Excavation Control Plan

St. Anthony Mine Closeout

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Table of Contents

1.0 INTRODUCTION 1

2.0 SITE DESCRIPTION 1

3.0 DATA QUALITY OBJECTIVES 2

4.0 SURVEY DESIGN 2
4.1 Soil Action Level and Performance Standards 2
4.2 Gamma Radiation Survey Concept 2
4.3 Gamma Survey Instrumentation 3
4.4 Gamma Survey Minimum Detection Concentration 3
4.5 Site Specific Gamma Radiation to Ra-226 Correlation 3
4.6 Gamma Radiation Levels for Soil Excavation 4
4.7 Excavation Control Surveys 5
4.7.1 Gamma Scan Radiation Survey 5
4.7.2 Gamma Static Radiation Survey 5
4.7.3 Soil Sampling and Ex-situ Gamma Radiation Soil Screening 6

5.0 EXCAVATION CONTROL IMPLEMENTATION 6
5.1 Excavation Control Using Gamma Radiation Surveys 6
5.2 Soil Sampling and Analysis 7
5.3 Documentation 7
5.4 Instrument Calibration and Function Checks 7
5.5 Safety and Radiation Protection 8
5.6 Field Decontamination 8

6.0 QUALITY ASSURANCE AND QUALITY CONTROL MEASURES 8

7.0 REFERENCES 9

TABLE

Table 1 Soil Excavation Action Level Gamma Count Rates 5

FIGURE

Figure 1 Soil Action Level Excavation Area

ATTACHMENT

Attachment 1 Gamma Radiation Level to Surface Soil Ra-226 Correlation St. Anthony Mine Site Excavation Control and Verification Survey

ACRONYMNS

Bi-214	Bismuth 214
cpm	counts per minute
DGPS	Differential Global Positioning System
DQO	Data Quality Objectives
FOV	field of view
g	gram
HBL	health-based level
kg	kilogram
keV	Kiloelectronvolt
L	liter
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MC	Materials Characterization
MDC	Minimum Detection Concentration
MMCX	Magellan Mobile Mapper CX
MSE	Mean Squared Error
NaI	Sodium Iodide
NUREG	US Nuclear Regulatory Commission Guide
Pb-214	Lead 214
pCi	picocuries
QA/QC	quality assurance/quality control
Ra-226	Radium 226
SAL	Soil Action Level
SRC	Supplemental Radiological Characterization
SOP	Standard Operating Procedure
UNC	United Nuclear Corporation
USEPA	United States Environmental Protection Agency
VS	Verification Survey

1.0 INTRODUCTION

This excavation control plan provides a framework for conducting excavation control surveys to support the excavation and placement of mining-impacted soil for reclamation at the St. Anthony Mine Site (site) near Seboyeta, New Mexico. The excavation control surveys in this Plan are consistent with the guidance found in the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (USEPA, 2000) Section 5.4, Remedial Action Support Surveys.

The objective of the excavation control survey is to support the excavation and removal of soil that exceeds the Soil Action Level (SAL) and placement in onsite Pit 2. The SAL is 6.6 pCi/g Ra-226 (5.0 pCi/g health-based level (HBL) plus the 1.6 pCi/g site background level) as specified in the Closeout Plan. The lateral and vertical extent of the soil impacted above the SAL has been characterized and established by the 2007 Materials Characterization (MC) (MWH, 2007) and the Supplemental Radiologic Characterization (SRC) (AVM 2018). The site characterizations identified approximately 360 acres, which include mine features such as mine waste piles, areas between mine features and roads that exceeded the SAL, as shown in Figure 5 and 6 of the 2018 SRC Report.

The mine impacted material will be excavated and placed in Pit 2, as discussed in the Closeout Plan (the Plan). Of the approximate total of 360 acres, material from about 225 acres of area, as shown in Figure 1, will be excavated to meet the RAL and placed in the pits for disposal and reclamation. Pile 4, Pile 5 and the Topsoil/Overburden pile will be regraded and stabilized in place. Therefore, radiologic excavation control will not be necessary for regrading activities at Pile 4, Pile 5. A summary of the nature and extent of contamination is provided in the 2007 MC and 2018 SRC reports.

This Plan is based on available information from the 2007 MC and 2018 SRC. Site excavation control surveys will be conducted to support waste piles and other mine-impacted materials excavation and placement, provide updated estimates of site-specific parameters for planning the Verification Survey (VS), and to determine when a survey area is ready for the VS. The excavation control survey will rely on direct gamma radiation levels near the surface as an indicator of effectiveness. The gamma radiation level for excavation control below which there is an acceptable level of assurance that the SAL has been attained is determined as discussed in Section 4.5, which will be used for immediate in-field decisions.

2.0 SITE DESCRIPTION

The site was an open pit and underground shaft uranium mine located on the Cebolleta Land Grant in Cibola County, approximately 4.6 miles southeast of Seboyeta, New Mexico. The site is in a remote, sparsely populated area with limited access. A site map is shown in Figure 1. United Nuclear Corporation (UNC) operated the site from 1975 to 1981, pursuant to a mineral lease with the Cebolleta Land Grant, the current owner of the surface and mineral rights. The original lease covered approximately 2,560 acres. This lease was obtained on February 10, 1964 and surrendered by a Release of Mineral Lease dated October 24, 1988.

