Appendix A STANTEC SITE CHARACTERIZATION MEMO

Stantec

Memorandum

To:	Roy Blickwedel General Electric	From:	Toby Leeson, PG Stantec, Steamboat Springs, Colorado
File:	St. Anthony Mine, 233001076	Date:	September 4, 2018

Reference: Summary of Supplemental Materials Characterization, St. Anthony Mine

INTRODUCTION

This memorandum summarizes the results of the Supplemental Materials Characterization of mine waste at the St. Anthony Mine (the site). The work was conducted in accordance with the *Supplemental Investigations Work Plan*, dated February 20, 2018. The Site is located 40 miles west of Albuquerque, New Mexico, approximately 4.6 miles southeast of Seboyeta, New Mexico on the Cebolleta Land Grant. The mine was an open pit and underground shaft uranium mine that includes one sealed shaft, one surface-sealed vent shaft, two open pits, five inactive ponds, seven piles of non-economical mine materials (partially revegetated), three topsoil piles, and several small piles of non-economical mine materials. The mine permit boundary area covers approximately 430 acres that includes these mine features along with roads and other disturbed areas. A site layout map is included on Figure 1.

A Materials Characterization was conducted in 2007 to characterize radiological contamination in surface and subsurface soils within the mine site features, such as the waste piles (MWH, 2007). The Mining and Minerals Division (MMD) noted that soils within the areas between the mine site features were not characterized and an outer boundary for the radiological contamination was not determined, as stated in their letter dated November 24, 2015. Therefore, the Supplemental Radiological Characterization was conducted to characterize the areas within the permit boundary that were excluded from the 2007 Materials Characterization and to estimate the location of the outer boundary (lateral extent) of the mine waste. The results of the Materials Characterization (2007 and 2018) were used to estimate the location and volume of mine waste at the site and will be used in the development of the *Closeout Plan*.

The investigation field work was conducted by AVM Environmental Services, Inc. (AVM) with oversight from Stantec. AVM prepared a *Supplemental Radiologic Characterization Report* that is included as Attachment A to this memorandum. Their report describes the field investigation methods and results of the investigation, and includes gamma survey measurements, subsurface sampling and analytical results, a correlation between gamma radiation and Ra-226 concentrations, and radiologic instrument calibration and function check records.

METHODS

The field investigation included static gamma radiologic survey measurements, Global Positioning System (GPS) based scan surveys, ex-situ and in-situ gamma radiation soil screening, soil sampling and laboratory analysis. Instrumentation for direct gamma radiation level measurements included 2x2 NaI scintillation detectors (Eberline SPA-3 and Ludlum 44-10), paired with a Ludlum 2221 or 2241 scale/rate meter. The scale/rate meters were connected to a Differential Global Positioning system (DGPS) of sub-meter accuracy that has data logging and surveying software capabilities.

The site was divided into 26 zones and surveys were taken along geo-projected transects spaced 30 feet apart, with the detector held one foot above the ground surface. A scan rate of around three feet per second was used and data were collected at a one to two second interval. Transects were created within the survey areas. The survey data were then mapped onto a site map, using different colors delineating the gamma level ranges. In addition to survey areas identified in the work plan, Stantec collected gamma survey data in step-out areas (e.g., areas outside the permit boundary) where gamma measurements exceeded the investigation levels (IL) for Ra-226. The IL for Ra-226 that was used for this investigation was 6.1 pCi/g (5.0 pCi/g above mean background level). The mean background level for Ra-226 was 1.6 pCi/g (MWH, 2007).

Based on the results of the gamma scan, Stantec targeted areas with the highest Ra-226 levels and selected 24 locations for subsurface sampling and analysis from test pits (Figure 3 of Attachment A). Stantec conducted subsurface soil sampling for on-site ex-situ gamma soil screening from April 16 to April 19, 2018. Subsurface samples were taken at one-foot depth intervals from the test pits, with sampling continuing until the gamma readings were below the IL (6.6 pCi/L).

Field personnel conducted ex-situ gamma radiation soil screening from the test pits by measuring the 609 KeV region gamma radiations of Bi-214, a decay product of Ra-226. This was done by using a Ludlum 2221 paired with a Ludlum 44-20 3x3 NaI scintillation detector. As soil sample was collected and then placed in a heavily shielded counting chamber, around a plastic lined detector.

A total of 57 subsurface samples were collected from test pits and 44 soil samples were sent to the laboratory for analysis (ALS Inc., Fort Collins CO). Field QA/QC duplicates, taken at 10 percent frequency (five samples), were split in the field and included in the batch sent to the laboratory. These soil samples were analyzed for Ra-226 using EPA Method 901.1 modified.

AVM developed a site-specific correlation using regression analysis for the collimated and bare 2x2 NaI detectors to convert the detector gamma radiation levels (in cpm) to surface soil Ra-226 concentration (in pCi/g). Correlation locations were determined after investigation confirmed that elevated levels of Ra-226 in the chosen locations were limited to the surface soil and that sources of lateral gamma radiation shine were minimal. Fourteen correlation samples were sent to the laboratory for Ra-226 analysis using EPA Method 901.1 modified. Eight additional samples with some particles greater than 0.25 inches were submitted the laboratory for analysis that included all particle sizes to evaluate if there was a difference compared to the initial samples which were sieved to remove particles greater than 0.25 inches. The results of the correlation are included in Appendix C of Attachment A.

RESULTS

Gamma radiation surveys began March 19, 2018 and were completed on May 12, 2018. The gamma radiation measurements in counts per minute (cpm) were converted to Ra-226 concentrations (activity) in pCi/g using the site-specific correlation. The 2007 Materials Characterization was conducted using exposure rate measurements, which were also converted to Ra-226 concentrations using the site-specific correlation.

The results of the gamma radiation survey in cpm are shown on Figures 1 and 2 of Attachment A, and in equivalent Ra-226 concentrations in pCi/g on Figures 5 and 6 of Attachment A.

The results of the 2007 Material Characterization are also shown on Figure 5 of Attachment A. The 2007 gamma survey results showed that Waste Piles 3, 4, 6, and 7, the Crusher/Stockpile, Pit 1, and the smaller piles at the West Shaft and Ore Storage 1 and 2 areas all had gamma radiation levels above 10 pCi/g. Pile 4 had some readings of 10.1 to 25.0 pCi/g; however, the majority ranged from <1.6 pCi/g to 10 pCi/g. Soils within the other mine features surveyed in 2017 were below the IL of 6.6 pCi/g.

The lateral extent of surface soils with Ra-226 concentrations greater than the IL is generally within the permit boundary, as shown on Figure 5 of Attachment A, except for the access road and some other small areas. The access road extends to the north of the permit boundary and had consistently high gamma measurements (generally between 10.1 and 100.0 pCi/g), as shown on Figure 6 of Attachment A. Other areas where IL exceedances were measured slightly outside the permit boundary included the following:

- South of Shale Pile 1
- South of Pit 1
- Around the West Shaft Area
- North of Pit 1

The highest Ra-226 concentrations within the Site were measured in the central portion of the Site adjacent to the west side of Pile 6, within the Crusher/Stockpile, and within Pile 7. There are numerous small waste piles in the area adjacent to Pile 6 where gamma radiation was measured above 100 pCi/g. The gamma radiation levels tended to decrease with increased distance from the piles and towards the permit boundaries. Ponds 1 through 4 in the West Shaft Area had similarly elevated readings that were generally contained within the pond boundaries. Additionally, the arroyo had readings of approximately 10 to 100 pCi/g in the deepest parts of the channel and readings of 6.6 to 10 pCi/g on the banks and adjacent areas.

Laboratory testing and ex-situ soil screening results are included in Appendix B of Attachment A. These results were generally consistent with the gamma measurements converted to Ra-226 levels. The on-site ex-situ soil screening results, laboratory analytical results, and observations made in the test pits, were used to estimate the depth of IL exceedances. These depth estimates were then used to interpolate the depth of IL exceedances for the remainder of the site. The lateral extent and depths of IL exceedances (excavation limits) are shown on Figure 2 and Figure 3. Maximum depths of IL exceedances were 5.0 to greater than 6.5 feet bgs in the following areas:

- 6.5 feet bgs (or greater) between Pile 3 and Pit 2 at Test Pit 24
- 6 feet bgs near Borrow Area South at Test Pit 23
- 5 ft bgs west of the Crusher/Stockpile Area at Test Pits 4 and 5
- 5 to 6 feet bgs between Pit 1 and Pile 6 at Test Pits 11 and 13

The ground surface elevations, the lateral extent (outer boundary) of Ra-226 above the IL, the depths of IL exceedances (including the mine features that were characterized in 2007) and the interpolated depths in other areas of the site, were used to estimate the volume of mine waste with Ra-226 concentrations above the IL (6.6 pCi/g). The volume was estimated to be 8.1 million cubic yards.

CONCLUSION

The overall goal to characterize the materials between site features and estimate the lateral and vertical extent of mine waste with Ra-226 greater than the IL of 6.1 pCi/g was completed. The IL exceedances are generally contained within the permit boundary, except for the access road and small areas south of Shale Pile 1, south of Pit 1, around the West Shaft Area, and north of Pit 1. The depth of impacts throughout the site was characterized from 24 test pits and was measured from 0.5 feet to approximately 6.5 feet bgs. This information along with the results of the 2007 Materials Characterization were used to estimate the volume of mine waste at 8.1 million cubic yards.

ATTACHMENTS

Figure 1 – Site Layout
Figure 2 – Excavation Limits
Figure 3 – Excavation Limits (no contours)
Attachment A – Supplemental Radiologic Characterization, St. Anthony Mine Site

REFERENCES

MWH, 2007. *Materials Characterization Report: Saint Anthony Mine Site.* MWH. October 26.

Stantec, 2018. *St. Anthony Supplemental Investigations Work Plan.* Stantec. February 23.

Stantec Consulting Services Inc.

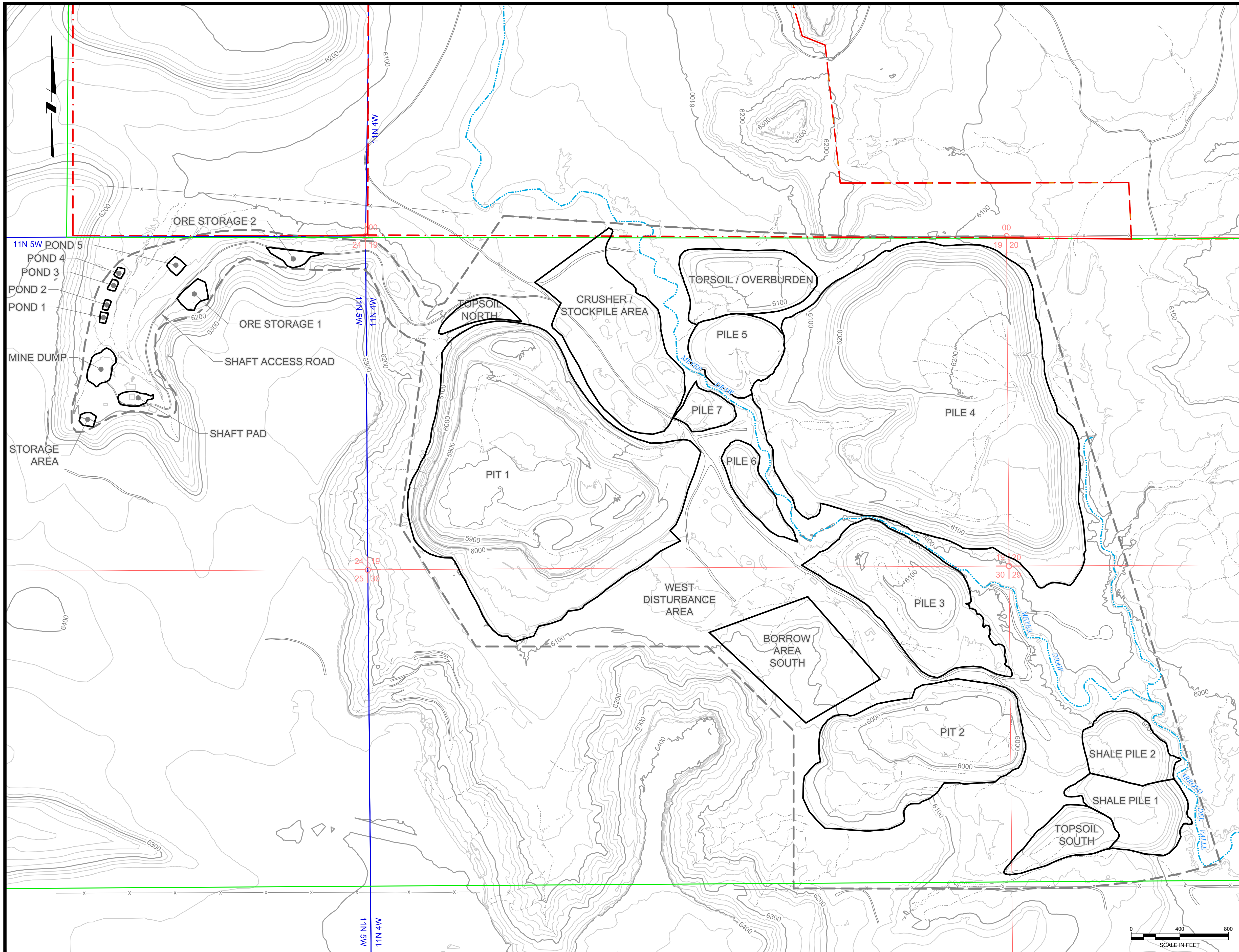
Toby Leeson

Toby Leeson, PG
Principal Hydrogeologist

Phone: (970) 871-4361
Toby.leeson@stantec.com

ATTACHMENTS

FIGURES



LEGEND:

6100	EXISTING GROUND SURFACE CONTOUR & ELEVATION, FEET
	DRAINS
	ARROYO
	EXISTING ROAD
	EXISTING FENCE
	EXISTING OVERHEAD ELECTRIC AND POWER POLES
11N 5W	TOWNSHIP LINE AND NUMBER
25	SECTION LINE AND NUMBER
	CEBOLLETA LAND GRANT
	PARCEL - LOBO PARTNERS,LLC
	PARCEL - UNITED NUCLEAR CORP (UNC)
	UNC MINE PERMIT BOUNDARY
	FACILITY OUTLINES

DESIGNED K REED
CHECKED B VAN
APPROVED T LEESON

Stantec

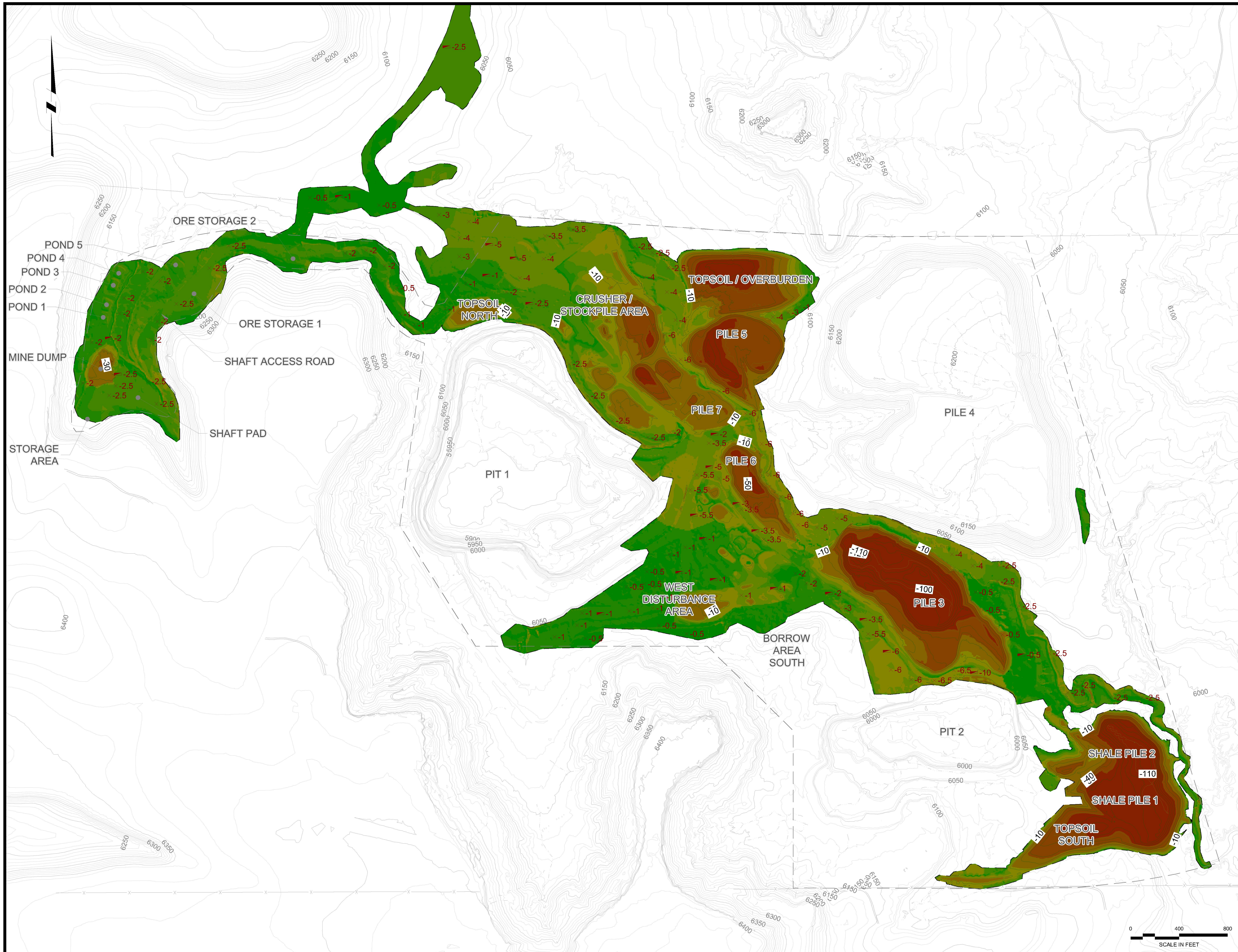
unc

UNITED NUCLEAR CORPERATION AND ST. ANTHONY MINE
CIBOLA COUNTY, NEW MEXICO

SITE LAYOUT

FIGURE
1
233001076
SEPT 2018

Tuesday, September 04, 2018 10:48:01 AM KWREED C:\PWWORKDIR\D0492656\STA_SITE LAYOUT.DWG Layout:Site Layout



LEGEND:

- 6100 EXISTING GROUND SURFACE CONTOUR & ELEVATION, FEET
- DRAINS
- ARROYO
- EXISTING ROAD
- EXISTING FENCE
- EXISTING OVERHEAD ELECTRIC AND POWER POLES
- UNC MINE PERMIT BOUNDARY
- -1.5 TEST PIT AND EXCAVATION DEPTH (STANTEC, 2018)

Excavation Depths

NUMBER	COLOR	MINIMUM DEPTH (FT)	MAXIMUM DEPTH (FT)
1		-138.9	-52.8
2		-52.8	-27.3
3		-27.3	-12.0
4		-12.0	-5.8
5		-5.8	-3.1
6		-3.1	-1.9
7		-1.9	-0.5
8		-0.5	34653465.0

DESIGNED K REED
CHECKED B VAN
APPROVED T LEESON

Stantec

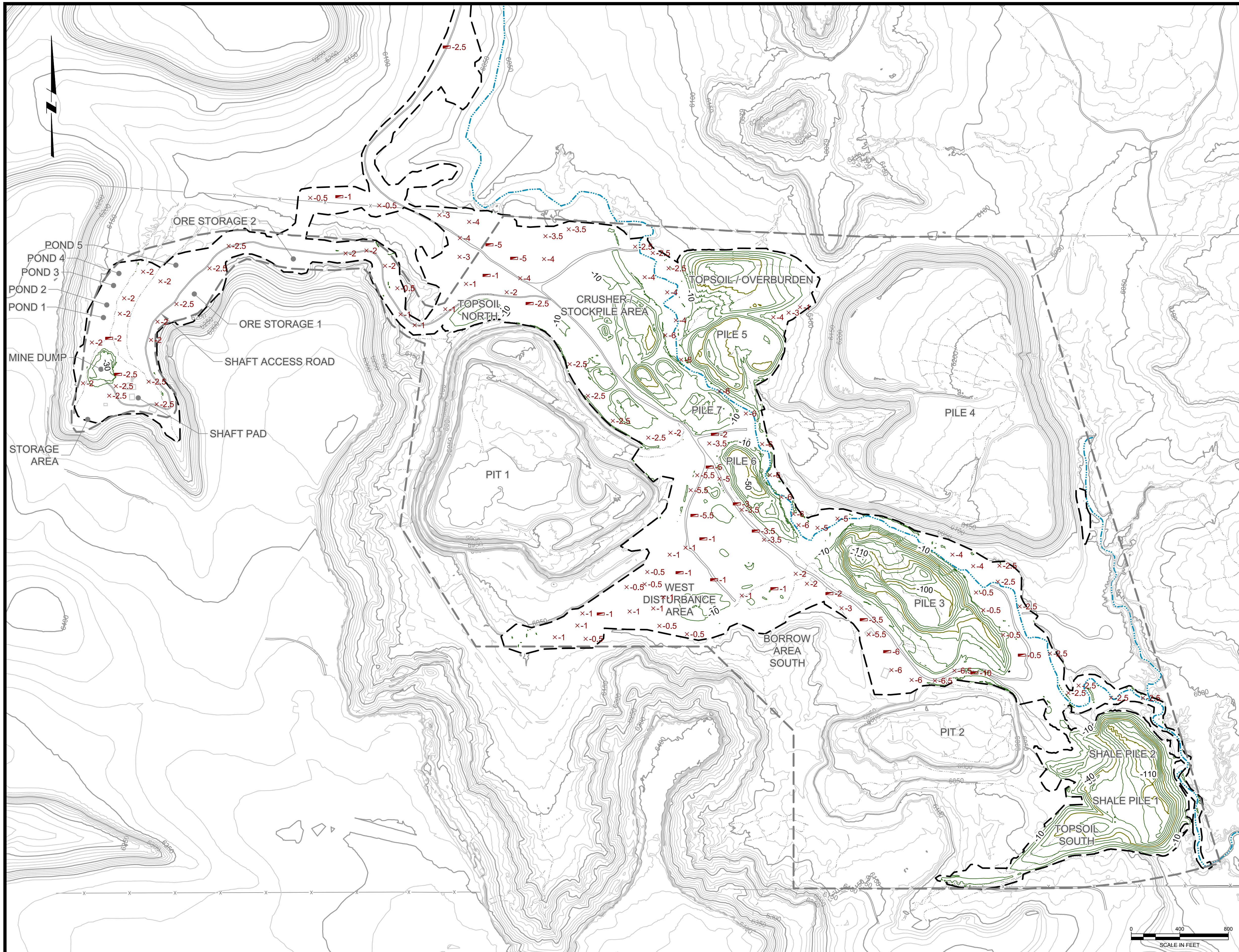
unc

UNITED NUCLEAR CORPERATION AND ST. ANTHONY MINE
CIBOLA COUNTY, NEW MEXICO

EXCAVATION LIMITS

FIGURE
2
233001076
SEPT 2018

Tuesday, September 04, 2018 10:46:50 AM KWREED C:\PWWORKDIR\D0492656\STA-EXCAVATION_LIMITS.DWG Layout:Figure



LEGEND:

6100	EXISTING GROUND SURFACE CONTOUR & ELEVATION, FEET
-10	EXCAVATION DEPTH CONTOUR & ELEVATION, FEET
	DRAINS
	ARROYO
	EXISTING ROAD
	EXISTING FENCE
	EXISTING OVERHEAD ELECTRIC AND POWER POLES
	UNC MINE PERMIT BOUNDARY
	LIMITS OF EXCAVATION
-1.5	TEST PIT AND EXCAVATION DEPTH (FT) (STANTEC, 2018)
×-2.5	EXCAVATION DEPTH (FT)

Tuesday, September 04, 2018 10:47:20 AM KWREED C:\PWWORKDIR\D0492656\STA-EXCAVATION_LIMITS.DWG Layout:Figure (2)

DESIGNED K REED
CHECKED B VAN
APPROVED T LEESON

Stantec

unc

UNITED NUCLEAR CORPORATION AND ST. ANTHONY MINE
CIBOLA COUNTY, NEW MEXICO

EXCAVATION LIMITS

FIGURE
3
233001076
SEPT 2018

SUPPLEMENTAL RADIOLOGIC CHARACTERIZATION
AVM ENVIRONMENTAL SERVICES, INC.

