 Carnotite Encapsulated by Orthoclase and Rimmed Around Quartz	 Carnotite (red) Associated with Orthoclase (orange)	 Carnotite (red) Associated with Quartz (green) Encapsulated by Orthoclase (orange)

Notes:

* Refer to Sample Nomenclature in Section 2.3.3

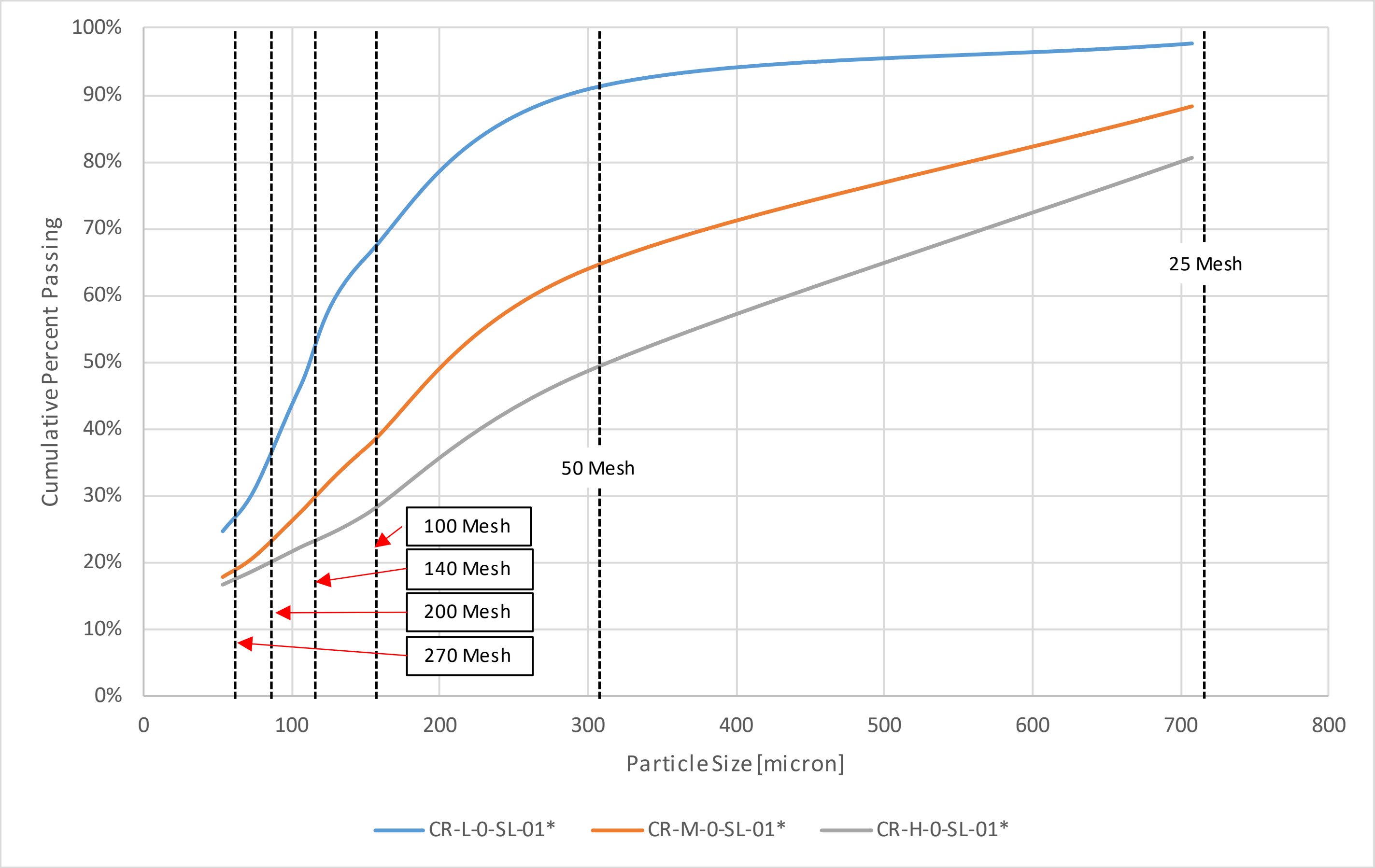
Figure 11. Quivira Church Rock 1 Mine Site Feed Sample AMICS Images Grouped by Associated Samples

Sample ID	Automated Mineralogy Identification and Characterization System Images		
CR-L-0-SL-01* (Low Concentration)	 Free Carnotite (red)	 Carnotite (red) Associated with Quartz (green)	 Carnotite (red) Rimming Around Quartz Particle (green)
CR-M-0-SL-01* (Medium Concentration)	 Carnotite (red) Encapsulated by Albite (blue)	 Carnotite (red) Associated with Quartz (green)	 Carnotite (red) Associated with Quartz (green)
CR-H-0-SL-01* (High Concentration)	 Free Carnotite (red)	 Carnotite (red) Associated with Orthoclase (orange)	 Carnotite (red) Encapsulated by Albite (blue)

Notes:

* Refer to Sample Nomenclature in Section 2.3.3

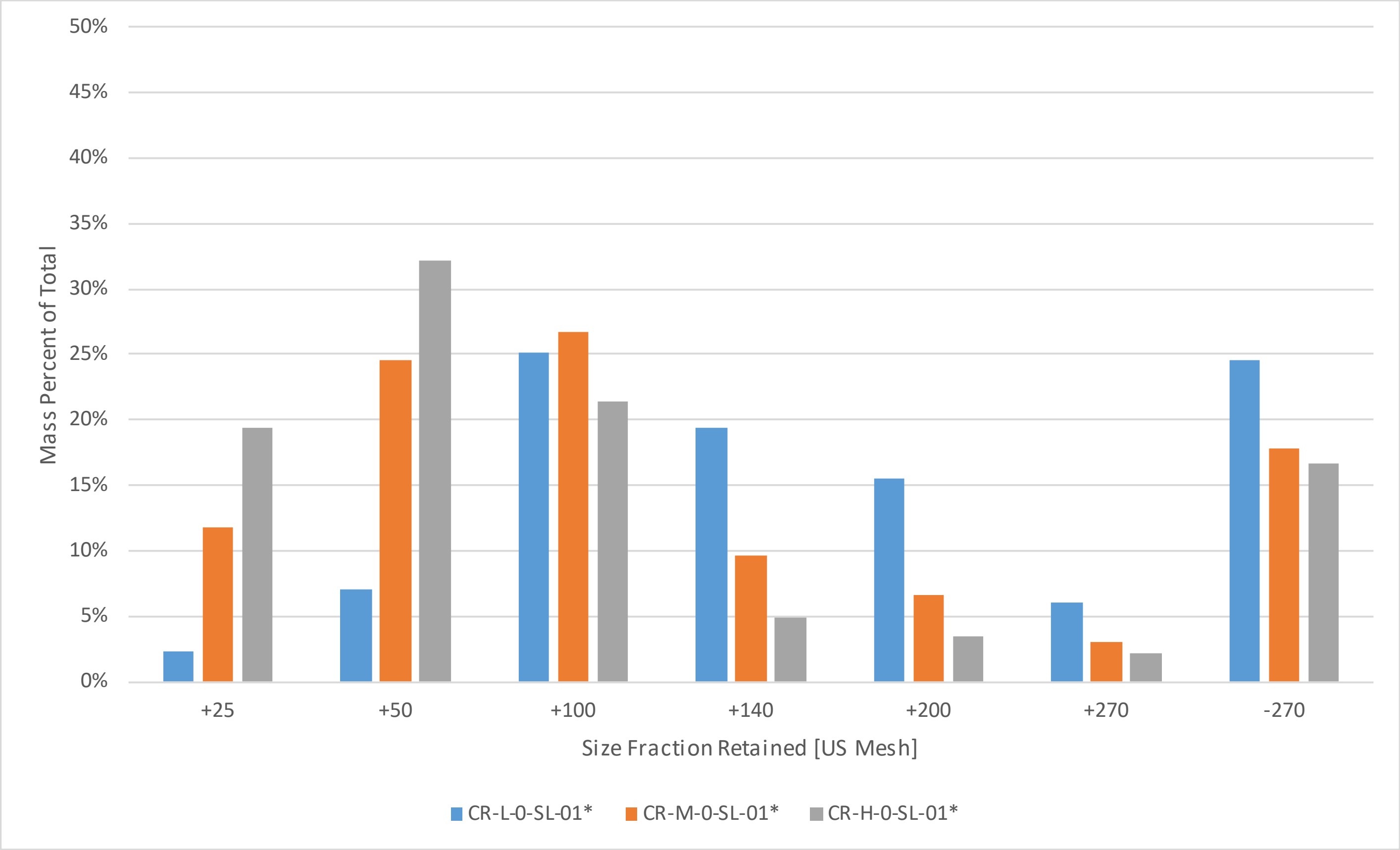
Figure 12. Old Church Rock Mine Site Feed Sample AMICS Images Grouped by Associated Samples



Notes:

* Refer to Sample Nomenclature in Section 2.3.3

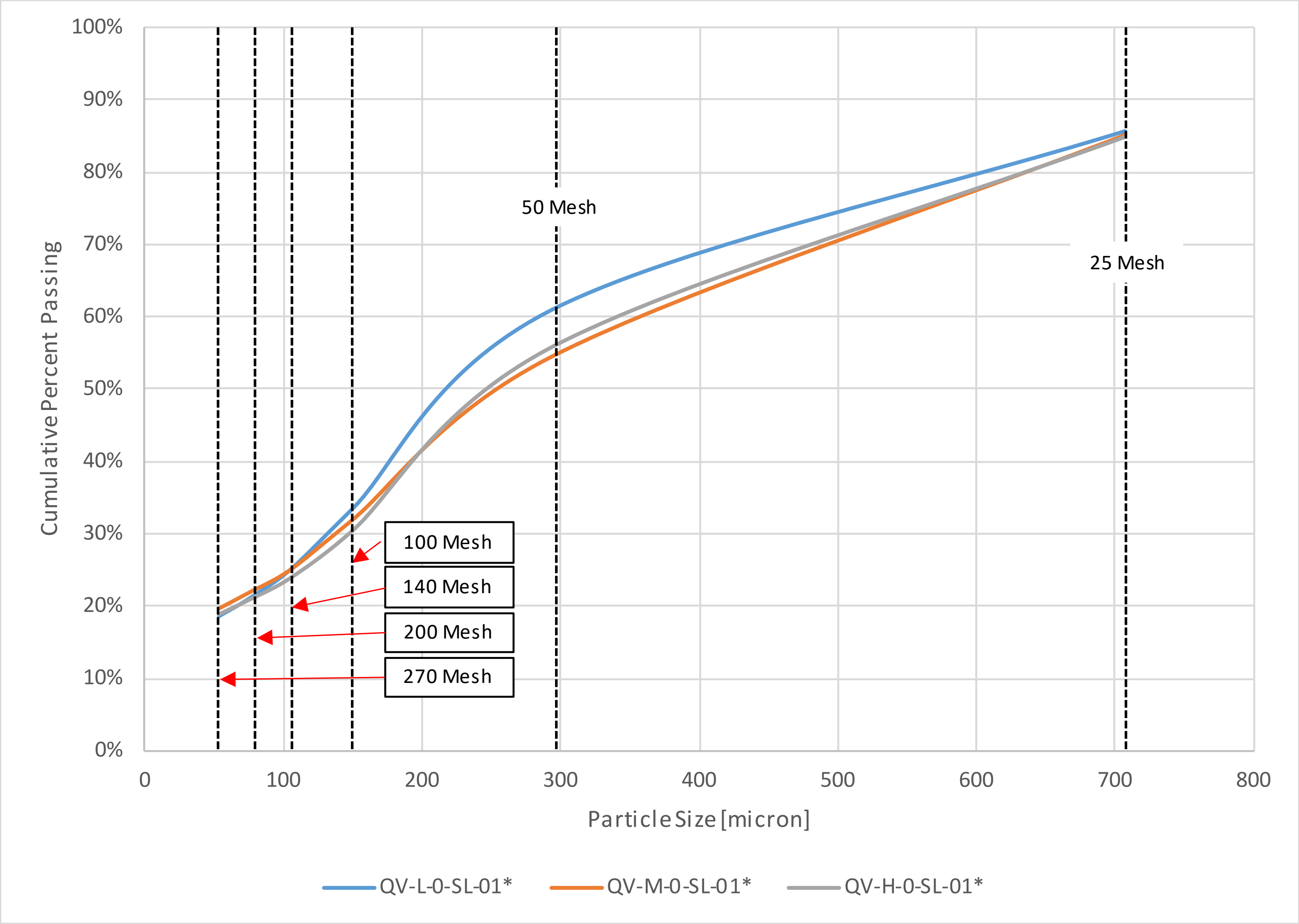
Figure 13. Old Church Rock Mine Sample Feed Particle Size Distributions by Cumulative Mass Percent Passing



Notes:

* Refer to Sample Nomenclature in Section 2.3.3

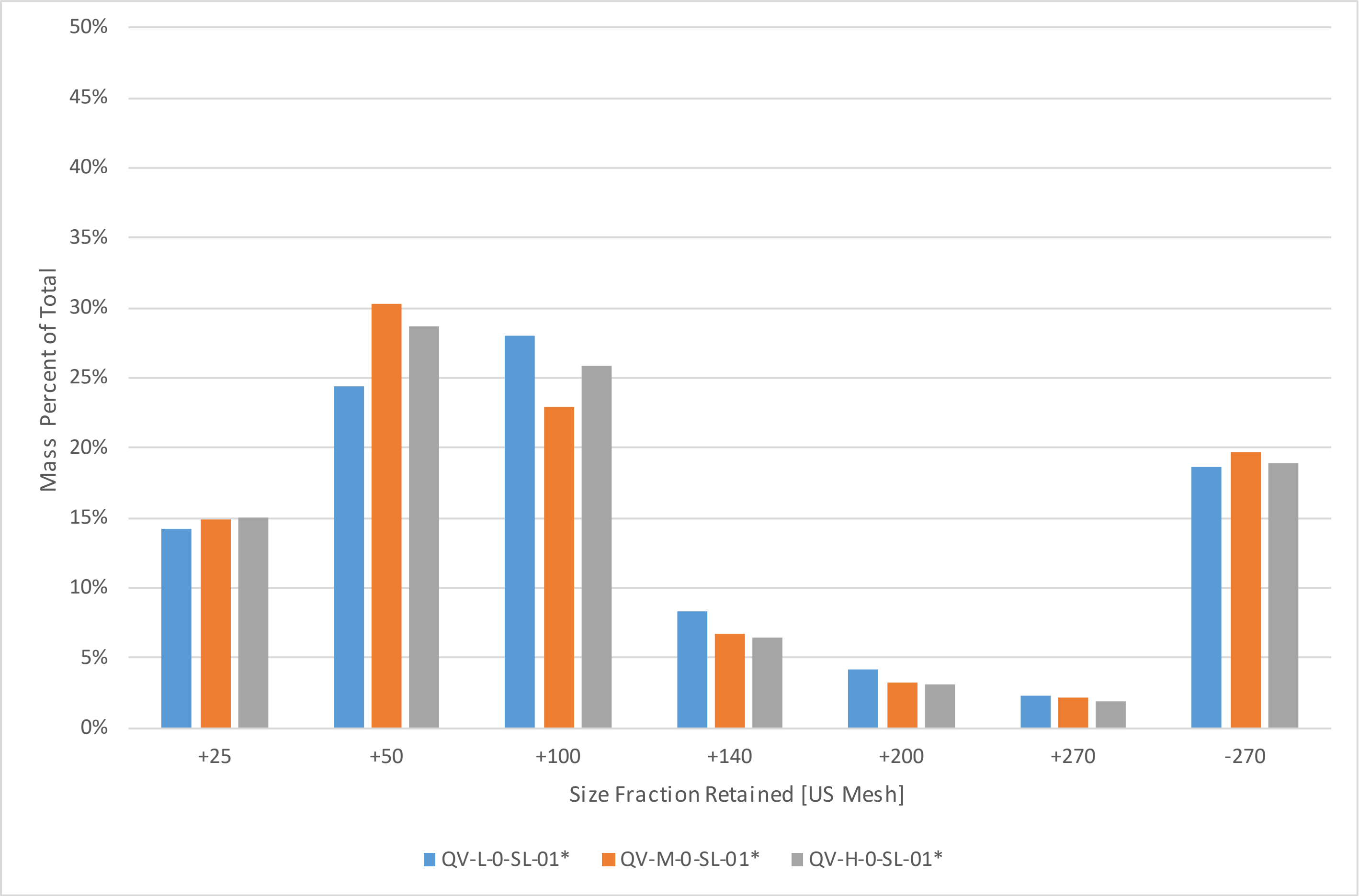
Figure 14. Old Church Rock Mine Sample Feed Particle Size Distributions by Percent Mass Retained



Notes:

* Refer to Sample Nomenclature in Section 2.3.3

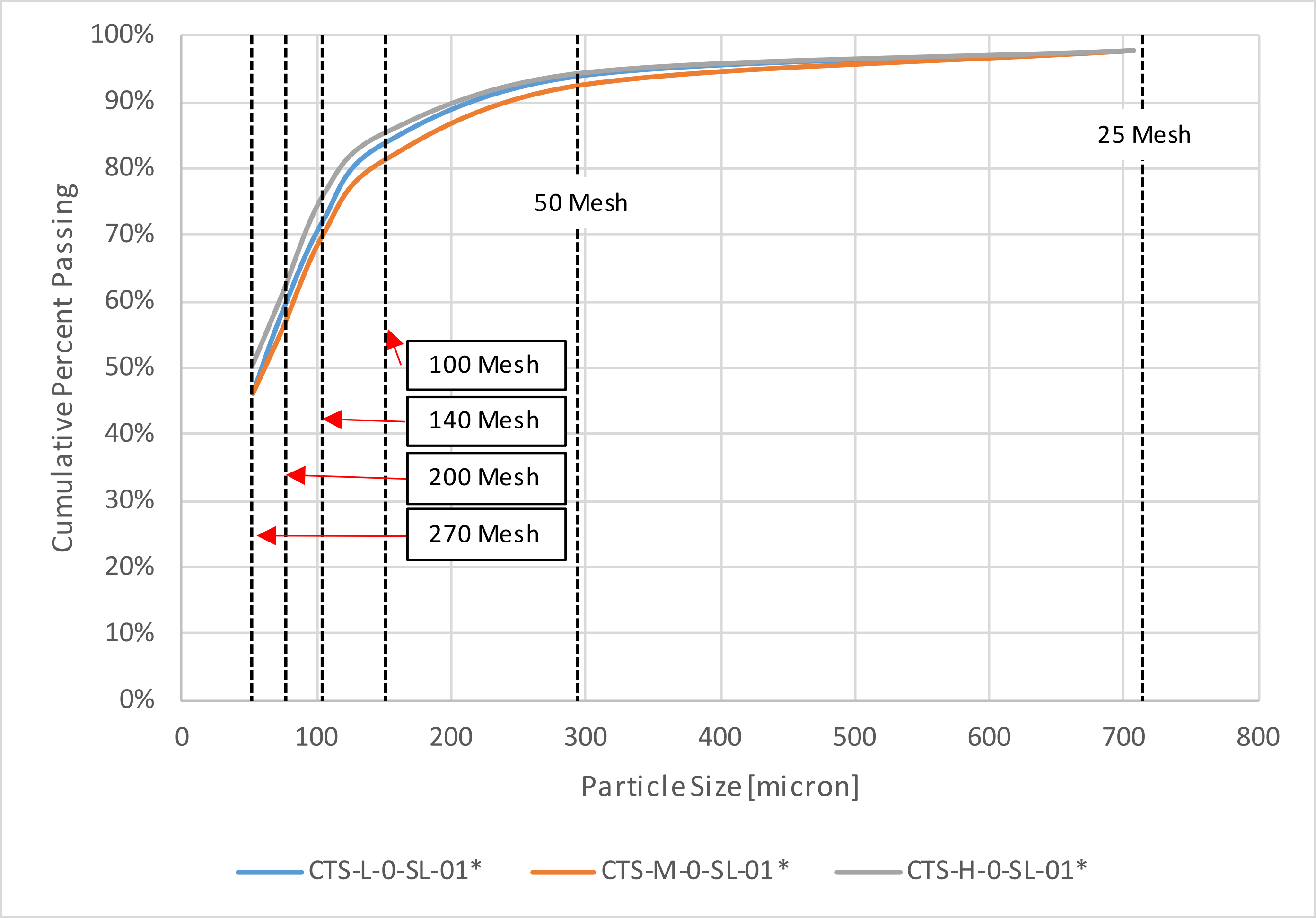
Figure 15. Quivira Church Rock 1 Mine Sample Feed Particle Size Distributions by Cumulative Mass Percent Passing



Notes:

* Refer to Sample Nomenclature in Section 2.3.3

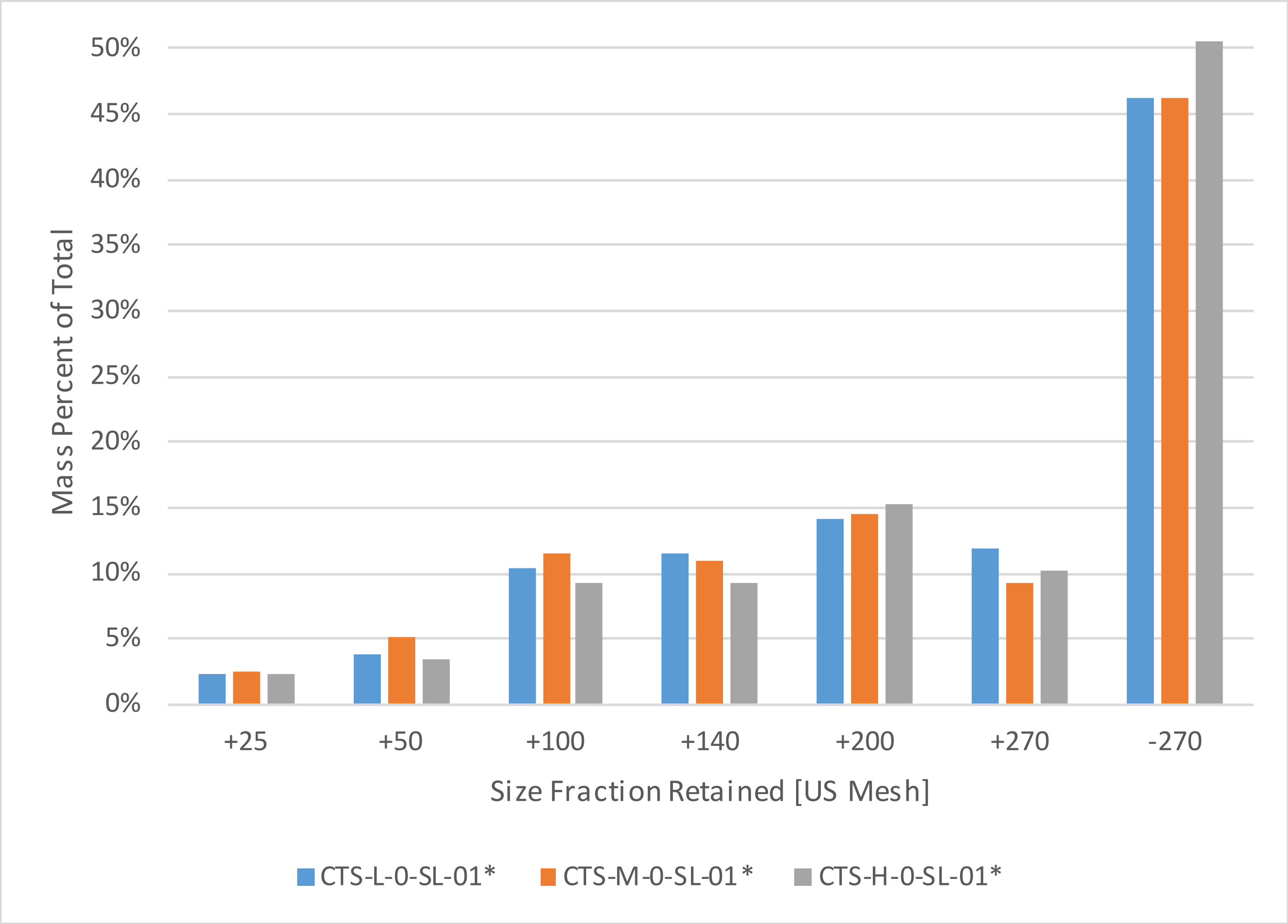
Figure 16. Quivira Church Rock 1 Mine Sample Feed Particle Size Distributions by Percent Mass Retained



Notes:

* Refer to Sample Nomenclature in Section 2.3.3

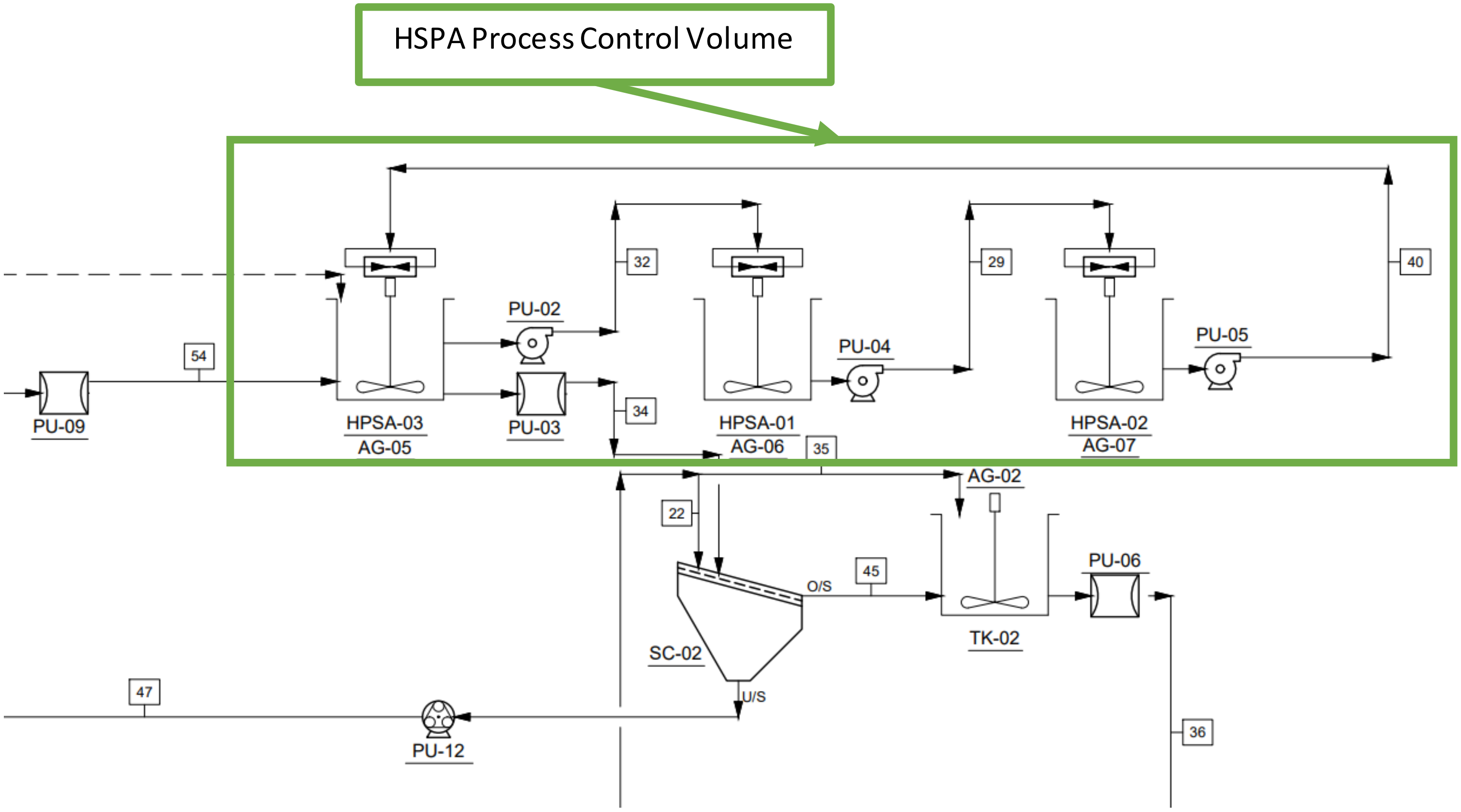
Figure 17. Cove Transfer Station 2 Sample Feed Particle Size Distributions by Cumulative Mass Percent Passing



Notes:

* Refer to Sample Nomenclature in Section 2.3.3

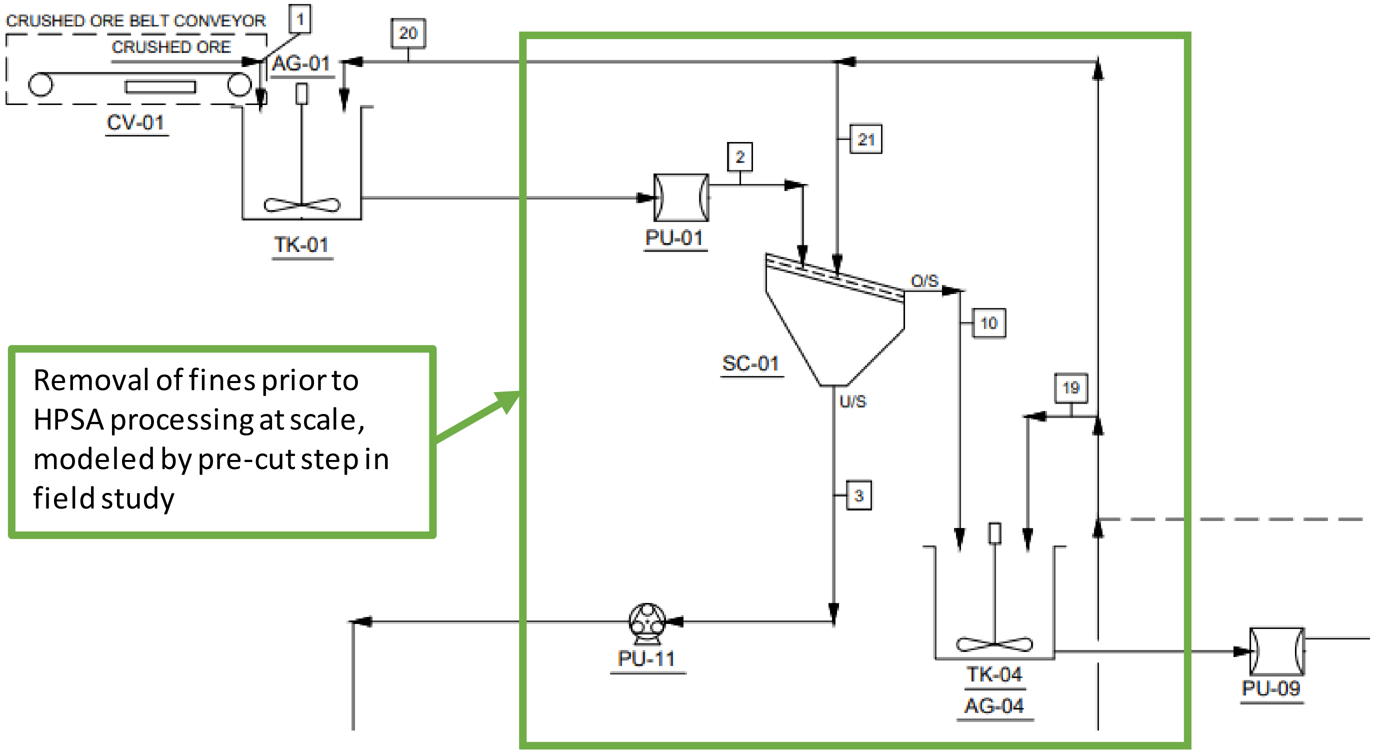
Figure 18. Cove Transfer Station 2 Sample Feed Particle Size Distributions by Percent Mass Retained



Notes:

AG	Agitator	SC	Screen
HPSA	High-Pressure Slurry Ablation	TK	Tank
PU	Pump		

Figure 19. Disa 5-Ton per Hour HPSA Process Flow Diagram



Removal of fines prior to HPSA processing at scale, modeled by pre-cut step in field study

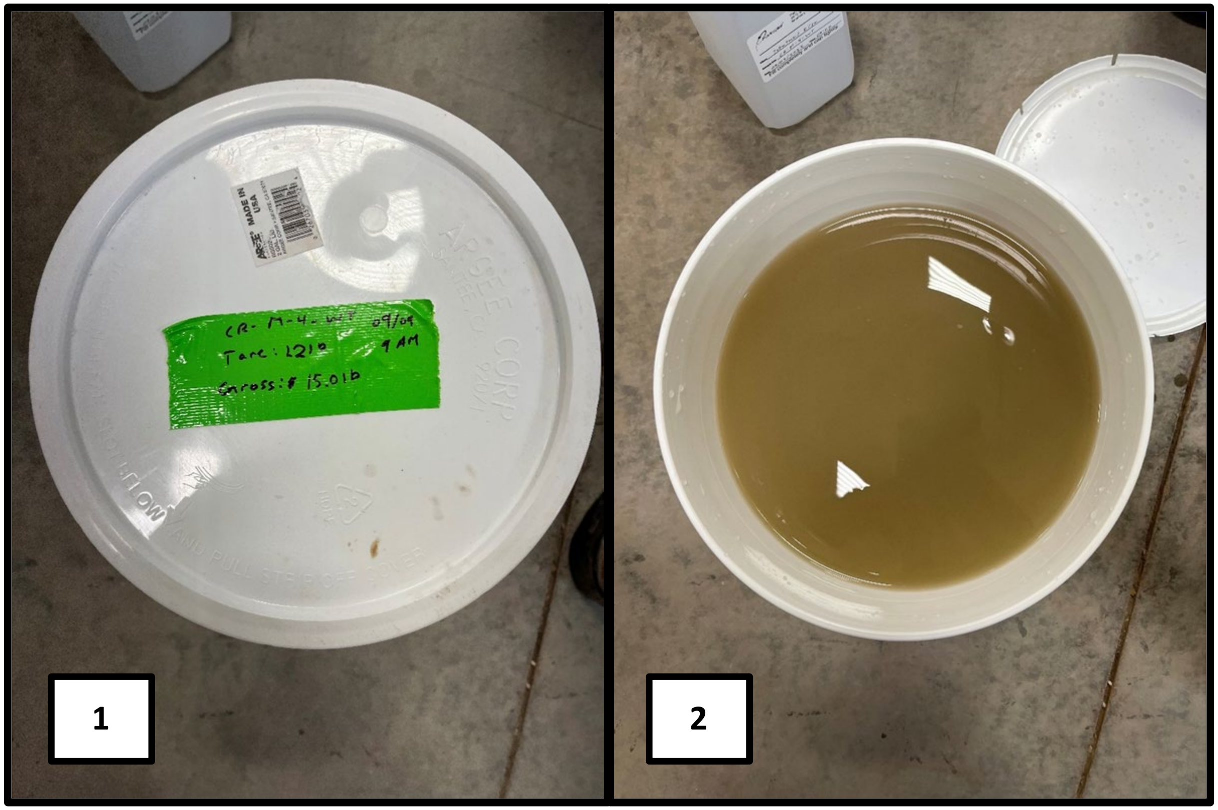
Notes:

AG	Agitator	PU	Pump
CV	Conveyor	SC	Screen
HPSA	High-Pressure Slurry Ablation	TK	Tank
O/S	Oversize	U/S	Undersize

Figure 20. Removal of Fines (Pre-Cut Step) before HPSA Treatment at Scale

Figure 21. Disa Personnel Performing the Pre-Cut Step at the Old Church Rock Mine during the Field Study

Figure 22. Vibratory Sieve Shaker Used for Wet Sieving Determination of Particle Size Distribution at the Disa Process Laboratory Post-Field Study



Notes:
1 Sample bucket lid with sample identification
2 Visibly turbid water sample

Figure 23. Visibly Turbid Water from Medium-Concentration 4-Minute HPSA Water Sample Sent to Pace Analytical for Analysis after Solids-Water Separation by 5-Micron Pressure Filtration

Figure 24. Pressure Filter Apparatus at the Disa Process Laboratory Used for Removing Water from the Passing 270-Mesh Fraction after Wet Sieving with All Components Laid Out on the Table

Church Rock Low Concentration Mass Balance (Part A)

Original Mass Collected			
Bucket	Tare [lb]	Gross [lb]	Net [lb]
CR-L-Unscreened-01	2.2	51.8	49.6
CR-L-Unscreened-02	2.2	48.8	46.6
Totals	4.4	100.6	96.2

Material Screening over 1/4 inch

1/4" Screened Material				
Bucket	Tare [lb]	Gross [lb]	Net [lb]	Percent of Total
CR-L-0-SL +1/4 inch-01	2.2	2.6	0.4	0.4%
CR-L-0-SL -1/4 inch-01	2.2	45.8	43.6	99.6%
CR-L-0-SL -1/4 inch-02	2.2	54.2	52	
	6.6	102.6	96	

Mixing and Subsampling

Subsample Taken	
Net Mass [g]	1462.31
Estimated Remaining Mass 8/26 [lb]	92.78

Moisture Content as Determined at Disa Lab

% Moisture	4.23%
Estimated True Dry Mass [lb]	88.9

Material Pre-Cutting over 270-mesh screen at site 8/27/2022

Continued on Church Rock Low Concentration Mass Balance 2

-270 Feed Fines Brought Back to Shop and Dried

Dried Pan ID	Tare Mass [lb]	Gross Mass [lb]	Net Mass [lb]
CR-L-0-F-01	2.8	3	0.2
CR-L-0-F-02	2.8	8.2	5.4
CR-L-0-F-03	2.8	9.4	6.6
CR-L-0-F-04	2.8	5	2.2
			14.4

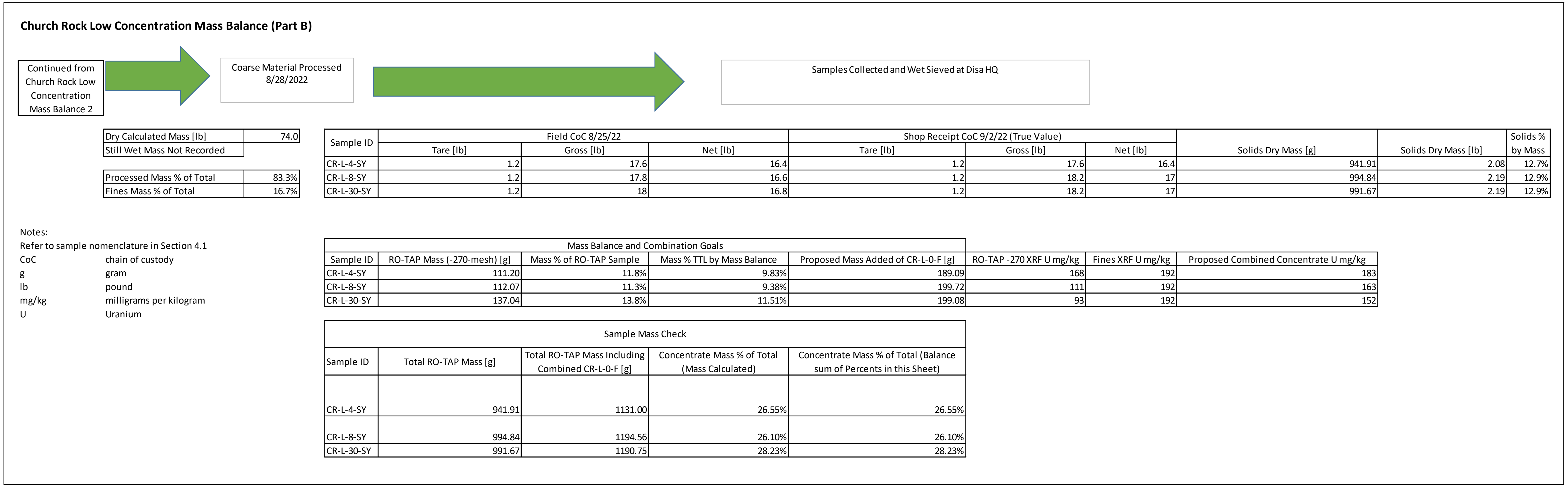
Unsettled Water Collection	
Depth Drum Total [in]	34
Volume Drum Total [gal]	55
Full Volume Used	
Collected Unsettled Water Bucket Net Mass [lb]	14.8
Collected Unsettled Water Volume [gal]	1.77
Sampled as % of Total	3.2%
Net Mass Unsettled Water Sample [g]	6.66
Approximate Unsettled Mass [lb]	0.46

Notes:

Refer to sample nomenclature in Section 4.1

lb	pound
g	gram

Figure 25. Example of Mass Balance Used for Determination of Proper Fines Mixing for Old Church Rock Mine Low Sample Treatment (Part A)



Church Rock Low Concentration Mass Balance (Part B)

Continued from Church Rock Low Concentration Mass Balance 2

Coarse Material Processed 8/28/2022

Samples Collected and Wet Sieved at Disa HQ

Dry Calculated Mass [lb]	74.0
Still Wet Mass Not Recorded	

Processed Mass % of Total	83.3%
Fines Mass % of Total	16.7%

Sample ID	Field CoC 8/25/22			Shop Receipt CoC 9/2/22 (True Value)			Solids Dry Mass [g]	Solids Dry Mass [lb]	Solids % by Mass
	Tare [lb]	Gross [lb]	Net [lb]	Tare [lb]	Gross [lb]	Net [lb]			
CR-L-4-SY	1.2	17.6	16.4	1.2	17.6	16.4	941.91	2.08	12.7%
CR-L-8-SY	1.2	17.8	16.6	1.2	18.2	17	994.84	2.19	12.9%
CR-L-30-SY	1.2	18	16.8	1.2	18.2	17	991.67	2.19	12.9%

Notes:

Refer to sample nomenclature in Section 4.1

CoC	chain of custody
g	gram
lb	pound
mg/kg	milligrams per kilogram
U	Uranium

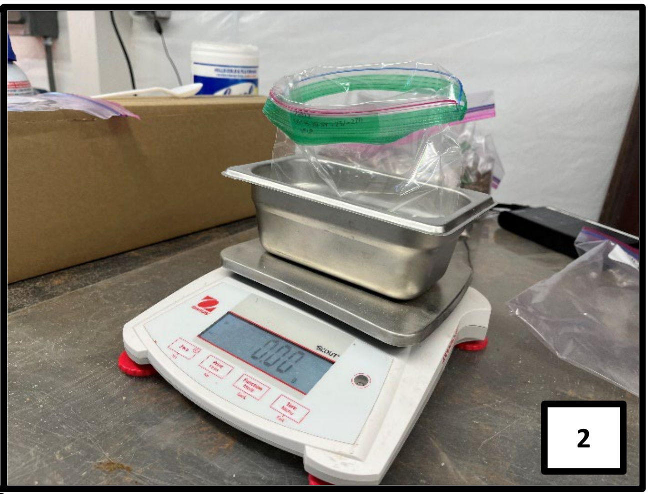
Mass Balance and Combination Goals

Sample ID	RO-TAP Mass (-270-mesh) [g]	Mass % of RO-TAP Sample	Mass % TTL by Mass Balance	Proposed Mass Added of CR-L-0-F [g]	RO-TAP -270 XRF U mg/kg	Fines XRF U mg/kg	Proposed Combined Concentrate U mg/kg
CR-L-4-SY	111.20	11.8%	9.83%	189.09	168	192	183
CR-L-8-SY	112.07	11.3%	9.38%	199.72	111	192	163
CR-L-30-SY	137.04	13.8%	11.51%	199.08	93	192	152

Sample Mass Check

Sample ID	Total RO-TAP Mass [g]	Total RO-TAP Mass Including Combined CR-L-0-F [g]	Concentrate Mass % of Total (Mass Calculated)	Concentrate Mass % of Total (Balance sum of Percents in this Sheet)
CR-L-4-SY	941.91	1131.00	26.55%	26.55%
CR-L-8-SY	994.84	1194.56	26.10%	26.10%
CR-L-30-SY	991.67	1190.75	28.23%	28.23%

Figure 26. Example of Mass Balance Used for Determination of Proper Fines Mixing for Old Church Rock Mine Low Sample Treatment (Part B)



Notes:

1	Quivira High Concentration 30 Minute HPSA Processing Sample Bags After Wet Sieve Separation and Drawing
2	Setup at Disa's Laboratory for Sample Splitting Into Subsamples
3	Final Sample Prepared for SPLP Analysis at Disa's Laboratory for Quivira High Concentration 30 Minute HPSA Processing
Disa	Disa Technologies, Inc.
HPSA	High-Pressure Slurry Ablation
SPLP	Synthetic Precipitation Leaching Procedure

Figure 27. Illustration of Sample Splitting Process After Wet Sieve Separation

Block Flow Diagram of Water Treatment System

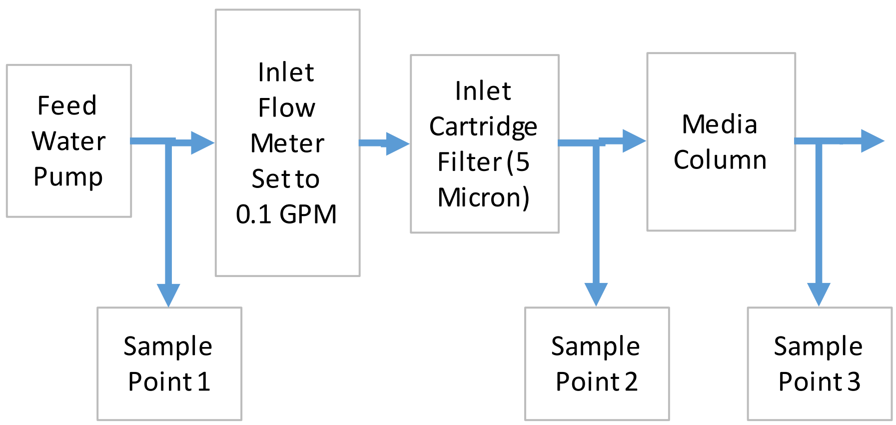
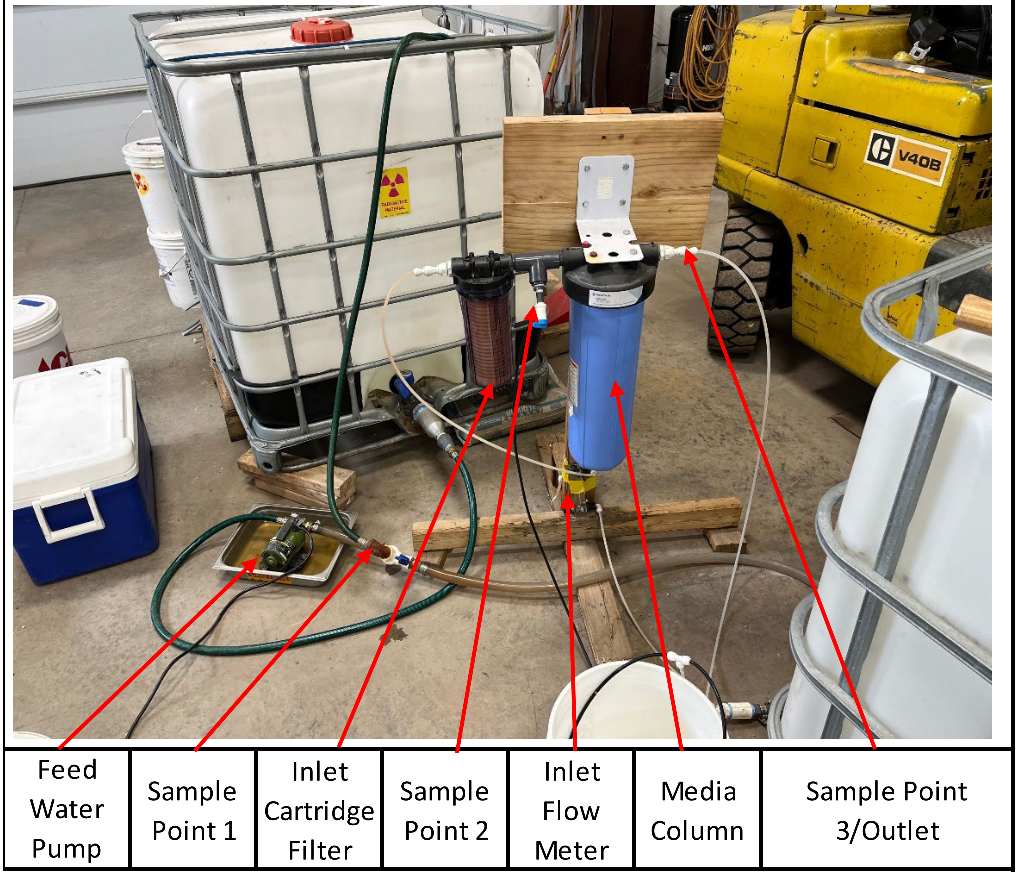


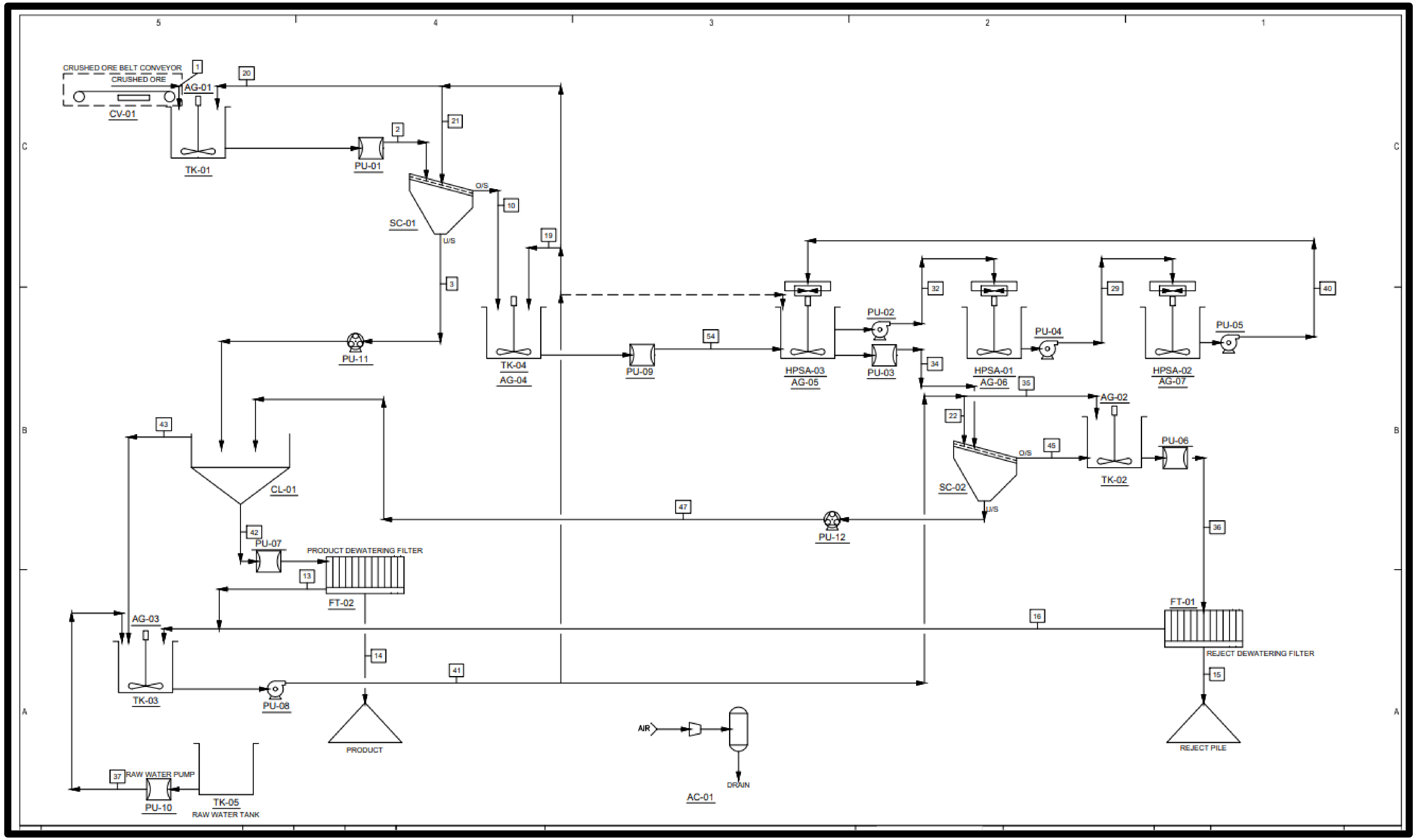
Photo of Water Treatment System



Notes:

GPM gallons per minute

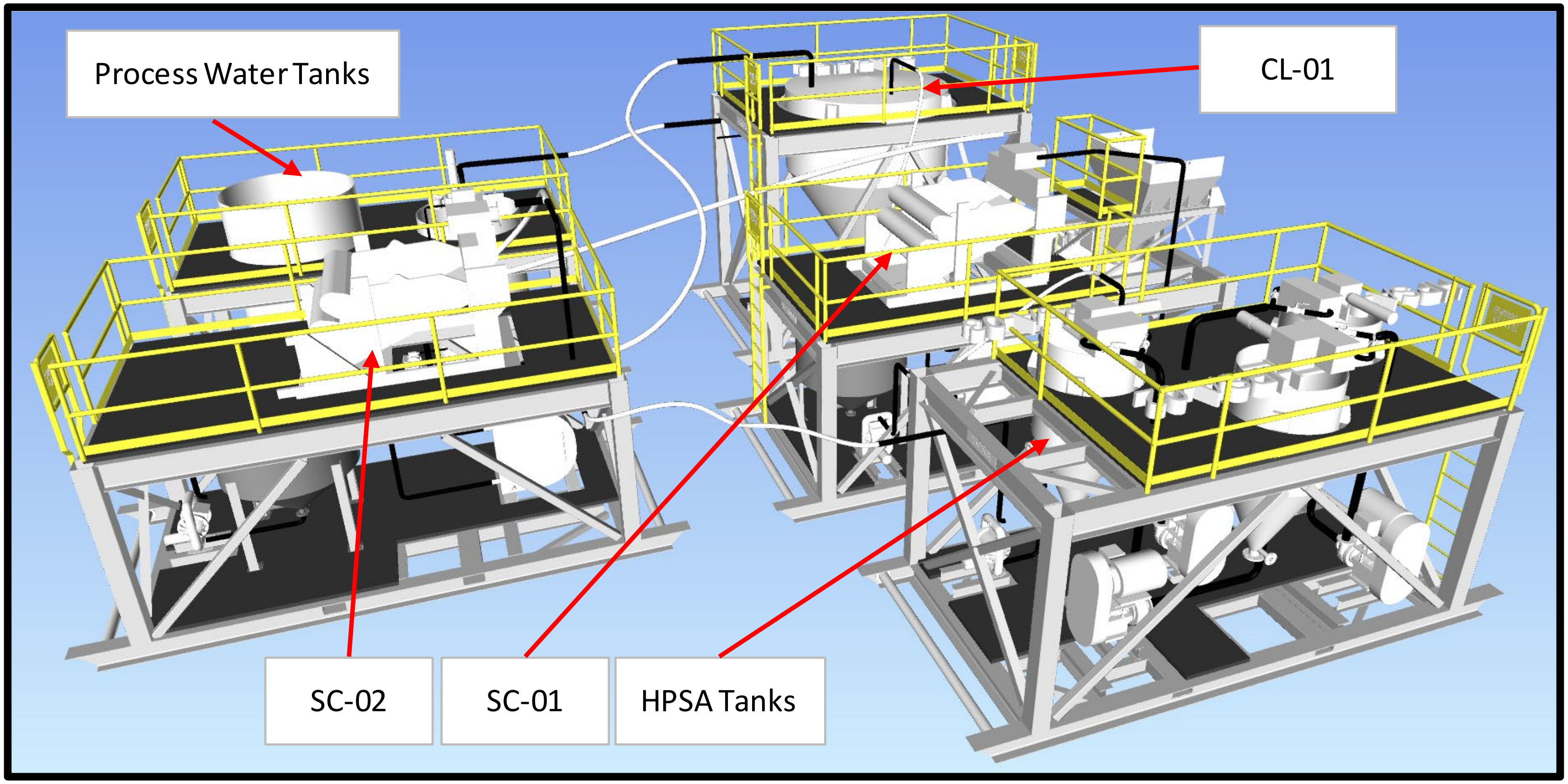
Figure 28. Block Flow Diagram and Photograph of Process Water Treatment System Tested Separately by Disa



Notes:

AC	air compressor	CV	conveyor	SC	screen
AG	agitator	FT	filter press	TK	tank
CL	clarifier	PU	pump		

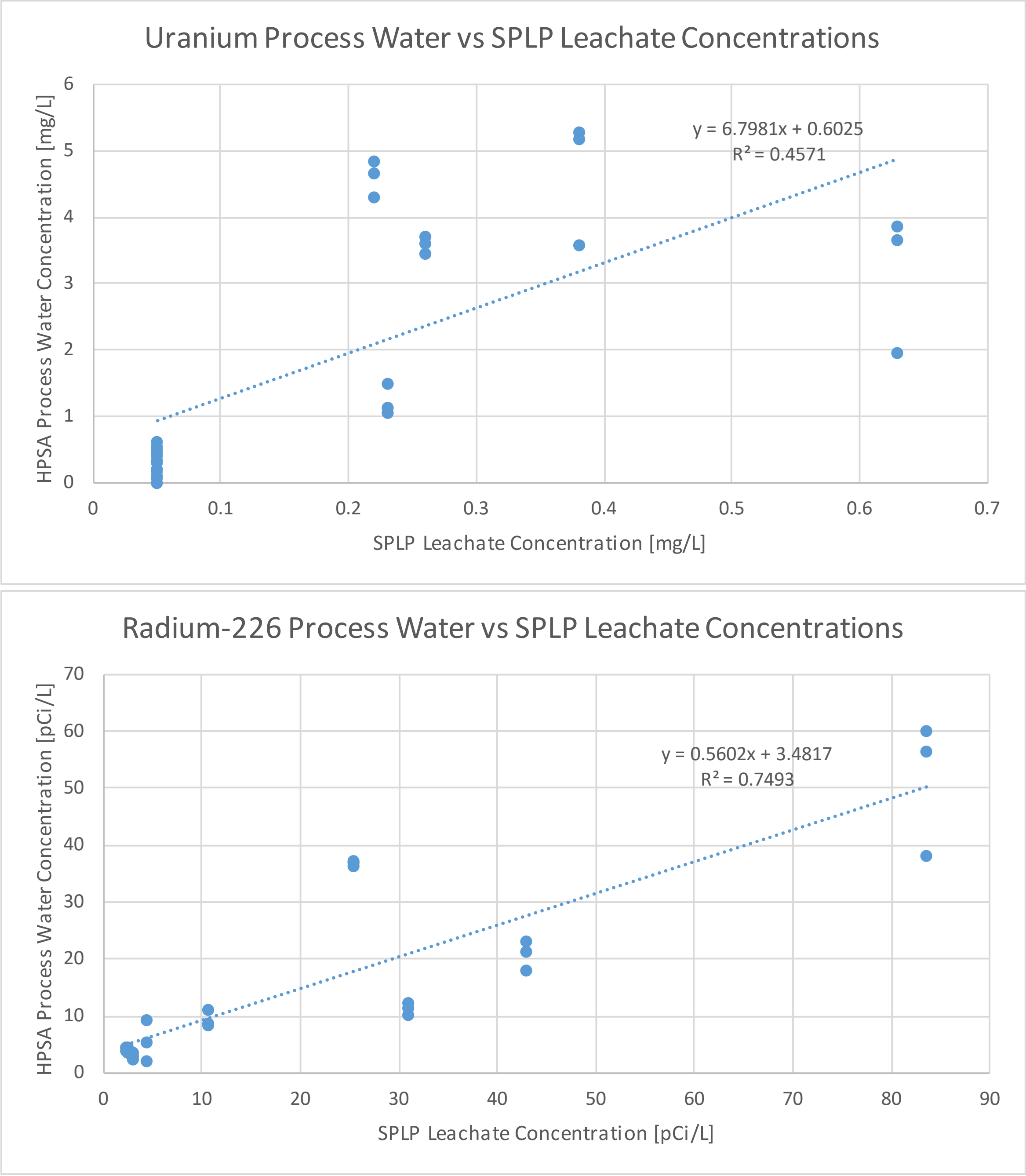
Figure 29. Process Flow Diagram for a Scaled Disa HPSA Full-Scale System with Associated Equipment



Notes:

CL	clarifier
HPSA	High-Pressure Slurry Ablation
SC	screen

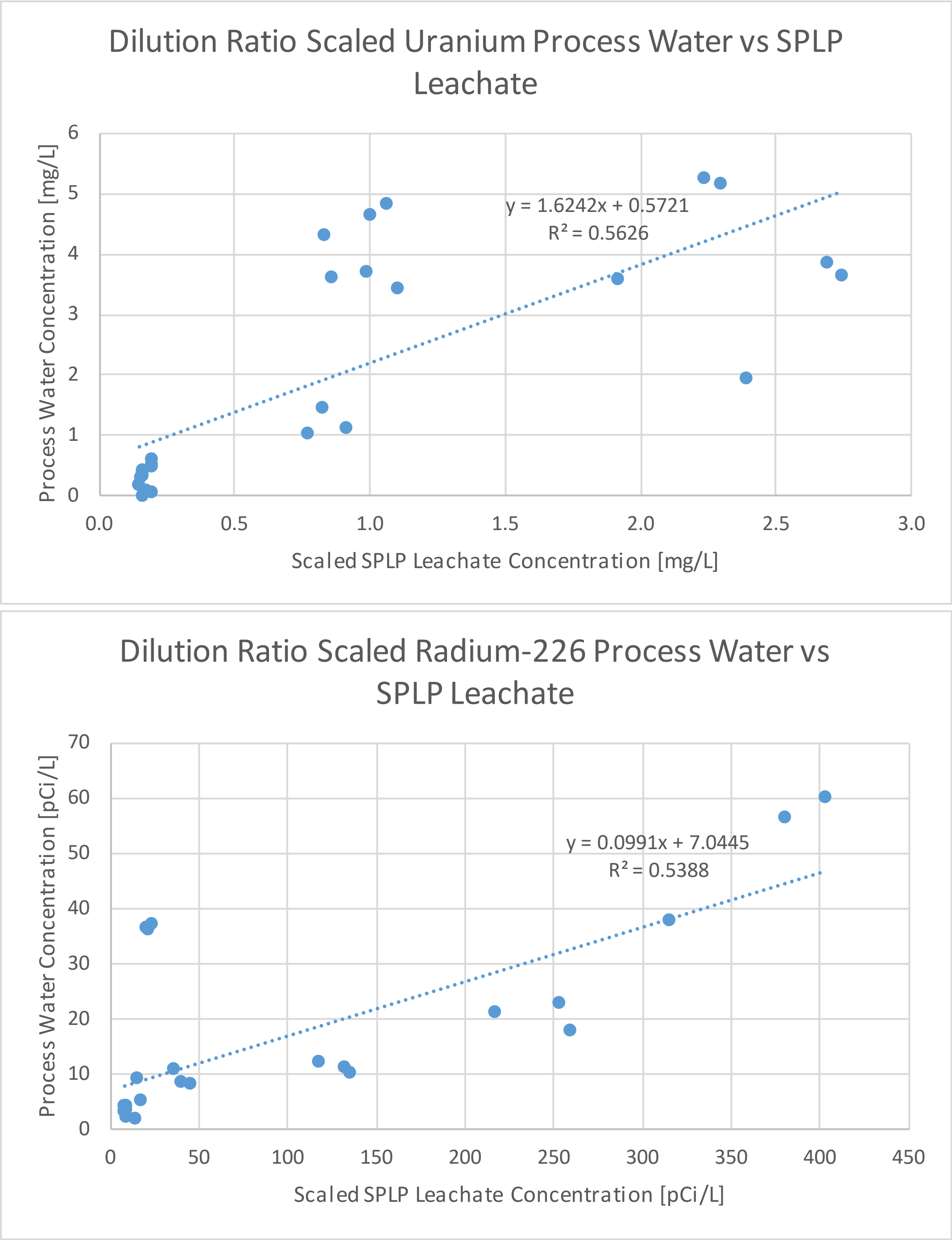
Figure 30. 3D Model for a Scaled Continuous Throughput Disa HPSA Full-Scale System with Associated Equipment



Notes:

mg/L	milligram per liter
pCi/L	picocuries per liter
SPLP	Synthetic Precipitation Leaching Procedure

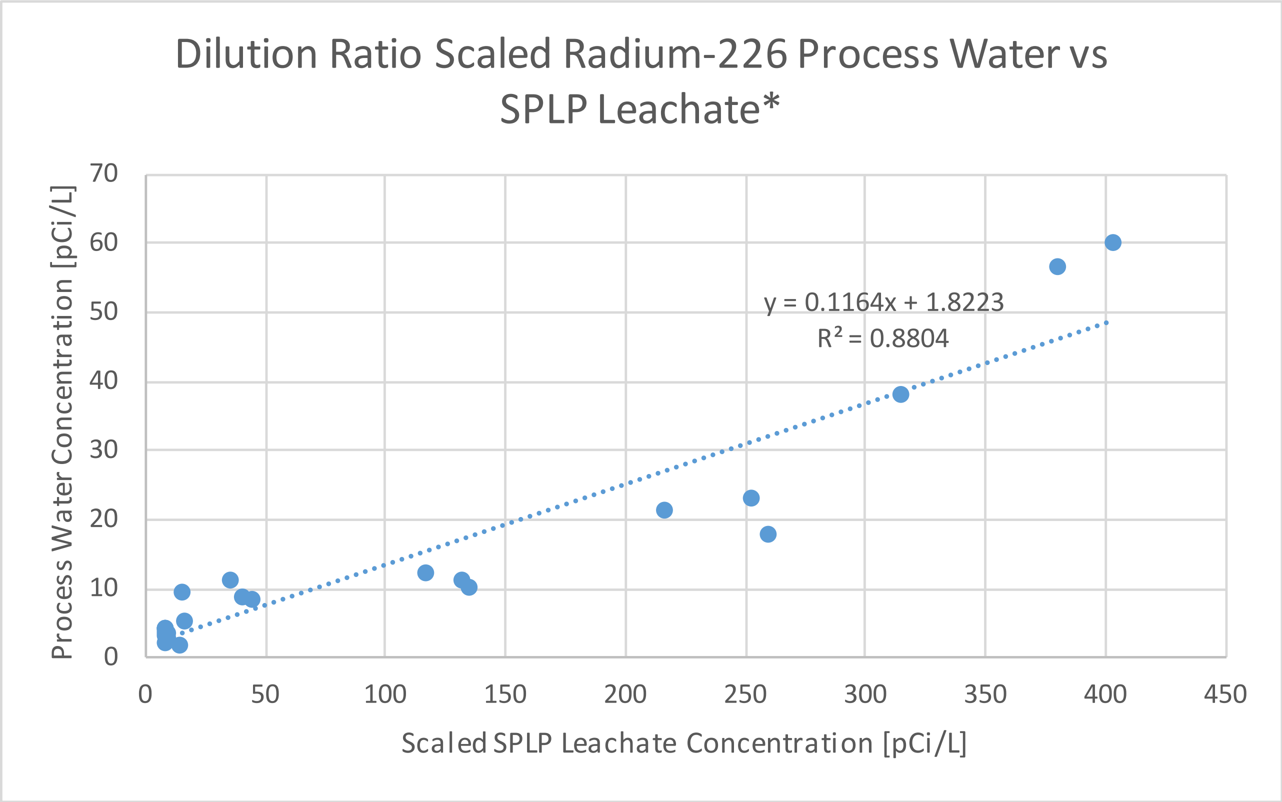
Figure 31. SPLP Leachate Concentrations of Uranium and Radium-226 Versus HPSA Process Water Sample Total Concentrations



Notes:

SPLP	Synthetic Precipitation Leaching Procedure
mg/L	milligram per liter
pCi/L	picocuries per liter