The site includes underground workings consisting of one shaft, approximately eight vent shafts that are sealed at the surface, two open pits (one containing a pond), seven large piles of non-economical mine materials with some revegetation, numerous smaller piles of non-economical mine materials, and three topsoil piles. No perennial streams occur within the site, but an ephemeral stream or arroyo (Meyer Gulch) passes through the site. The layout of the site is shown in Figure 1 and shows the site features and the UNC mine permit boundary (permit boundary). The actively mined area encompasses approximately 430 acres and includes site roads and the other disturbed areas along with the features previously characterized.

3.0 DATA QUALITY OBJECTIVES

Excavation control surveys will be conducted to support excavation of mine impacted soil that exceeds the SAL, determined when an area at the site is ready for the VS, and updated estimates of site-specific parameters, such as final excavation footprint for planning of the VS. Excavation control surveys serve to monitor the effectiveness of soil excavation efforts that are intended to reduce residual radioactivity to acceptable levels. This type of survey guides the excavation in real-time. Excavation control surveys typically depend on a simple radiological parameter, such as direct gamma radiation near the surface as an indicator of effectiveness. The SAL will be used for immediate in-field decisions. Excavation control surveys are intended for expediency and cost effectiveness and do not provide thorough or accurate data describing the radiological status of the site. This survey is not intended to provide information that can be used to demonstrate compliance with the SAL and is an interim step in the compliance demonstration process. The excavation control survey data may also be used for VS decision-making if that excavation control data is collected in a manner consistent with DQOs specified in the Verification Survey Plan.

The objective of the excavation control survey is to detect levels of residual radionuclides at, or below, the SAL. Excavation control survey instrumentation and techniques have been selected based on detection capabilities for the SAL as described in Sections 4.0 and 5.0.

4.0 SURVEY DESIGN

The excavation control survey will be used to support excavation of soil exceeding the SAL.

4.1 Soil Excavation Level and Performance Standards

The waste piles and other mine-impacted soil, with Ra-226 concentration exceeding the SAL, will be excavated and placed within the two open pits and stabilized. The value of 6.6 pCi/g Ra-226 (5.0 pCi/g HBL plus the 1.6 pCi/g background level determined during the 2007 Characterization) was used as the Investigation Level for site characterization, and is used as the soil SAL.

4.2 Gamma Radiation Survey Concept

The excavation control survey will rely on direct radiation near the surface as an indicator of effectiveness. The excavation and removal of soil is most efficient when real-time information for excavation control is available. In-situ direct gamma radiation surveys will provide real-time information and enable excavation control for efficient removal of impacted soil, as compared to soil sampling and analysis. Ra-226 in soil will be detected by direct gamma radiation level measurements. Ra-226 is primarily an alpha emitting radionuclide with a gamma radiation emission of 186 KeV at about 4 percent intensity. Direct field measurement of alpha radiation is not feasible. The low energy and intensity of the Ra-226 gamma radiation emission makes it impractical to determine Ra-226 in the field by direct gamma radiation measurement. However, Pb-214 and Bi-214, Ra-226 decay products, emit high energy gamma radiation at high intensities. This results in a direct correlation between Pb-214/Bi-214 gross gamma radiation levels and Ra-226 concentrations in the soil. The high energy gamma radiation of Pb-214 and Bi-214 can be easily measured in the field utilizing a Sodium Iodide (NaI) scintillation detector, such as 2x2 NaI scintillation detector having a high gamma radiation sensitivity. The Ra-226 levels in soil will be measured as a surrogate by gamma radiation measurement of Pb-214 and Bi-214 gamma radiation levels, as described in Section 4.3.2 of the MARSSIM.

4.3 Gamma Survey Instrumentation

The instrumentation configuration for direct gamma radiation level measurements will consist of a 2x2 NaI scintillation detector (Eberline SPA-3 and/or Ludlum 44-10) connected to a scaler/rate meter (such as Ludlum 2221 or Ludlum 2241). This instrument configuration has been used widely for this type of application and is recommended by the MARSSIM. The SPA-3 and L44-10 scintillation detectors are rugged with the highest sensitivity gamma radiation detection for field application and this type of field survey. When necessary, such as for investigation surveys during excavation control, the Scaler/Rate meter will be interfaced with a sub-meter accurate Differential Global Positioning System (DGPS) with a data logger/controller for electronically recording the gamma radiation levels to the corresponding coordinates corrected in real time. The scaler/rate meter used for gamma scan surveys will be equipped with the firmware to output a two-second integrated count output, such as Ludlum firmware 26106N03 to integrate measurements during a two-second period, and output a value based on the time interval.

For radiation surveys where significant shine interference is present, the 2x2 NaI crystal scintillation detector will be installed in a 0.5-inch-thick lead collimator. The collimator will reduce lateral gamma shine interference and will focus on an observational area with an approximate 36-inch diameter under the detector at 12 inches from the ground surface.