Supplemental Radiologic Characterization
St. Anthony Mine Site
Seboyeta, New Mexico

Prepared by:
AVM Environmental Services, Inc.
1717 Del Norte Blvd.
Grants, NM 87020

Prepared for:
Stantec Consulting Services Inc.
2130 Resort Dr., Ste. 350
Steamboat Springs, CO 80487

And

United Nuclear Corporation
PO Box 3077
Gallup, NM 87305

August 13, 2018

Table of Contents

1.0 Introduction and Background 1
2.0 Previous Characterization 1
3.0 Objective of Supplemental Radiologic Characterization 2
4.0 Field Investigation 2
4.1 Investigation Level 3
4.2 Gamma Radiation Surveys 3
4.3 Test Pits and Ex-Situ Gamma Radiation Soil Screening 4
4.4 Site Specific Gamma Radiation Level to Surface Soil Ra-226 Correlation 6
4.5 Ra-226 Investigation Level Contamination Boundary 7
5.0 Soil Sampling and Analysis 8
6.0 Quality Assurance and Quality Control Measures 9

Tables

Table 1 Typical Gamma Scan Data Exported From Scan System Data Logger
Table 2 St. Anthony Mine Site Test Pits Subsurface Soil Sample Field Gamma Radiation Screening Summary
Table 3 St. Anthony Mine Site Test Pits SubsurfaceRa-226 Contamination Depth Summary
Table 4 St. Anthony Mine Site Gamma Radiation Level to Ra-226 Correlation Data Summary

Figures

Figure 1 St. Anthony Mine Site Supplemental Radiologic Characterization Gamma Radiation Level Scan
Figure 2 St. Anthony Mine Site Access Road Supplemental Radiologic Characterization Gamma .... Radiation Level Scan
Figure 3 St. Anthony Mine Site Supplemental Radiologic Characterization Subsurface Investigation
Test Pit Test Pit locations
Figure 4 St. Anthony Mine Site Supplemental Radiologic Characterization Correlation Sampling locations
Figure 5 St. Anthony Mine Site Supplemental Radiologic Characterization Lateral Extent of Ra-226 Contamination
Figure 6 St. Anthony Mine Site Supplemental Radiologic Characterization Access Road Lateral Extent of Ra-226 Contamination

Appendices

Appendix A St. Anthony Mine Site Gamma Survey Data
Appendix B Subsurface Contamination Field Investigation Documentation
Appendix C St. Anthony Mine Site Correlation Data
Appendix D Radiologic Instrument Calibration and Operational Function Check Documentation

1.0 Introduction and Background

This report provides the framework and results of the Supplemental Radiologic Characterization that was conducted at the St. Anthony Mine Site (Site) near Seboyeta, New Mexico. The methods and procedures used were consistent with Section 4 of the February 23, 2018 Supplemental Investigation Work Plan (Work Plan) and the applicable survey methods described in the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM, EPA 2000a). The purpose of this Supplemental Radiological Characterization was to delineate the radiologic contamination boundary based upon an appropriate Investigation Level (IL), and to characterize the Site by performing radiological surveys and collecting soil samples in the areas between the mine features, as shown in Figure 4 of the Work Plan. Site features were characterized in 2007, as described in the *Materials Characterization Report, Saint Anthony Mine Site* (MWH, 2007b). The following sections describe the strategy, methods and procedures that were used and the results of the Supplemental Radiological Characterization of the Site.

The Site was an open pit and underground shaft uranium mine located on the Cebolleta Land Grant located in Cibola County, approximately 4.6 miles southeast of Seboyeta, New Mexico. The Site is in a remote, sparsely populated area with limited access. The location of the Site 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 4 of the Work Plan 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.

2.0 Previous Characterization

As discussed above, only the site features were radiologically characterized during the 2007 Materials Characterization. The features defined in the 2007 Materials Characterization included the Background Area, Borrow Sources, Top Soil Stockpiles, Non-Economic Materials Storage Piles, and Western Shaft Area. Gamma exposure rate surveys and soil sampling were conducted during the 2007 Material Characterization. The gamma exposure rate surveys included exposure rate measurements performed at one meter above the ground surface. The areas between the site features were not radiologically characterized during the 2007 Material Characterization. Additionally, the lateral extent of radiologic contamination at the Site was not identified in the 2007 Materials Characterization. A Ra-226 background level of 1.6 pCi/g for the Site was established during the 2007 Materials Characterization.

3.0 Objective of the Supplemental Characterization

The Site is a former uranium mine therefore the surface and subsurface soil is expected to be impacted by radionuclides associated with the uranium decay series, with Ra-226 being the primary Constituent of Concern (COC). Current and anticipated land use surrounding the Site is grazing and wildlife habitat, which is the designated post-mining land use supported by the land owner. Even though an IL based on risk-based cleanup criteria for a ranching scenario would be appropriate for the site characterization, Radiation Cleanup Criteria specified in the March 2016 *Joint Guidance for the Cleanup and Reclamation of Existing Uranium Mining Operations in New Mexico* (NMMMD, 2016) by the State of New Mexico Mining and Mineral Division (NMMMD) and New Mexico Environment Department (NMED) was used for the IL as a conservative measure. The Ra-226 cleanup criteria of 5.0 pCi/g above the background level in land averaged over 100 square meters in surface soil (top six inches) specified in the Joint Guidance are taken from the UMTRCA (40 CFR 192), which are based on an unrestricted land use exposure scenario. A 6.6 pCi/g Ra-226 IL (5.0 pCi/g plus 1.6 pCi/g background level) is used for the Site Characterization.

The objective of this Supplemental Radiological Characterization was to delineate the radiologic contamination boundary corresponding to the Ra-226 IL and radiologic characterization of the areas between the site features to estimate surface and subsurface Ra-226 soil concentrations. The objective included a site-specific correlation to convert the results of the supplemental characterization gamma radiation scan surveys in counts per minute (cpm) to Ra-226 soil concentration (pCi/g). An additional objective was to perform a cross-calibration and correlation of exposure rate survey equipment to convert and normalize the 2007 Material Characterization exposure rate measurements to direct gamma radiation levels to cpm and equivalent of Ra-226 surface soil concentrations to normalize the data consistent with the supplemental characterization data and the Ra-226 soil concentration IL.

4.0 Field Investigation

Field investigations for the Supplemental Radiologic Characterization were conducted consistent with the Work Plan during the period March 19, 2018 to May 12, 2018. The supplemental characterization areas and the site features previously characterized are shown in Figure 4 of the Work Plan. The field investigation included, both static gamma radiologic survey measurements and Global Positioning System (GPS) based gamma scan surveys, along with ex-situ and in-situ soil screening, and soil sampling and analysis. The geo-located gamma scans were conducted to provide Ra-226 concentration level estimates in surface soil and to determine the radiologic contamination boundary relative to the IL. Ex-situ gamma radiation soil screening and in-situ gamma radiation level measurements were performed to provide real-time information to estimate subsurface contamination depth. Subsurface soil sampling and analysis was performed to confirm subsurface contamination depth estimated by field ex-situ gamma radiation soil screening. Additionally, gamma radiation static surveys (cpm), exposure rate (μR/hr) measurements, and surface soil samples and analysis were performed at selected locations for the site-specific correlation.

4.1 Investigation Level

The 6.6 pCi/g Ra-226 IL for the Supplemental Radiological Characterization specified in the Work Plan is presented in terms of Ra-226 mass activity concentration and is expressed in units of activity per unit mass of soil, pCi/g. The direct gamma radiation surveys using a NaI scintillation detector provide radiation levels in counts per unit time, generally obtained as cpm. A gamma radiation level cpm equivalent to the IL from a site-specific correlation is useful to guide the field gamma scan activities and estimate the survey boundary relative to the lateral extent of contamination. As discussed in the Work Plan, a site-specific correlation was not available during the field activities for making decisions. As specified in the Work Plan, a correlation between direct gamma radiation levels in cpm and Ra-226 soil concentrations in pCi/g at a similar uranium mine site was used to determine the cpm of approximately 25,000 equating to 6.6 pCi/g Ra-226 in surface soil. However, a 22,500 cpm gamma radiation level was used for a conservative measure and to provide a safety margin for a real time estimate of lateral extent of surface soil contamination during the field gamma scan activities. As discussed in section 4.3 below, a site-specific correlation was developed to convert the gamma scan survey results in cpm to surface soil Ra-226 concentration.

4.2 Gamma Radiation Survey

Direct gamma radiation surveys, gamma exposure rate surveys, ex-situ and in-situ gamma radiation soil screening, and soil sampling and analysis were used for the supplemental radiologic characterization of the Site as described in the Work Plan. The instrumentation configuration for direct gamma radiation level measurements during this characterization consisted of 2x2 NaI scintillation detectors (Eberline SPA-3 and Ludlum 44-10) for detection of gamma radiation, coupled to a scaler/rate meter (Ludlum 2221 or Ludlum 2241). This instrument configuration is used widely for this type of survey and is recommended by the MARSSIM. The scaler/rate meters were interfaced with a sub-meter accurate Differential Global Positioning System (DGPS) with surveying software and a data logger controller for electronically recording the gamma radiation levels to the corresponding location coordinates. The coordinate system that was used for this work was the State Plane Coordinate System (NAD83, New Mexico West, US Feet). The direct gamma radiation surveys using a NaI scintillation detector provide radiation levels in counts per unit time, generally obtained as cpm. A Ludlum Model 19 µR Meter was used for gamma exposure rate (µR/hr) measurements.

DGPS based systematic gamma radiation scan surveys using bare detectors were performed at the Site to determine the lateral extent of Ra-226 in surface soil during this Supplemental Radiological Characterization. The field gamma scan activities began on March 19, 2018. Although bare detectors do not avoid any lateral gamma radiation shine, the bare detectors have a significantly larger field of view and provide a larger scan coverage for an efficient lateral extent of contamination assessment for larger areas. Since the Site encompasses a large area with varying types of terrain, the Site scan area was divided into 26 zones for management and organization of the field gamma scan activities. The gamma scan surveys were performed consistent with AVM SOP-3, included in the Work Plan, to provide a 20 percent coverage of the ground surfaces. Based on a conservative field of view (FOV) of at least six feet diameter for a bare detector for Ra-226 gamma radiations, a 20% coverage would require a scanning transect spacing of 30 feet. The 30-feet spaced geo-projected transects for each area were digitally created using mapping software and loaded on the field data logger/controller. The gamma scan survey was performed by scanning along these transects with a bare detector at 12 inches above the ground surface at a scan rate of about three feet per second, with a data collection time interval of one and two seconds, depending upon the scaler/ratemeter used. Technicians walked along these transects with the gamma scan survey instruments for the gamma scans in accordance with AVM SOP-3.

The gamma scan survey was conducted by first scanning the areas between site features within the permit boundary, as shown in Figure 4 of the Work Plan, to determine if the radiologic contamination boundary based on the IL cpm is contained within the permit boundary, or if any contamination has migrated beyond the permit boundary. The geo-located gamma scan data includes the gamma scan point ID, date and time, location coordinates, and gamma cpm. The scan data was exported from the data logger, mapped using a mapping software, arranged in color coded ranges, and then reviewed to determine the areas that exceeded the IL cpm. The color-coded range was structured to include the cpm equivalent to the Ra-226 6.6 pCi/g screening level, as discussed previously.

Based on the review of the scan data, additional step-out gamma scans were conducted within and outside the permit boundary identified during field investigation, such as North Wash Area, Arroyo bed and the Access Road, until gamma radiation levels below the IL were detected. The field gamma scan activities were completed on May 12, 2018. The supplemental characterization gamma scan survey included approximately 154,000 gamma scan data points within a total of approximately 370 acres at the Site. The gamma scan data were exported from the scan system data logger into Excel files. The detector cpm were converted into equivalent estimated surface soil Ra-226 concentration in pCi/g using the site-specific correlation for the bare detector as discussed in Section 4.5. A typical gamma scan data export from the scan system data logger is shown in Table 1. Gamma scan data for all the gamma scan surveys during this supplemental characterization are provided in spreadsheet files on a compact disc included in Appendix A. Figure 1 and Figure 2 show the extent of gamma scan at the Site and results in cpm from a 2x2 NaI detector. As shown in Figure 1, the gamma scan surveys included the areas of potential surface contamination that were discussed in UNC's June 15, 2018 response to the NMMMDs April 17, 2018 comments on the Work Plan.

4.3 Test Pits and Ex-Situ Gamma Radiation Soil Screening

Test pit trench excavations and on-site ex-situ gamma radiation soil screening were performed from April 16 through April 19, 2018. These methods were used to define the vertical extent of subsurface contamination at the Site. The ex-situ gamma radiation soil screening was conducted in accordance with the AVM SOP-4 included in the Work Plan and provides a real-time estimate of Ra-226 concentrations in soil samples. This method is more reliable than the in-situ direct gamma surveys for real-time Ra-226 assessment in soils. The on-site ex-situ soil screening method consists of selectively measuring the 609 KeV region gamma radiations of Bi-214, a decay product of Ra-226 as discussed in AVM SOP-4 included in the Work Plan. A single channel analyzer (Ludlum L2221) integrated with a Ludlum 44-20 3x3 NaI scintillation detector was used to measure the 609 keV energy peak region of Bi-214. The soil sample was placed around the plastic lined detector in a heavily shielded counting chamber. The heavily shielded counting chamber lowers the system background counts, thus improving the system's minimum detectable concentration (MDC). A reference soil with the same concentration as the IL of 6.6 pCi/g was prepared as described in Appendix B and was used for soil screening at the Site.

An estimated Ra-226 soil concentration was created using a correlation from a similar uranium mine site to show the ranges of Ra-226 concentrations by mapping the geo-located gamma scan data using a color ramp, as shown in Figure 3. Also shown in Figure 3, a total of 24 locations were selected for subsurface assessment in areas with an estimated Ra-226 concentration level above 10 pCi/g at the surface, and where Ra-226 contamination was considered likely to be deeper than one foot below ground surface (bgs). No locations were selected in periphery areas where Ra-226 contamination was low and considered likely to be only in surface soils.

A track excavator was used to excavate trenches at each test pit location for subsurface soil sample collection. The trench was excavated at approximately one-foot depth intervals. At each interval, a subsurface soil sample was collected from the base of the excavation for ex-situ soil screening. The excavation continued until the on-site ex-situ soil screening indicated that Ra-226 concentrations of the soils samples were below the 6.6 pCi/g IL. The test pit excavation geotechnical logs along with the field soil screening forms are included in Appendix B. The test pit subsurface soil screening data is summarized in Table 2. The subsurface soil samples above or below the 6.6 pCi/g IL are shown in Table 2 based on the field soil screening results.

Although the primary objective of the ex-situ gamma radiation soil screening was to determine the Ra-226 concentrations above or below the 6.6 pCi/g IL, Ra-226 concentrations were estimated in all test pit excavation subsurface soil samples screened. During the set up of the soil screening system prior to mobilizing in the field, a calibration/correlation of the ex-situ soil screening system was performed using the 6.6 pCi/g reference soil sample, a 100 pCi/g reference soil sample and a background soil sample. This correlation is included in Appendix B. The estimated Ra-226 concentration in the borehole samples determined using this correlation are included in Table 2.

For the test pit subsurface soil investigation, 44 samples out of a total of 57 borehole subsurface soil samples screened onsite were sent to the off-site vendor laboratory, ALS, Inc. in Fort Collins, CO (ALS). These soil samples were analyzed for Ra-226 using EPA Method 901.1 (modified for soil matrix) for confirmation of the onsite soil screening results. The 44 samples sent to the laboratory included at least one sample from each test pit excavation that screened at a Ra-226 concentration below the IL. Also, 10% (5 samples) of the samples sent to the lab were split in the field and sent to the lab for QA/QC duplicates. The laboratory results reports are included in Appendix B and are summarized in Table 2. As shown in Table 2, the estimated Ra-226 levels by on-site ex-situ soil screening are consistent with the laboratory Ra-226 results, specifically in regard to determining the depth of Ra-226 levels above or below the IL, except for two samples. The first sample, SB-TP04-05, taken at a depth of five feet, from Test Pit 04, had an estimated Ra-226 concentration of 7.3 pCi/g, while the laboratory reported concentration was 4.9 pCi/g. In sample SB-TP04-06, which was collected at a depth of six feet, both the ex-situ field soil screening and laboratory results were below the IL. As a result, for a conservative measure, a six-foot Ra-226 contamination level depth will be used at this location for subsurface contamination assessment. The second sample, SB-TP12-04, taken at a depth of four feet from Test Pit 12, had an estimated Ra-226 concentration at 2.9 pCi/g, while the laboratory reported concentration was 16.0 pCi/g. Sample SB-TP12-03, which was taken at a shallower depth of three feet, had an estimated Ra-226 concentration of 6.2 pCi/g, while the laboratory reported concentration was 2.3 pCi/g, a lower concentration than SB-TP12-04. Generally, the contamination level decreased with depth, not increased. Therefore, Ra-226 contamination at or above the IL at this location is likely extend to three feet bgs. Based on the field soil screening and the laboratory sample results, the depth of Ra-226 concentrations above the 6.6 pCi/g IL at each test pit location is summarized in Table 3 and shown in Figure 3.

4.4 Site-Specific Gamma Radiation Level to Surface Soil Ra-226 Correlation

A site-specific correlation was developed for both collimated and bare 2x2 NaI detectors, consistent with AVM SOP-2 that was included in the Work Plan. The correlation was developed to convert gamma radiation levels in cpm for the detector to surface soil Ra-226 concentration in pCi/g. Although a collimated detector was not used for gamma surveys during this supplemental characterization, the data were collected and a correlation was developed for a 0.5-inch thick collimated detector for future use at the Site. Correlation locations were identified and investigated to ensure that the Ra-226 contamination distribution was limited to the surface soil, and that there was not a source of significant lateral gamma radiation shine. Prior to collecting the correlation surface soil samples at each location, one-minute static gamma measurements using detectors at 12 inches above the ground surface and a gamma exposure rate (µR/hr) measurement from 1 meter above ground surface using a calibrated µR meter were taken. The µR measurements were taken at each location to convert the 2007 Materials Characterization gamma exposure rate survey results to a Ra-226 concentration. The 14 correlation sample locations are shown in Figure 4. The correlation field gamma radiation level survey field forms and soil sampling logs are included in Appendix C.

The correlation soil samples were sent to ALS for Ra-226 analysis using EPA Method 901.1 (modified for soil matrix). Initially, ALS sieved out the +0.25-inch (rocks and pebbles) fraction from the samples during sample preparation and took an aliquot for gamma spectroscopy analysis, rather than processing the entire sample (i.e., all particles). Eight samples with noticeable rocks and pebbles greater than 0.25 inches were re-submitted to ALS for sample preparation and analysis including all of the sample material. The laboratory results report is included in Appendix C. The correlation data, gamma radiation levels, exposure rate measurements and laboratory Ra-226 analytical results of the soil samples are summarized in Table 4. Three linear regressions between the co-located soil sample Ra-226 and gamma radiation levels were performed for the correlations: 1) Bare 2x2 NaI detector cpm at 12 inches above the ground surface, 2) 0.5-inch thick lead collimated 2x2 NaI detector cpm at 12 inches above the ground surface, and 3) Ludlum 19 exposure rate µR/hr measurements at one meter above the ground surface. Data from location SA-COR-011 was not included in the correlation regression because it was determined to be an outlier due to a significantly elevated gamma radiation level and potential lateral gamma shine interference from scattered waste ore rocks and berms around this location. All three correlations with regression analysis summaries are included in Appendix C, and the regression equations are summarized as follow:

- **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 24,200 cpm equivalent to the 6.6 pCi/g surface soil Ra-226 IL.

- **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 7,870 cpm equivalent to the 6.6 pCi/g surface soil Ra-226 IL.

- **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 IL.

This site specific correlation for the bare detector is comparable to the correlation (pCi/g = cpm x 0.0005 - 6.14) from a similar uranium mine site that was used to guide the field gamma scan activities as discussed in Section 4.1 As discussed above, this correlation was developed to predict Ra-226 concentrations only in surface soil (0" to 6" depth). The correlation used a survey geometry consisting of a 2x2 NaI detector held at 12 inches above the ground surface and a scan rate of about three feet per second. This correlation may over estimate Ra-226 in surface soil in areas with Ra-226 contamination deeper than six inches, such as waste ore rock piles and backfill areas. Also, the correlation may over estimate Ra-226 levels in areas with significant lateral gamma radiation shine, such as areas near waste piles.

4.5 Ra-226 Investigation Level Contamination Boundary

The radiation level data in cpm collected during this Supplemental Radiological Characterization was converted to the equivalent estimated Ra-226 pCi/g concentration using the regression equation for bare 2x2 detectors, as described above and shown in Figure 5 and Figure 6. The data were structured in the maps into ranges of pCi/g and set to a color ramp. The 6.6 pCi/g Ra-226 IL contamination boundary was delineated using the color ramped ranges as a guide, as shown in Figure 5 for the Site and Figure 6 for the Site Access Road.

A total of 421 surface gamma exposure rate measurements in µR/hr at one meter above the ground surface were made during the 2007 Materials Characterization. The 2007 gamma exposure rate measurements are summarized in Table 3 and shown on Figure 3 of the *Materials Characterization Report*. These gamma exposure rates at one meter above the ground surface in µR/hr were converted to estimated surface soil Ra-226 in pCi/g using the site specific gamma exposure rate to surface soil Ra-226 correlation (pCi/g = µR/hr x 0.19 - 5.10) discussed in Section 4.4 above, and included in Appendix C. The 2007 Materials Characterization gamma survey measurements are shown on Figure 5 and Figure 6, and included in Appendix A.

As shown in Figure 5, the contamination boundary at the IL is contained within the permit boundary on the east side of the Site, south of the shale piles and Pit 2, and west of Pit 2 and Borrow Area South. There is a small area south of Shale Pile 1 just outside the permit boundary above the IL, which is a road leading to a monitoring well. The contamination level above the IL in the arroyo bed appears to cease at the southern permit boundary. The contamination boundary south of Pit 1 extends just outside the permit boundary. However, as indicated in the UNC's June 15, 2018 response to the State of New Mexico Energy, Mineral and Natural Resource Departments April 17, 2018 comments on the Work Plan, the area south of Pit 1 is not within the permit boundary because it was not mined or operated by UNC, and records indicate that an underground mine was operated in that area by another entity. Therefore, the contamination boundary south of Pit 1 is delineated at the permit boundary.

The IL contamination boundary near the West Shaft Area is mostly just inside or at the permit boundary with some small isolated areas just outside of the permit boundary east and southeast of Ore Storage 1, south of the Shaft Pad, east of the Mine Dump, Pond 1 area. The contamination boundary extends outside the permit boundary in areas northeast of the West Shaft Area and an area near the entrance gate. The contamination boundary north of the Crusher Stockpile area is contained inside the permit boundary. The contamination boundary north of the Topsoil/Overburden and Pile 4 areas is well inside the permit boundary. Overall, the IL contamination boundary at the Site is mostly within the permit boundary, but extends slightly outside permit boundary in a few locations, as discussed above. As shown in Figure 6, the Site Access Road contains Ra-226 levels in soil above the IL, and is likely to extend at a minimum to the road shoulders. Contamination above the IL appears to have migrated east of the Site Access Road near the entrance to the Site.