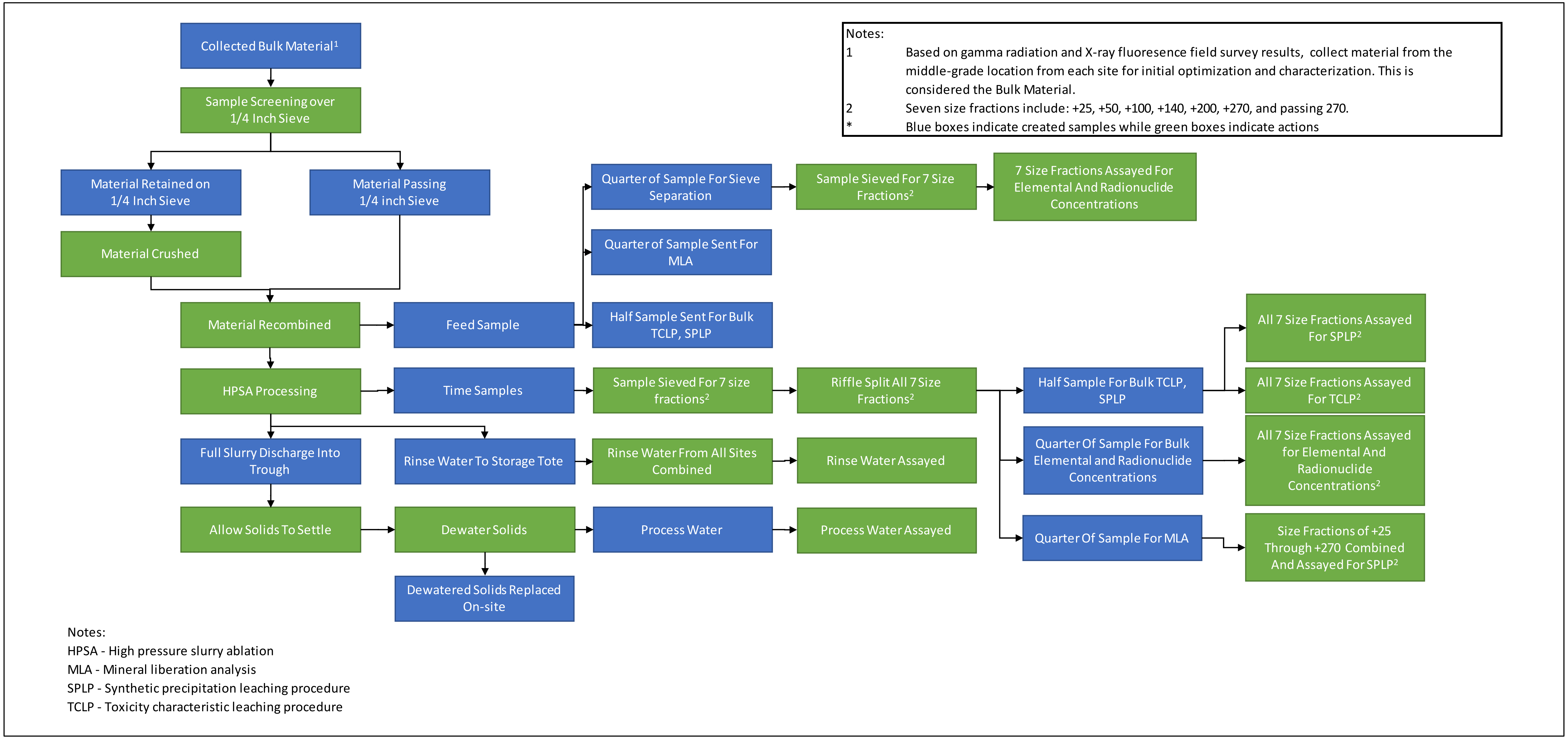
Figure 32. SPLP Leachate Concentrations of Uranium and Radium-226 Versus HPSA Process Water Sample Total Concentrations Scaled to Dilution Ratio



Notes:

*	Church Rock medium process water samples excluded for determination of effect on correlation
mg/L	milligram per liter
pCi/L	picocuries per liter
SPLP	Synthetic Precipitation Leaching Procedure

Figure 33. SPLP Leachate Concentration of Radium-226 Versus HPSA Process Water Sample Dissolved Concentrations Scaled to Dilution Ratio

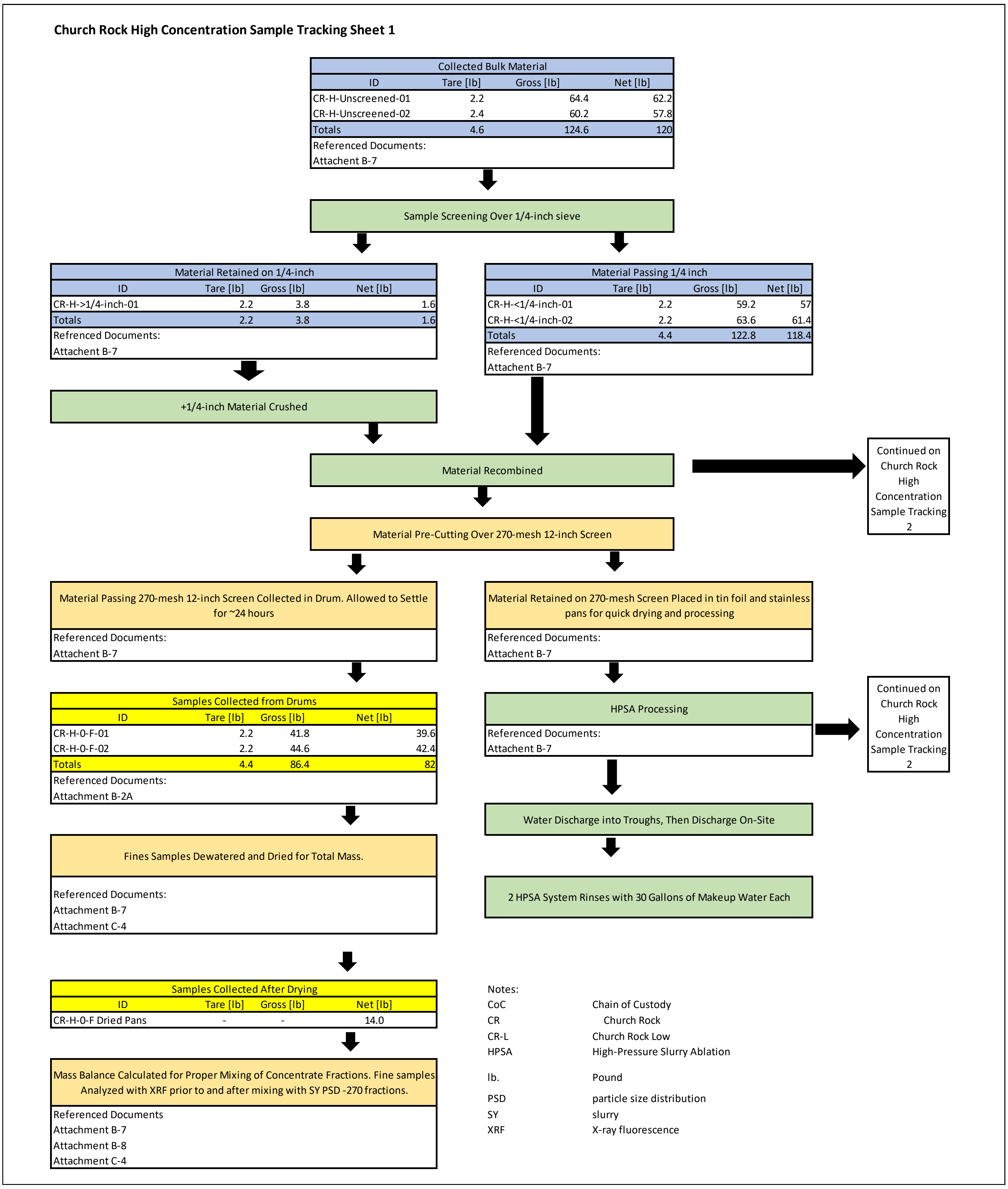


Notes:

1	Based on gamma radiation and X-ray fluoresence field survey results, collect material from the middle-grade location from each site for initial optimization and characterization. This is considered the Bulk Material.
2	Seven size fractions include: +25, +50, +100, +140, +200, +270, and passing 270.
*	Blue boxes indicate created samples while green boxes indicate actions

Notes:
HPSA - High pressure slurry ablation
MLA - Mineral liberation analysis
SPLP - Synthetic precipitation leaching procedure
TCLP - Toxicity characteristic leaching procedure

Figure 34. Originally Planned Handling of Material



Church Rock High Concentration Sample Tracking Sheet 1

Collected Bulk Material			
ID	Tare [lb]	Gross [lb]	Net [lb]
CR-H-Unscreened-01	2.2	64.4	62.2
CR-H-Unscreened-02	2.4	60.2	57.8
Totals	4.6	124.6	120
Referenced Documents: Attachent B-7			

Sample Screening Over 1/4-inch sieve

Material Retained on 1/4-inch			
ID	Tare [lb]	Gross [lb]	Net [lb]
CR-H->1/4-inch-01	2.2	3.8	1.6
Totals	2.2	3.8	1.6
Refrenced Documents: Attachent B-7			

Material Passing 1/4 inch			
ID	Tare [lb]	Gross [lb]	Net [lb]
CR-H-<1/4-inch-01	2.2	59.2	57
CR-H-<1/4-inch-02	2.2	63.6	61.4
Totals	4.4	122.8	118.4
Referenced Documents: Attachent B-7			

+1/4-inch Material Crushed

Material Recombined

Continued on Church Rock High Concentration Sample Tracking 2

Material Pre-Cutting Over 270-mesh 12-inch Screen

Material Passing 270-mesh 12-inch Screen Collected in Drum. Allowed to Settle for ~24 hours

Referenced Documents:
Attachent B-7

Material Retained on 270-mesh Screen Placed in tin foil and stainless pans for quick drying and processing

Referenced Documents:
Attachent B-7

Samples Collected from Drums			
ID	Tare [lb]	Gross [lb]	Net [lb]
CR-H-0-F-01	2.2	41.8	39.6
CR-H-0-F-02	2.2	44.6	42.4
Totals	4.4	86.4	82
Referenced Documents: Attachment B-2A			

HPSA Processing

Referenced Documents:
Attachent B-7

Continued on Church Rock High Concentration Sample Tracking 2

Water Discharge into Troughs, Then Discharge On-Site

2 HPSA System Rinses with 30 Gallons of Makeup Water Each

Fines Samples Dewatered and Dried for Total Mass.

Referenced Documents:
Attachment B-7
Attachment C-4

Samples Collected After Drying			
ID	Tare [lb]	Gross [lb]	Net [lb]
CR-H-0-F Dried Pans	-	-	14.0

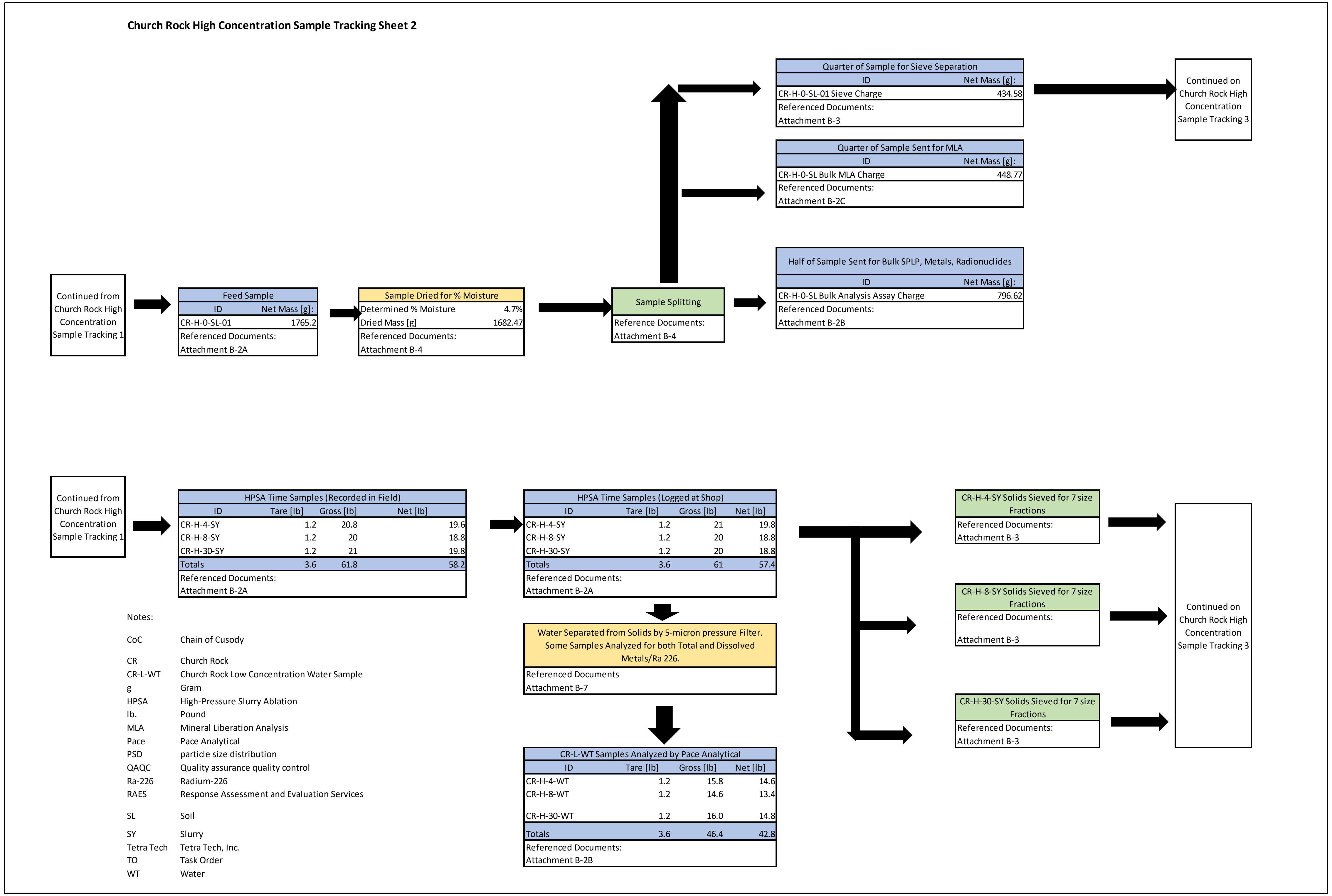
Mass Balance Calculated for Proper Mixing of Concentrate Fractions. Fine samples Analyzed with XRF prior to and after mixing with SY PSD -270 fractions.

Referenced Documents
Attachment B-7
Attachment B-8
Attachment C-4

Notes:

CoC	Chain of Custody
CR	Church Rock
CR-L	Church Rock Low
HPSA	High-Pressure Slurry Ablation
lb.	Pound
PSD	particle size distribution
SY	slurry
XRF	X-ray fluorescence

Figure 35. Example of Actual Handling of Material – Tracking Sheet 1



Church Rock High Concentration Sample Tracking Sheet 2

Continued from Church Rock High Concentration Sample Tracking 1

Feed Sample	
ID	Net Mass [g]:
CR-H-0-SL-01	1765.2
Referenced Documents:	
Attachment B-2A	

Sample Dried for % Moisture	
Determined % Moisture	4.7%
Dried Mass [g]	1682.47
Referenced Documents:	
Attachment B-4	

Sample Splitting

Reference Documents:
Attachment B-4

Quarter of Sample for Sieve Separation	
ID	Net Mass [g]:
CR-H-0-SL-01 Sieve Charge	434.58
Referenced Documents:	
Attachment B-3	

Quarter of Sample Sent for MLA	
ID	Net Mass [g]:
CR-H-0-SL Bulk MLA Charge	448.77
Referenced Documents:	
Attachment B-2C	

Half of Sample Sent for Bulk SPLP, Metals, Radionuclides	
ID	Net Mass [g]:
CR-H-0-SL Bulk Analysis Assay Charge	796.62
Referenced Documents:	
Attachment B-2B	

Continued on Church Rock High Concentration Sample Tracking 3

Continued from Church Rock High Concentration Sample Tracking 1

HPSA Time Samples (Recorded in Field)			
ID	Tare [lb]	Gross [lb]	Net [lb]
CR-H-4-SY	1.2	20.8	19.6
CR-H-8-SY	1.2	20	18.8
CR-H-30-SY	1.2	21	19.8
Totals	3.6	61.8	58.2
Referenced Documents:			
Attachment B-2A			

HPSA Time Samples (Logged at Shop)			
ID	Tare [lb]	Gross [lb]	Net [lb]
CR-H-4-SY	1.2	21	19.8
CR-H-8-SY	1.2	20	18.8
CR-H-30-SY	1.2	20	18.8
Totals	3.6	61	57.4
Referenced Documents:			
Attachment B-2A			

Water Separated from Solids by 5-micron pressure Filter. Some Samples Analyzed for both Total and Dissolved Metals/Ra 226.