4.4 Gamma Survey Minimum Detection Concentration

The selected instrumentation will meet the Minimum Detection Concentration (MDC) for gamma radiation surveys. The MDCs will be calculated as discussed in Standard Operating Procedure (SOP)-1 included in Appendix C.3, which is consistent with Sections 6.7.1 and 6.7.2 of MARSSIM. More detail on signal detection theory and instrument response is provided in U.S. Nuclear Regulatory Commission Regulation (NUREG)-1507, Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions (U.S. Nuclear Regulatory Commission, 1998). Based on gamma surveys conducted using this instrumentation during the 2007 Characterization and the 2018 SRC, the instrument MDC is expected to be below 50 percent of the SAL for static and scan surveys during excavation control.

4.5 Site-Specific Gamma Radiation to Ra-226 Correlation

Direct gamma radiation measurements, using a NaI scintillation detector, provide radiation levels in counts per unit time. The gamma survey results in counts per unit time have no intrinsic meaning to SAL in pCi/g. The counts per unit time for a given radioactivity depend on the efficiency of the detector. The direct gamma radiation level in detector counts per minute (cpm) for the collimated and bare detectors, below which there is an acceptable level of assurance that the established SAL is attained, will be based on the site-specific correlations between gamma radiation count rates and surface soil Ra-226 activity. Final gamma radiation level to surface soil Ra-226 correlations for 2x2 NaI bare and 0.5-inch lead collimated detectors are developed, as described in Attachment 1, from data collected for previous correlations during the site 2007 Characterization and 2018 SRC. The correlations exceeded the minimum R^2, and the p-value as specified DQO Type I error of 0.05, and had low Mean Squared Errors (MSEs). The correlation equations are summarized below:

- **2x2 NaI Bare Detector:**

  Ra-226 pCi/g = (cpm x 0.0005 pCi/g/cpm, slope) - 5.51, intercept or constant, with an R^2 = 0.98, and results into approximately 24,220 cpm equivalent to the 6.6 pCi/g surface soil Ra-226 SAL.

- **0.5 inch-thick lead collimated 2x2 NaI Detector:**

  Ra-226 pCi/g = (cpm x 0.0015 pCi/g/cpm, slope) - 5.21, intercept or constant, with an R^2 = 0.90, and results into approximately 7,873 cpm equivalent to the 6.6 pCi/g surface soil Ra-226 SAL.

- **Exposure Rate (µR/hr) Meter:**

  Ra-226 pCi/g = (µR/hr x 0.49 pCi/g/µR/hr, slope) - 5.10, intercept or constant, with an R^2 = 0.90, and results into approximately 24 µR/hr equivalent to the 6.6 pCi/g surface soil Ra-226 SAL.

The previous correlations for the site were developed for surface soils, with low moisture conditions similar to those expected during the soil excavation action (i.e., no recent rain or temperature below freezing, no snow cover or frozen ground surface). The gamma surveys during the soil excavation action will not be conducted if the ground surface is covered with snow or frozen, or within two hours following a rain storm. The ground surface will be inspected for excessive moisture prior to restarting gamma surveys.

4.6 Gamma Radiation Levels for Soil Excavation Action

The correlations for the direct gamma radiation level in cpm are for Ra-226 distribution in surface soil. Any lateral gamma radiation shine from the nearby elevated areas would skew gamma radiation level measurement and overestimate Ra-226 concentration at a survey location. Therefore, a 0.5-inch-thick lead collimator will be used to mitigate the lateral shine interference. Vertical gamma radiation shine in areas with subsurface soil with elevated Ra-226 levels will also skew the gamma radiation level measurements and overestimate the surface soil Ra-226 concentration at those locations. Eliminating the vertical shine is not practical in the field, however vertical shine results in a conservative approach for excavation control and facilitates detecting elevated Ra-226 levels in subsurface soil which is six inches below ground surface.

The radiation detection measurements have associated inherent uncertainties due to the random nature of radioactive disintegration. The gamma radiation levels in cpm for the SAL are lowered by 1.96 standard deviation (σ), below which there is an acceptable level of assurance that the established SAL has been attained to address the counting uncertainties at a 95% confidence level. The SAL equivalent gamma radiation cpm lowered by 1.96σ that will be used for excavation control is summarized in Table 1.

Table 1: Soil Excavation Action Level Gamma Count Rates

Soil Excavation Action Level	2x2 NaI Bare Detector Gamma Count Rate (cpm)	0.5-inch Pb Collimated 2x2 NaI Detector Gamma Rate (cpm)	Gamma Exposure Rate (μR/hr)
6.6 pCi/g Ra-226 SAL	23,900	7700	24

4.7 Excavation Control Surveys

Gamma radiation surveys will primarily be used for soil excavation control. Gamma scan surveys in combination with gamma static measurements will be used for excavation control until the impacted soil exceeding the SAL has been removed. Soil sampling and ex-situ gamma radiation soil screening will also be used as necessary for excavation control. Excavation control surveys will be performed primarily with collimated detectors to mitigate any lateral gamma radiation shine interference and focus on areas of interest under the detector, specifically at the early stages of soil removal when lateral shine is expected due to variable contaminant distribution. An uncollimated detector may be used when the lateral contaminant distribution is fairly homogeneous. The excavation control will also utilize soil sampling and ex-situ gamma radiation soil screening, as needed.