5.0 Soil Sampling and Analysis

Surface soil correlation samples and subsurface soil samples from the test pit excavations for onsite ex-situ gamma radiation soil screening were collected consistent with AVM-SOP-5, included in the Work Plan. Field QA/QC duplicate samples were split at a frequency of 10% of the total number of soil samples collected. A total of 71 surface and subsurface soil samples were collected during the supplemental characterization. Field sampling equipment used for soil sampling, which included: stainless steel scoops, bowls, spoons, and hand auger barrels, were decontaminated between sample locations. The soil sampling equipment decontamination was conducted by brushing off loose visible soil, washing the equipment with a detergent/water solution and rinsing with distilled water. Track excavator buckets were cleaned by removing any loose, visible soil. Any soils generated from the excavation of test pits created were put back into the excavations from which the soil came. All equipment decontamination water/rinsate was poured on top of excess soil from the test pits. Personal protection equipment (PPE), such as gloves, were brushed off and scanned for residual contamination and disposed of as solid waste.

Subsurface soil samples were analyzed by on-site ex-situ gamma radiation soil screening (AVM SOP-4) to estimate Ra-226 concentrations. A completed Chain-of-Custody (COC) along with the surface soil samples and confirmatory subsurface soil samples were placed in labeled Ziploc bags, and packaged in five gallon buckets with sealed lids and shipped to ALS for Ra-226 analysis. The soil samples were analyzed for Ra-226 with a reporting limit of 0.5 pCi/g, using EPA Method 901.1 (modified for soil matrix). The laboratory completed COCs are included with the analytical results reports in appropriate appendices to this report.

6. 0 Quality Assurance and Quality Control Measures

Quality Assurance/Quality Control (QA/QC) measures as specified in the Work Plan were implemented during the Supplemental Radiological Characterization to ensure that decisions are made based on data of acceptable quality. All radiologic survey instruments, including personnel and vehicle contamination friskers, have been calibrated annually, as specified in AVM SOP-1. Additionally, operational functions checks were performed on all radiologic instruments daily prior to use in accordance with AVM SOP-1. The calibration and function check documents are included in Appendix D. During this Supplemental Radiological Characterization, no instruments were found to be out of calibration or inoperable as indicated by the operational function checks. The instrument background measurements for bare 2x2 NaI detectors during daily operational function checks were less than 10,000 cpm as shown in Appendix D. The bare detector field of view (FOV) at 12 inches above the ground surface is conservatively assumed at an area of six feet diameter. The 2x2 NaI detector response factor is determined to be 0.0006 pCi/g/cpm from the linear regression for the site-specific correlation included in Appendix C. Based on the above detector parameters, the Ra-226 minimum detectable concentrations (MDCs) for scan survey at scan speed of three feet per second calculated MARSSIM guidance as shown in AVM SOP-1 were less than 1.0 pCi/g, significantly less than 50% of the 6.6 pCi/g IL. The ex-situ soil gamma radiation screening system was calibrated prior to mobilization in the field and daily operational function checks were performed prior to use. The calibration and function check documentation are included in Appendix D. Based on the highest system background (blank) measurements from daily operational function checks and efficiency (pCi/g/cpm), the highest Ra-226 MDC for the screening system calculated, as shown in AVM SOP-4, was less than 0.8 pCi/g, significantly less than the 6.6 pCi/g IL. The MDCs during the supplemental characterization met the QA objective.

The QA/QC measures also included field QA/QC duplicate soil sampling at a frequency of 10% of the soil samples collected for laboratory analysis. As discussed above, field QA/QC duplicate soil samples were collected and sent to the laboratory for analysis, and the QA/QC duplicate results are included in appropriate summary tables.

Tables

Table 1
Typical Gamma Scan Data Exported From the Scan System Data Logger

ID	Time	Northing[(1)] (feet)	Easting[(1)] (feet)	MSL Elevation (feet)	CPM 2x2 NaI Detector	Ra-226 pCi/g	Zone_ID
1	3/29/2018 9:40:21	1514268	2881680	6051.796	17401	3.19	Pit_1
2	3/29/2018 9:40:23	1514265	2881675	6051.789	17141	3.06	Pit_1
3	3/29/2018 9:40:25	1514261	2881669	6051.904	18457	3.72	Pit_1
4	3/29/2018 9:40:27	1514257	2881663	6052.176	17774	3.38	Pit_1
5	3/29/2018 9:40:29	1514252	2881657	6052.058	17937	3.46	Pit_1
6	3/29/2018 9:40:31	1514246	2881652	6052.019	18383	3.68	Pit_1
7	3/29/2018 9:40:33	1514241	2881647	6051.927	18223	3.60	Pit_1
8	3/29/2018 9:40:35	1514237	2881640	6051.986	18429	3.70	Pit_1
9	3/29/2018 9:40:37	1514232	2881634	6052.166	17831	3.41	Pit_1
10	3/29/2018 9:40:39	1514227	2881628	6051.953	18942	3.96	Pit_1
11	3/29/2018 9:40:41	1514222	2881621	6052.009	18395	3.69	Pit_1
12	3/29/2018 9:40:43	1514216	2881615	6052.035	18316	3.65	Pit_1
13	3/29/2018 9:40:45	1514211	2881609	6052.127	19453	4.22	Pit_1
14	3/29/2018 9:40:47	1514207	2881602	6052.029	19185	4.08	Pit_1
15	3/29/2018 9:40:49	1514202	2881595	6051.878	19125	4.05	Pit_1
16	3/29/2018 9:40:51	1514197	2881589	6052.038	18106	3.54	Pit_1
17	3/29/2018 9:40:53	1514194	2881583	6051.845	18761	3.87	Pit_1
18	3/29/2018 9:40:55	1514192	2881580	6051.769	18926	3.95	Pit_1
19	3/29/2018 9:41:06	1514188	2881575	6051.819	17473	3.23	Pit_1
20	3/29/2018 9:41:08	1514184	2881569	6052.068	17936	3.46	Pit_1
21	3/29/2018 9:41:10	1514179	2881562	6051.842	17904	3.44	Pit_1
22	3/29/2018 9:41:12	1514174	2881555	6051.888	17817	3.40	Pit_1
23	3/29/2018 9:41:14	1514168	2881549	6051.956	18075	3.53	Pit_1
24	3/29/2018 9:41:16	1514163	2881543	6051.812	18881	3.93	Pit_1
25	3/29/2018 9:41:18	1514157	2881537	6051.848	19111	4.05	Pit_1
26	3/29/2018 9:41:20	1514152	2881531	6051.694	19098	4.04	Pit_1
27	3/29/2018 9:41:22	1514146	2881525	6051.779	18165	3.57	Pit_1
28	3/29/2018 9:41:24	1514141	2881520	6051.678	17647	3.31	Pit_1
29	3/29/2018 9:41:26	1514135	2881514	6051.704	16679	2.83	Pit_1
30	3/29/2018 9:41:28	1514130	2881507	6051.723	17441	3.21	Pit_1
31	3/29/2018 9:41:30	1514126	2881501	6051.553	17220	3.10	Pit_1
32	3/29/2018 9:41:32	1514121	2881494	6051.543	17687	3.33	Pit_1
33	3/29/2018 9:41:34	1514117	2881487	6051.796	18375	3.68	Pit_1
34	3/29/2018 9:41:36	1514112	2881479	6051.746	18552	3.77	Pit_1
35	3/29/2018 9:41:38	1514108	2881473	6051.779	18808	3.89	Pit_1
36	3/29/2018 9:41:40	1514103	2881466	6051.609	17910	3.45	Pit_1
37	3/29/2018 9:41:42	1514099	2881459	6051.618	18145	3.56	Pit_1
38	3/29/2018 9:41:44	1514095	2881452	6051.366	18277	3.63	Pit_1
39	3/29/2018 9:41:46	1514090	2881445	6051.353	18827	3.90	Pit_1
40	3/29/2018 9:41:48	1514085	2881438	6051.714	17861	3.42	Pit_1

(1) Projection: NAD 1983, New Mexico West, Feet.

Table 2
St. Anthony Mine Site Test Pits Subsurface Soil Sample Field Gamma Radiation Screening Summary

Sample Data					Field Soil Screening Data				Laboratory Data			
Test Pit ID	Soil Sample ID	Northing(1) (feet)	Easting(1) (feet)	Date	6.6 pCi/g SSL Reference Soil CPM	Soil Sample CPM	Comments	Estimated Ra-226 pCi/g	Sample Sent to Lab	Ra-226 pCi/g	Error Estimate pCi/g	MDC pCi/g
01	SB-TP01-01 (@ 1.1 ft)	1,519,977.7	2,879,801.1	4/19/2018	628	734	**>SSL**	**7.2**	Y	9.20	1.20	0.50
	SB-TP01-02 (@ 2.5 ft)			4/19/2018		286	**<SSL**	**1.7**	Y	1.26	0.30	0.50
02	SB-TP02-01 (@ 1.1 ft)	1,518,527.1	2,880,209.9	4/19/2018	628	2325	**>SSL**	**26.8**	Y	35.40	4.20	0.60
	SB-TP02-02 (@ 2.5 ft)			4/19/2018		383	**<SSL**	**2.9**	Y	1.38	0.32	0.51
03	SB-TP03-01 (@ 1.0 ft)	1,517,294.7	2,879,324.8	4/16/2018	667	243	**<SSL**	**1.2**	Y	1.61	0.35	0.48
04	SB-TP04-03 (@ 3.0 ft)	1,516,898.8	2,880,561.8	4/16/2018	667	3587	**>SSL**	**42.3**	N	-	-	-
	SB-TP04-05 (@ 5.0 ft)			4/16/2018		741	**>SSL**	**7.3**	Y	4.87	0.69	0.44
	SB-TP04-06 (@ 6.0 ft)			4/16/2018		457	**<SSL**	**3.8**	Y	2.79	0.39	0.33
05	SB-TP05-01 (@ 1.0 ft)	1,516,786.8	2,880,764.9	4/16/2018	667	1864	**>SSL**	**21.1**	N	-	-	-
	SB-TP05-02 (@ 2.0 ft)			4/16/2018		2286	**>SSL**	**26.3**	N	-	-	-
	SB-TP05-03 (@ 3.0 ft)			4/16/2018		2574	**>SSL**	**29.8**	N	-	-	-
	SB-TP05-04 (@ 4.0 ft)			4/16/2018		2750	**>SSL**	**32.0**	N	-	-	-
	SB-TP05-05 (@ 5.0 ft)			4/16/2018		496	**<SSL**	**4.3**	Y	0.65	0.19	0.34
06	SB-TP06-01 (@ 1.0 ft)	1,516,646.2	2,880,538.3	4/16/2018	667	402	**<SSL**	**3.1**	Y	4.79	0.71	0.67
07	SB-TP07-01 (@ 1.0 ft)	1,516,414.4	2,880,892.5	4/16/2018	667	2295	**>SSL**	**26.4**	y	29.30	3.50	0.90
	SB-TP07-201 Field QA/QC Dup of SB-TP07-01								Y	27.80	3.40	1.10
	SB-TP07-02 (@ 2.5 ft)			4/16/2018		244	**<SSL**	**1.2**	Y	0.69	0.18	0.31

(1) Projection: NAD 1983, New Mexico West, Feet.

Table 2 (Continued)
St. Anthony Mine Site Test Pits Subsurface Soil Sample Field Gamma Radiation Screening Summary

Sample Data					Field Soil Screening Data				Laboratory Data			
Test Pit ID	Soil Sample ID	Northing[(1)] (feet)	Easting[(1)] (feet)	Date	6.6 pCi/g SSL Reference Soil CPM	Soil Sample CPM	Comments	Estimated Ra-226 pCi/g	Sample Sent to Lab	Ra-226 pCi/g	Error Estimate pCi/g	MDC pCi/g
	SB-TP08-01 (@ 1.0 ft)			4/16/2018		733	**>SSL**	**7.2**	Y	15.30	1.90	0.70
08	SB-TP08-02 (@ 2.1 ft)	1,516,128.0	2,877,428.9	4/16/2018	667	210	**<SSL**	**0.8**	Y	0.92	0.25	0.40
	SB-TP08-03 (@ 3.0 ft)			4/16/2018		211	**<SSL**	**0.8**	N	-	-	-
	SB-TP09-01 (@ 1.0 ft)			4/16/2018		2108	**>SSL**	**24.1**	N	-	-	-
09	SB-TP09-02 (@ 2.5 ft)	1,515,831.1	2,877,501.9	4/16/2018	667	267	**<SSL**	**1.5**	Y	1.54	0.32	0.47
	SB-TP09-03 (@ 3.5 ft)			4/16/2018		266	**<SSL**	**1.4**	Y	-	-	-
	SB-TP10-01 (@ 1.0 ft)								Y	15.10	1.80	0.50
10	SB-TP10-201, Field QA/QC Dup of SB-TP10-01	1,515,336.8	2,882,418.7	4/18/2018	628	974	**>SSL**	**10.2**	Y	8.10	1.10	0.60
	SB-TP10-02 (@ 2.0 ft)			4/18/2018		450	**<SSL**	**3.7**	Y	5.03	0.70	0.58
	SB-TP11-01 (@ 1.0 ft)			4/18/2018		533	**<SSL**	**4.7**	N	-	-	-
	SB-TP11-02 (@ 2.1 ft)			4/18/2018		2674	**>SSL**	**31.1**	N	-	-	-
11	SB-TP11-03 (@ 3.0 ft)	1,515,067.3	2,882,375.8	4/18/2018	628	1879	**>SSL**	**21.3**	N	-	-	-
	SB-TP11-04 (@ 4.0 ft)			4/18/2018		2284	**>SSL**	**26.3**	Y	21.70	2.70	0.90
	SB-TP11-05 (@ 5.0 ft)			4/18/2018		599	**<SSL**	**5.5**	Y	4.30	0.61	0.44
	SB-TP12-02 (@ 2.0 ft)			4/18/2018		1197	**>SSL**	**12.9**	N	-	-	-
12	SB-TP12-03 (@ 3.0 ft)	1,514,764.1	2,882,599.4	4/18/2018	628	653	**≈SSL**	**6.2**	Y	2.25	0.42	0.52
	SB-TP12-04 (@ 4.0 ft)			4/18/2018		387	**<SSL**	**2.9**	Y	16.00	2.00	0.60
	SB-TP13-04 (@ 4.0 ft)			4/18/2018		3255	**>SSL**	**38.2**	N	-	-	-
13	SB-TP13-05 (@ 5.0 ft)	1,514,669.1	2,882,250.3	4/18/2018	628	1605	**>SSL**	**17.9**	Y	12.60	1.60	0.80
	SB-TP13-06 (@ 5.5 ft)			4/18/2018		792	**>SSL**	**7.9**	Y	6.93	0.95	0.58
	SB-TP14-02 (@ 2.0 ft)								Y	16.40	2.00	0.50
14	SB-TP14-202, Field QA/QC Dup of SB-TP14-02	1,514,540.5	2,882,755.6	4/18/2018	628	1452	**>SSL**	**16.0**	Y	14.40	1.80	0.80
	SB-TP14-03 (@ 3.5 ft)			4/18/2018		393	**<SSL**	**3.0**	Y	2.08	0.39	0.46

(1) Projection: NAD 1983, New Mexico West, Feet.

Table 2 (Continued)
St. Anthony Mine Site Test Pits Subsurface Soil Sample Field Gamma Radiation Screening Summary

Sample Data					Field Soil Screening Data				Laboratory Data			
Test Pit ID	Soil Sample ID	Northing(1) (feet)	Easting(1) (feet)	Date	6.6 pCi/g SSL Reference Soil CPM	Soil Sample CPM	Comments	Estimated Ra-226 pCi/g	Sample Sent to Lab	Ra-226 pCi/g	Error Estimate pCi/g	MDC pCi/g
15	SB-TP15-01 (@ 1.1 ft)	1,514,476.2	2,882,323.8	4/18/2018	628	247	**<SSL**	**1.2**	Y	1.04	0.24	0.36
	SB-TP15-02 (@ 2.0 ft)			4/18/2018		253	**<SSL**	**1.3**	Y	0.76	0.25	0.45
16	SB-TP16-01 (@ 1.0 ft)	1,514,197.5	2,882,127.8	4/18/2018	628	242	**<SSL**	**1.1**	Y	0.77	0.25	0.41
	SB-TP16-02 (@ 2.0 ft)			4/18/2018		247	**<SSL**	**1.2**	Y	0.87	0.24	0.43
17	SB-TP17-01 (@ 1.2 ft)	1,514,139.3	2,882,412.6	4/18/2018	628	275	**<SSL**	**1.6**	Y	1.42	0.24	0.35
	SB-TP17-02 (@ 2.1 ft)			4/18/2018		236	**<SSL**	**1.1**	Y	0.91	0.26	0.41
18	SB-TP18-01 (@ 1.0 ft)	1,514,065.8	2,882,908.7	4/18/2018	628	330	**<SSL**	**2.2**	Y	1.02	0.24	0.35
	SB-TP18-02 (@ 2.1 ft)			4/18/2018		276	**<SSL**	**1.6**	Y	0.94	0.27	0.50
19	SB-TP19-01 (@ 1.3 ft)	1,514,025.5	2,883,361.9	4/18/2018	628	1918	**>SSL**	**21.8**	Y	29.00	3.60	0.90
	SB-TP19-201, Field QA/QC Dup of SB-TP19-01								Y	26.80	3.30	0.70
	SB-TP19-02 (@ 2.3 ft)			4/18/2018		265	**<SSL**	**1.4**	Y	0.90	0.24	0.42
20	SB-TP20-01 (@ 1.0 ft)	1,513,518.0	2,884,947.0	4/19/2018	628	272	**<SSL**	**1.5**	Y	1.60	0.38	0.58
	SB-TP20-02 (@ 2.0 ft)			4/19/2018		268	**<SSL**	**1.5**	Y	1.32	0.32	0.50
	SB-TP10-202, Field QA/QC Dup of SB-TP20-02								Y	1.26	0.34	0.61
21	SB-TP21-01 (@ 1.0 ft)	1,513,857.6	2,881,478.5	4/18/2018	628	291	**<SSL**	**1.7**	Y	1.35	0.30	0.43
	SB-TP21-02 (@ 2.0 ft)			4/18/2018		254	**<SSL**	**1.3**	Y	0.78	0.22	0.37
22	SB-TP22-03 (@ 3.1 ft)	1,513,810.0	2,883,645.0	4/19/2018	628	683	**≈SSL**	**6.6**	Y	6.63	0.38	0.50
	SB-TP22-07 (@ 7.5 ft)			4/19/2018		296	**<SSL**	**1.8**	Y	1.97	0.35	0.42
23	SB-TP23-04 (@ 4.0 ft)	1,513,547.0	2,883,838.0	4/19/2018	628	2870	**>SSL**	**33.5**	Y	31.20	3.80	0.90
	SB-TP23-06 (@ 6.0 ft)			4/19/2018		486	**<SSL**	**4.1**	Y	2.26	0.40	0.48
24	SB-TP24-05 (@ 5.5 ft)	1,513,371.5	2,884,557.1	4/19/2018	628	3463	**>SSL**	**40.8**	Y	30.00	0.80	0.50
	SB-TP24-06 (@ 6.5 ft)			4/19/2018		2693	**>SSL**	**31.3**	Y	55.50	6.60	0.50

(1) Projection: NAD 1983, New Mexico West, Feet.

Table 3
St. Anthony Mine Site Test Pit Subsurface Ra-226 Contamination Depth Summary

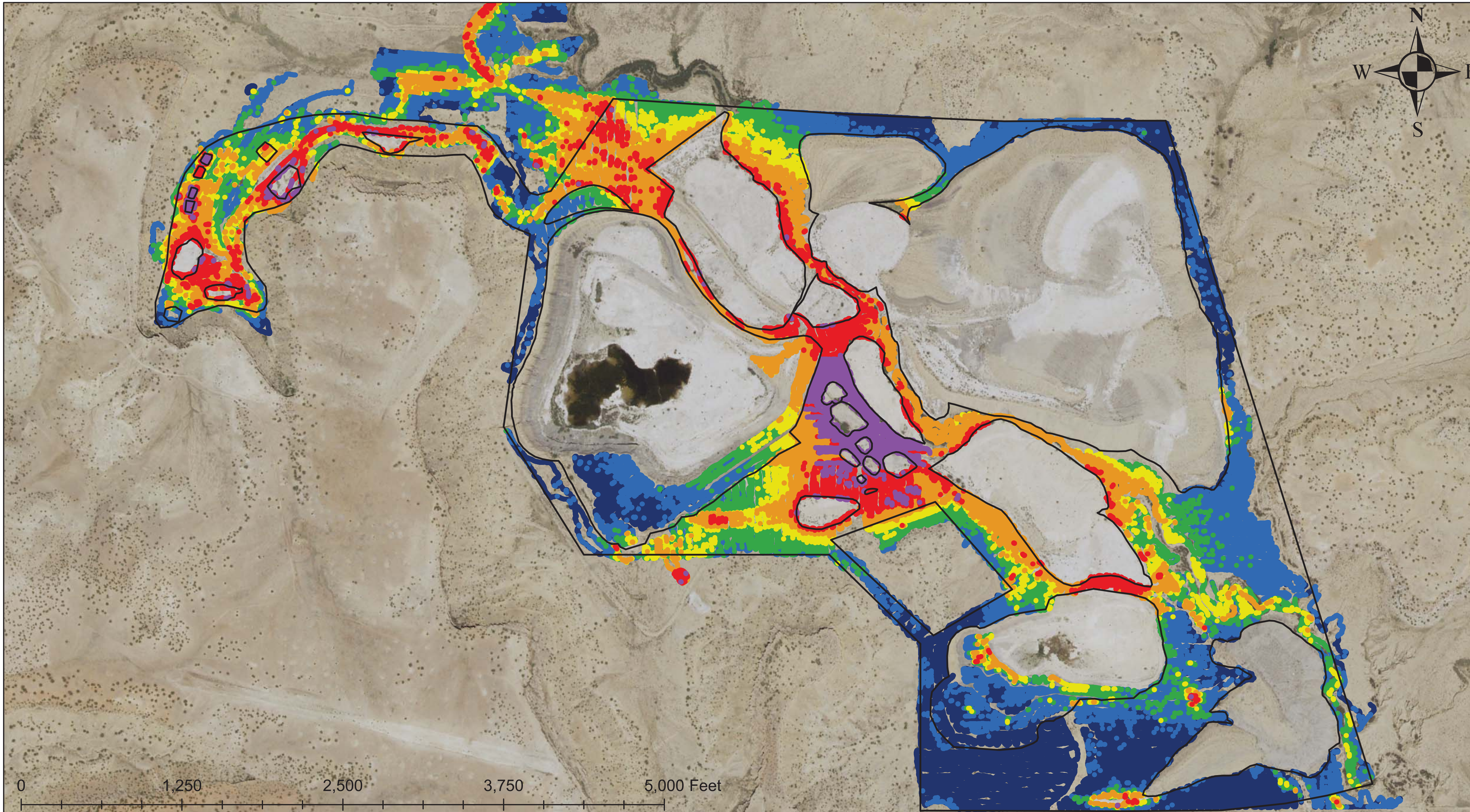
Test Pit ID	Test Pit Location Coordinates (1) (Feet)		Date	Depth of Subsurface Ra-226 Contamination >SSL (Feet)
	Northing	Easting		
1	1,519,977.7	2,879,801.1	4/19/2018	**2.5**
2	1,518,527.1	2,880,209.9	4/19/2018	**2.5**
3	1,517,294.7	2,879,324.8	4/16/2018	**1.0**
4	1,516,898.8	2,880,561.8	4/16/2018	**6.0**
5	1,516,786.8	2,880,764.9	4/16/2018	**5.0**
6	1,516,646.2	2,880,538.3	4/16/2018	**1.0**
7	1,516,414.4	2,880,892.5	4/16/2018	**2.5**
8	1,516,128.0	2,877,428.9	4/16/2018	**2.1**
9	1,515,831.1	2,877,501.9	4/16/2018	**2.5**
10	1,515,336.8	2,882,418.7	4/18/2018	**2.0**
11	1,515,067.3	2,882,375.8	4/18/2018	**5.0**
12	1,514,764.1	2,882,599.4	4/18/2018	**3.0**
13	1,514,669.1	2,882,250.3	4/18/2018	**6.0**
14	1,514,540.5	2,882,755.6	4/18/2018	**3.5**
15	1,514,476.2	2,882,323.8	4/18/2018	**1.1**
16	1,514,197.5	2,882,127.8	4/18/2018	**<1.0**
17	1,514,139.3	2,882,412.6	4/18/2018	**<1.0**
18	1,514,065.8	2,882,908.7	4/18/2018	**1.0**
19	1,514,025.5	2,883,361.9	4/18/2018	**2.3**
20	1,513,518.0	2,884,947.0	4/19/2018	**<1.0**
21	1,513,857.6	2,881,478.5	4/18/2018	**<1.0**
22	1,513,810.0	2,883,645.0	4/19/2018	**3.1**
23	1,513,547.0	2,883,838.0	4/19/2018	**6.0**
24	1,513,371.5	2,884,557.1	4/19/2018	**>6.5**

(1) Projection: NAD 1983, New Mexico West, U.S. Feet.