Referenced Documents
Attachment B-7

CR-L-WT Samples Analyzed by Pace Analytical			
ID	Tare [lb]	Gross [lb]	Net [lb]
CR-H-4-WT	1.2	15.8	14.6
CR-H-8-WT	1.2	14.6	13.4
CR-H-30-WT	1.2	16.0	14.8
Totals	3.6	46.4	42.8
Referenced Documents:			
Attachment B-2B			

CR-H-4-SY Solids Sieved for 7 size Fractions

Referenced Documents:
Attachment B-3

CR-H-8-SY Solids Sieved for 7 size Fractions

Referenced Documents:
Attachment B-3

CR-H-30-SY Solids Sieved for 7 size Fractions

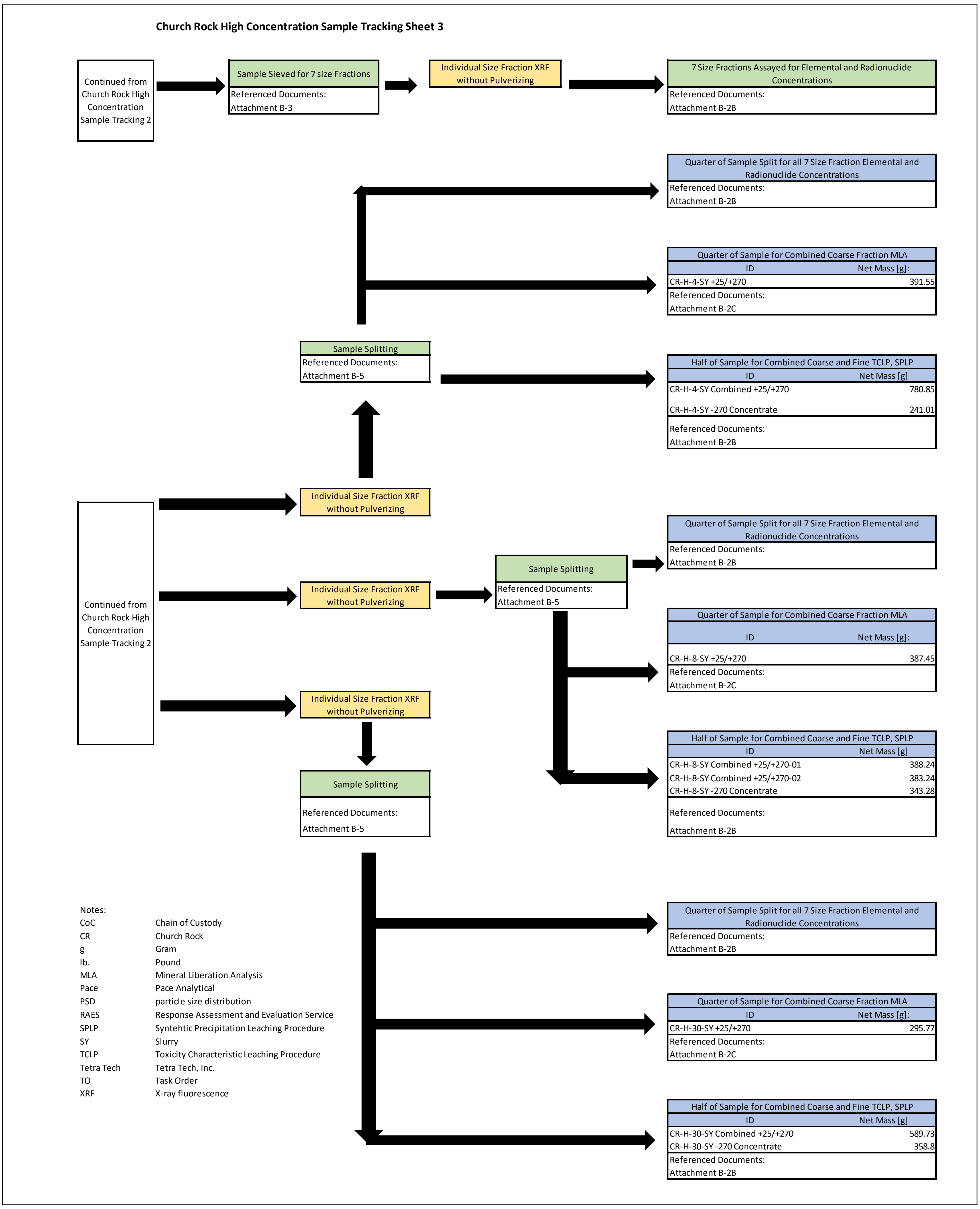
Referenced Documents:
Attachment B-3

Continued on Church Rock High Concentration Sample Tracking 3

Notes:

CoC	Chain of Cusody
CR	Church Rock
CR-L-WT	Church Rock Low Concentration Water Sample
g	Gram
HPSA	High-Pressure Slurry Ablation
lb.	Pound
MLA	Mineral Liberation Analysis
Pace	Pace Analytical
PSD	particle size distribution
QAQC	Quality assurance quality control
Ra-226	Radium-226
RAES	Response Assessment and Evaluation Services
SL	Soil
SY	Slurry
Tetra Tech	Tetra Tech, Inc.
TO	Task Order
WT	Water

Figure 36. Example of Actual Handling of Material – Tracking Sheet 2



Notes:

CoC	Chain of Custody
CR	Church Rock
g	Gram
lb.	Pound
MLA	Mineral Liberation Analysis
Pace	Pace Analytical
PSD	particle size distribution
RAES	Response Assessment and Evaluation Service
SPLP	Syntehtic Precipitation Leaching Procedure
SY	Slurry
TCLP	Toxicity Characteristic Leaching Procedure
Tetra Tech	Tetra Tech, Inc.
TO	Task Order
XRF	X-ray fluorescence

Figure 37. Example of Actual Handling of Material – Tracking Sheet 3

Notes:

1 Bucket with lid still placed on top for sample identification

2 Settled solids at the bottom of the bucket to illustrate two sample splits for wet sieving remain

Figure 38. Old Church Rock Mine Sample (CR-H-4-SY) and Settled Solids at the Bottom of the Bucket

TABLES

Table 1. Analysis of Pre-HPSA Uranium Waste and Post-HPSA Coarse Fraction for Daughter Product Activity at a Different Site

Parameter	Unit	Waste Feed	Precision (±)	Coarse Fraction	Precision (±)	Total Reduction	Percent Reduction
Lead-210	pCi/g	149	4.7	37.1	1.5	111.9	75.1%
Radium-226	pCi/g	125	3	70.4	1.9	54.6	43.7%
Radium-228	pCi/g	1.9	1.2	1	1.1	0.9	47.4%
Thorium-230	pCi/g	153	22.8	74.7	10.2	78.3	51.2%
Thorium-232	pCi/g	<0.2	NA	<0.2	NA	NC	NC

Notes:
Performed as part of a previous project by Disa Technologies, Inc. for a private site. Data generated from the previous project is not a part of this treatability study.
A “<” symbol indicates a nondetect result less than the corresponding method detection limit.

HPSA	High-pressure slurry ablation
NA	Not analyzed
NC	Not calculated
pCi/g	Picocurie per gram

Table 2. Results of SPLP Metals and Radionuclides Analysis at a Different Site Performed on Pre-HPSA Treated Uranium Waste Rock and Post-HPSA Coarse Fraction

Constituent	Unit	Feed	Coarse Fraction	Percent Difference
Fluoride	mg/L	< 0.1	< 0.1	NC
Nitrate/Nitrite	mg/L	< 0.5	< 0.5	NC
Cyanide, Free	mg/L	0.07	< 0.01	85.7
Nitrogen, Nitrate	mg/L	< 0.5	< 0.5	NC
Nitrogen, Nitrite	mg/L	< 0.5	< 0.5	NC
pH	-	7.8	7.6	2.6
Antimony	mg/L	< 0.005	< 0.005	NC
Arsenic	mg/L	0.664	0.148	77.7
Barium	mg/L	< 0.1	< 0.1	NC
Beryllium	mg/L	< 0.004	< 0.004	NC
Cadmium	mg/L	< 0.001	< 0.001	NC
Chromium	mg/L	< 0.1	< 0.1	NC
Lead	mg/L	0.014	0.006	57.1
Mercury	mg/L	< 0.002	< 0.002	NC
Molybdenum	mg/L	< 0.02	< 0.02	NC
Nickel	mg/L	< 0.1	< 0.1	NC
Selenium	mg/L	0.02	0.006	0.7
Silver	mg/L	< 0.03	< 0.03	NC
Thallium	mg/L	< 0.001	< 0.001	NC
Uranium	mg/L	0.1	0.06	0.4
Vanadium	mg/L	0.57	0.14	75.4
Lead-210	pCi/L	9.9	6.2	37.4
Radium-226	pCi/L	20	9.8	0.51
Radium-228	pCi/L	< 2	< 2	NC
Thorium-230	pCi/L	7.4	4	45.9
Thorium-232	pCi/L	< 0.2	< 0.2	NC

Notes:

Performed as part of previous project by Disa Technologies, Inc. for a private site. Data generated from the previous project is not a part of this treatability study.

A “<” symbol indicates a nondetect result less than the corresponding method detection limit.

-	Not applicable
HPSA	High-pressure slurry ablation
mg/L	Milligram per liter
NC	Not calculated
pCi/L	Picocurie per liter
SPLP	Synthetic precipitation leaching procedure

Table 3. May 2022 Reconnaissance Survey Results for Low-, Medium-, and High-Concentration Samples at Each Site

Site	Sample Date	Sample Concentration	Field XRF Average Uranium Concentration (mg/kg)	Field Excavation			Disa XRF Average Uranium Concentration (mg/kg)	Pace Uranium Concentration (mg/kg)	Pace Radium-226 Concentration (pCi/g)
				Depth (feet)	Gamma Radiation Activity (cpm)	XRF Uranium Concentration Range (mg/kg)			
Quivira CR-1	5/10/2022	Low	75	Surface	22,000	NA			
				1	110,000	NA			
				1.5	NA	34-71			
				2	NA	27-113			
				2.5	NA	< 2-106			
		Medium	65	Surface	23,000	NA	99	75	64.5
				1	80,000	NA			
				1.5	195,000	NA			
				2.0	NA	15-65			
				2.25	NA	15-27			
				2.50	NA	47-93			
				2.75	260,000	40-59			
				3.00	NA	51-187			
		High	689	Surface	35,000	NA			
				0.5	NA	357-444			
				1	400,000	210-1,571			
				2	NA	26-1,649			
OCRM	5/11/2022	Low	171	Surface	110,000	12-15			
				1	NA	163-338			
				2	NA	40-375			
		Medium	212	Surface	450,000	99-113	262	204	11.4
				0.5	NA	104-128			
				1	NA	236-462			
				1.5	NA	314-404			
				2	NA	125-136			
		High	1,143	Surface	600,000	693-944			
				1	NA	782-1,438			
				2	NA	819-1,954			

Table 3. May 2022 Reconnaissance Survey Results for Low-, Medium-, and High-Concentration Samples at Each Site

Site	Sample Date	Sample Concentration	Field XRF Average Uranium Concentration (mg/kg)	Field Excavation			Disa XRF Average Uranium Concentration (mg/kg)	Pace Uranium Concentration (mg/kg)	Pace Radium-226 Concentration (pCi/g)
				Depth (feet)	Gamma Radiation Activity (cpm)	XRF Uranium Concentration Range (mg/kg)			
CTS 2	5/12/2022	Low	161	Surface	20,500	27-1,600			
				0.33	20,000	NA			
				0.5	NA	9-1,864			
				1	NA	8-12			
		Medium	2,873	Surface	41,000	118-67,106	78*	48*	52*
				0.5	NA	15-34			
				1.0	38,000	< 1-62			
				1.5	40,000	5-11			
				2.0	NA	22-25			
		High	208	Surface	60,000	12-42			
				1	NA	11-1,350			
				2	NA	21-909			

Notes:

*	Average of duplicate samples
cpm	Counts per minute
CR-1	Quivira Church Rock Mine 1
CTS 2	Cove Transfer Station 2
Disa	Disa Technologies, Inc.
mg/kg	Milligram per kilogram
NA	Not analyzed
OCRM	Old Church Rock Mine
Pace	Pace Analytical Services, LLC
pCi/g	Picocurie per gram
XRF	X-ray fluorescence

Table 4. Previous Waste Characterization Data for Each Site

Analyte	Units	Minimum Concentration	Maximum Concentration
Cove Transfer Station 2 (Surface Soil)*			
Radium-226**	pCi/g	1.4	76.6
Arsenic	mg/kg	1.3	7.7
Selenium	mg/kg	0.46	2.3
Thallium	mg/kg	NA	NA
Uranium	mg/kg	0.1	19
Vanadium	mg/kg	8	51
Quivira Church Rock 1 Mine (Surface Soil)			
Radium-226	pCi/g	0.82	47.1
Arsenic	mg/kg	2.7	11
Molybdenum	mg/kg	0.15	0.7
Selenium	mg/kg	0.79	14
Thallium	mg/kg	0.044	0.22
Uranium	mg/kg	0.61	55
Vanadium	mg/kg	8.6	21
Old Church Rock Mine (Surface Soil)			
Radium-226***	pCi/g	10.1	238
Uranium****	mg/kg	0	473

Notes

*	Concentration data are from CTS Complex sites (except CTS 2 stockpile) and reflect conditions after the 2013 removal action and restoration unless otherwise noted.
**	Concentration data are from CTS 2 stockpile surface soil after the 2013 removal action at CTS 1 based on gamma correlation. No other metals were evaluated in the removal action.
***	Concentration data are from a Disa 2019 ablation study (Disa 2020). Samples (three samples) are from a limited area and are not reflective of the site characterization or range of concentrations present.
****	Concentration data are from a Disa 2019 ablation study (Disa 2020). X-ray fluorescence measurements during sample collection (six samples) are from a limited area and are not reflective of the site characterization or range of concentrations present.
CTS	Cove Transfer Station
Disa	Disa Technologies, Inc.
mg/kg	Milligram per kilogram
NA	Not analyzed
pCi/g	Picocurie per gram

Reference:

Disa Technologies, Inc. (Disa). 2020. “Abstract of Disa’s High Pressure Slurry Ablation (HPSA) Process: Preliminary Report on Navajo Nation Abandoned Uranium Mine Materials.” April 8.

Table 5. Uranium Results Summaries for All Three Sites Treated at the Disa Process Laboratory During Bench-Scale Study

Old Church Rock Mine	Amenability Test			Close Nozzle Test		
Parameter	HPSA Treatment Time			HPSA Treatment Time		
	4 Minutes	8 Minutes	30 Minutes	60 Minutes	4 Minutes	8 Minutes
Feed Concentration (mg/kg)	203	239	210	259	218	228
Coarse Fraction (mg/kg)	18	13	18	11	18	16
Fines Fraction (mg/kg)	680	810	720	620	1067	1013
Contaminant Reduction	91.1%	94.6%	91.4%	95.8%	91.8%	93.0%
Contaminant Recovery in Fines	92.8%	95.9%	93.8%	97.4%	93.4%	94.5%
Treated Mass to Fines Fraction	27.7%	28.3%	27.3%	40.7%	19.1%	21.3%

Quivira Church Rock 1 Mine	Amenability Test		Close Nozzle Test	
Parameter	HPSA Treatment Time		HPSA Treatment Time	
	4 Minutes	8 Minutes	4 Minutes	8 Minutes
Feed Concentration (mg/kg)	111	85	86	84
Coarse Fraction (mg/kg)	22	14	14	14
Fines Fraction (mg/kg)	373	346	511	502
Contaminant Reduction	80.2%	83.0%	84.2%	83.8%
Contaminant Recovery in Fines	85.2%	83.0%	81.0%	86.1%
Treated Mass to Fines Fraction	25.5%	20.4%	13.7%	14.4%

Cove Transfer Station 2	Amenability Test		Close Nozzle Test		
Parameter	HPSA Treatment Time		HPSA Treatment Time		
	4 Minutes	8 Minutes	2 Minutes	4 Minutes	15 Minutes
Feed Concentration (mg/kg)	58	47	50	50	50
Coarse Fraction (mg/kg)	59	39	30	28	21
Fines Fraction (mg/kg)	56	57	63	69	70
Contaminant Reduction	NC	18.0%	39.4%	43.7%	58.3%
Contaminant Recovery in Fines	43.8%	56.5%	69.3%	78.6%	83.3%
Treated Mass to Fines Fraction	45.1%	47.0%	54.8%	57.3%	59.5%

Notes:

Disa	Disa Technologies, Inc.
HPSA	High-pressure slurry ablation
mg/kg	Milligram per kilogram
NC	Not calculated

Table 6. Cove Transfer Station 2 Low-, Medium-, and High-Concentration Feed Material Total Metals and Radium-226 Concentrations and SPLP Leachable Metals and Radium-226 Concentrations

Sample ID	Low-Concentration Fee		Medium-Concentration Feed		High-Concentration Feed		Lowest of Surface Water Quality Standard (mg/L or pCi/L)
Analyte	Soil Sample (mg/kg or pCi/g)	SPLP Leachate (mg/L or pCi/L)	Soil Sample (mg/kg or pCi/g)	SPLP Leachate (mg/L or pCi/L)	Soil Sample (mg/kg or pCi/g)	SPLP Leachate (mg/L or pCi/L)	
Antimony	< 1.96	< 0.000389	< 1.96	< 0.000389	< 1.96	< 0.000389	0.006
Aluminum	NA	**17.2**	NA	**5.1**	NA	**12.6**	0.087
Arsenic	< 4.85	< 0.00154	< 4.85	0.0048	< 4.85	0.00528	0.01
Barium	220	0.11	270	0.0444	240	0.08	2
Beryllium	0.833	< 0.0257	0.731	< 0.0257	0.721	< 0.0257	0.004
Cadmium	< 0.344	< 0.00008	< 0.344	< 0.00008	< 0.344	< 0.00008	0.005
Chromium	< 15.9	0.01	< 15.9	0.00329	< 15.9	0.00817	0.1
Cobalt	4.81	0.00238	4.6	< 0.00169	4.72	0.00199	0.05
Copper	7.11	0.005	5.65	0.00267	6.18	0.00283	0.2
Iron	NA	7.85	NA	2.24	NA	5.68	NP
Lead	8.65	0.00187	7.77	< 0.00159	10	< 0.00159	0.015
Manganese	400	0.0922	430	0.0225	380	0.0584	NP
Molybdenum	< 0.725	< 0.00819	< 0.725	< 0.00819	< 0.725	< 0.00819	1
Nickel	12.2	0.00221	11.5	< 0.0009	11.8	0.00138	2
Selenium	< 4.64	< 0.004	8.27	< 0.004	< 4.64	< 0.004	0.002
Silver	< 0.312	< 0.000577	< 0.312	< 0.000577	< 0.312	< 0.000577	4.67
Thallium	< 0.511	< 0.0266	< 0.511	< 0.0266	< 0.511	< 0.0266	0.001
Uranium	4.52	< 0.0241	40	< 0.0241	50	< 0.0241	0.03
Vanadium	31.2	0.093	240	**2**	280	**1.88**	0.1
Zinc	NA	0.0162	NA	< 0.0113	NA	< 0.0113	5.1
Radium-226	1.6	4.3	12.7	2.5	15	2.3	5

Notes:

🟩 U.S. Environmental Protection Agency maximum contaminant level (mg/L)

🟥 Minimum Navajo Nation surface water criterion (mg/L)

A “<” symbol indicates a nondetect result less than the corresponding method detection limit.