4.7.1 Gamma Scan Radiation Survey

Gamma scan radiation surveys (walkover surveys) will be performed by walking in a serpentine pattern at a scan rate of up to three feet per second in excavated areas to identify and locate any areas above the SAL. The scan surveys during excavation control will be performed for complete area coverage to detect residual Ra-226 activity in surface soil. The field of view for the Ra-226 decay products gamma radiation is conservatively established at 6.0 feet diameter for bare detectors and 3.0 feet diameter for collimated detectors with the detector held at about 12 inches from the ground surface. The gamma scan speed will be maintained so as not to exceed the scan MDC limit, which was calculated using approved survey and instrumentation parameters as presented in Section 4.4, and in SOP-1 (see Appendix C.3). Details of the gamma scan survey are described in SOP-3, which is included in Appendix C.3.

A DGPS-based gamma radiation scan survey may be performed to log gamma radiation count rates with corresponding point location coordinates in a data logger/controller. This scan survey can be performed by walking the area with a 2x2 NaI detector and rate meter coupled with a DGPS/data logger unit. The GPS-gamma scan survey system will consist of a Ludlum 2221 Rate meter/Scaler with SPA-3 2x2 NaI Detector coupled to a DGPS/Data collector, such as Magellan Mobile Mapper CX (MMCX). The MMCX is a real-time DGPS with a controller and data logging capability utilizing a surveying software. The Ludlum 2221 will be operated in rate meter mode, allowing a gamma count rate (cpm) to be logged with its corresponding coordinates in one or two second intervals. Appropriate walk-over transect spacing will be based on the 100 percent scan coverage rate during the excavation control.

4.7.2 Gamma Static Radiation Survey

Gamma static radiation surveys will be performed for confirmation of the scan survey results at any point or location of interest during excavation control, such as questionable measurements, measurements near the SAL or small areas of elevated activity during the scan survey. The detector will be held about 12 inches above the ground surface. The scaler/Rate meter will be set in the count SCALER MODE and a one-minute count of gamma radiation levels will be conducted at each location for gamma static radiation survey. Details of the gamma static survey are described in SOP-3.

4.7.3 Soil Sampling and Ex-Situ Gamma Radiation Soil Screening

Judgmental soil sampling for ex-situ gamma radiation soil screening will be performed for excavation control, as necessary. If the gamma static survey, following an excavation control scan at a discrete location, does not provide an acceptable level of assurance that the SAL has been attained for any questionable measurements, measurements above the SAL, or small areas of elevated activity, ex-situ soil screening will be used. This screening method will allow corrective actions (e.g., expedited confirmation, additional removal, and re-sampling) to be taken immediately before committing resources to off-site laboratory analyses.

The on-site ex-situ soil screening method consists of measuring 609 KeV gamma radiations of Bi-214, a decay product of Ra-226 (see SOP-4 in Appendix C.3). This method, which is more reliable than the in-situ direct gamma survey, was successfully implemented previously, including during the 2018 SRC for expedited estimates of Ra-226 in soil. A single channel analyzer, such as Ludlum L2221 integrated with a Ludlum 44-20 3x3 NaI scintillation detector will be used to measure the 609 KeV energy peak region of Bi-214. The sample is placed around the plastic lined detector in a heavily shielded counting chamber. The shielded counting chamber lowers the system background counts, improving the system MDC. Based on data from previous use of this system at the site, the MDC is expected to be less than 50 percent of the SAL. A typical MDC calculated from the previous ex-situ analysis at the site is provided in SOP-4. A reference soil with the same concentration as the SAL of 6.6 pCi/g will be used for ex-situ soil screening during excavation control at the site.

5.0 EXCAVATION CONTROL IMPLEMENTATION

Soils exceeding the SAL will be excavated, hauled, and placed into the onsite Pit 2. Excavation control will be performed to support soil excavation. Radiologic excavation control will be performed to meet the SAL in the approximate 225-acre SAL excavation area at the site as shown in Figure 1.

5.1 Excavation Control Using Gamma Radiation Surveys

This section describes excavation control for soil exceeding the SAL. Excavation control will begin with field delineation of the soil excavation and removal areas. If the gamma scan shows that the outer SAL boundary has expanded, the SAL boundary will be revised and used to guide soil excavation.

The excavation areas may be divided into smaller subareas for excavation control surveys (narrow strips or small blocks) to more efficiently control excavation, depending on the equipment used for excavation. In addition to the lateral extent (SAL boundary), the 2007 Characterization and 2018 SRC defined the vertical extent of impacted subsurface soils. The Plan Drawings 5 and Drawing 6 show the excavation cut contours based on the assessed vertical extent of subsurface soils exceeding the SAL in each area.