Table 4
St. Anthony Mine Site Gamma Radiation Level to Ra-226 Correlation Data Summary

Surface Soil Sample ID	Exposure Rate µR/hr	2x2 NaI 0.5-Inch Lead Collimated Detector		2x2 NaI Bare Detector		Soil Sample Ra-226 Laboratory Analysis pCi/g (EPA Method 901.1 Modified)		
		CPM	Avg. CPM	CPM	Avg. CPM	Ra-226	Uncertainty	MDC
SA-COR-001	10	3324 3383 3381	3363	9937 10077 10013	10009	0.85	0.27	0.45
SA-COR-002	11	3165 3070 3238	3158	10406 10441 10425	10424	0.83	0.20	0.28
SA-COR-003	95	25600 25894 25731	25742	84039 83117 83689	83615	43.9	5.3	0.9
SA-COR-003 Field QA/QC Duplicate						41.1	4.9	0.8
SA-COR-004	70	22796 20739 22490	22008	68362 64884 65222	66156	25.3	3.1	0.9
SA-COR-004 Lab QA/QC Duplicate						34.7	4.1	0.6
SA-COR-005	20	7439 6924 7043	7135	19346 19412 19769	19509	6.36	0.86	0.55
SA-COR-006	12	3124 3328 3251	3234	11405 11685 11194	11428	0.75	0.22	0.40
SA-COR-006 Field QA/QC Duplicate						0.74	0.27	0.44
SA-COR-007	15	4991 5241 5096	5109	14131 14174 14372	14226	2.73	0.45	0.48
SA-COR-008	20	6881 6849 7065	6932	20219 20268 20155	20214	5.17	0.73	0.47
SA-COR-009	70	26362 26596 26725	26561	64037 64428 63871	64112	29.7	3.5	0.60
SA-COR-010	25	8515 8672 8635	8607	22943 23060 22997	23000	6.78	0.92	0.50
SA-COR-011	110	35912 36235 35798	35982	99965 96941 98212	98373	69.2	8.2	1.0
SA-COR-012	30	7748 8050 8126	7975	25242 25514 25390	25382	6.63	0.87	0.47
SA-COR-012 Lab QA/QC Duplicate						5.91	0.82	0.51
SA-COR-013	25	8293 8192 8199	8228	21581 21295 21891	21589	5.45	0.74	0.46
SA-COR-014	12	4358 4412 4496	4422	11945 11972 11970	11962	1.25	0.27	0.41

Figures

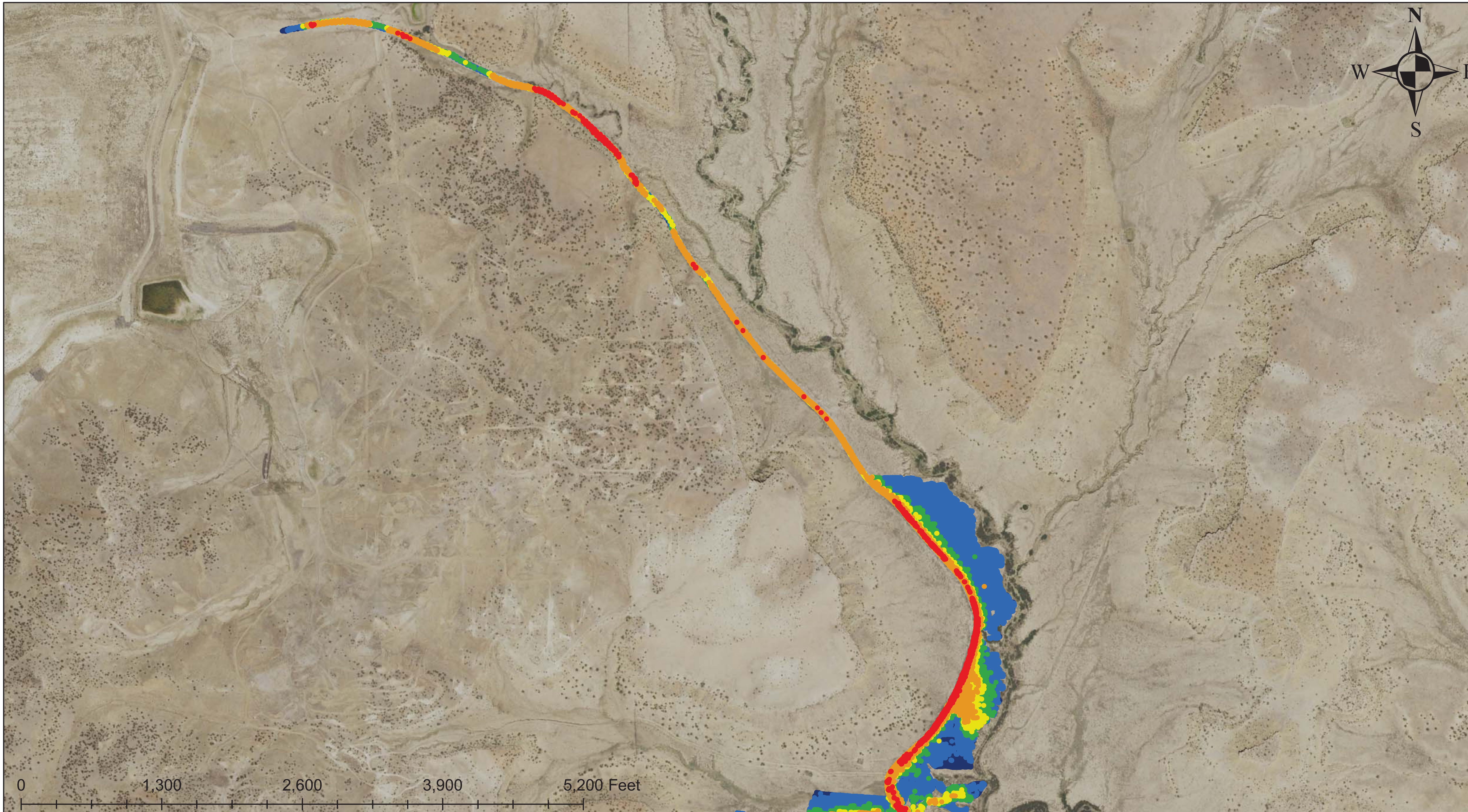


AVM Environmental Services, Inc.

Figure 1
St. Anthony Mine Site Supplemental Radiologic Characterization
Gamma Radiation Level Scan

Legend

- <15,000 cpm
- 15,001 - 20,000 cpm
- 20,001 - 25,000 cpm
- 25,001 - 32,000 cpm
- 32,001 - 62,000 cpm
- 62,001 - 212,000 cpm
- >212,000 cpm

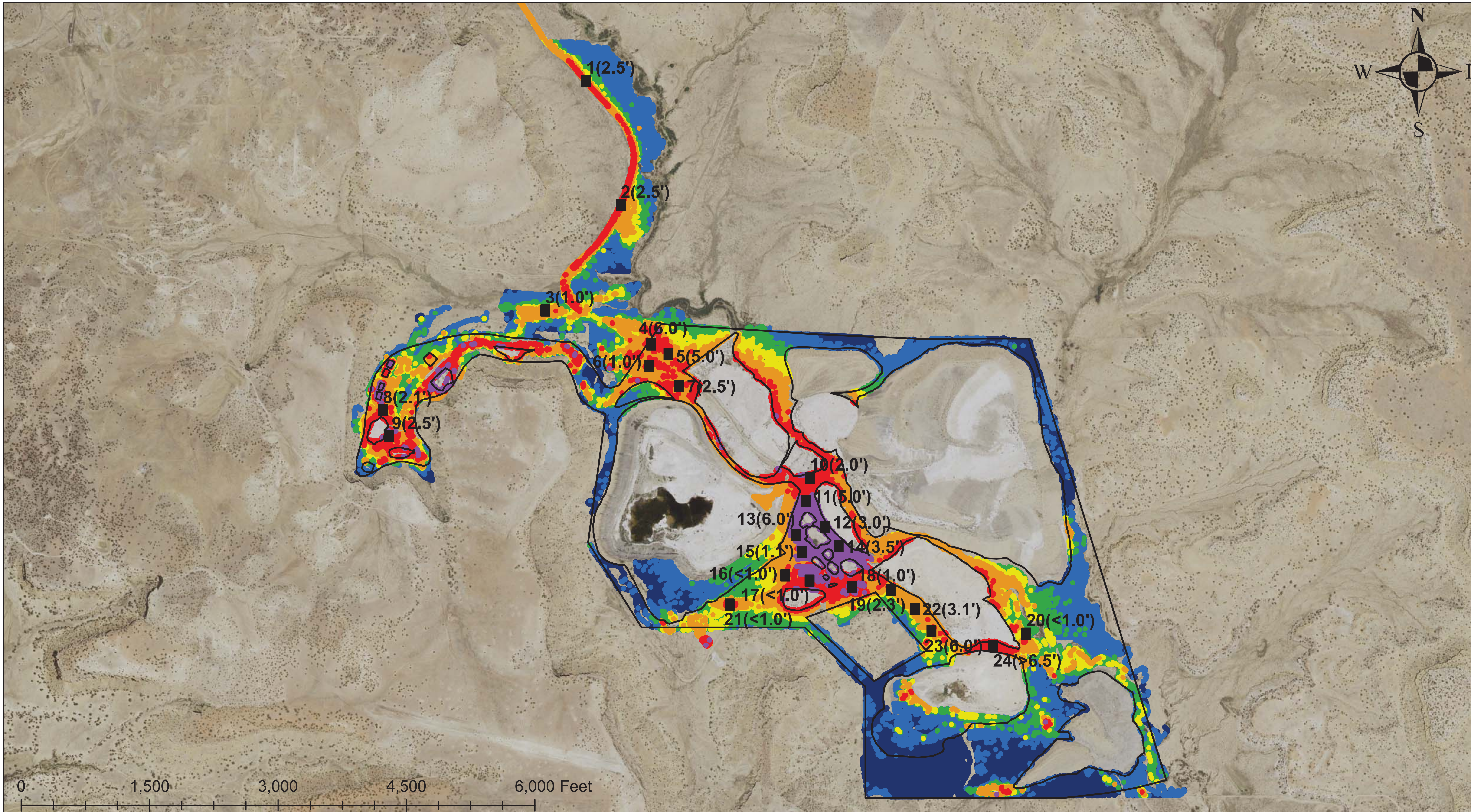


AVM Environmental Services, Inc.

Figure 2
St. Anthony Mine Site Access Road
Supplemental Radiologic Characterization
Gamma Radiation Level Scan

Legend

- <15,000 cpm
- 15,001 - 20,000 cpm
- 20,001 - 25,000 cpm
- 25,001 - 32,000 cpm
- 32,001 - 62,000 cpm
- 62,001 - 212,000 cpm
- >212,000 cpm

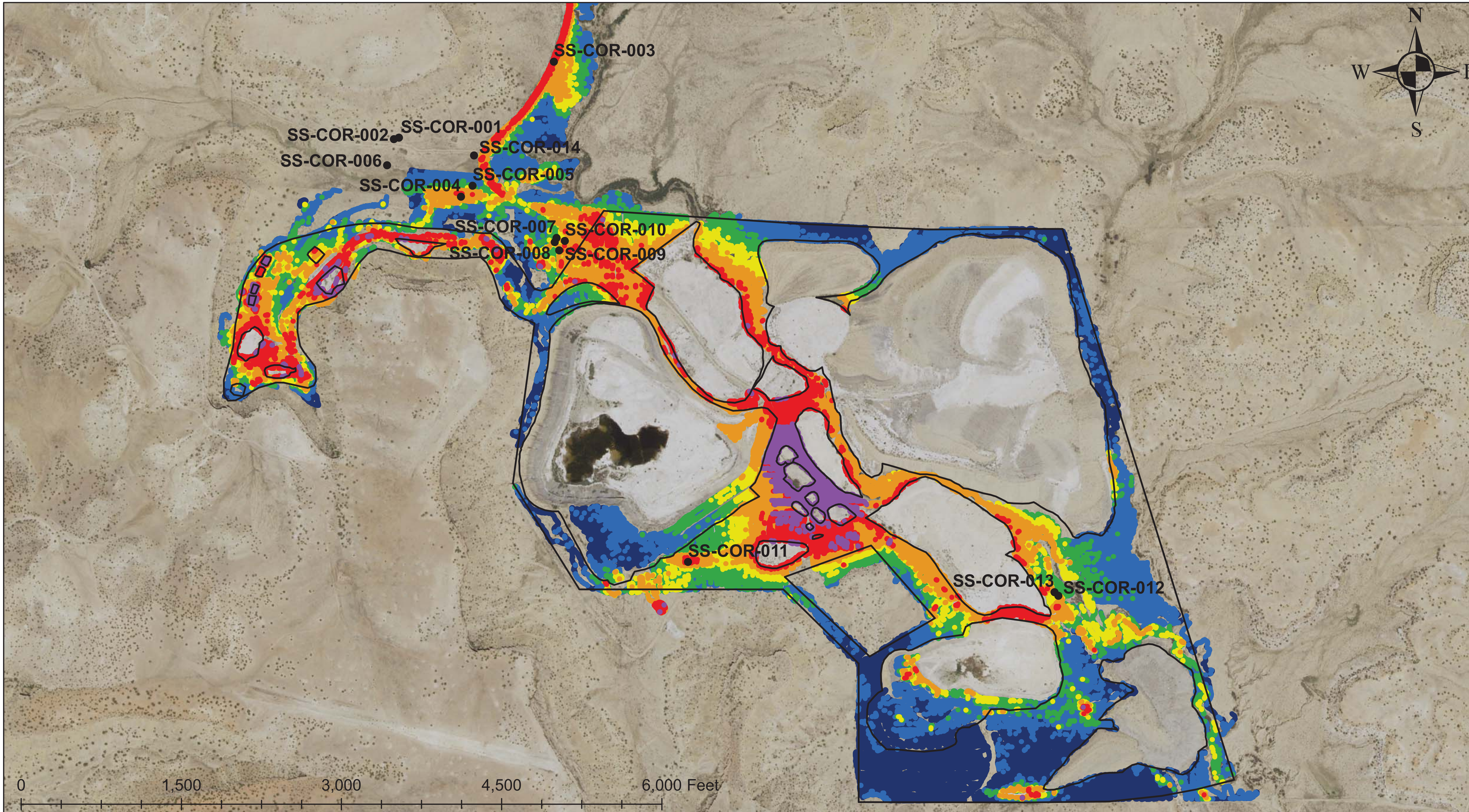


AVM Environmental Services, Inc.

Figure 3
St. Anthony Mine Site Supplemental Radiologic Characterization
Subsurface Investigation Test Pit Locations

Legend

- Test Pit Location - ID(contamination depth)
- <15,000 cpm (bkg) (1.6 pCi/g)
- 15,001 - 20,000 cpm (1.7 - 4.0 pCi/g)
- 20,001 - 25,000 cpm (4.1 - 6.6 pCi/g)
- 25,001 - 32,000 cpm (6.7 - 10.0 pCi/g)
- 32,001 - 62,000 cpm (10.1 - 25.0 pCi/g)
- 62,001 - 212,000 cpm (25.1 - 100.0 pCi/g)
- >212,000 cpm (>100 pCi/g)

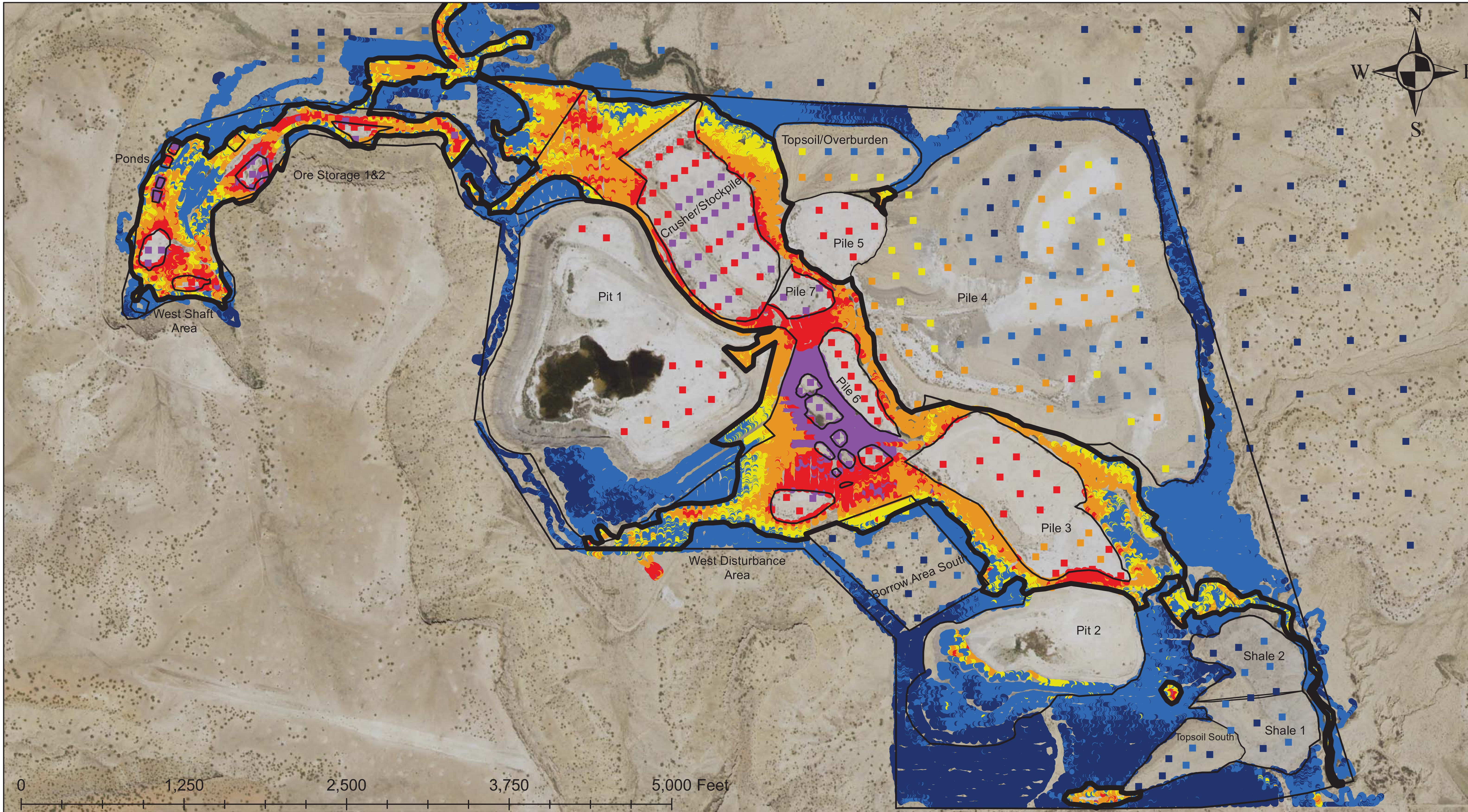


AVM Environmental Services, Inc.

Figure 4
St. Anthony Mine Site Supplemental Radiologic Characterization
Correlation Sampling Locations

Legend

- Correlation Sample Location
- <15,000 cpm
- 15,001 - 20,000 cpm
- 20,001 - 25,000 cpm
- 25,001 - 32,000 cpm
- 32,001 - 62,000 cpm
- 62,001 - 212,000 cpm
- >212,000 cpm



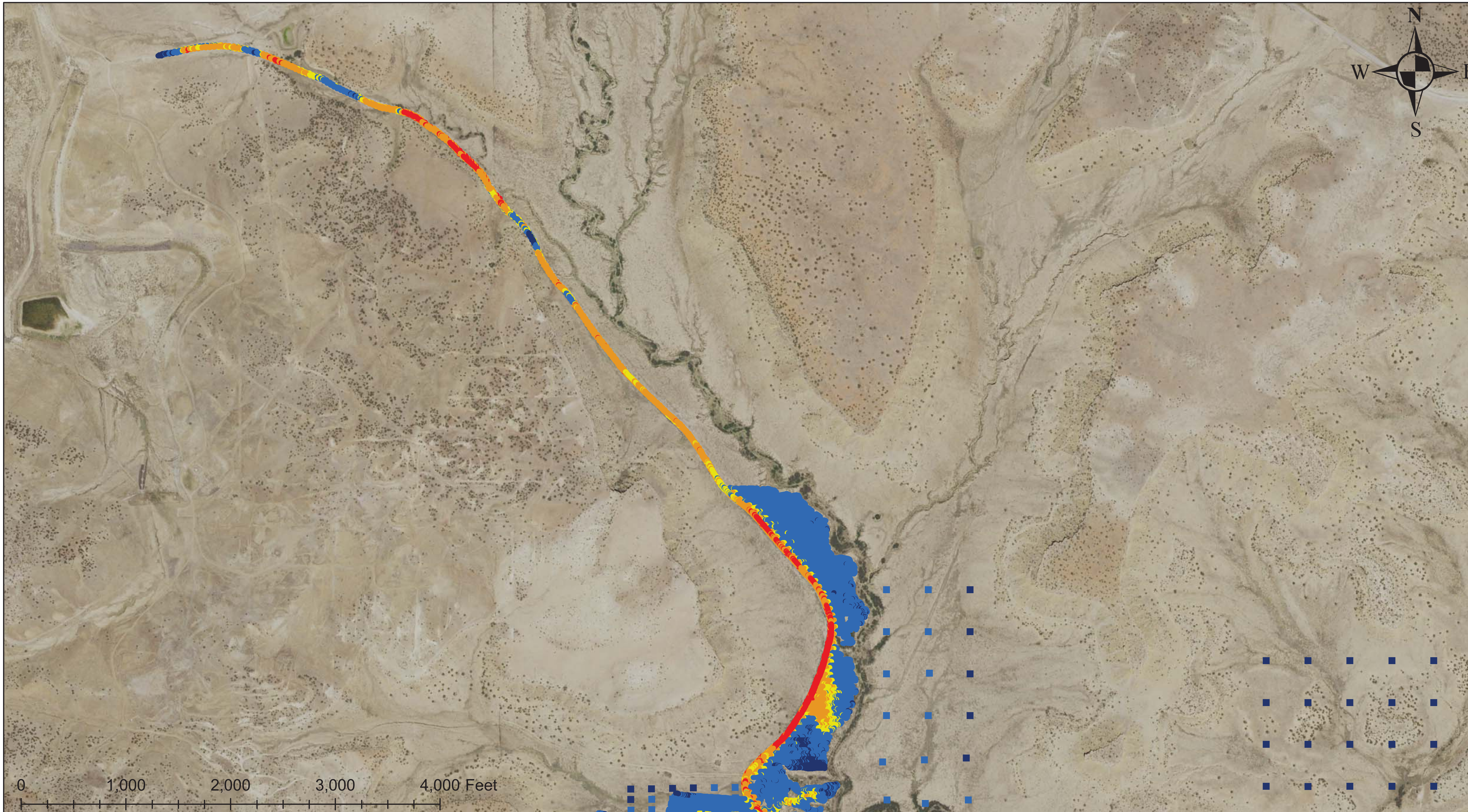
AVM Environmental Services, Inc.