Bolded values indicate an exceedance.

mg/kg	Milligram per kilogram	pCi/g	Picocuries per gram
mg/L	Milligram per liter	pCi/L	Picocuries per liter
NA	Not analyzed	SPLP	Synthetic precipitation leaching procedure
NP	Not promulgated		

Table 7. Quivira Church Rock 1 Low-, Medium-, and High-Concentration Feed Material Total Metals and Radium-226 Concentrations and SPLP Leachable Metals and Radium-226 Concentrations

Sample ID	Low-Concentration Feed		Medium-Concentration Feed		High-Concentration Feed		Lowest of Surface Water Quality Standard (mg/L or pCi/L)
Analyte	**Soil Sample (mg/kg or pCi/g)**	**SPLP Leachate (mg/L or pCi/L)**	**Soil Sample (mg/kg or pCi/g)**	**SPLP Leachate (mg/L or pCi/L)**	**Soil Sample (mg/kg or pCi/g)**	**SPLP Leachate (mg/L or pCi/L)**	
Antimony	< 1.96	< 0.000389	< 1.96	< 0.0257	< 1.96	< 0.0257	0.006
Aluminum	NA	**7.9**	NA	**18.8**	NA	**4.8**	0.087
Arsenic	< 4.85	< 0.00154	< 4.85	0.00271	< 4.85	< 0.00154	0.01
Barium	90	0.05	90	0.17	100	0.0482	2
Beryllium	0.517	< 0.0257	0.409	0.00051	0.551	< 0.000389	0.004
Cadmium	< 0.344	< 0.00008	< 0.344	< 0.00008	< 0.344	< 0.00008	0.005
Chromium	< 15.9	0.0048	< 15.9	0.00901	< 15.9	0.00212	0.1
Cobalt	2.77	< 0.0009	2.21	0.00248	2.24	< 0.00169	0.05
Copper	5.12	0.0043	4.25	0.00604	3.6	0.00245	0.2
Iron	NA	4.47	NA	10.8	NA	2.79	NP
Lead	6.86	0.00395	6.52	0.00968	6.8	0.00324	0.015
Manganese	150	0.0442	140	0.1	150	0.0327	NP
Molybdenum	< 0.725	< 0.00819	0.895	0.01	2.9	0.00841	1
Nickel	< 4.71	< 0.00169	< 4.71	< 0.00169	5.51	< 0.0009	2
Selenium	21.7	**0.0694**	37.4	**0.0742**	45.7	**0.0821**	0.002
Silver	< 0.312	< 0.000577	< 0.312	< 0.000577	< 0.312	< 0.000577	4.67
Thallium	< 0.511	< 0.0266	< 0.511	< 0.0266	< 0.511	< 0.0266	0.001
Uranium	110	0.26	230	**0.63**	400	**0.38**	0.03
Vanadium	40	0.038	70	0.147	90	0.066	0.1
Zinc	NA	0.0211	NA	0.0337	NA	< 0.0113	5.1
Radium-226	31.8	**10.6**	91.9	**30.9**	121	**42.9**	5

Notes:

🟩 U.S. Environmental Protection Agency maximum contaminant level (mg/L)

🟥 Minimum Navajo Nation surface water criterion (mg/L)

A "<" symbol indicates a nondetect result less than the corresponding method detection limit.

Bolded values indicate an exceedance.

mg/kg	Milligram per kilogram	pCi/g	Picocurie per gram
mg/L	Milligram per liter	pCi/L	Picocurie per liter
NA	Not analyzed	SPLP	Synthetic precipitation leaching procedure
NP	Not promulgated		

Table 8. Old Church Rock Mine Low-, Medium-, and High-Concentration Feed Material Total Metals and Radium-226 Concentrations and SPLP Leachable Metals and Radium-226 Concentrations

Sample ID	Low-Concentration Feed		Medium-Concentration Feed		High-Concentration Feed		Lowest of Surface Water Quality Standard (mg/L or pCi/L)
Analyte	Soil Sample (mg/kg or pCi/g)	SPLP Leachate (mg/L or pCi/L)	Soil Sample (mg/kg or pCi/g)	SPLP Leachate (mg/L or pCi/L)	Soil Sample (mg/kg or pCi/g)	SPLP Leachate (mg/L or pCi/L)	
Antimony	< 1.96	< 0.0257	< 1.96	< 0.0257	< 1.96	< 0.0257	0.006
Aluminum	NA	**19.7**	NA	**14.4**	NA	**2**	0.087
Arsenic	< 4.85	< 0.00154	< 4.85	< 0.00154	< 4.85	< 0.00154	0.01
Barium	180	0.06	140	0.05	150	0.09	2
Beryllium	0.763	0.00041	0.476	0.00042	0.468	< 0.000389	0.004
Cadmium	< 0.344	< 0.00008	< 0.344	< 0.00008	< 0.344	< 0.00008	0.005
Chromium	< 15.9	0.01	< 15.9	0.00734	< 15.9	0.00107	0.1
Cobalt	5.12	0.00224	2.52	0.00217	2.11	< 0.00169	0.05
Copper	7.59	0.00733	4.47	0.00511	< 2.92	0.00119	0.2
Iron	NA	8.79	NA	8.04	NA	1.43	NP
Lead	7.93	0.00331	6.46	0.00553	5.64	0.00206	0.015
Manganese	180	< 0.00819	170	< 0.00819	100	< 0.00819	NP
Molybdenum	< 0.725	0.049	< 0.725	0.061	< 0.725	0.0112	1
Nickel	6.82	0.00245	< 4.71	< 0.0009	< 4.71	< 0.0009	2
Selenium	9.03	< 0.004	80	< 0.004	48.7	**0.155**	0.002
Silver	< 0.312	< 0.000577	< 0.312	< 0.000577	< 0.312	< 0.000577	4.67
Thallium	< 0.511	< 0.0266	< 0.511	< 0.0266	< 0.511	< 0.0266	0.001
Uranium	40	< 0.0241	260	**0.23**	940	**0.22**	0.03
Vanadium	32.8	0.062	90	**0.241**	170	0.084	0.1
Zinc	NA	0.0266	NA	0.023	NA	< 0.0113	5.1
Radium-226	19.7	3	104	**25.4**	228	**83.6**	5

Notes:

🟩 U.S. Environmental Protection Agency maximum contaminant level (mg/L)

🟧 Minimum Navajo Nation surface water criterion (mg/L)

A “<” symbol indicates a nondetect result less than the corresponding method detection limit.

Bolded values indicate an exceedance.

mg/kg	Milligram per kilogram
mg/L	Milligram per liter
NA	Not analyzed
NP	Not promulgated
pCi/g	Picocurie per gram
pCi/L	Picocurie per liter
SPLP	Synthetic precipitation leaching procedure

Table 9. Comparison of Fractionation Water from Disa Process Laboratory Wet Sieving Totes to Casper, Wyoming, Municipal Discharge Limits

Metal	Casper Municipal Local Limit* (mg/L)	Fractionation Water Results		
		Old Church Rock Mine Fractionation Water (mg/L)	Quivira Church Rock 1 Mine Fractionation Water (mg/L)	Cove Transfer Station 2 Fractionation Water (mg/L)
Arsenic	6.42	0.0016	0.00211	0.00242
Cadmium	3.48	< 0.0000474	< 0.0000474	< 0.0000474
Chromium	39.44	< 0.0011	0.00119	0.00126
Copper	27.66	0.14	0.16	0.08
Lead	6.84	0.000458	0.000246	0.000607
Molybdenum	4.11	0.00265	0.00615	0.00349
Nickel	20.49	0.00293	< 0.00252	< 0.00252
Selenium	3.08	0.013	0.014	0.008
Silver	18.08	< 0.000206	< 0.000206	< 0.000206
Zinc	43.6	0.06	0.06	0.03
Mercury	0.49	NA	NA	NA

Notes:
A “<” symbol indicates a nondetect result less than the corresponding method detection limit.

*	Limits per the Casper, Wyoming, municipal code at Title 13, Chapter 13.32.
Disa	Disa Technologies, Inc.
mg/L	Milligram per liter
NA	Not analyzed

Table 10. Comparison of Fractionation Water from Disa Process Laboratory Wet Sieving Totes to NRC Regulations

Constituent	Radionuclide Limits*			Fractionation Water Results		
	Monthly Average Release to Sewers (µCi/mL)	Monthly Average Release to Sewers (pCi/L)	Monthly Average Release to Sewers (mg/L)	Old Church Rock Mine Fractionation Water (mg/L or pCi/L)	Quivira Church Rock 1 Mine Fractionation Water (mg/L or pCi/L)	Cove Transfer Station 2 Fractionation Water (mg/L or pCi/L)
Radium-226	6.00E-07	600	Not applicable	23.9	20.2	8.2
Thorium-230	1.00E-06	1,000	Not applicable	1.6	0.8	1.6
Uranium	3.00E-06	3,000	4.23**	0.456	0.726	0.039

Notes:

*	Limits under NRC regulation at 10 *Code of Federal Regulations* Part 20, Appendix B, Table 3.
**	Calculated limit based on specific activity of 7.10e-7 pCi/g for natural uranium.
µCi/mL	Microcurie per milliliter
Disa	Disa Technologies, Inc.
mg/L	Milligram per liter
NRC	Nuclear Regulatory Commission
pCi/g	Picocurie per gram
pCi/L	Picocurie per liter

Table 11. Process Water After 5-Micron Pressure Filtration and No Water Treatment

Analyte	Gallup Makeup Water (mg/L)	Old Church Rock Mine (mg/L)	Quivira Church Rock 1 Mine (mg/L)	Cove Transfer Station 2 (mg/L)	Lowest Surface Water Quality Standard (mg/L)
TDS	900	**940 - 1,890**	**930 - 1,070**	**930 - 1,020**	500
TSS	< 1	2 - **518**	5 - 78	20 - 72	80
Aluminum	< 0.0515	**5.5 -120**	**2 - 7.6**	< 0.0515 - **7**	0.087
Antimony	0.0002025	0.000569 - 0.00158	0.00111 - 0.012	0.000388 - 0.000808	0.006
Arsenic	0.000976	0.009 - 0.065	0.005 - **0.012**	0.008 - **0.032**	0.01
Barium	0.01815	0.0737 - 1.2	0.062 - 0.247	0.0819 - 0.239	2
Beryllium	< 0.000389	< 0.000338 - **0.008**	< 0.000338 - 0.000612	< 0.000389	0.004
Cadmium	< 0.0000771	0.0000651 - 0.003	< 0.0000474 - 0.000152	< 0.0000474 - 0.000116	0.005
Chromium	< 0.000964	0.01 - **0.41**	0.011 - **0.142**	0.00166 - 0.035	0.1
Cobalt	< 0.00169	< 0.00178 - 0.0029	< 0.00178 - 0.00335	< 0.00169 - 0.035	0.05
Copper	0.001665	0.03 - **0.22**	0.04 - 0.07	0.02 - 0.11	0.2
Lead	0.000276	0.004 - **0.124**	0.003 - 0.013	< 0.000155 - 0.006	0.015
Manganese	0.005185	0.018 - 2.59	0.028 - 0.152	< 0.0019 - 0.719	NP
Molybdenum	< 0.00568	0.00398 - 0.0174	0.03 - 0.07	0.0171 - 0.04	1
Nickel	0.0009405	0.00277 - 0.11	< 0.00252 - 0.01	< 0.00252 - 0.01	2
Selenium	0.0002	**0.00272 - 0.071**	**0.029 - 0.068**	0.00155 - **0.006**	0.002
Silver	< 0.0000761	< 0.000206 - 0.000361	< 0.000206	< 0.000206	4.67
Thallium	< 0.000253	< 0.000223 - 0.001	< 0.000223	< 0.000253	0.001
Thorium	< 0.0322	< 0.0268 - 0.2	0.0555 - 0.1	< 0.0322	NP
Uranium	0.003	**0.205 - 4.85**	**2.15 - 5.27**	**0.063 - 0.619**	0.03
Vanadium	0.01645	**0.16 - 0.72**	0.03 - **0.1**	0.04 - **4.52**	0.1
Zinc	0.0208	< 0.0134 - 0.5	< 0.0134 - 0.04	< 0.0113 - 0.0175	5.1
Dissolved Ra-226 (pCi/L)	1.5 - 1.6	2.3 - **60.2**	**8.5 - 23.1**	2 - **9.4**	5
Total Ra-226 (pCi/L)	NA	**29.6 - 412.8**	**17.4 - 144.4**	3.8 - **13.1**	5

Notes:

🟩	USEPA maximum contaminant level
🟥	Minimum Navajo Nation surface water criterion
🟨	USEPA secondary maximum contaminant level

A “<” symbol indicates a nondetect result less than the corresponding method detection limit.

Bolded values indicate an exceedance.

mg/L	Milligram per liter	Ra-226	Radium 226
NA	Not applicable	TDS	Total dissolved solid
NP	Not promulgated	TSS	Total suspended solid
pCi/L	Picocurie per liter	USEPA	U.S. Environmental Protection Agency

Table 12. Old Church Rock Mine Sample Passing 270-Mesh Concentrate Fraction TCLP Extract Results

Analyte	RCRA Standard (mg/L)	4-Minute HPSA Minus 270-Mesh Concentrate (mg/L)	8-Minute HPSA Minus 270-Mesh Concentrate (mg/L)	30-Minute HPSA Minus 270-Mesh Concentrate (mg/L)
Low-Concentration Samples				
Arsenic	5	< 0.0079	< 0.0079	< 0.0079
Barium	100	1	1	1
Cadmium	1	0.00168	0.00112	0.0011
Chromium	5	0.0029	0.00403	0.00479
Lead	5	< 0.00951	< 0.00951	< 0.00951
Selenium	1	< 0.0126	< 0.0126	< 0.0126
Silver	5	< 0.0142	< 0.0142	< 0.0142
Mercury	0.2	< 0.0000304	0.0000441	< 0.0000304
Medium-Concentration Samples				
Arsenic	5	< 0.0079	0.0095	< 0.0079
Barium	100	1.2	1.1	1.2
Cadmium	1	0.0025	0.00254	0.00236
Chromium	5	0.00424	0.00379	0.0051
Lead	5	0.0165	0.0136	< 0.00951
Selenium	1	0.0316	0.0305	0.0303
Silver	5	< 0.0142	< 0.0142	< 0.0142
Mercury	0.2	0.000037	0.0000414	0.0000411
High-Concentration Samples				
Arsenic	5	0.00918	0.011	0.0086
Barium	100	1	1	1.2
Cadmium	1	0.00254	0.00249	0.00208
Chromium	5	0.02	0.02	0.02
Lead	5	0.0306	0.0193	0.0204
Selenium	1	0.0405	0.0417	0.0293
Silver	5	< 0.0142	< 0.0142	< 0.0142
Mercury	0.2	0.0000492	0.0000478	< 0.0000304

Notes:

A “<” symbol indicates a nondetect result less than the corresponding method detection limit.

HPSA	High-pressure slurry ablation
RCRA	Resource Conservation and Recovery Act
TCLP	Toxicity characteristic leaching procedure

Table 13. Quivira Church Rock 1 Mine Sample Passing 270-Mesh Concentrate Fraction TCLP Extract Results

Analyte	RCRA Standard (mg/L)	4-Minute HPSA Minus 270-Mesh Concentrate (mg/L)	8-Minute HPSA Minus 270-Mesh Concentrate (mg/L)	30-Minute HPSA Minus 270-Mesh Concentrate (mg/L)
Low-Concentration Samples				
Arsenic	5	< 0.0079	< 0.0079	< 0.0079
Barium	100	1	1	1.1
Cadmium	1	0.00292	0.00268	0.00281
Chromium	5	0.0026	0.00356	0.00573
Lead	5	< 0.00951	< 0.00951	< 0.00951
Selenium	1	< 0.0126	< 0.0126	0.0146
Silver	5	< 0.0142	< 0.0142	< 0.0142
Mercury	0.2	< 0.0000304	< 0.0000304	< 0.0000304
Medium-Concentration Samples				
Arsenic	5	< 0.0079	< 0.0079	< 0.0079
Barium	100	1	1	1
Cadmium	1	0.00247	0.00244	0.00266
Chromium	5	0.00422	0.00546	0.01
Lead	5	0.0125	0.0119	0.0131
Selenium	1	0.0345	0.0301	0.0258
Silver	5	< 0.0142	< 0.0142	< 0.0142
Mercury	0.2	< 0.0000304	< 0.0000304	< 0.0000304
High-Concentration Samples				
Arsenic	5	< 0.0079	< 0.0079	< 0.0079
Barium	100	1.3	1.3	1.3
Cadmium	1	0.00241	0.00252	0.00264
Chromium	5	0.00402	0.00443	0.01
Lead	5	0.0183	0.0169	0.0147
Selenium	1	0.0413	0.0311	0.0191
Silver	5	0.0154	0.0145	< 0.0142
Mercury	0.2	< 0.0000304	< 0.0000304	< 0.0000304

Notes:

A “<” symbol indicates a nondetect result less than the corresponding method detection limit.