The excavation control survey procedure is described in detail in SOP-3 included in Appendix C.3. A gamma scan survey in combination with gamma static measurements (as needed) will be performed to guide excavation in lifts, until the residual impacted soil exceeding the SAL has been removed.

Following the excavation of impacted soil at the specified excavation cut depths, a gamma scan will be performed with the collimated detector in the excavated areas to identify any locations that exceed the SAL equivalent count rate. The gamma scan survey will be conducted for 100 percent coverage of the area. If no location exceeding the SAL count rate is identified within the area by the scan, the excavation will be considered complete. Judgmental gamma static surveys at various locations within the area may be performed to confirm excavation of soil exceeding the SAL count rate, if determined necessary. If the excavation depth is greater than two feet, the walls of the excavation will be scanned with a collimated detector to verify that the horizontal extent of soil above the SAL does not expand with excavation depth.

If the gamma scans following the initial soil excavation lift show portions of the area above the SAL count rate or any static measurement point above the SAL count rate, the area will be field marked with pin flags or marking paint. The excavation contractor will be informed that the area needs additional excavation at that location. The results observed during the gamma scan survey will be documented on a field form and on excavation area maps for excavation control coordination and documentation of field conditions. The excavations will be repeated in lifts, as necessary, until the gamma scan survey indicates that soil exceeding the SAL count rates has been excavated and removed, or the excavation reaches bedrock.

5.2 Soil Sampling and Analysis

Excavation control soil samples for onsite ex-situ gamma radiation soil screening will be collected judgmentally during the soil excavation. The soil samples will be collected using a stainless-steel scoop or spoon and will be homogenized in a stainless-steel bowl and placed in a sample bag and labeled as discussed in SOP-5. The excavation control confirmatory surface soil samples will be shipped to an off-site laboratory for analysis of Ra-226 with a reporting limit of 0.5 pCi/g using USEPA Method 901.1. Laboratory methods, instruments, and sensitivities will be in accordance with USEPA protocols for environmental analysis. Any laboratory used for environmental sample analysis will have appropriate Environmental Laboratory Approval Program certification or equivalent. All laboratory instrumentation will be calibrated by using National Institute of Standards and Technology traceable standards.

5.3 Documentation

Excavation control surveys and sampling results will be recorded on field forms included with the SOP-3. The scan gamma survey results will be summarized on area maps and updated as excavation progresses for review, excavation control, and coordination of the excavation activities with the excavation fleet.

5.4 Instrument Calibration and Function Checks

Instruments and equipment used during the excavation control will be operated, calibrated, and maintained according to SOP-1 and/or manufacturer's guidelines and recommendations. Instruments will be calibrated annually. Daily operational and functional checks will be performed for radiological instruments before first use, with a mid-day check performed if necessary. Equipment that fails calibration or becomes otherwise inoperable during the excavation control surveys will be removed from service and segregated to prevent inadvertent use. Such equipment will be tagged to indicate that it should not be used until the problem is corrected. Equipment requiring repair or recalibration must be approved for use by the Radiation Safety Officer or designee before being placed back into service. Equipment that cannot be repaired or recalibrated will be replaced. Potentially affected data acquired on such equipment will be identified and evaluated for usability and potential impact on data quality.

5.5 Safety and Radiation Protection

The excavation control will require working around heavy equipment, which poses an elevated potential safety risk. Safety and radiation protection during excavation control will be addressed in the Radiation Protection Plan. A Health and Safety Plan will be developed later by the construction contractor.

5.6 Field Decontamination

Field sampling equipment used during soil sampling will be decontaminated between samples. Equipment to be decontaminated includes stainless steel scoops, bowls, and spoons. Other equipment used during sampling activities that does not directly contact sample materials (e.g., shovels) will be cleaned to remove visible soil contamination.

Field equipment decontamination activities will be conducted at the lined sump at the site. Liquid decontamination water will be collected and disposed of in one of the two pits.

6.0 QUALITY ASSURANCE AND QUALITY CONTROL MEASURES

Quality Assurance/Quality Control (QA/QC) measures will be employed throughout the excavation control process to ensure that decisions are made based on data of acceptable quality. The QA/QC measures during the excavation control process will include appropriate instrument calibrations, meeting specified MDC requirements, daily instrument operational function checks, replicate measurements, judgment-based soil sampling for measurement confirmation (if determined necessary by the survey crew), marking areas on a map and on the ground surface for excavation control. These measures are described in the appropriate SOP-1, SOP-3, SOP-4 and SOP-5 (Appendix C.3).

7.0 REFERENCES

AVM 2018. Supplemental Radiologic Characterization Report, St. Anthony Mine Site, Seboyeta, New Mexico, August.

MWH, 2007. St. Anthony Mine Materials Characterization Report, October.

USEPA, 2000. Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), EPA 402-R-97-016.

U.S. Nuclear Regulatory Commission, 1998, Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions, NUREG- 1507, June.