Figure 5
St. Anthony Mine Site Supplemental Radiologic Characterization
Lateral Extent of Ra-226 Contamination

Legend

Ra-226 pCi/g

- <1.6 pCi/g
- 1.61 - 6.6 pCi/g
- 6.61 - 10.0 pCi/g
- 10.1 - 25.0 pCi/g
- 25.1 - 100.0 pCi/g
- >100 pCi/g
- 2007 MC Survey Point
- Boundary above the 6.6 pCi/g Ra-226 Investigation Level



AVM Environmental Services, Inc.

Figure 6
St. Anthony Mine Site Access Road Supplemental Radiologic Characterization
Lateral Extent of Ra-226 Contamination

Legend
Ra-226 pCi/g
- <1.6 pCi/g
- 1.61 - 6.6 pCi/g
- 6.61 - 10.0 pCi/g
- 10.1 - 25.0 pCi/g
- 25.1 - 100.0 pCi/g
- >100 pCi/g
- 2007 MC Survey Point

Appendix B AVM CLEANUP VERIFICATION PLAN

B.1 EXCAVATION CONTROL PLAN

Excavation Control Plan

St. Anthony Mine Closeout

Prepared by

AVM Environmental Services, Inc.

Grants, New Mexico

March 26, 2019

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 Cleanup Levels and Performance Standards 2
- 4.2 Gamma Radiation Survey Concept 3
- 4.3 Gamma Survey Instrumentation 3
- 4.4 Gamma Survey Minimum Detection Concentration 3
- 4.5 Site Specific Gamma Radiation to Ra-226 Correlation 4
- 4.6 Gamma Radiation Levels for Cleanup Action 4
- 4.7 Excavation Control Surveys 5
  - 4.7.1 Gamma Scan Radiation Survey 5
  - 4.7.2 Gamma Static Radiation Survey 6
  - 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 8
- 5.4 Instrument Calibration and Function Checks 8
- 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 Cleanup Action Level Gamma Count Rates 5

FIGURE

Figure 1 Cleanup Action Level Area

ATTACHMENT

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

ACRONYMNS

Bi-214	Bismuth 214
CAL	Cleanup Action Level
cpm	counts per minute
CVS	Cleanup Verification Survey
DGPS	Differential Global Positioning System
DQO	Data Quality Objectives
FOV	field of view
g	gram
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
SRC	Supplemental Radiological Characterization
SOP	Standard Operating Procedure
UNC	United Nuclear Corporation
USEPA	United States Environmental Protection Agency

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 Cleanup Action Level (CAL) and placement in onsite Pit 1 and Pit 2. The CAL is 6.6 pCi/g Ra-226 (5.0 pCi/g health-based cleanup level 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 CAL 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 CAL, as shown in Figure 5 and 6 of the 2018 SRC Report.

The mine impacted material will be excavated and placed in Pit 1 and Pit 2, as discussed in the Closeout Plan (the Plan). Of the approximate total of 360 acres, material from about 225 acres of cleanup area (excludes Pile 4, Pile 5 and the Topsoil/Overburden pile), as shown in Figure 1, will be excavated to meet the CAL and placed in the pits for disposal and reclamation. Material from Pile 5 and the Topsoil/Overburden pile consisting of approximately 21.2 acres will be excavated to the excavation depth contours, as shown in Drawing 5 of the Plan and placed into Pit 1. Part of the material from the 120-acre Pile 4 will be excavated to the excavation contours as shown in Drawing 5 and transported for placement in Pit 1. The remaining material in Pile 4 will be regraded and stabilized in place. The stabilization of Pile 4 to the 191-acre configuration shown on Drawing 8 of the Closure Plan will include pushing remaining in-situ pile material into low-lying areas to the south, west, and northwest over the excavated Pile 5 and the Topsoil/Overburden Pile as fill to maintain consistent slopes on all sides of the pile. The pile footprint will expand to accommodate a stable slope. A radon and erosion protection cover will be constructed over the stabilized Pile 4. Therefore, radiologic excavation control will not be necessary for this 191-acre Pile 4 area. 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 Cleanup Verification Survey (CVS), and to determine when a survey area is ready for the CVS. 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 CAL 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 CAL, determined when an area at the site is ready for the CVS, and updated estimates of site-specific parameters, such as final excavation footprint for planning of the CVS. Excavation control surveys serve to monitor the effectiveness of cleanup efforts that are intended to reduce residual radioactivity to acceptable levels. This type of survey guides the cleanup 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 CAL 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 CAL and is an interim step in the compliance demonstration process. The excavation control survey data may also be used for CVS decision-making if that excavation control data is collected in a manner consistent with DQOs specified in the Cleanup Verification Survey Plan.

The objective of the excavation control survey is to detect levels of residual radionuclides at, or below, the CAL. Excavation control survey instrumentation and techniques have been selected based on detection capabilities for the CAL 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 CAL.

4.1 Cleanup Level and Performance Standards

The waste piles and other mine-impacted soil, with Ra-226 concentration exceeding the CAL, 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 health-based cleanup level 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 CAL.

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 B.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 CAL 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 CAL 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 CAL 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 CAL.

- **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 CAL.

- **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 CAL.

The previous correlations for the site were developed for surface soils, with low moisture conditions similar to those expected during the cleanup action (i.e., no recent rain or temperature below freezing, no snow cover or frozen ground surface). The gamma surveys during the cleanup 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 Cleanup 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 CAL are lowered by 1.96 standard deviation (σ), below which there is an acceptable level of assurance that the established CAL has been attained to address the counting uncertainties at a 95% confidence level. The CAL level equivalent gamma radiation cpm lowered by 1.96σ that will be used for excavation control is summarized in Table 1.

Table 1: Soil Excavation Cleanup Action Level Gamma Count Rates

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

4.7 Excavation Control Surveys

Gamma radiation surveys will primarily be used for soil excavation control during the cleanup. Gamma scan surveys in combination with gamma static measurements will be used for excavation control until the impacted soil exceeding the CAL 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 CAL. 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 B.3). Details of the gamma scan survey are described in SOP-3, which is included in Appendix B.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 CAL 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 CAL has been attained for any questionable measurements, measurements above the CAL, 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 B.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 CAL. 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 CAL 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 CAL will be excavated, hauled, and placed into the onsite Pit 1 and Pit 2. Excavation control will be performed to support soil excavation. Radiologic excavation control will be performed to meet the CAL in the approximate 225-acre CAL 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 CAL. Excavation control will begin with field delineation of the soil excavation and removal areas. If the gamma scan shows that the outer CAL boundary has expanded, the CAL 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 (CAL 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 CAL in each area.

The excavation control survey procedure is described in detail in SOP-3 included in Appendix B.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 CAL 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 CAL equivalent count rate. The gamma scan survey will be conducted for 100 percent coverage of the area. If no location exceeding the CAL 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 CAL 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 CAL does not expand with excavation depth.

If the gamma scans following the initial soil excavation lift show portions of the area above the CAL count rate or any static measurement point above the CAL 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 CAL 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 B.3).

7.0 REFERENCES

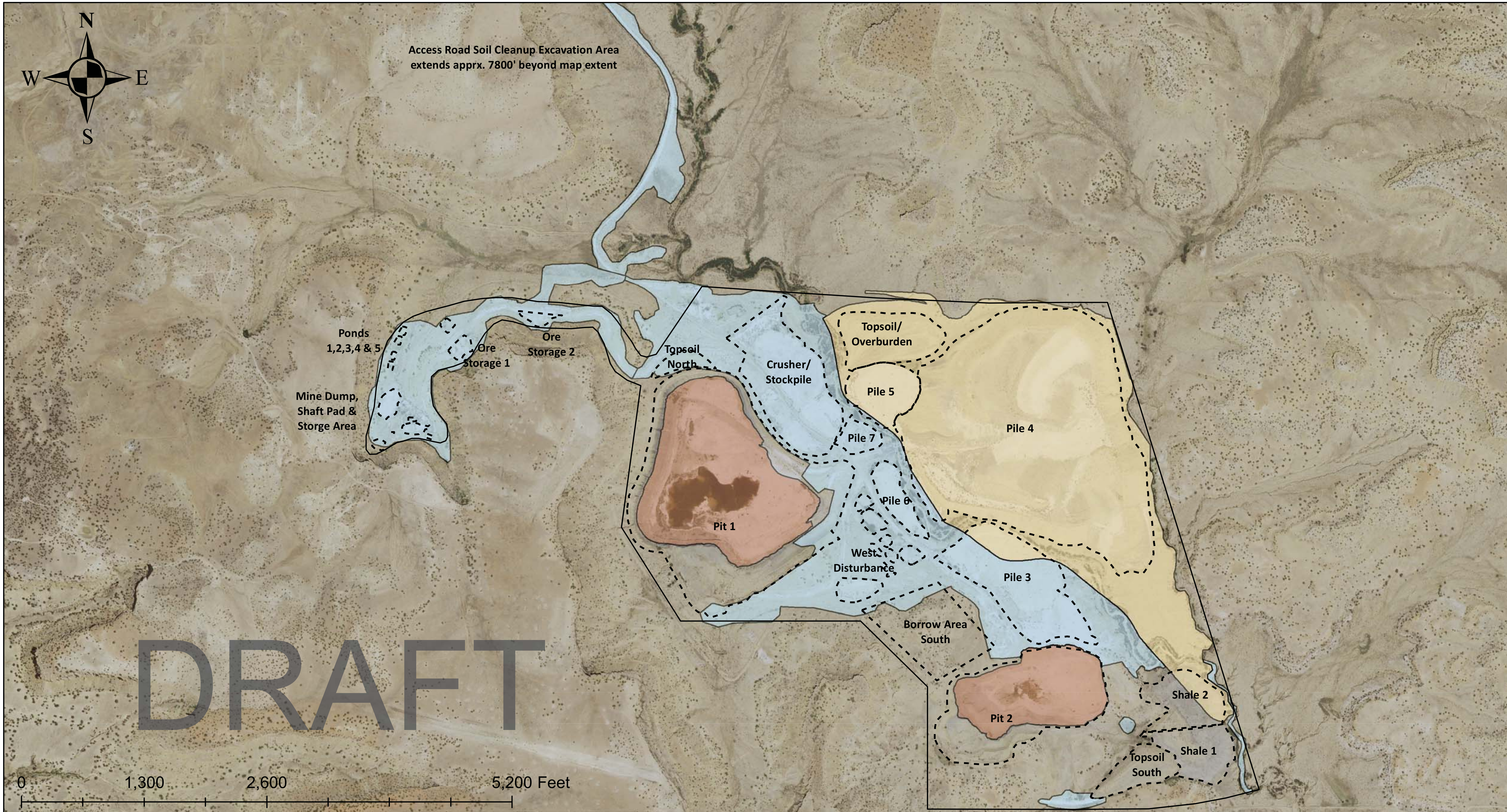
AVM 2018. Supplemental Radiologic Characterization Report, St. Anthony Mine Site, Seboyeta, New Mexico, August.

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



AVM Environmental Services, Inc.

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

Legend

- Cleanup Action Level Excavation Area
- Excavated, Stabilized and Covered Area
- Backfilled, Stabilized and Covered Area
- Permit Boundary
- Site Feature Boundary

March 2019

Attachment

Attachment 1

Gamma Radiation Level to Surface Soil Ra-226 Correlation
St. Anthony Mine Site Excavation Control and Cleanup 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 (cleanup action support) and Cleanup Verification Survey (CVS) during the soil cleanup action at the St. Anthony Mine Site (the site). The cleanup 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 cleanup level in surface soils. Therefore, the contaminant distribution assumption for the correlation for remedial action support surveys and the CVS will be fairly homogeneous in surface soils near the 6.6 pCi/g soil Cleanup Action Level (CAL).

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 CAL during excavation control, and to convert gamma radiation level measurements in cpm to surface soil Ra-226 concentration in pCi/g for CVS.

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

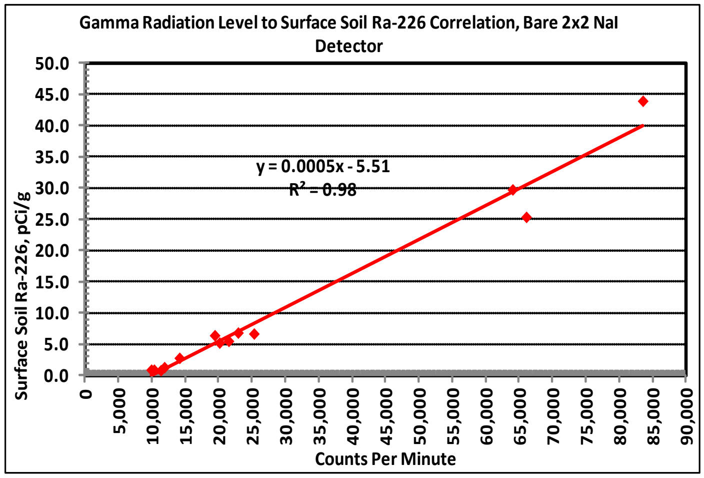
Figure 3, the correlation yielded a correlation equation of Ra-226 pCi/g = (uR/hr x 0.49) - 5.10 with a R^2 of 0.98. The regression analysis yielded a p-value significantly lower than the specified DQO Type I error of 0.05 with a low MSE.

This bare detector correlation will be used as appropriate during the site cleanup action excavation control and CVS for scan surveys. The collimated detector correlation will be used for gamma static surveys during CVS 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

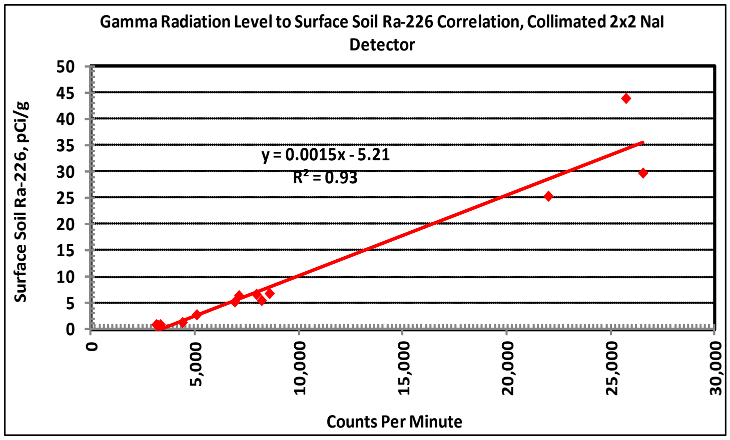
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2181.64119	2181.64119	489.3050341	1.80856E-10
Residual	11	49.04517922	4.458652656		
Total	12	2230.686369			

	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

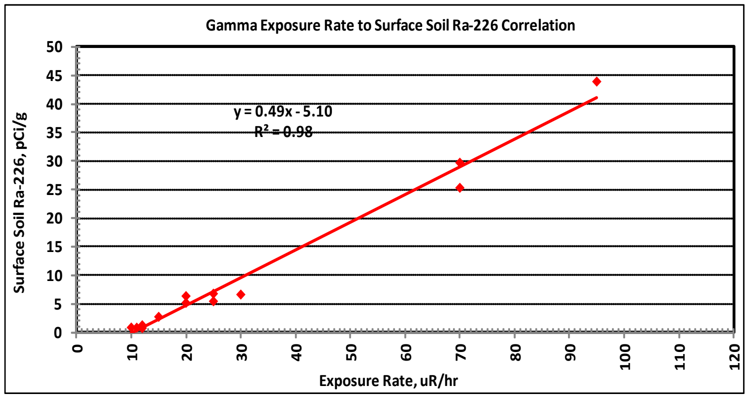
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2084.207312	2084.207312	156.5157566	7.57125E-08
Residual	11	146.479057	13.31627791		
Total	12	2230.686369			

	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

B.2 CLEANUP VERIFICATION SURVEY

Cleanup Verification Survey Plan

St. Anthony Mine Closeout

Prepared by

AVM Environmental Services, Inc.

Grants, New Mexico

March 26, 2019

Table of Contents

1.0 INTRODUCTION 1

2.0 SITE DESCRIPTION 1

3.0 DATA QUALITY OBJECTIVES 2
3.1 State the Problem 2
3.2 Identify the Goals of the Study 3
3.3 Identify Input Information 3
3.4 Define the Boundary of the Study 4
3.5 Develop the Analytical Approach 4
3.6 Specify Performance or Acceptance Criteria 4
3.7 Develop the Plan for Obtaining the Data 5

4.0 CVS DATA COLLECTION PLAN 5
4.1 Cleanup Verification Survey Area 6
4.2 Background Area 7
4.3 Sample Number Calculations 7
4.4 Survey Units, Sampling Grid and Scan Transect Spacing 8
4.4.1 Cleanup Verification Survey Units 8
4.4.2 Cleanup Verification Survey Data Point Grid 9
4.4.3 Cleanup Verification Gamma Scan Survey Transects 10
4.5 Small Area of Elevated Activity 10
4.6 Gamma Radiation Surveys 11
4.6.1 Gamma Survey Instrumentation 12
4.6.2 Gamma Scan surveys 13
4.6.3 Gamma Static surveys 13
4.6.4 Investigation Levels 14
4.7 Soil Samples 14
4.7.1 Judgment Based Soil Samples 14
4.7.2 Systematic Soil Samples 14

5.0 FIELD ACTIVITIES 14
5.1 Gamma Scan Surveys 15
5.2 Gamma Static Surveys 15
5.3 Field Gamma Radiation Ex-Situ Soil Screening 16
5.4 Judgment Based Soil Samples 16
5.5 Systematic Soil Samples 17
5.6 Laboratory Analysis 17
5.7 Instrument Calibration and Function Checks 17
5.8 Corrective Actions 17
5.9 Sample Chain of Custody and Documentation 18
5.10 Correction to Documentation 18
5.11 Sample Packaging and Shipping 18
5.12 Field Decontamination 18
5.13 Radiation Protection 18

6.0 DATA EVALUATION AND CONCLUSIONS 18
6.1 Demonstrating CALemc Compliance 19
6.2 Demonstration Compliance with CAL 19

7.0 QUALITY ASSURANCE AND QUALITY CONTROL MEASURES 20

Table of Contents (Continued)

8.0 REPORT OF CVS FINDINGS 20

9.0 REFERENCES 22

TABLES

Table 1 St. Anthony Mine Site CVS Data 6
Table 2 Parameters for Number for Data Point Calculation 7
Table 3 Grid Length Calculation Parameters 9
Table 4 CALemc Calculation Parameters 11

FIGURES

Figure 1 St. Anthony Mine Site Soil Cleanup Areas
Figure 2 St. Anthony Mine Site CVS Areas
Figure 3 St. Anthony Mine Site Cleanup Verification Survey Units with Data Points
Figure 4 St. Anthony Mine Site Access Road Cleanup Verification Survey Units with Data Points

ACRONYMNS

Bi-214	Bismuth 214
CAL	Cleanup Action Level
CPM	counts per minute
CL	Cleanup Level
CVS	Cleanup Verification Survey
DGPS	Differential Global Positioning System
DQA	data quality assessment
DQO	Data Quality Objective
emc	elevated measurement comparison
FOV	field of view
g	gram
keV	Kiloelectronvolt
L	liter
m^2	square meters
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	Minimum Detectable Concentration
NaI	Sodium Iodide
NCR	Nonconformance Report
NIST	National Institute of Standards and Technology
NUREG	U.S. Nuclear Regulatory Commission Regulation
PARCC	Precision, Accuracy, Representatives, Comparability, and Completeness
Pb-214	Lead 214
pCi	picocuries
Plan	St. Anthony Closure Plan
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
QC	quality control
Ra-226	Radium 226
Rn-222	Radon 222
RPP	Radiation Protection Plan
RSO	Radiation Safety Officer
site	St. Anthony Mine Site
SOP	standard operating procedure
UNC	United Nuclear Corporation
USEPA	U.S. Environmental Protection Agency
USNRC	U.S. Nuclear Regulatory Commission

1.0 INTRODUCTION

This document provides a framework for performing a Cleanup Verification Survey (CVS) of excavated areas following the completion of cleanup activities for closure of the St. Anthony Mine Site (the site) near Seboyeta, New Mexico. The soil cleanup for the site addresses excavation and removal of soil exceeding the Ra-226 Cleanup Action Level (CAL) as specified in Section 2.1 of the St. Anthony Mine Closeout Plan (the Plan). The CAL is 6.6 pCi/g for radium 226 (Ra-226) for excavation and removal of soils at the site, which is based on the 5.0 pCi/g Ra-226 health based Cleanup Level (CL) plus the 1.6 pCi/g Ra-226 site background area concentration level as determined by the 2007 Materials Characterization (MWH, 2007). The objective of the CVS is to demonstrate that the residual Ra-226 concentrations in the soil in the excavated areas meet the CAL. The 2007 Materials Characterization and the 2018 Supplemental Radiologic Characterization (AVM, 2018) identified areas totaling approximately 360 acres including mine features, such as piles and roads that exceeded the CAL. The mine impacted material will be excavated and placed in Pit 1 and Pit 2 as discussed in the Plan. Material from Pile 5 and the Topsoil/Overburden pile will be excavated as discussed in the Excavation Control Plan and placed into Pit 1. Part of the material from Pile 4 will be excavated and transported for placement in Pit 1. The remaining material in Pile 4 will be regraded and stabilized in place. The stabilization of Pile 4 to the configuration shown on Drawing 8 of the Plan will include pushing remaining in-situ pile material into areas to the south, west, and northwest over the excavated Pile 5 and the Topsoil/Overburden Pile as fill for pile stabilization. The stabilized Pile 4 footprint area will expand to an approximate 191-acre area to accommodate a stable slope. A radon and erosion protection cover will be constructed over the stabilized Pile 4. Therefore, the stabilized Pile 4 area will not require cleanup verification to the CAL. The approximate remaining 225 acres of cleanup area will be excavated to meet the CAL. This approximate 225-acre cleanup area, as shown in Figure 1, will require a CVS to demonstrate the cleanup action meets the CAL. A summary of the nature and extent of the contamination is provided in the 2018 Supplemental Radiologic Characterization report.

Upon completion of the soil excavation and placement, as discussed in Section 3.2 of the Plan, a CVS will be performed to ensure the cleanup to the CAL has been met. Applicable aspects of the sampling and survey methods outlined in the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (USEPA 2000) will be used to demonstrate compliance with the CAL. The MARSSIM guidance was developed for use in designing, implementing, and evaluating cleanup verification surveys, known as final status radiological surveys. This Plan includes processes for evaluating residual Ra-226 activity and outlines the contents of the CVS for survey areas at the site.

2.0 SITE DESCRIPTION

The site was an open pit and underground shaft uranium mine located on the Cebolleta Land Grant located in Cibola County, approximately 4.6 miles southeast of Seboyeta, New Mexico. The site is in a remote, sparsely populated area with limited access. 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 Drawing 3 of the Plan 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 described.

3.0 DATA QUALITY OBJECTIVES

The Data Quality Objectives (DQOs) for the CVS are provided below to establish a systematic procedure for CL that will be met for the data collection design to be satisfied. The DQO process includes a description of when to collect samples, where to collect samples, the tolerable level of errors for the study, and how many samples to collect. The DQO process consists of the seven steps listed below (USEPA 2006):

1. State the problem.
2. Identify the goals of the study.
3. Identify information inputs.
4. Define the boundaries of the study.
5. Develop the analytic approach.
6. Specify performance or acceptance criteria.
7. Develop the plan for obtaining data.