HPSA	High-pressure slurry ablation
RCRA	Resource Conservation and Recovery Act
TCLP	Toxicity characteristic leaching procedure

Table 14. Cove Transfer Station 2 Sample Passing 270-Mesh Concentrate Fraction TCLP Extract Results

Analyte	RCRA Standard (mg/L)	4-Minute HPSA Minus 270-Mesh Concentrate (mg/L)	8-Minute HPSA Minus 270-Mesh Concentrate (mg/L)	30-Minute HPSA Minus 270-Mesh Concentrate (mg/L)
Low-Concentration Samples				
Arsenic	5	< 0.0079	< 0.0079*	< 0.0079
Barium	100	2.07	2.5*	2.6
Cadmium	1	0.00138	0.00298*	0.00288
Chromium	5	< 0.0011	0.00135*	0.0022
Lead	5	< 0.00951	< 0.00951*	< 0.00951
Selenium	1	< 0.0126	0.0147*	< 0.0126
Silver	5	< 0.0142	< 0.0142*	< 0.0142
Mercury	0.2	< 0.0000304	< 0.0000304*	< 0.0000304
Medium-Concentration Samples				
Arsenic	5	< 0.0079	< 0.0079	< 0.0079
Barium	100	2.1	2.1	2.1
Cadmium	1	0.00208	0.00194	0.0019
Chromium	5	0.00193	0.00136	0.00284
Lead	5	< 0.00951	< 0.00951	< 0.00951
Selenium	1	< 0.0126	< 0.0126	0.0139
Silver	5	< 0.0142	< 0.0142	< 0.0142
Mercury	0.2	< 0.0000304	< 0.0000304	< 0.0000304
High-Concentration Samples				
Arsenic	5	<.0079*	< 0.0079	< 0.0079
Barium	100	2.3*	2.3	2.3
Cadmium	1	0.00205*	0.00211	0.00214
Chromium	5	0.00167*	0.00259	0.00233
Lead	5	< 0.00951*	< 0.00951	< 0.00951
Selenium	1	< 0.0126*	< 0.0126	< 0.0126
Silver	5	< 0.0142*	< 0.0142	< 0.0142
Mercury	0.2	< 0.0000304*	0.000301	< 0.0000304

Notes:

A “<” symbol indicates a nondetect result less than the corresponding method detection limit.

*	Calculation of average between two duplicate samples.
HPSA	High-pressure slurry ablation
RCRA	Resource Conservation and Recovery Act
TCLP	Toxicity characteristic leaching procedure

Table 15. Technology Evaluation Criteria for Engineering Evaluation/Cost Analyses and Feasibility Studies

Criteria	Technology Evaluation
Overall Protection of Human Health and the Environment	HPSA treatment has been shown to be effective at reducing concentrations of uranium by up to 98.1 percent and radium-226 levels by up to 94.6 percent in waste rock; however, conservative site-specific cleanup goals were not obtained for Ra-226 background and Navajo residential future use scenario for uranium. Therefore, to be fully protective, coarse material remaining on site that does not meet cleanup goals must be covered to reduce direct exposure. HPSA treatment reduced leachability by up to 93 percent; therefore, no metals or radionuclides would leach to surface water or groundwater above water quality criteria. Fines fraction must be disposed of off site at a RCRA C or LLRW facility.
Compliance with ARARs	No chemical-specific ARARs exist for metals and radionuclides at AUMs on the Navajo Nation. Implementation of HPSA technology would require dust control to protect workers and any nearby communities. If coarse fraction material not meeting cleanup goals is placed under a cover, potential radon gas emissions would be modeled to determine if controls are necessary. Fines fraction would require disposal at a RCRA C facility licensed to receive radiological material or a LLRW facility. The fines fraction is not a RCRA hazardous waste. Process and rinse water discharged post-treatment would require treatment before discharge to comply with the Clean Water Act and Safe Drinking Water Act.
Long-Term Effectiveness and Permanence	Long-term effectiveness and permanence would be achieved through contaminant mass reduction from the coarse fraction into the fines fraction and disposal of the fines off site at a RCRA C or LLRW facility. The coarse fraction that remains on site could require a soil cover if cleanup goals are not attained. If a soil cover is required, effectiveness and permanence of the cover would need to be designed for a minimum period of 200 years. Potential for radon gas emissions would be modeled and controlled if necessary. HPSA technology also reduces the concentrations of leachable metals and radionuclides in the coarse fraction to below water quality criteria; therefore, no surface water or groundwater impacts would remain at a site.
Reduction of Toxicity, Mobility, or Volume through Treatment	HPSA technology concentrates metals and radionuclides in a smaller volume of material and reduces leachability of metals and radionuclides through ablating uranium minerals from the surfaces of waste rock material. A large volume of coarse fraction material remains after HPSA treatment with reduced toxicity (contaminant mass removal) and leachability (mobility). A small volume of fines fraction contains increased contaminant mass and leachable metals and radionuclides, requiring offsite recycling for uranium recovery or disposal because of radioactivity at a RCRA C or LLRW facility. If the clean coarse fraction remaining on site does not meet cleanup goals, mobility would be eliminated through the use of a soil cover.
Short-term Effectiveness	The timeframe until treatment is complete depends on the volume of waste rock to be treated and the throughput and number of HPSA treatment units used. Using Quivira Mines as an example, cleanup of 1 million cubic yards would require about 2 years using two 100-TPH HPSA units at two shifts per day, 20 days per month. This time frame is longer than consolidation and disposal on site but shorter than the time required to permit, design, and build an offsite disposal facility and haul untreated waste to the facility or the very long time required to haul to an RCRA C or LLRW facility. HPSA technology does not use chemicals to remove contaminants from the waste rock. The primary impacts to the community are trucks used to import water for processing, trucks hauling fines fraction off site for disposal, and noise. Dust impacts would be minimized through engineering controls and wetting of soils during transfer to the HPSA treatment system.

Table 15. Technology Evaluation Criteria for Engineering Evaluation/Cost Analyses and Feasibility Studies

Criteria	Technology Evaluation
Implementability	The HPSA treatment system is scalable and currently designed to treat 5, 50, and 100 TPH. HPSA treatment system components are generally available, but the design of the collision chamber and nozzles is proprietary. Disa offers turnkey HPSA systems, licensing, and operational training to vendors or could operate the HPSA technology. HPSA treatment systems can be constructed in 1 month provided major components are available from suppliers. HPSA treatment system components are skid mounted for ease of mobilization and to minimize footprint. The maximum skid length is 25 feet; therefore, truck and trailer kingpin limits are not a concern. Front-end loaders for moving feed material to the HPSA treatment system and coarse and fine materials from the HPSA treatment system will also be required. For difficult access sites, a separate staging area can be set up for bulk storage and material transferred to the site for daily use.
Cost	An economic analysis performed on the results of this treatability study demonstrated that treating waste rock from AUM sites on the Navajo Nation using a full-scale, 50- or 100-TPH HPSA treatment system operating 24 hours a day would cost \$31.48 to \$38.27 per ton treated. The initial fixed project costs for the HPSA treatment are \$137,500 for the 50-TPH system and \$212,500 for the 100-TPH system. Fixed costs consist of site preparation, permitting, mobilization, and installation and setup of HPSA skids. Variable costs to operate the HPSA system are approximately \$31 per ton treated. The variable costs consist of consumables and rentals, labor, water purchase and delivery, water treatment, analytical services, maintenance, and indirect costs. These costs do not include the costs for disposal of fines fraction or placement of the coarse fraction remaining on site (backfill or placement under a soil cover). Overall, disposal of a typical fines fraction (20 to 25 percent by mass) at a RCRA C or LLRW facility would be more than the HPSA treatment cost by itself.
Community Acceptance (No State Acceptance on Navajo Nation)	Community acceptance of HPSA technology is very positive. The Cove community attended a demonstration day at an AUM site in Cove, Arizona. The Navajo see treatment of waste rock as a good alternative to disposing of waste on or off site as no other treatment options are currently being evaluated on the Navajo Nation. The community is interested in the removal of the metals and radionuclides from material that remains on site. Operation of the HPSA treatment system presents minimal risk to the public since all system components and treatment operations occur within a contained site. Hauling of the fines fraction off site for disposal would pose a risk to the community because of the number of trucks passing through the community during and following treatment. Hazardous chemicals used to support the HPSA treatment system include diesel fuel for generator power and construction equipment. During HPSA treatment system operation, the equipment used to move stockpiled material to and from the treatment system and the diesel generator used to power the treatment system would create the most noise and air emissions at the site. Dust emissions would be controlled through water controls.

Notes:

ARAR	Applicable or relevant and appropriate requirement
AUM	Abandoned uranium mine
Disa	Disa Technologies, Inc.
HPSA	High-pressure slurry ablation
LLRW	Low-level radioactive waste
RCRA	Resource Conservation and Recovery Act
TPH	Ton per hour
USEPA	U.S. Environmental Protection Agency

Table 16. Differences between Calculated PSD Mass Balance and Bulk Analytical Results for Uranium and Radium-226

OCRM Feed Samples	**Low Concentration**		**Medium Concentration**		**High Concentration**	
Parameter	**Mass Balanced PSD Result**	**Bulk Analytical Result**	**Mass Balanced PSD Result**	**Bulk Analytical Result**	**Mass Balanced PSD Result**	**Bulk Analytical Result**
Uranium (mg/kg)	45.0	40	257.2	260	932.2	940
Uranium % Difference	12.4%		-1.1%		-0.8%	
Radium-226 (pCi/g)	23.0	19.7	111.4	104	273.1	228
Radium-226 % Difference	17.0%		7.1%		19.8%	
Quivira CR-1 Feed Samples	**Low Concentration**		**Medium Concentration**		**High Concentration**	
Parameter	**Mass Balanced PSD Result**	**Bulk Analytical Result**	**Mass Balanced PSD Result**	**Bulk Analytical Result**	**Mass Balanced PSD Result**	**Bulk Analytical Result**
Uranium (mg/kg)	76.7	110	214.6	230	316.0	400
Uranium % Difference	-30.3%		-6.7%		-21.0%	
Radium-226 (pCi/g)	32.3	31.8	91.2	91.9	132.8	121
Radium-226 % Difference	1.4%		-0.7%		9.8%	
CTS 2 Feed Samples	**Low Concentration**		**Medium Concentration**		**High Concentration**	
Parameter	**Mass Balanced PSD Result**	**Bulk Analytical Result**	**Mass Balanced PSD Result**	**Bulk Analytical Result**	**Mass Balanced PSD Result**	**Bulk Analytical Result**
Uranium (mg/kg)	2.3	4.52	51.2	40	58.3	50
Uranium % Difference	-48.9%		28.0%		16.6%	
Radium-226 (pCi/g)	1.5	1.6	13.2	12.7	16.7	15
Radium-226 % Difference	-3.7%		4.3%		11.5%	

Notes:

CR-1	Church Rock 1 Mine
CTS 2	Cove Transfer Station 2
mg/kg	Milligram per kilogram
OCRM	Old Church Rock Mine
pCi/g	Picocurie per gram
PSD	Particle size distribution

Table 17. Absolute Value Average Differences between Calculated PSD Mass Balance and Bulk Analytical Results for Uranium and Ra-226

Site Sample	Absolute Value Average	All Three Sites Grouped	Absolute Value Average
OCRM Uranium	4.8%	Low Sample Uranium	30.5%
OCRM Radium-226	14.6%	Low Sample Radium-226	7.4%
Quivira CR-1 Uranium	19.3%	Medium Sample Uranium	11.9%
Quivira CR-1 Radium-226	4.0%	Medium Sample Radium-226	4.0%
CTS 2 Uranium	31.2%	High Sample Uranium	12.8%
CTS 2 Radium-226	6.5%	High Sample Radium-226	13.7%

Notes:

CR-1	Church Rock 1 Mine
CTS 2	Cove Transfer Station 2
OCRM	Old Church Rock Mine
PSD	Particle size distribution

Table 18. Average Standard Deviation of Slurry PSD Sample Split Masses and Error Rate of PSDs Performed with Masses Greater than 500 Grams

Particle Size Distributions	OCRM Slurry Samples	Quivira CR-1 Slurry Samples	CTS 2 Slurry Samples
Average Standard Deviation of Sample Splits	42.3	63.6	144.9
Total PSDs	34	40	30
Total PSDs over 500 Grams	0	2	4
Error Rate	0%	5%	13%

Notes:

CR-1	Church Rock 1 Mine
CTS 2	Cove Transfer Station 2
OCRM	Old Church Rock Mine
PSD	Particle size distribution

APPENDIX A

PHOTOGRAPHIC DOCUMENTATION

APPENDIX B

FIELD AND POST-PILOT STUDY ACTIVITIES DOCUMENTATION

APPENDIX B-1A

STANDARD OPERATING PROCEDURES FOR DISA BATCH SYSTEM OPERATION

APPENDIX B-1B
STANDARD OPERATING PROCEDURE FOR MATERIAL TRACKING POST-DEMONSTRATION

APPENDIX B-1C

STANDARD OPERATING PROCEDURES FOR RO-TAP MATERIAL PROCESSING

APPENDIX B-1D
STANDARD OPERATING PROCEDURES FOR SAMPLING AFTER RO-TAP MATERIAL PROCESSING

APPENDIX B-2A
DISA FIELD STUDY CHAINS OF CUSTODY

APPENDIX B-2B
PACE LABORATORY CHAINS OF CUSTODY

APPENDIX B-2C
EAGLE ENGINEERING CHAINS OF CUSTODY

APPENDIX B-3
DISA LABORATORY PARTICLE SIZE DISTRIBUTION FORMS

APPENDIX B-4
GRAB FEED SAMPLE MASS LOGGING, SAMPLE MOISTURE DETERMINATION, AND SAMPLE SPLITTING FORMS

APPENDIX B-5

OLD CHURCH ROCK MINE, COVE TRANSFER STATION 2, AND QUIVIRA CHURCH ROCK 1 MINE FRACTIONATION SAMPLE SPLITTING FORMS

APPENDIX B-6
DISA SAMPLE WEIGHT TRACKING FORMS

APPENDIX B-7
DISA SUMMARIZED FIELD AND LABORATORY NOTES

APPENDIX B-8

OLD CHURCH ROCK MINE, QUIVIRA CHURCH ROCK 1 MINE, AND COVE TRANSFER STATION 2 PULVERIZING TRACKERS

APPENDIX B-9
2021 ANNUAL DRINKING WATER QUALITY REPORTS

APPENDIX C

MATERIALS HANDLING FLOWCHARTS AND CALCULATIONS

The following project files are available by request from the USEPA TOCOR and include backup calculations used in the development of tables and figures in this report.

1. Recon Samples Table.xlsx
2. RAES T033 Bulk Feed XRF Analyzer.xlsx
3. CR Fractionation XRF Analyzer.xlsx
4. CTS Fractionation XRF Analyzer.xlsx
5. QV Fractionation XRF Analyzer.xlsx
6. Treatability Study XRF Analyzer Summary.xlsx
7. CR Mass Balance.xlsx
8. QV Mass Balance.xlsx
9. Pace Sample Compositing Ra 226.xlsx
10. CR Water Results Summary.xlsx
11. CTS Water Results Summary.xlsx
12. QV Water Results Summary.xlsx
13. CR SPLP Summary.xlsx
14. CTS SPLP Summary.xlsx
15. QV SPLP Summary.xlsx
16. CR Fractionation Summary.xlsx
17. CTS Fractionation Summary.xlsx
18. QV Fractionation Summary.xlsx
19. Water and SPLP Comparison.xlsx
20. Disa PSD QAQC.xlsx
21. Process Water QAQC.xlsx
22. RAES T033 Sample Weight Tracking.xlsx

APPENDIX C-1
OLD CHURCH ROCK MINE SAMPLE TRACKING SHEETS

APPENDIX C-2
COVE TRANSFER STATION 2 SAMPLE TRACKING SHEETS

APPENDIX C-3
QUIVIRA CHURCH ROCK 1 MINE SAMPLE TRACKING SHEETS

APPENDIX C-4
OLD CHURCH ROCK MINE MASS BALANCE SHEETS

APPENDIX C-5
QUIVIRA CHURCH ROCK 1 MINE MASS BALANCE SHEETS

APPENDIX D

INSPECTION OF POST-PILOT STUDY ACTIVITIES AT THE DISA PROCESS LABORATORY

APPENDIX E

LABORATORY DATA

Data from this study are provided below in summary tables for the two primary chemicals of concern, uranium and radium-226. Table E-1 presents the analytical results from the reconnaissance Survey, Table E-2 the analytical results used to evaluated primary project objectives, and Tables E-3 and E-4 leachability analytical results. Laboratory reports from Eagle Engineering follow the data summary tables. Because of the number of pages (11,000) and file size (262 MB), Pace Analytical reports are available by request from the USEPA TOCOR.

APPENDIX F

DATA VALIDATION REPORTS

APPENDIX G

FURTHER DESCRIPTION OF PROCESS LABORATORY ACTIVITIES AND DEVIATIONS FROM STANDARD OPERATING PROCEDURES