Figure

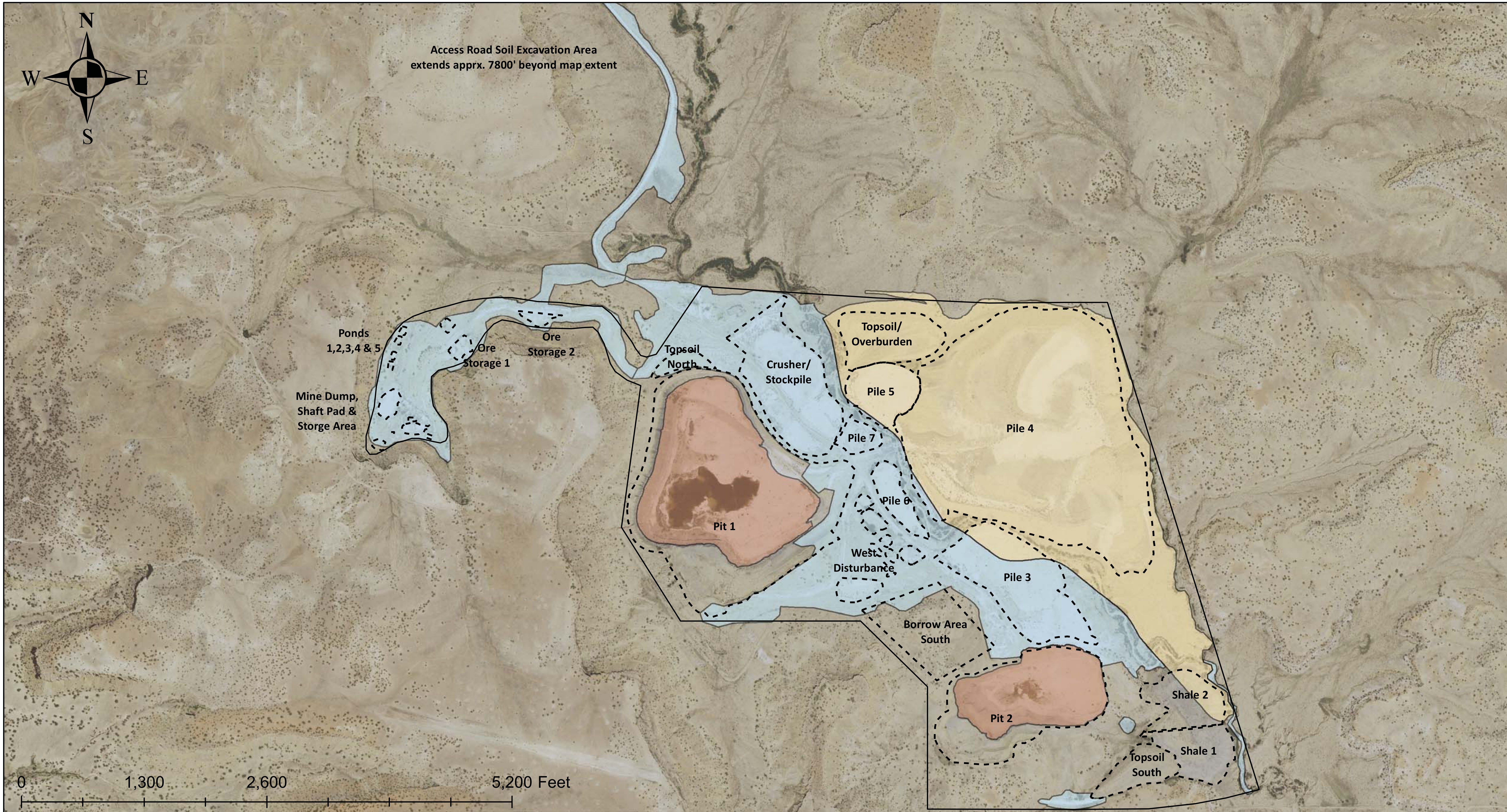

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Figure 1
Soil Action Level Excavation Area
St. Anthony Mine Site Excavation Control Plan

Legend

- Soil Action Level Excavation Area
- Regraded, Stabilized and Covered Area
- Backfilled, Stabilized and Covered Area
- Permit Boundary
- Site Feature Boundary

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Attachment

Attachment 1

Gamma Radiation Level to Surface Soil Ra-226 Correlation
St. Anthony Mine Site Excavation Control and Verification Survey

Gamma radiation level to surface soil Ra-226 Correlations for 2x2 NaI bare and 0.5-inch lead collimated detectors were developed to meet the acceptable criteria of a R^2 at greater than 0.80, p-value of less than 0.05 (DQO Type I error) and low mean squared error (MSE) for excavation control during soil excavation and Verification Survey (VS) following completion of soil excavation action at the St. Anthony Mine Site (the site). The soil excavation action of the contaminated soil at the site is expected to change the contamination distribution and concentration to a fairly homogeneous distribution at or near the removal action level in surface soils. Therefore, the contaminant distribution assumption for the correlation for remedial action support surveys and the VS will be fairly homogeneous in surface soils near the 6.6 pCi/g Soil Action Level (SAL).