The DQO process is described in the following sections as it applies to the site CVS.

3.1 State the Problem

The Closure Plan includes excavation, removal and placement of site soils that exceed the CAL. The problem is to determine if the residual Ra-226 levels in survey unit soil meets the CAL after soil cleanup.

This CVS Plan will be used to determine whether residual Ra-226 concentrations in the soil at the site meet the CAL. The MARSSIM provides guidance for planning, conducting, evaluating and documenting final status surveys (herein referred to as CVS) for demonstrating compliance with the CAL and is geared towards structures, such as buildings, and relatively small land areas. It is not as useful for larger impacted land area, such as this site, which consists of nearly 225 acres of impacted area. Therefore, this document includes adjustments to the approach (e.g., survey unit size) and data evaluation to facilitate an efficient CVS design.

The CAL for the site refers to area average that must be met for each survey unit. Second, the CAL elevated measurement comparison (CALemc) refers to an elevated measurement comparison that addresses more localized elevated areas that may exceed the CAL based on single point measurements as opposed to the average over a survey unit. The CAL is developed so that post-cleanup residual activity concentrations meet the cleanup criteria.

Since Ra-226 is present in the site background soils, the CVS data collected in the field will be inclusive of the background level, similar to the CAL (health-based CL of 5.0 pCi/g plus the 1.6 pCi/g background area concentration). The data evaluation process will consider that the data from the

CVS survey units include the background concentration during any comparison and evaluation. Therefore, the terms CAL (indicating the 5.0 CL plus the background level) and CALemc (indicating health-based CL emc plus the background level) will be used in this document.

3.2 Identify the Goals of the Study

The goal of this CVS is to confirm that excavation and removal of soil meets the Ra-226 CAL specified in the Plan, which is 6.6 pCi/g.

Compliance with the CAL will be demonstrated by conducting gamma surface scans and systematic static surveys associated with grids consistent with the MARSSIM, and collecting systematic confirmatory soil samples (i.e., samples associated with a grid), and additional samples if deemed necessary based on professional judgment (i.e., samples targeting specific areas of concern).

The principal study question is whether Ra-226 concentrations exceed the CAL in soil following the soil excavation. The possible alternative actions are: 1) release of the survey areas, or 2) additional excavation. The decision statement is:

- If the survey unit mean Ra-226 concentration in soil is below the CAL, the areas meet the CAL.
- If the mean Ra-226 concentrations in soil is above the CAL, the areas do not meet the release criterion and require investigation and may require additional soil excavation and removal.

3.3 Identify Input Information

The following information is needed to resolve the decision statement:

- This is a new Ra-226 data collection effort for cleanup verification by conducting gamma radiation surveys and collecting soil samples from soil excavated areas.

- The area-specific nature and extent of contamination based on gamma static and scan survey data, and surface and subsurface soil sampling data, to guide excavation during the cleanup action

- Gamma scan survey and any soil analytical results from the excavation control surveys.

- An emc will be calculated for the CAL. The emc for the CAL is established at the CL plus the background level.

- The collected CVS data, which includes gamma scan and static surveys of excavated areas and confirmatory soil sample analytical results, for static surveys.

- The site-specific regression equations to convert field gamma radiation survey measurements in counts per minute (CPM) to the surface soil Ra-226 pCi/g concentrations.

In addition to this quantitative information, visual observations will also be used to determine if there is an indication of contamination or buried mine waste or debris during the excavation.

The combination of the CL criteria, applicable sampling methods, surveying, and guidance of the MARSSIM is the basis for this CVS Plan.

CVS data will be used to address CVS decision-making. The excavation control survey data will also be used for CVS decision-making where the excavation control data are collected in a manner consistent with CVS protocols and the DQOs.

3.4 Define the Boundaries of the Study

This CVS Plan will address the site areas undergoing the soil cleanup activities. The cleanup activities include excavation and removal of soils exceeding the CAL. The site cleanup boundary was developed based on the 2018 Supplemental Radiologic Characterization (AVM, 2018). The CVS area may change depending on the actual excavation footprint following the soil excavation and removal. Definitive CVS area footprints will be established prior to the initiation of the CVS data collection based on the excavation control survey of the footprint of the excavated area. Areas within the site soil excavation and removal footprint will be included in the CVS.

3.5 Develop the Analytic Approach

Implementing the steps for CVS data analytic approach for the decision rule will be as follows:

- **Statistical parameter of interest**: The CVS data statistical parameter of interest for the decision rule for the site is the mean (average) concentration of Ra-226, specified in the Plan.

- **CAL**: The Plan specifies a CAL of 6.6 pCi/g for Ra-226 for excavation and removal of soils at the site, based on the pre-determined CL at 5.0 pCi/g, plus the 1.6 pCi/g background area mean concentration, since Ra-226 is present in background at the site.

The data evaluation and conclusions for release of survey units is described in Section 6.0 and includes demonstrating compliance with the CALemc and CAL.

3.6 Specify Performance or Acceptance Criteria

The CVS data evaluation for demonstrating compliance with CL is stated in Section 6.2. A conclusion will be drawn from the CVS data evaluation. Since the CAL is a single average value over an area, the mean of the CVS area data will be used to demonstrate that the site meets the cleanup criteria. For the CALemc requirements, gamma scan and static surveys, along with any soil sample results will be compared against a CALemc detector CPM equivalent to the CALemc Ra-226 pCi/g criteria.

To enable data testing relative to the CL, there are two types of fundamental decision errors, a Type I decision error of 0.05 and a Type II decision error of 0.10. The fundamental decision errors will be used to calculate the minimum number of samples required for each survey unit, which will be used for data evaluation to demonstrate compliance with the CAL. A 0.05 Type I error rate will also be used for the p-value associated with the gamma radiation to Ra-226 correlations.

Data quality indicators for precision, accuracy, representativeness, comparability, and completeness (PARCC) have been established:

- Precision will be determined by a comparison of replicate values from field measurements and from duplicate sample analyses; the objective is a relative difference of 30 percent, or less of the CAL or CALemc values.

- Accuracy for field gamma measurements is the degree of agreement with the true or known (confirmatory laboratory analysis); the objective for this parameter is ±30 percent of the CAL or CALemc values.

- Representativeness and comparability will be confirmed through selecting and properly implementing systematic sampling and measurement techniques. Representativeness is a qualitative expression of the degree to which sample data accurately and precisely represent a characteristic of a population, a sampling point, or an environmental condition. Representativeness is maximized by confirming that, for a given task, the number and location of sampling points and the sample collection and analysis techniques are appropriate for the specific investigation, and that the sampling and analysis program provides information that reflects "true" site conditions.

- Completeness refers to the portion of the data that meets acceptance criteria and is therefore usable for statistical testing. The objective is a 95 percent completeness goal. The number of data points calculated for data evaluation will be increased by 20 percent to account for possible lost or unusable data, which is assumed to be sufficient to assure that the completeness goal will be met.

The generic PARCC criteria that focus on activity concentration results and analytical performance around the CAL requirements may not be meaningful if very low contamination is encountered, which is expected to be the case during CVS work. Other factors, such as activity concentrations relative to the CAL, should be considered when evaluating the quality and usability of the produced data sets.

3.7 Develop the Plan for Obtaining Data

Field screening techniques, gamma surveys, soil sampling, soil sample analysis, and the Data Quality Assessment (DQA) process will be used, as appropriate, throughout the CVS. As data are collected and analyzed from initial survey units, assumptions in this plan will be reviewed for accuracy.

4.0 CVS DATA COLLECTION PLAN

This section describes the general CVS data collection activities that will take place to satisfy the DQO described in Section 3. Section 5 provides details about field implementation of this plan.

4.1 Cleanup Verification Survey Area

Areas that exceed the CAL and require soil excavation to achieve the CAL will be designated as CVS areas. The 2007 Materials Characterization and the 2018 Supplemental Radiologic Characterization identified an area of approximately 360 acres exceeding the CAL. Approximately 142 acres (Pile 4, Pile 5 and Topsoil/Overburden) of this area will be stabilized in place covering approximately 191 acres and will receive a radon and erosion protection cover, as discussed in the Plan. Mine impacted material from the remaining 225 acres at the site exceeding the CAL, will be excavated, placed and stabilized in Pit 1 and Pit 2. These 225 acres will be designated as CVS areas (see Figure 1) and a CVS will be performed in these areas

As shown in Figure 2 and Table 1, the CVS area will be divided into three separate areas based on their locations to facilitate a manageable and efficient CVS. The Mine Access Road and associated step-out excavation areas, which are outside of the mine permit boundary, cover an estimated area of approximately 22 acres and contain soil impacted by mine waste above the CAL to a depth of about one foot, designated as CVS Area 1. An approximate 40 acre of excavation area in the West Shaft Area, including the West Shaft access road and associated step-out areas to the north are grouped and designated as CVS Area 2. The approximate 162 acres of excavation area within the mine site area and associated step-out areas are grouped and designated as CVS Area 3.

Although control measures will be implemented during the cleanup activities, there may be a potential for contaminant migration into adjacent areas during the soil excavation, transportation, and placement activities. During the CVS, the gamma scan survey will be extended into the adjacent areas, the buffer zones outside the boundaries of the CVS areas. The width of some of the buffer zone areas may be physically limited due to rock outcrops, cliffs and steep arroyo banks adjacent to the CVS area boundary. If the CALemc is exceeded in buffer zones, the buffer zone will be investigated, excavated if needed, and the CVS will be included in these buffer zone areas.

Table 1: St. Anthony Mine Site CVS Data

CVS Area ID	CVS Area Description	Area Approximate Size, Ft^2	Area Approximate Size, Acres	Estimated No. of Survey Units (1)	Estimated Survey Unit Average size, Acres	Estimated No. of Data (Static Survey) Points	Estimated Confirmatory Soil Samples @5% of SS Points
1	Mine Site Access Road with associated Step-out areas	940,896	21.6	9	2.4	70	4
2	West Shaft Area (Includes road out to shaft area, West Shaft Mine features, areas between features and associated Step-out areas north of the Shaft Area)	1,707,988	39.2	16	2.5	132	7
3	St. Anthony Mine Site and associated Step-out areas	7,041,910	161.7	67	2.4	524	27
TOTAL		**9,690,793**	**222.5**	**92**		**726**	**38**

Notes: (1) Typical Survey Unit Size 2.5 Acres

4.2 Background Area

A Ra-226 background value in soils for the site was established in the 2007 Material Characterization (MWH, 2007b). Background sampling consisted of 8 samples from the approximate 4-acre background area. The background area was selected from an area believed to be un-impacted by mining activities. Background sampling results showed an average Ra-226 concentration in soil of 1.6 pCi/g with a standard deviation of 1.0 pCi/g.

4.3 Sample Number Calculations

The CAL is a Ra-226-specific activity concentration average within a survey area corresponding to the release criterion. Site compliance with the CAL is demonstrated by using discrete sampling data points and sampling data evaluation. By using appropriate equations, one can determine the sample numbers required per survey area to achieve desired Type I and Type II error rates for a particular data evaluation.

The number of data points for the CVS survey units for statistical data evaluation was determined. A nonparametric statistical data evaluation was selected because Ra-226 is present in background soil at the site. Sample standard deviation from the background area data set is included for calculating the minimum number of required data points. A standard deviation of 1.0 as determined from the site 2007 Material Characterization background sampling data set, which is very conservative, is used for the required number of data point calculations. The statistical parameters and the calculations used to determine the data points needed for the site are shown in Table 2.

Table 2: Parameters for Number of Data Point Calculation

Parameter	Value
Type I Error (alpha, α)	0.05
$Z_{1-\alpha}$, percentile for α = 0.05 (MARSSIM Table 5.2)	1.645
Type II Error (beta, ß)	0.10
$Z_{1-\beta}$, percentile for ß = 0.10 (MARSSIM Table 5.2)	1.282
Health-Based Cleanup Level	5.0
Standard Deviation, σ (From Background Dataset)	1.0
LBGR @ 95%, 1.96σ	1.96
Shift Δ (DCGLw - LBGR)	3.04
Relative Shift Δ/σ	3.040
Pr, probability for relative shift Δ/σ (MARSSIM Table 5.1)	**0.97891**
Number of data points from reference area/ survey unit pair, MARSSIM Equation 5.1 $N = (Z_{1-\alpha} + Z_{1-\beta})^2 / 3(Pr - 0.5)^2$	**12.45**
Adding additional 20% and rounded up to next even number	**15**
Number of data points from Background Area	**8**
Number of data points from Survey Unit	**8**

The statistical parameters shown in Table 2 were selected to achieve low error rates, as specified for the DQOs. The relative shift is based on the CL (lower bound of the gray region and the standard deviation). As shown in Table 2, the minimum number of data points needed for the site calculates to six data points per survey unit. The number of data points determined for data evaluation was increased by 20 percent to account for possible lost or unusable data. The final rounded up number of data points resulted in eight data points being collected in each survey unit for all CVS areas. The results from a minimum of six usable data points from gamma static survey locations in each survey unit will be used for the CVS data statistical evaluation.

4.4 Survey Units, Sampling Grid and Transect Spacing

The cleanup verification survey units, the sampling grid (data points) and transects for gamma scan survey (discussed in Section 4.6) spacing are described in the following sections.

4.4.1 Cleanup Verification Survey Units

The CVS data evaluation for cleanup verification for the average CAL value is based on a 100 m^2 area (survey unit), which is approximately 0.025 acres. The number of samples (data points) in the CVS areas is calculated as discussed in Section 4.3. The CVS areas will be divided into appropriate size survey units. The suggested survey unit size of 0.025 acre would result in approximately 9,000 survey units with a total of approximate 45,000 data points, with the assumption of about five points in each survey unit. Thus, using a 0.025-acre survey unit size would require an unnecessarily inefficient and complex management system with onerous verification surveys and data evaluation over a large homogeneous area with uniform type of contamination/media following excavation. Therefore, the survey unit size for the CVS has been modified from the suggested 0.025-acre size to a practical 2.5-acre size for cleanup verification. This will help facilitate an efficient and practical CVS, as well as allow acceptable evaluation of CVS data used for demonstrating compliance with the CAL for this large of a site. The 2.5-acre CVS unit size conforms to risk assessment assumptions for establishing release criterion CL. The Ra-226 CL for the site is based on risk from an acceptable land use exposure scenario. The RESRAD code for risk assessment uses an average concentration value for a default contamination zone of 10,000 m^2, or about 2.5 acres, which is the survey unit size proposed for the CVS. Generally, an area or site may be divided into smaller survey units to facilitate considerations for different types of contamination/media of very small areas, such as drywall areas, ceiling material areas, floor material areas, outdoor paved yards and outdoor unpaved yards for an overall risk/dose assessment. At the site, there is only one media (soil) and one form of contamination (soil impacted by uranium ore). Thus, the contamination type/media would be the same in a 0.025 acre or a 2.5-acre survey unit and would not impact the overall radiologic dose/risk.

Using an average over an area (survey unit) for compliance with the CAL could allow for locations with elevated levels of residual contamination. For example, if measurements from five locations are collected within a survey unit, with four locations at about 2 pCi/g, the residual Ra-226 contamination could be as high as 25 pCi/g at the fifth location and still meet the CAL of 6.6 pCi/g. The MARSSIM approach with elevated measurement comparison (emc) incorporated into the CVS would result in a more uniform cleanup to the CAL. For example, using a calculated CALemc of 6.84, as discussed in Section 4.5, would confirm that the site meets the 6.6 pCi/g CAL. The CVS for the site also includes a gamma scan survey at 30-foot transect spacing to be performed prior to measurements at the grid data points as discussed in Section 5.1. Thus, the gamma scan survey will provide additional assurance with the cleanup criteria.

Each CVS area will generally be divided into 2.5-acres survey units and are rounded to the nearest whole number of survey units. The survey units at the perimeter of the CVS areas may not be 2.5 acres due to the irregular shapes of the CVS areas. The size of some survey units at the CVS area perimeter may deviate up to 25% from the typical 2.5 acre area. The number of survey units may change depending on the actual excavation footprint following the soil excavation and removal. The conceptual boundaries of the CVS survey units are shown in Figure 3 and Figure 4.

4.4.2 Cleanup Verification Survey Data Point Grid

A triangular grid system was selected to locate data points within the survey units. The grid length calculation parameters are included in Table 3. The length of the triangular grid is determined based on the number of samples per survey unit and the typical survey unit size of 2.5 acres. The calculation results in a triangular grid length of 125 feet. Each survey unit will be sampled at a rate of eight samples per survey unit. Because the survey unit numbers are rounded to whole numbers and the size of survey units may vary slightly from the typical survey unit size, the number of sampling data points will be maintained at eight per survey unit. Also, the survey unit size at the perimeters of the CVS areas may be more than the 2.5 acres typical size due to the irregular shape of the CVS areas as discussed above. For the survey units with a different area than 2.5 acres, the number of data points will be adjusted to confirm that the area bounded by each point in the survey unit does not exceed the 13,530 square feet area bounded by a 125-foot triangular grid node. If a survey unit has less than six useable data points, random data points will be added to make up the difference. In no case will the number of obtained useable data points be less than six per the typical 2.5-acre survey unit, as discussed in Section 4.3.

Table 3: Grid Length Calculation Parameters

Parameter	Survey Unit Values
Survey Unit Area, square Feet, A	108,900
Survey Unit Area, square meters, A	10117
Number of data points required per survey unit, n	8
Calculated Length (L) of Triangular grid, L= √(A/0.866n), Feet	125.4
Length (L) of Triangular grid, Rounded Down	**125**

The 21.6-acre CVS Area 1 consists of approximately 11,070 linear feet of Access Road totaling an area of about 16.5 acres, plus about 5.1 acres of associated step-out areas. CVS Area 1 is divided into nine survey units with an average size of about 2.4 acres each. A 125-foot triangular grid within the Access Road survey units with an average width of about 50 feet is not realistic due to its narrow shape. In two of the CVS Area 1 survey units with a width of more than 125 feet, eight data points were located using the 125-foot triangular grid system. In the other seven CVS Area 1 survey units with a width less than 125 feet, eight data points were located at near equal spacing along the length of the survey unit. This data point placement will result in a conservative area of less than the 13,530 square feet per triangular grid node.

A one-minute gamma static survey will be conducted at each node of the triangular grid in each survey unit. A total of approximately 726 grid nodes are estimated for the CVS survey units, as shown in Table 1. The conceptual grid nodes for the CVS gamma static survey are based on the excavation footprint determined by the 2018 Supplemental Radiological Characterization, as shown in Drawing 5 and Drawing 6 of the Closeout Plan. The actual number of grid nodes may change depending on the actual excavation footprint.

4.4.3 Cleanup Verification Gamma Scan Survey Transects

A systematic gamma scan survey will be performed in each survey unit at 20 percent scan coverage, similar to the 2018 Supplemental Radiological Characterization scan coverage, prior to the one-minute gamma static survey. Transect spacing for the CVS systematic gamma scan surveys is calculated using the detector field of view (FOV) for gamma radiations from Ra-226 sources (transect spacing = FOV/% scan coverage). For example, using a conservative FOV of at least 6.0 feet for 2x2 Sodium Iodide (NaI) detectors for Ra-226 gamma radiation, a 20 percent scan coverage requires a transect spacing of 30 feet. The detector baseline (background) counts will be obtained with the detector held 12 inches above the ground surface and without exposing the detector to the source. The detection range limit will be verified by obtaining gamma counts for the source under the detector and moving the source at an increment of one foot away from the detector on the ground and obtaining counts until the counts are not significantly (95 percent confidence level) above the baseline counts.

4.5 Small Areas of Elevated Activity

Elevated areas of concern are assumed to be primarily associated with the cleanup areas (i.e., excavation areas). Small isolated and elevated areas may be encountered. This CVS Plan addresses these areas through the definition of the CALemc requirement. Locations with elevated Ra-226 concentrations are expected to be excavated before CVS work begins. It is expected that these types of areas will be initially identified by the scan results as being above the CAL and that this finding will be confirmed based on soil sample results.

When a measurement at a discrete location and scan exceeds the CALemc, the first action will be to confirm the CALemc exceedance and to confirm the instrumentation is functioning properly. A CALemc exceedance is not conclusive of exceeding the CAL but may require further investigation. This may involve making further measurements to determine that the level of the elevated residual contamination in the area is such that the resulting residual contamination assessment meets the release criterion, which may require re-survey. If the investigation indicates that the elevated residual contamination in the area will result in the dose exceeding the CL, the location or area may require further excavation.

The systematic sampling densities in CVS areas should be verified to be sufficient to also address CALemc concerns, given the expected scan Minimum Detectable Concentration (MDC) values. The CALemc was calculated consistent with MARSSIM guidance. The area factor needed for CALemc calculation was determined using RESRAD 7.2. A total dose with all exposure pathways and assuming a unity concentration of 1 pCi/g of Ra-226 with the 10,000 m^2 default area of contamination zone in RESRAD 7.2 calculated at 17.4 mrem/year. The total dose with replacing the default 10,000 m^2 contamination zone area by the 1257 m^2 (13,530 ft^2) bounded by the 125-foot triangular grid node, and keeping all other RESRAD default values, was calculated at 16.61 mrem/year. The area factor was computed by taking the ratio of the 17.4 mrem/yr dose per unit concentration generated by RESRAD for the default 10,000 m^2 to the 16.61 mrem/yr generated for the 1,257 m^2 bounded by the triangular grid nodes. If the CL for residual radioactivity distributed over 10,000 m^2 is multiplied by this value, the resulting concentration distributed over the specified smaller area results in the same calculated dose. As shown in Table 4, a Ra-226 CALemc of 6.84 pCi/g was calculated for the 125-foot triangular grids, using Ra-226 CL of 5.0 pCi/g plus 1.6 pCi/g mean background concentration. Gamma survey techniques (i.e., surficial surveys) with a 2x2 NaI scintillation detector and soil sample analysis using USEPA Method 901.1 modified (gamma spectroscopy) will be adequate to detect any CALemc exceedances.

Table 4: CALemc Calculation Parameters

Parameter	Survey Units 125-foot TRG
Area Bounded by grid nodes (TRG grid node for CVS), m^2, Contamination zone area	1257
Dose, mrem/yr, RESRAD 7.2 (Ra-226 concentration @ unity (1 pCi/g) and all default pathways and parameters, including default contamination zone area @ 10,000 m^2)	17.4
Annual dose, mrem/yr, RESRAD 7.2 (Ra-226 concentration @ unity (1 pCi/g) and all default pathways and parameters, except contamination zone area)	16.61
Area Factor	1.05
Site Ra-226 Cleanup Level, pCi/g	5.00
Ra-226 Cleanup Levelemc, pCi/g	**5.24**
Site CALemc (Cleanup Level+Background) pCi/g	**6.84**

4.6 Gamma Radiation Surveys

Direct gamma radiation surveys will be used to detect Ra-226 in soils for the CVS. Ra-226 is primarily an alpha emitting radionuclide with a gamma radiation emission of 186 KeV at about 4 percent intensity. Field measurement of alpha radiation from soils using radiation detection is an inadequate technique. Due to the low energy of its gamma radiation emission, field determination of Ra-226 is not practical. However, Ra-226 in soil can be determined by measuring gamma radiation levels of its decay products (Pb-214 and Bi-214), which emit high energy gamma radiation at higher intensities and are easily detected and quantified by a sodium iodide (NaI) scintillation detector. This is a surrogate method consistent with MARSSIM guidance (Section 4.3.2).