During excavation control surveys, it is likely that the Ra-226 concentration in soil near the excavated areas will be elevated. Gamma radiation shine from such areas may interfere with gamma radiation level measurements at excavated areas, since the high-energy gamma radiation can travel long distances in air before ionizing. In areas with heterogeneous contamination distribution with nearby isolated hotspots, shine interference will be mitigated by placing the detector in a 0.5-inch-thick collimator. In addition to a correlation for a bare (un-collimated) detector, a correlation was also developed for a lead collimated detector from gamma radiation level measurements and co-located soil samples during the site 2018 Supplemental Radiologic Characterization. In addition to the 2x2 NaI detectors, a correlation for gamma exposure rate to surface soil Ra-226 concentration was also developed during the 2018 Supplemental Radiologic Characterization. These correlations were provided in the 2018 SRC Report. The correlations will be used to calculate equivalent detector counts per minute (cpm) to the 6.6 pCi/g SAL during excavation control, and to convert gamma radiation level measurements in cpm to surface soil Ra-226 concentration in pCi/g for VS.

Bare 2x2 NaI Detector Correlation

A correlation for a bare (un-collimated) detector was developed using data from the 13 points collected at the site as discussed above. As shown in Figure 1, the correlation yielded a correlation equation of Ra-226 pCi/g = (cpm x 0.0005) - 5.51 with a R^2 of 0.98. The regression analysis yielded a p-value significantly lower than the specified DQO Type I error of 0.05 with a low MSE.

Collimated 2x2 NaI Detector Correlation

The site correlation data for collimated detectors were collected at the same 13 points as for the bare detector during the 2018 Supplemental Radiological Characterization. A linear regression was performed using data from the 13 points. The regression yielded a correlation equation of Ra-226 pCi/g = (cpm x 0.0015) - 5.21 with a R^2 of 0.93 as shown in Figure 2, which exceeds the acceptable criteria of greater than 0.80. The correlation regression also yielded a p-value significantly lower than the acceptable criteria of less than specified DQO Type I error of 0.05.

Gamma Exposure Rate (μR) Meter Correlation

A correlation for a uR meter (Ludlum Model 19) was developed by collecting gamma exposure rate measurements at same 13 locations as the 2x2 NaI detector at the site as discussed above. As shown in

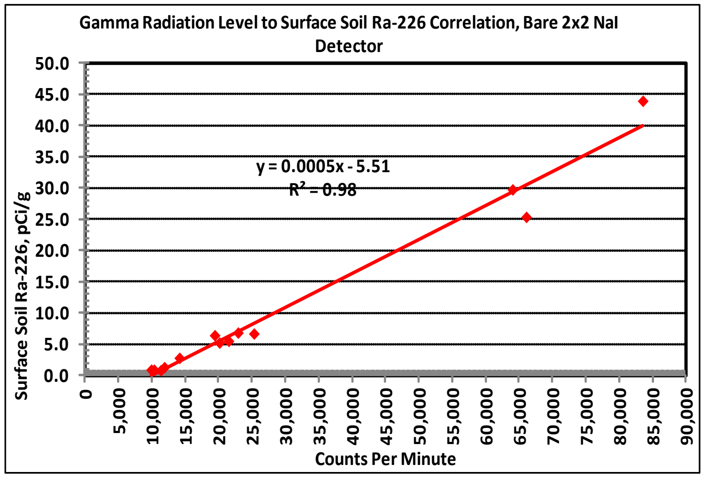
Figure 3, the correlation yielded a correlation equation of Ra-226 pCi/g = (uR/hr x 0.49) - 5.10 with a R^2 of 0.98. The regression analysis yielded a p-value significantly lower than the specified DQO Type I error of 0.05 with a low MSE.

This bare detector correlation will be used as appropriate during the site soil excavation control and VS for scan surveys. The collimated detector correlation will be used for gamma static surveys during VS and as needed during the excavation control survey. The gamma exposure rate correlation will be used to develop the site post-reclamation radiation level (PRRL). If any soil sampling is performed with a co-located static survey location where surface contamination distribution during excavation control, the data may be used to update the correlations.

Figure 1

Gamma Radiation Level to Soil Ra-226 Concentration Correlation
St. Anthony Mine Site
2x2 NaI Bare Detector (SPA-3)

Surface Soil Sample ID	2x2 NaI Bare Detector CPM	Ra-226 pCi/g
SA-COR-001	10009	0.85
SA-COR-002	10424	0.83
SA-COR-003	83615	43.90
SA-COR-004	66156	25.30
SA-COR-005	19509	6.36
SA-COR-006	11428	0.75
SA-COR-007	14226	2.73
SA-COR-008	20214	5.17
SA-COR-009	64112	29.70
SA-COR-010	23000	6.78
SA-COR-012	25382	6.63
SA-COR-013	21589	5.45
SA-COR-014	11962	1.25



REGRESSION SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.988945607
R Square	0.978013413
Adjusted R Square	0.976014633
Standard Error	2.111552191
Observations	13

ANOVA

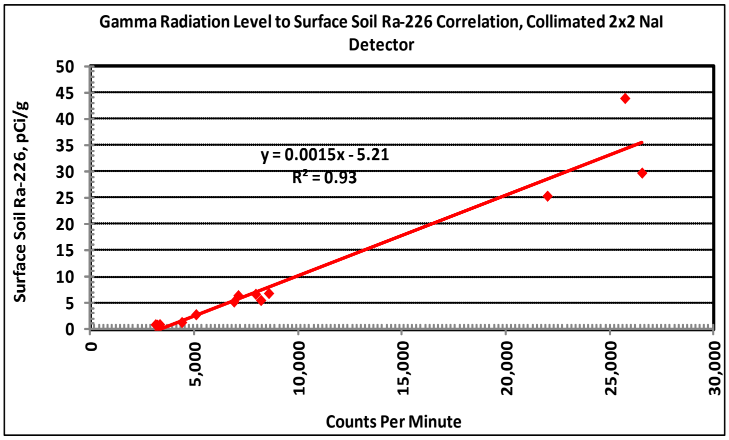
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2181.64119	2181.64119	489.3050341	1.80856E-10
Residual	11	49.04517922	4.458652656		
Total	12	2230.686369			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-5.512824494	0.928968951	-5.934347414	9.81159E-05	-7.557471369	-3.46817762	-7.557471369	-3.46817762
X Variable 1	0.000543377	2.45647E-05	22.12024037	1.80856E-10	0.00048931	0.000597443	0.00048931	0.000597443

Figure 2

Gamma Radiation Level to Soil Ra-226 Concentration Correlation
St. Anthony Mine Site
0.5 Inch Thick Lead Collimated 2x2 NaI Detector (SPA-3)

Surface Soil Sample ID	2x2 NaI Collimated Detector CPM	Ra-226 pCi/g
SA-COR-001	3363	0.85
SA-COR-002	3158	0.83
SA-COR-003	25742	43.90
SA-COR-004	22008	25.30
SA-COR-005	7135	6.36
SA-COR-006	3234	0.75
SA-COR-007	5109	2.73
SA-COR-008	6932	5.17
SA-COR-009	26561	29.70
SA-COR-010	8607	6.78
SA-COR-012	7975	6.63
SA-COR-013	8228	5.45
SA-COR-014	4422	1.25



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.966609815
R Square	0.934334535
Adjusted R Square	0.928364948
Standard Error	3.649147559
Observations	13

ANOVA

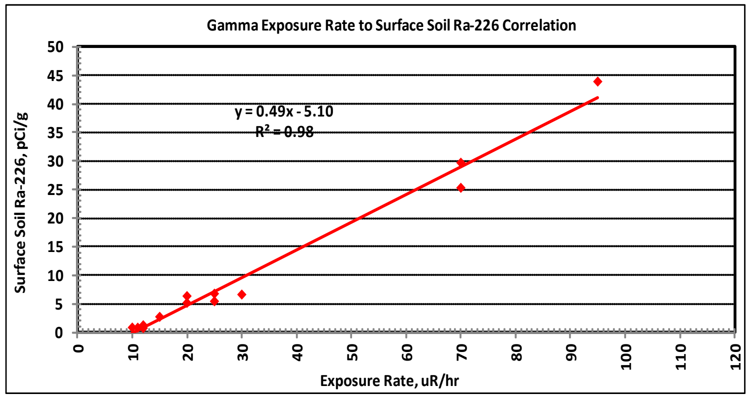
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2084.207312	2084.207312	156.5157566	7.57125E-08
Residual	11	146.479057	13.31627791		
Total	12	2230.686369			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-5.206105492	1.608752692	-3.236112995	0.007928568	-8.746946291	-1.665264693	-8.746946291	-1.665264693
X Variable 1	0.00153524	0.000122715	12.51062575	7.57125E-08	0.001265146	0.001805334	0.001265146	0.001805334

Figure 3

Gamma Exposure Rate to Soil Ra-226 Concentration Correlation
St. Anthony Mine Site
Ludlum 19 Micro R meter

Surface Soil Sample ID	Exposure Rate Ludlum 19	Ra-226 pCi/g
SA-COR-001	10	0.85
SA-COR-002	11	0.83
SA-COR-003	95	43.90
SA-COR-004	70	25.30
SA-COR-005	20	6.36
SA-COR-006	12	0.75
SA-COR-007	15	2.73
SA-COR-008	20	5.17
SA-COR-009	70	29.70
SA-COR-010	25	6.78
SA-COR-012	30	6.63
SA-COR-013	25	5.45
SA-COR-014	12	1.25



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.991471657
R Square	0.983016046
Adjusted R Square	0.981472051
Standard Error	1.855847609
Observations	13

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2192.800495	2192.800495	636.6701629	4.36259E-11
Residual	11	37.88587381	3.444170346		
Total	12	2230.686369			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-5.095319041	0.802456682	-6.349649965	5.4476E-05	-6.861514288	-3.329123794	-6.861514288	-3.329123794
X Variable 1	0.486600356	0.019284802	25.23232377	4.36259E-11	0.444154794	0.529045917	0.444154794	0.529045917