The CL is presented in terms of mass activity concentration. When applied to soil, the CL is expressed in units of activity per unit mass of soil, pCi/g. The direct gamma radiation measurements, using a NaI scintillation detector, provide radiation levels in counts per unit time. The counts per unit time for a given radioactivity depend on the efficiency of the detector. Pb-214 and Bi-214 are decay products of Ra-226 through radon-222 (Rn-222), a gaseous form, some of which emanates from soil. This process results in activity disequilibrium between Ra-226 and Bi-214 in the soil. The Rn-222 gas emanation fraction from the soil varies with different geometric characteristics of a particular soil type. Therefore, a site-specific calibration is necessary. Typically, about 20 percent of the Rn-222 gas decayed from Ra-226 in soil emanates out of the surface soil, indicating that a significant percentage (about 80 percent) of this will decay into Pb-214 and Bi-214 in the soil matrix. If the soil geometry and other parameters such as moisture, radon emanation fraction, contamination distribution profile, gamma ray shine from nearby sources, and land topography are assumed to be consistent, the ratio of Pb-214/Bi-214 to Ra-226 is consistent. This results in a direct correlation between Pb-214/Bi-214 gross gamma radiation levels and Ra-226 concentrations in the soil. Therefore, a site-specific correlation between direct gamma radiation levels and Ra-226 soil concentrations in pCi/g included in Attachment 1 to the Excavation Control Plan will be used to convert the CPM measurement to equivalent Ra-226 in soil.

4.6.1 Gamma Survey Instrumentation

Similar to the instrumentation used for the site Characterization, the instrumentation configuration for direct gamma radiation level measurement during this survey consists of a 2x2 NaI scintillation detector (such as Eberline SPA-3 and Ludlum 44-10) for detection of gamma radiation, connected to a scaler/rate meter (such as Ludlum 2221 or Ludlum 2241) for processing and counting the detected gamma radiation. 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. For radiation surveys where significant shine interference is present from nearby areas, such as areas with deep excavation and areas within close proximity of waste piles, the 2x2 NaI scintillation detector will be installed in a 0.5-inch-thick lead collimator to reduce lateral gamma shine interference. During the surveys, the detector will be held approximately 12 inches above ground level, which should focus on, and be most sensitive to, an approximately 6-foot diameter area under the bare detector and 3-foot diameter area under the collimated detector. The Scaler/Rate meter will be interfaced with a sub-meter accurate differential global positioning system (DGPS) and a data logger controller for electronically recording the gamma radiation levels to corresponding location coordinates for systematic gamma scan surveys. The instrumentation will be calibrated consistent with Standard Operating Procedure (SOP)-1, provided in Appendix B.3.

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 Ra-226 CAL 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 CPM for the collimated and bare detectors, below which there is an acceptable level of assurance that the established CAL 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 were developed, as described in Attachment 1 to the Excavation Control Plan (Appendix B.1) from data collected for previous correlations during the 2018 Supplemental Radiological Characterization.

The 2018 correlations were developed for surface soils at the site, with no recent rain or temperatures below freezing, and no snow cover or frozen ground surface. Gamma radiation surveys will not be conducted if the ground surface is covered with snow or is frozen. Also, the survey will not be conducted for at least two hours following a rainstorm and the ground surface will be inspected to verify that there is no excessive moisture.

MDCs for both the static and gamma scan radiation surveys will be calculated as discussed in SOP-1. Based on data collected with this instrumentation during the 2018 Supplemental Radiological Characterization surveys, the instrument MDC is expected to be well below 3.3 pCi/g (50 percent of the 6.6 CAL for static surveys). The instrument scan MDC is expected to be below 3.4 pCi/g, which will be less than 50 percent of the 6.84 pCi/g limit (the CALemc).

4.6.2 Gamma Scan Surveys

Gamma scan survey data will be collected from excavated soil surfaces as part of the CVS data collection process. The gamma scan surveys serve three primary roles:

1. Establish that an area is ready for CVS gamma static surveys and soil sampling (i.e., no significant evidence of elevated gross activity that may indicate CAL exceedances).
2. Identify Ra-226 activity anomalies that might indicate CALemc exceedances within CVS areas.
3. Identify spatial trends in Ra-226 activity within or across CVS areas that will assist in interpreting systematic static gamma survey results at data point locations if there are CAL exceedances in systematic sampling results.

The MARSSIM provides procedures for calculating scan MDCs for particular survey instruments. More detail on signal detection theory and instrument response is provided in NUREG-1507, Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions (USNRC, 1998). A typical/example scan MDC calculation for Land Areas, based on site-specific survey and proposed instrumentation parameters is described in SOP-1. The actual scan MDC will be calculated using actual CVS instrumentation and survey parameters to demonstrate that it does not exceed the CAL. It will generally be below 50 percent of the 6.84 pCi/g CALemc for the survey units. Based on operational and function check data, and survey parameters for this instrumentation during previous surveys at the site, the scan MDC is estimated at less than 1.0 pCi/g for the bare and collimated 2x2 NaI detectors.

Prior to static gamma surveys and confirmatory soil sampling, gamma scan surveys will be conducted for 20 percent coverage in each CVS area. The CVS gamma scans will be digitally recorded, including date, time, location and count rate.

4.6.3 Gamma Static Surveys

Following the CVS gamma scan surveys, a one-minute gamma static survey will be conducted at each triangular grid node in survey units as a part of the CVS systematic sampling as discussed above. The estimated 726 gamma static survey data points within the 92 survey units listed in Table 1 are shown on Figure 3 and Figure 4. The CVS systematic static surveys will be used to evaluate compliance with CAL requirements and to confirm that the emc exceedances are not an issue for the survey units each systematic sample represents.

An example of a typical static measurement MDC calculation based on site-specific survey and instrumentation parameters is described in SOP-1, which was calculated in accordance with MARSSIM Section 6.7.1. Based on operational and function check data, and survey parameters for this instrumentation during previous surveys at the site, the static gamma measurement MDC for a

2x2 NaI detector is estimated at less than 1.0 pCi/g for the bare and collimated detector, far below 50 percent of the 6.6 pCi/g CAL for the site.

4.6.4 Investigation Levels

Investigation levels are established for use during the CVS. The CVS area measurements are subject to the emc. Since Ra-226 is present in the background at the site, the CALemc will be the investigation level for the CVS. Any static measurement at a discrete location or scan measurements in a discrete area above the CALemc will be flagged for further investigation. Supplemental investigation may be necessary in some areas if the CALemc is exceeded and would involve taking further measurements to determine that the area and level of the elevated residual radioactivity are such that the residual activity meets the CAL. The investigation may also require additional excavation and/or a resurvey depending on investigation results.

4.7 Soil Samples

Systematic confirmatory and judgment-based surface soil samples will be collected from the excavated areas as a part of the CVS. The surface soil sample results will be used for confirmation of gamma static survey for CAL and CALemc requirements and will also be used for updating the gamma radiation level to surface soil Ra-226 concentration correlations, as discussed in SOP-2 provided in Appendix B.3.

4.7.1 Judgment Based Soil Samples

Surface soil samples will be collected based on professional judgment to target specific locations where there are concerns about potential CALemc exceedances from the scan and gamma static surveys within CVS areas. Judgment based sampling locations will be selected based on a variety of factors, such as an elevated gamma scan survey result (either collected as part of excavation control surveys or CVS), visual evidence of contamination, or the presence of physical infrastructure that still exists within the CVS area footprint. Soil samples for the CVS will be analyzed by field ex-situ soil screening as discussed in Section 5.3. If the ex-situ soil screening results show that the CALemc is not exceeded, it will be confirmed by vendor laboratory analysis. Soil samples collected during excavation control surveys will be collected consistent with the CVS requirements so that the soil sampling data obtained can be used for the CVS where appropriate.

4.7.2 Systematic Soil Samples

Systematic surface samples will be collected for vendor laboratory analysis as confirmation samples for the CVS systematic gamma static surveys to evaluate compliance with CAL requirements. Confirmatory surface soil samples will be collected at a rate of five percent of the gamma static survey locations from each Cleanup and buffer zone CVS area. A surface soil sample will be collected every 20th gamma static survey location.

5.0 FIELD ACTIVITIES

The CVS field activities follow the same general approach in each CVS area and include:

1. Initially collecting gamma scan survey data.

2. Performing judgment-based sampling as necessary with evaluation of the samples by on-site ex-situ soil gamma screening to determine if elevated area concerns (i.e., CALemc) exist that require additional excavation and removal.

3. Systematic one-minute gamma static surveys at the triangular grid nodes (125-foot grid length for survey units) to support CAL evaluations.

4. Confirmatory soil sampling with off-site laboratory analyses for systematic gamma static surveys.

A description of field activities is provided in the subsections below.

5.1 Gamma Scan Surveys

When excavation in an area is complete based on the excavation control survey, systematic gamma scan surveys of the excavated areas will be conducted. Gamma scan surveys will be performed in a manner that provides 20 percent coverage of excavated soil surfaces by walking along transects with the bare detector held 12 inches above the ground surface (see SOP-3, in Appendix B.3). Initially, a 30-foot transect spacing is determined based on a conservative detector FOV of 6.0 feet. If a different FOV is used, it will be verified by an FOV test. An average scan rate of three feet per second will be maintained depending on terrain, but will not exceed six feet per second.

The gamma scan survey measurements will be electronically logged with a suitable sub-meter DGPS which provides a real-time corrected location coordinates. If elevated activities above the applicable investigation level are encountered, one-minute static readings will be collected over the location of interest. In addition, for each location where a soil sample is collected, a one-minute gamma static measurement will be collected above each soil sampling location.

Gamma scan results will be compared to the CAL and CALemc discussed above and locations where the data indicate an anomaly will be flagged (defined as a contamination level that exceeds the CALemc). Judgment based soil samples will be collected at these locations for ex-situ analysis and compared to the CALemc, and/or the soil in that location will be excavated and removed.

Gamma scan survey data that satisfy quality control (QC) requirements will be archived electronically in a readily retrievable format along with appropriate metadata (e.g., date collected, detector identification, technician identification, purpose of survey, and any necessary explanatory notes).

5.2 Gamma Static Surveys

Following completion of the CVS gamma scan surveys in an area, a one-minute gamma static measurement will be conducted at each node of the 125-foot triangular grid, as shown in Figure 3 and Figure 4 as a part of the CVS systematic sampling. The numbers of the estimated static survey locations for each CVS area are shown in Table 1. The gamma static surveys will be conducted using the same instrumentation used for the excavation control survey and the CVS gamma scan surveys. The CVS gamma static surveys will be conducted with the detector fitted with 0.5-inch lead collimator. The gamma static surveys will be conducted for a one-minute counting time with the detector at 12 inches above the ground surface (see SOP-3, provided in Appendix B.3). The gamma static surveys will be electronically logged with a suitable sub-meter accuracy DGPS which provides real time corrected location coordinate data.

The gamma static survey results in CPM will be converted to equivalent Ra-226 concentration in surface soil by using the linear regression analysis equation from the site-specific correlation for Ra-226 concentration in soil. Gamma static survey data that satisfy quality control requirements will be archived electronically in a readily retrievable format along with appropriate metadata (e.g., date collected, detector identification, technician identification, purpose of survey, and any necessary explanatory notes).

5.3 Field Gamma Radiation Ex-Situ Soil Screening

CVS soil samples may be screened on-site (ex-situ soil screening) to verify the absence of significant contamination issues. Ex-situ soil screening by single channel analysis for Ra-226 content will be performed (see SOP-4 in Appendix B.3) specifically on the soil samples collected based on professional judgment. This screening allows corrective actions (e.g., additional excavation and re-sampling) to be taken immediately before committing resources to off-site laboratory analyses. Data from ex-situ soil screening will not be used to demonstrate CAL compliance.

For an expedited estimate of Ra-226 in soil, a reference soil with a known Ra-226 concentration (similar to 6.6 pCi/g CAL) will be used. This method, which is more reliable than the scan or the gamma static surveys, was successfully implemented during the 2018 Supplemental Radiological Characterization for expedited estimates of Ra-226 in soil. A single channel analyzer, Ludlum L2221 integrated with Ludlum 44-20 3x3 NaI scintillation detector will be used to measure 609 KeV radiation of the Ra-226 decay product Bi-214. The sample will be placed in a plastic liner around the detector in a heavily lead shielded counting chamber. The heavily shielded counting chamber lowers the system background noise, thus improving the MDC. The 609 KeV gamma radiation counts are obtained and compared to the reference soil and sample soil for field screening. Based on operational and function check data during the previous soil screening during the 2018 Supplemental Radiologic Characterization, the Ra-226 MDC for this screening system is estimated at less than 1.0 pCi/g.

5.4 Judgment Based Soil Samples

If elevated activities are encountered during the CVS gamma scan surveys, one-minute gamma static survey readings will be collected over the location of interest to confirm the elevated reading. If the one-minute reading is above the CALemc value, a soil sample based on professional judgment will be collected from that location. A one-minute static reading from a height of 12 inches will be collected above each soil sampling location. Field 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 (see SOP-5 in Appendix B.3). The soil sample will initially be field screened for expedited Ra-226 content by ex-situ soil screening, as discussed above. If the field screening of the soil sample shows Ra-226 content below the CALemc, the sample will be sent to a vendor laboratory for confirmation Ra-226 analysis.

5.5 Systematic Soil Samples

Systematic surface soil samples will be collected as confirmation samples for the CVS systematic gamma static survey measurements, which will be used to evaluate compliance with CAL requirements. Confirmation surface soil samples will be collected at five percent of the gamma static survey locations in all CVS areas, as shown on Figure 3 Figure 4. The estimated numbers of systematic confirmatory soil samples for each CVS area are listed in Table 1. Field samples will be collected by using a stainless-steel scoop or spoon and will be homogenized in a stainless-steel bowl and placed in a sample bag (see SOP-5). The systematic soil samples will be sent to an off-site vendor laboratory for Ra-226 analysis.

5.6 Laboratory Analysis

Confirmatory surface soil samples will be shipped to an off-site contract laboratory for Ra-226 (reporting limit of 0.5 pCi/g) analysis using USEPA Method 901.1 modified for soil media. Any laboratory used for environmental sample analysis will have appropriate Environmental Laboratory Approval Program certification or equivalent. Laboratory instrumentation will be calibrated by using National Institute of Standards and Technology (NIST) traceable standards.

5.7 Instrument Calibration and Function Checks

Instruments and equipment used during the CVS will be operated, calibrated, and maintained according to the manufacturer's guidelines and recommendations. Instruments will be calibrated annually. Daily operational and functional checks will be performed for radiological instruments before first use. Equipment that fails calibration or becomes otherwise inoperable during the CVS 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 can be corrected. Equipment requiring repair or recalibration must be approved for use by the Radiation Safety Officer (RSO) 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

5.8 Corrective Actions

Corrective actions will be initiated if problems related to survey/equipment errors or noncompliance with approved procedures are identified. Corrective actions include repair and/or recalibration or replacement of the equipment and resurvey of the area, as necessary. Corrective actions will be documented through a formal corrective action program at the time the problem is identified.

Nonconformance with the established procedures presented in this CVS Plan will be identified and corrected. A nonconformance report (NCR) will be prepared for each nonconforming condition. In addition, corrective actions will be implemented and documented in the appropriate field logbook.

5.9 Sample Chain of Custody and Documentation

Documentation of pertinent field activities, such as instrument calibrations/function check data, field measurements, and field sample data will be recorded in the field forms or field logbooks as necessary. Sample chain of custody will be completed.

5.10 Correction to Documentation

Original information and data in field forms and logbooks, on sample labels, on chain-of-custody forms, and any other project-related documentation will be recorded in waterproof ink in a legible manner. Errors made on any accountable document will be corrected by crossing out the error and entering the correct information or data. Any error discovered on a document will be corrected by the individual responsible for the entry. Erroneous information or data will be corrected in a manner that will not obliterate the original entry, and corrections will be initialed and dated by the individual responsible for the entry.

5.11 Sample Packaging and Shipping

Sample containers will be packaged in thermally insulated rigid-body coolers. Sample packaging and shipping will be conducted in accordance with applicable U.S. Department of Transportation specifications. A checklist will be used by the individual responsible for packaging environmental samples to verify completeness of sample shipment preparations. In addition, the laboratory will document the condition of the environmental samples upon receipt. All samples collected during the project will be shipped within the six-month sample holding time specified by the analytical method. Samples will be stored in a secure area between sample collection and shipment to the laboratory.

5.12 Field Decontamination

Field sampling equipment used during soil sampling will be decontaminated between samples. Equipment to be decontaminated includes stainless steel scoops, bowls, spoons and hand auger barrels.

5.13 Radiation Protection

Radiation protection for workers and the public during the CVS is addressed and included in the site-specific Radiation Protection Plan (RPP).

6.0 DATA EVALUATION AND CONCLUSIONS

The data collected for the CVS will include systematic gamma scans, static gamma measurements at systematic data points, static gamma measurement at discrete locations and soil samples. The CVS radiologic data collected by gamma surveys are in CPM, which have no intrinsic meaning relative to the CAL activity concentration in pCi/g. The gamma survey CPM will be converted to Ra-226 in surface soil using site-specific correlation. Basic statistical parameters (mean and standard deviation) of the CVS data set will be calculated for data evaluation. Through the course of the CVS design, implementation, and data collection process, there are a number of generic key decision points that include:

- Demonstrating there are no CALemc exceedances for cleanup areas through a combination of gamma scan surveys, soil sampling (as necessary) based on professional judgment, and systematic gamma static surveys and soil sampling.

- Demonstrating compliance with CAL requirements using systematic gamma static surveys and confirmatory soil samples from CVS areas and data evaluation.

The data evaluation is only applied to measurements made at systematic data points.

6.1 Demonstrating CALemc Compliance

Compliance with the CALemc is demonstrated through a combination of gamma scan surveys and sampling. Since the CVS gamma scan survey is sensitive enough to detect if CALemc exceedances exist, CALemc compliance may be demonstrated with gamma scan surveys alone. In the course of CAL compliance, sufficient systematic static surveys and samples will be collected to demonstrate CALemc compliance (or vice versa).

The generic process for demonstrating CALemc compliance is for CVS areas. Logged, spatially complete gamma survey data will be collected for each CVS area. These data will be compared to the CAL. If a result is above the CAL, the individual systematic survey result will be compared to the CALemc. If the result exceeds the CALemc, additional data may be collected to better define the excavated area, and additional excavation may be necessary before the CVS process continues. Locations flagged as potential anomalies by the gamma scan data or for any other reason (e.g., visual evidence of contamination, historical information, etc.) will be sampled based on professional judgment.

6.2 Demonstrating Compliance with CAL

Each survey unit will have systematic gamma static surveys and confirmatory soil samples collected to allow for a CAL compliance evaluation. The data evaluation will be applied to CVS systematic gamma static survey results collected at the nodes of 125-foot triangular grid in each survey unit. Examples of circumstances leading to specific conclusions based on a simple examination and evaluation of the data for this CVS are summarized below:

- If all Ra-226 measurements in a survey unit are less than the 6.6 pCi/g CAL, the survey unit meets the cleanup criteria.

- If the mean of the Ra-226 measurements in a survey unit is less than the 6.6 pCi/g CAL, with any measurement greater than the 6.6 pCi/g CAL but less than the 6.84 pCi/g CALemc, the survey unit meets the cleanup criteria.

- If the mean of the Ra-226 measurements in a survey unit is greater than the 6.6 pCi/g CAL, the survey unit does not meet the cleanup criteria.

- If the mean of the Ra-226 measurements in a survey unit is less than the 6.6 pCi/g CAL, with some measurements greater that the 6.84 pCi/g CALemc, the survey unit may not meet the cleanup criteria, and require further investigation and evaluation.

If the CVS data evaluation indicates that a survey area does not meet the cleanup criteria, the reason will be investigated and appropriate action will be taken. If additional excavation and removal is required within a survey unit, the CVS data collection process will be repeated in those specific areas.

7.0 QUALITY ASSURANCE AND QUALITY CONTROL MEASURES

Quality Assurance and Quality Control (QA/QC) measures will be employed throughout the CVS process to verify that decisions are made using data of acceptable quality. A QA/QC program will be conducted during surveys that, in accordance with established procedures, will specify and measure the performance of measurement methods through the collection of an appropriate number or frequency of field duplicate QC samples. Field instruments will be calibrated on NIST traceable standards at a frequency prescribed in the SOPs. A daily function check will be performed for all field instruments before use. Corrective actions will be conducted if performance falls outside expected ranges.

All surveys and sample collection for this CVS will be performed in accordance with established QC requirements. Replicate surveys, sample recounts, instrument performance checks, chain of custody, control of field survey data and databases, and QC investigations will provide a sufficient level of confidence in the data collected to support the survey outcome. The radiologic survey instrument QA/QC frequencies, such as calibration and function checks, are described in SOP-3, SOP-4 and SOP-5. The field QA/QC replicate survey and sampling include the following:

- Duplicate measurement at 5 percent of gamma static survey locations.
- Confirmatory soil sample for gamma static survey at 5 percent of gamma static measurement locations.
- Field QA/QC duplicate soil samples for offsite vendor laboratory analysis at a frequency of 5 percent of the soil samples collected.
- Replicate recounting of on-site ex-situ gamma soil screening at a frequency of 5 percent of the total number of samples screened with a minimum of one per day.

In addition, QA/QC measures will confirm that trained personnel conduct surveys with approved procedures and properly calibrated instruments. Procedures will cover sample documentation, chain of custody, field and laboratory QC measurements, and data management.

8.0 REPORT OF CVS FINDINGS

Survey procedures and sampling results will be documented in a CVS report. This CVS report will become an integral part of the Closure Report. This CVS report will contain, at a minimum, the following information:

1. A site map that shows scan data, locations of elevated direct radiation levels, and sampling locations from each survey area

2. Tables of Ra-226 concentrations in each sample from each survey unit, including, but not limited to, the results in pCi/g, measurement errors, detection limits, and sample depths

3. Summary statistics for analytical data, surface scan data, and gamma logging data from each survey area

4. Results of the CVS data evaluation

The last step of the DQA process will be documenting the results and drawing conclusions.

9.0 REFERENCES

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

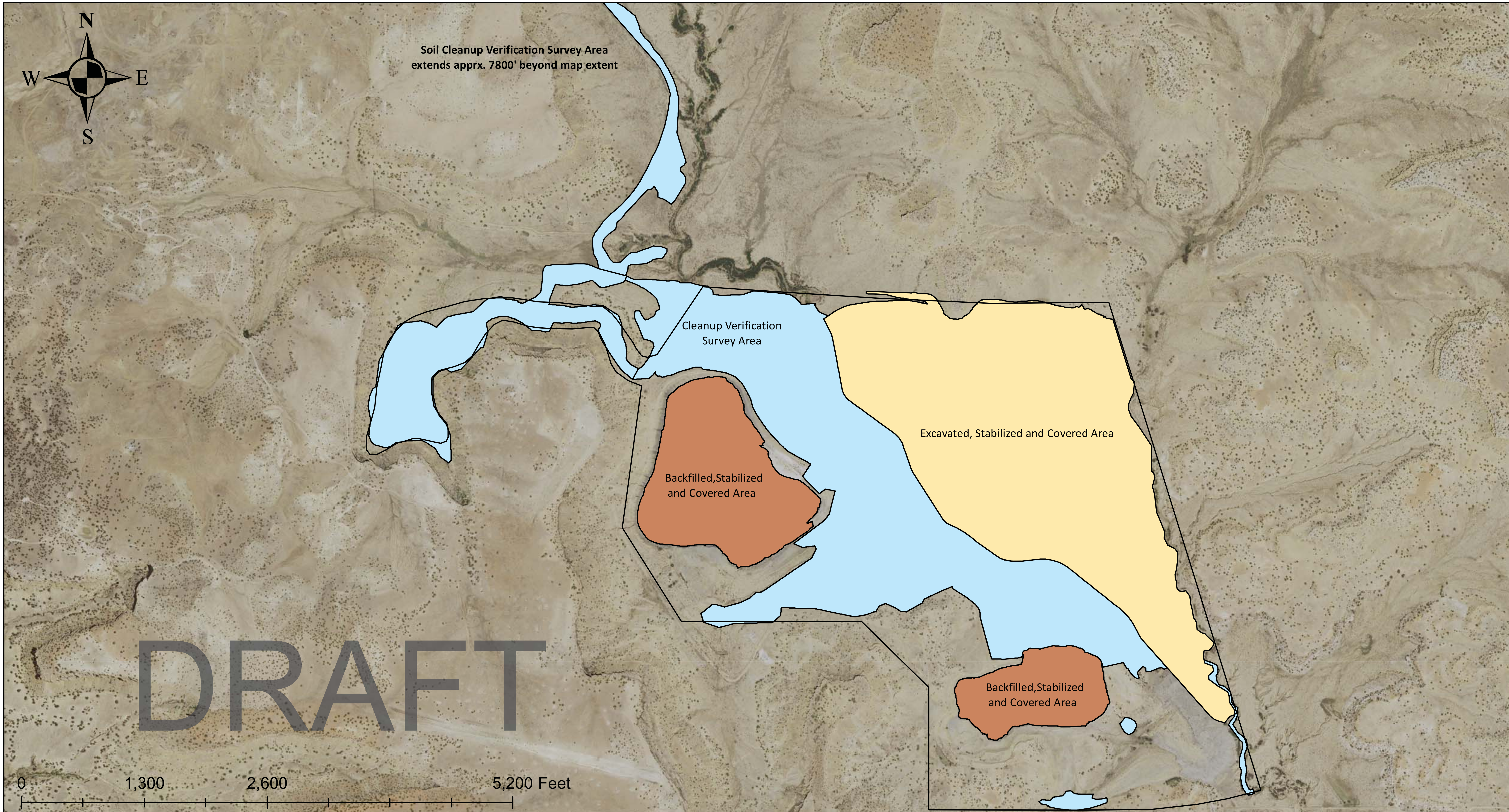
MWH, 2007. St. Anthony Mine Materials Characterization Report, October.

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

USEPA, 2006. Guidance on Systematic Planning Using the Data Quality Objectives Process, EPA QA/G-4, EPA/240/B-06/001, Office of Environmental Information, Washington, D.C., February

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

Figures



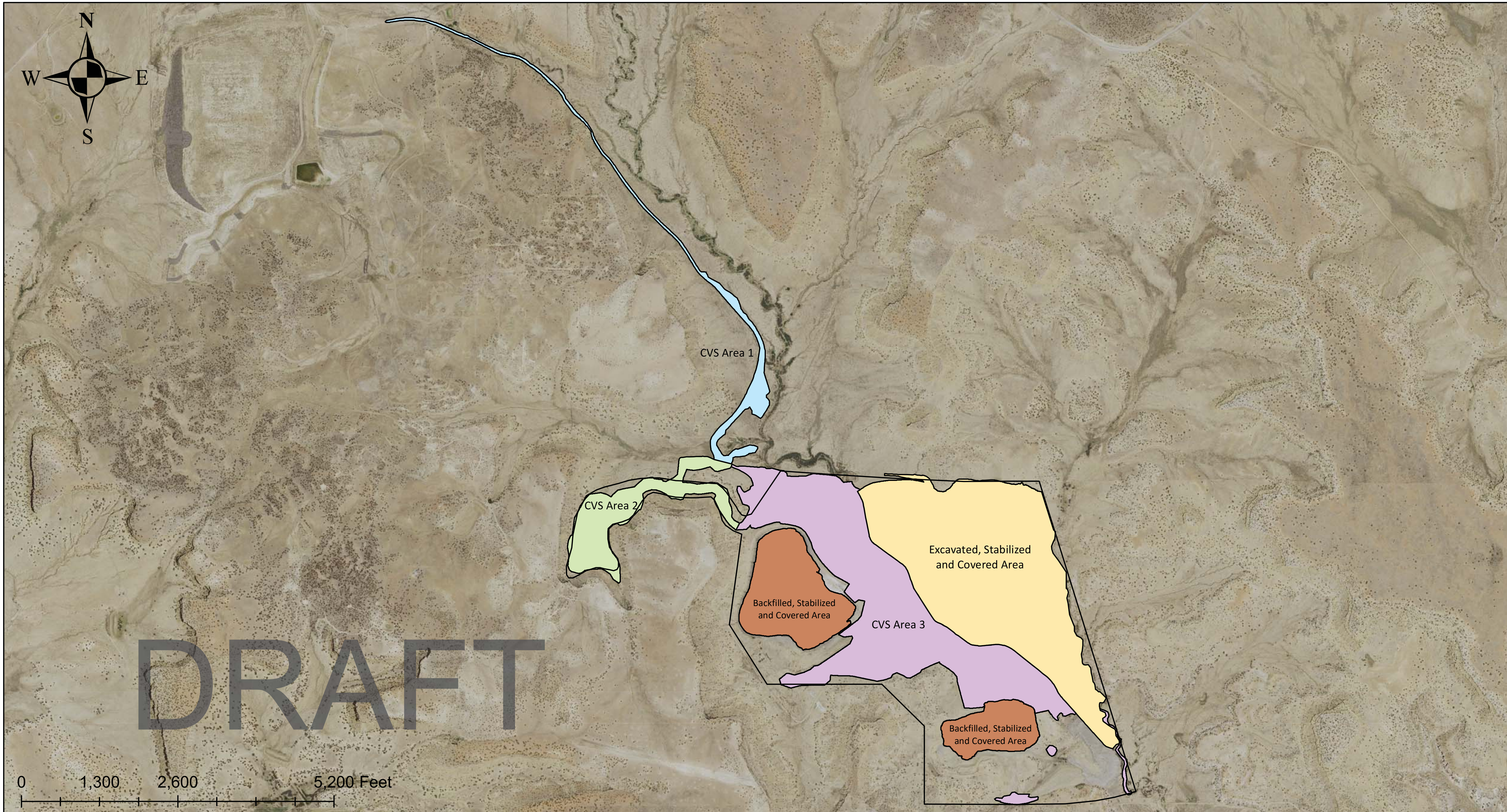
AVM Environmental Services, Inc.

Figure 1
Cleanup Verification Survey Areas
St. Anthony Mine Site Cleanup Verification Survey Plan

Legend

- Cleanup Verification Survey Area
- Excavated, Stabilized and Covered Area
- Backfilled, Stabilized and Covered Area
- Permit Boundary

March 2019



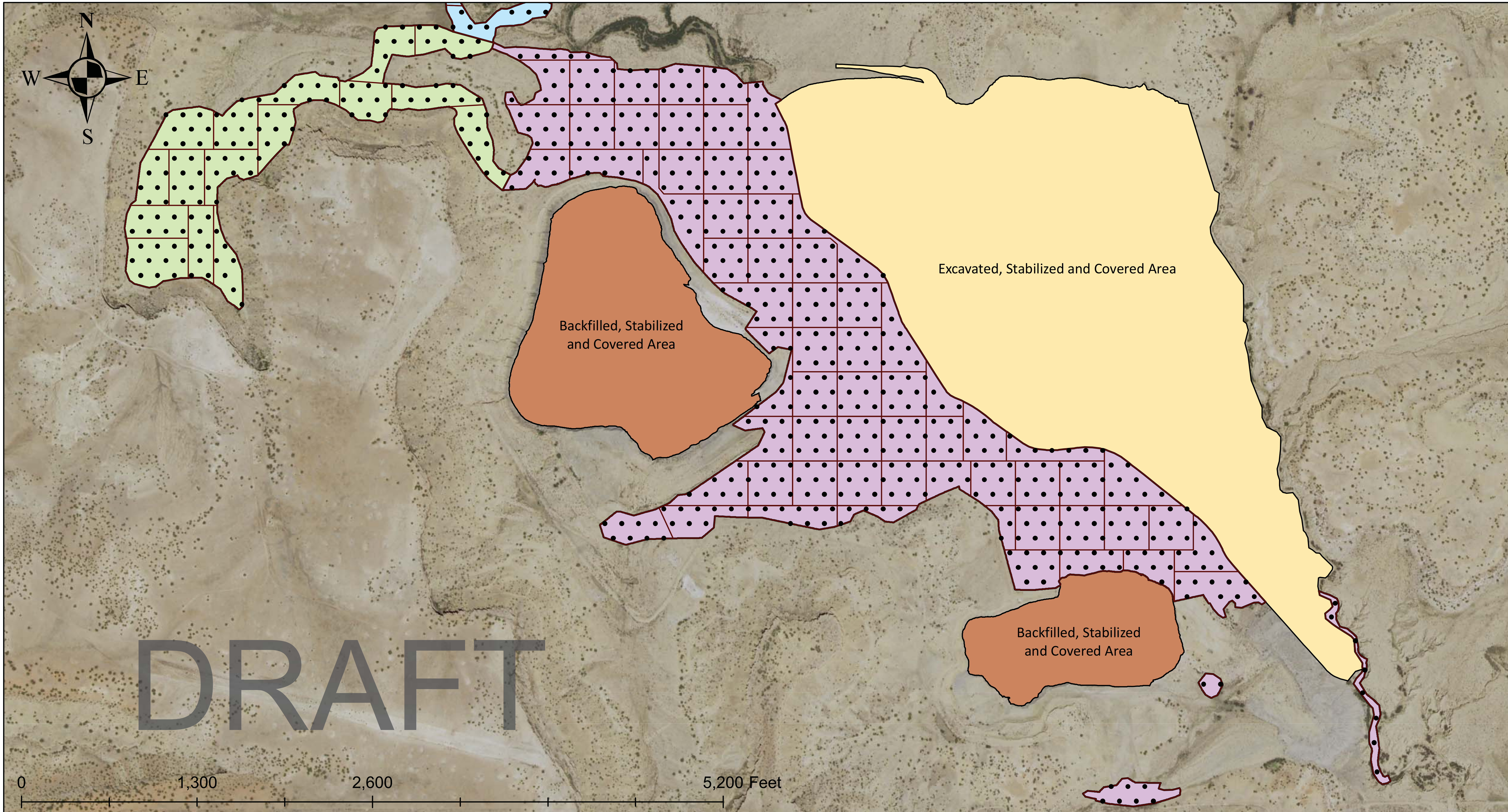
AVM Environmental Services, Inc.

Figure 2
Cleanup Verification Survey Areas
St. Anthony Mine Site Cleanup Verification Survey Plan

Legend

- Cleanup Verification Survey Area 1
- Cleanup Verification Survey Area 2
- Cleanup Verification Survey Area 3
- Excavated, Stabilized and Covered Area
- Backfilled, Stabilized and Covered Area
- Permit Boundary

March 2019



AVM Environmental Services, Inc.

Figure 3
Cleanup Verification Survey Area 2 and 3
Survey Units with Data Points
St. Anthony Mine Site Cleanup Verification Survey Plan

Legend

- 125ft Triangular Data Point
- Cleanup Verification Survey Area 1
- Cleanup Verification Survery Area 2
- Cleanup Verification Survery Area 3
- Survey Unit Boudary
- Excavated, Stabilized and Covered Area
- Backfilled, Stabilized and Covered Area

March 2019

AVM Environmental Services, Inc.

Figure 4
Cleanup Verification Survery Area 1
Survey Units with Data Points
St. Anthony Mine Site Cleanup Verification Survey Plan

Legend

- 125ft Triangular Data Point
- Survey Unit Boudary
- Cleanup Verification Survey Area 1
- Cleanup Verification Survey Area 2

March 2019

B.3 STANDARD OPERATING PROCEDURES (SOPS)

Standard Operating Procedures

Excavation Control & Cleanup Verification Surveys
St. Anthony Mine Closeout

Prepared by

AVM Environmental Services, Inc.

Grants, New Mexico

March 2019

SOP-1 Calibration of Gamma Radiation Survey Instruments

SOP-2 Direct Gamma Radiation Level to Ra-226 Soil Concentration Correlation Update

SOP-3 Field Gamma Radiation Survey for Ra-226 Concentration in Soil

SOP-4 Field Soil Gamma Radiation Screening Procedure

SOP-5 Surface Soil Sampling

SOP-1
AVM Environmental Services, Inc.
Calibration of Gamma Radiation Survey Instruments
St. Anthony Mine Closeout

1. SCOPE

1.1 Purpose

To provide a standard procedure for calibration of the Ludlum Scaler/Ratemeter, model 2221 with a 2”x2” NaI Scintillation Detector (the Ludlum 44-10 or Eberline SPA-3) for gamma radiation surveys during St. Anthony Mine Site (site) closeout activities.

The Ludlum 2221 is a portable, battery operated, self-contained counting instrument designed for operation with scintillation, proportional or G-M detectors. When combined with a 2”x2” NaI scintillation detector, the Ludlum 2221 is used for the detection and measurement of gamma radiations. This instrument configuration is used for detection of the soil Ra-226 gamma radioactivity.

1.2 Applicability

This instrument will be calibrated every twelve months, after repairs, or when the instrument function check fails. This method can be used with any Scaler/Ratemeter with a 2”x2” NaI scintillation detector configuration.

2. REFERENCES

2.1 Technical Manual for Scaler Ratemeter, Model 2221

3. REQUIREMENTS

3.1 Tools, Material, Equipment

3.1.1 Small flat head screwdriver.

3.1.2 Ludlum Model 500 Pulser or equivalent.

3.1.3 A source of sufficient gamma radiation activity to allow a response For high voltage plateau and function check. A 1% uranium ore in a sealed can is used.

3.1.4 Detector response factor for Ra-226 gamma survey is performed as described in Section 7

3.2 Precautions, Limit

3.2.1 The detector to Scaler/Ratemeter connector cable could easily be damaged if the weight of the 2”x2” NaI detector is suspended with it.

3.2.2 The NaI scintillation crystal is fragile. Shock to the crystal could cause a fracture or a crack, which could impact operation.

3.2.3 Do not leave the reading lamp on for any length of time as it will rapidly drain the battery voltage.

3.2.4 The meter firmware affects the measurements outputted via the RS-232 communication port. Based on the selected integrated count output for specific scan survey, verify appropriate firmware version installed for the Model L2221. The L2221 should have firmware version 261-02-N11 for one second integrated count output, and the firmware version 26106n03 two second integrated count output. The firmware version will appear on the L2221 display after turning it ON.

3.3 Acceptance Criteria

The instrument response to the calibration source should be within ± 20%.

4. LUDLUM 2221 OPERATION CALIBRATION

If the Ludlum 2221 has been calibrated by the vendor within 12 months, skip this procedure in this section and start with detector calibration in Section 5. Record Scaler/Ratemeter information (model and serial number, and calibration date) on the Scaler/Ratemeter Calibration Form. Record information about the calibration source (Pulser and/or source, 1% uranium ore standard).

4.1 Check the battery condition by pressing the “BAT” button with instrument switched on. If the meter does not indicate the battery charge above 5.3 volts, replace the four (4) D-cell batteries.

4.2 Set the threshold value as follows:

4.2.1 With the instrument turned on, press the threshold button. Read the displayed reading. If necessary adjust the **“**THR**”** adjustment screw until the threshold reads 100.

NOTE: The "THR” adjustment screw is located under the calibration cover

4.3 Set the WIN (window) IN/OUT to OUT.

4.4 Connect the Ludlum 500 Pulser to the 2221.

4.5 Switch SCALER/DIG RATEMETER switch to DIG RATEMETER.

4.6 Select 400 CPM on the Pulser (multiplier switch to 1 and count rate adjusted to 400 cpm).

4.7 Adjust the pulser amplitude above the set threshold (100 mV) until a steady count rate is observed.

4.8 Record the meter rate count response in AS FOUND column on the calibration form. If the meter response is not within 10% of the Pulser set count rate of 400 cpm, adjust the R40 Meter Cal (Labeled MCAL) on the processor board for 400 cpm on the meter.

4.9 Repeat steps 4.6 to 4.8 for 4000, 40,000 and 400,000 cpm pulses.

4.10 Switch the SCALER/DIG RATEMETER switch to SCALER. Select Count Time to 1 Minute.

4.11 Select 400 counts on the pulser (multiplier switch to 1 and count rate adjusted to 400)

4.12 Count the pulses on the meter for one minute by pressing COUNT switch.

4.13 Record the meter response counts in AS FOUND column on the calibration form. If the meter count is not within 10% of the pulser set counts of 400 cpm, adjust the R40 Meter Cal (Labeled MCAL) on the processor board and repeat step 5.12 until a count of 400 is observed on the meter.

4.14 Repeat steps 4.11 to 4.13 for 4000, 40,000 and 400,000 pulses.

If the meter reading could not be set within 10% of the pulses generated by the pulser, the meter requires repair and calibration prior to use.

The Ludlum 2221 is ready for detector calibration and operation.

5. DETECTOR HIGH VOLTAGE AND BACKGROUND CALIBRATION

Record Scaler/Ratemeter (Ludlum 2221) and 2"x2" NaI detector (Eberline SPA-3 or Ludlum 44-10) information (model and serial number, and calibration date) on the Scaler/Detector Calibration Form. Record information about the radiation source (1% uranium ore standard).

5.1 Connect the calibrated Ludlum 2221 to the 2"x2" NaI detector.

5.2 Turn the Ludlum 2221 ON. Set WIN ON/OFF to OFF.

5.3 Check Threshold setting. Should be at 100 mV.

5.4 Switch SCALER/DIG RATEMETER switch to SCALER. Select Count Time to 1 Minute.

5.5 Set HV to 500 VDC.

5.6 Expose the detector to the 1% uranium ore can by placing directly under the detector.

5.7 Obtain one-minute counts with the detector exposed to the source at every 50-volt increment until voltage plateau is passed and sudden increase in the counts is observed. (Usually for the 2"x2" NaI detector, the high voltage plateau maximum voltage is about 1300 to 1400 VDC.). Record the counts under the READING CPM SOURCE in the calibration form.

5.8 Return HV setting back to 500 VDC.

5.9 Remove the calibration source away from the detector. Obtain one-minute background counts with the detector shielded from the source at every 50-volt increment until similar voltage to the source high voltage plateau reading. Record the counts under the READING CPM BACKGROUND in the calibration form.

5.10 Plot voltage versus cpm reading for both the source and background high voltage data.
From the plot, select the optimum operating high voltage, which is usually at least about 50 volts above the knee of the source response plateau curve for greater counting stability. The optimum high voltage should be also within 50 volts of the background plateau curve for background counting stability.

5.11 Set the Ludlum HV at the optimum operating voltage determined above.

5.12 Record the HV voltage setting on the Scaler/Detector Calibration Form.

The Ludlum 2221 and the 2”x2” NaI detector configuration are ready for determining the detector response factor and establishing the operating background and source function check.

6. OPERATING BACKGROUND AND SOURCE FUNCTION CHECK DETERMINATION

6.1 Set the Ludlum 2221 to Scaler mode, Count Time at 1 minute, with WIN OUT and THR at 100.

6.2 Remove any type of sources of radioactivity from the detector. Obtain five one-minute background counts. Record the background counts in the calibration form. Average the five one-minute background counts. Record the average background counts in the calibration form. The daily function check background counts should be within 20% of this average.

6.3 Expose the 1% uranium ore source (in the sealed can). Note the exact location of the source to the detector. Obtain five one-minute background counts with the detector exposed to the source. Record the source counts in the calibration form. Average the five one-minute source counts. Record the average source counts in the calibration form. The source position to the detector for the function check should be exactly the same as this calibration, and the source counts for the daily source function check counts should be within 20% of this average.

7. DETECTOR RESPONSE FACTOR AND FIELD OF VISION

7.1 Filed Vision

A detector field of vision (FOV) is used for determining observation interval of gamma scan survey for scan MDC calculations, and for transects spacing calculations for scan gamma survey coverage. Detection range of a photon from a particular source by a detector is related to FOV for that detector. The detection range is dependent on the energy of radiation (photon) being detected since it is a characteristic of photon energy, not a detector. Detection range will be longer for a photon with higher energy than a photon of lower energy. FOV is a circular area with the detection range as radius. A minimum FOV of 6.0 feet for bare and 3.0 feet for collimated 2x2 NaI detectors for Ra-226 (uranium ore) photons will be used for observation interval for MDC calculations. If a different FOV is used, it will be verified by conducting a FOV test.

7.2 Detector Response Factor

For the calculation of minimum detectable concentrations (MDCs), the detector response factor, a.k.a detector efficiency, which is a conversion constant in units of cpm per pCi/g is required. There are several methods for determining the detector response factor, such as using calibration pads, source modeling or a concentration to gamma radiation level correlation study. Since final gamma radiation level to Ra-226 surface soil concentration correlations for bare and collimated detectors have been established for the site, the appropriate detector response factor from these correlations will be initially used for MDC calculations for gamma surveys during the St. Anthony mine site field gamma survey activities. The correlations were developed for the ground surface assumptions similar to what is expected at the St. Anthony mine site, i.e. fairly homogeneous and distribution of Ra-226 concentration in surface soils by using sampling data from appropriate conditions. These correlations meet the statistical acceptance criteria and the project data quality objectives.

The slope of the regression represents the relationship between the field gamma measurement in cpm and the Ra-226 surface soil concentration in pCi/g. Thus, the slope is in units of pCi/g/cpm. The derivations of the correlations are described in the Attachment 1 to the Attachment B.1 to Appendix B of the Closure Plan, Excavation Control Plan. The final correlations yielded a regression slope of 0.0005 pCi/gm/cpm (or 2000 cpm/pCi/g) for bare 2x2 NaI Detectors, and 0.0013 pCi/gm/cpm (or 970 cpm/pCi/g) for 0.5-inch lead collimated 2x2 NaI detectors.

Response factor for all 2x2 NaI scintillation detectors are fairly comparable. However, if a detector is repaired, replaced or new one is used, the comparability of the response factor should be verified by cross measurement against the original calibrated detector using a constant uranium ore source with sufficient activity, or preferably at the DOE uranium ore calibration pad. The response should be within ±20%.

8. DETECTOR MINIMUM DETECTABLE CONCENTRATION CALCULATION

8.1 MDC for Static Gamma Radiation Measurement (for 0.05 probability for both false positive and false negative errors)

The calculation below is an example for illustrative purposes and the static MDC will be calculated in the field based on actual field background measurements from function checks. It is important to note that these MDC calculations necessarily depend on several assumptions of consistent conditions in the field such as homogeneous distributions of contamination in soil, infinite plane geometry, consistent thickness of the contaminated layer of material, and consistent detector to soil surface relationship. Those conditions will not be ideal when field measurements are performed and the MDC will likely be greater than the value calculated below.

$$MDC = C \times [3 + 4.65\sqrt{B}]$$

Where,

C = Detector response factor, cpm/pCi/g

B = Background count rate in cpm.

Example:

- For the bare 2x2 NaI detector, estimated background count rate of 10,000 cpm from previous function checks at the site, detector response of 0.0005 pCi/g/cpm from Section 7.2 above, then the MDC for a one minute static measurement would be:

$$MDC = 0.0005\ pCi/g/cpm \times [3 + 4.65\sqrt{(10{,}000\ cpm}] = 0.23\ pCi/gm$$

- For the 0.5-inch lead collimated 2x2 detector, estimated background count rate of 3,000 cpm from previous function checks at the site, detector response of 0.0013 pCi/g/cpm from

Section 7.2 above, then the MDC for a one minute static measurement would be:

MDC = 0.0015 pCi/g/cpm x [3 + 4.65√ (3,000 cpm] = 0.63 pCi/gm

The integration count time for static measurement may be changed to attain MDCs to required levels. Tolerable maximum instrument background count rate to attain a specified MDC can be calculated by solving the above equation using other accepted parameters (integration time and detector response factor). A daily function check must be performed prior to use.

The total propagated uncertainty will be calculated for the static survey measurement and reported with the static MDC values in all reports, tables, and figures.

8.2 MDC for Scan Gamma Radiation survey

The scan MDC is assumed for a scan rate of about 3 feet per second and a 2 second interval. For a single component scan, such as GPS based gamma scan for St. Anthony mine site Soil Cleanup Action, the scan CPM is recorded using DGPS and Data logger for later evaluation of data with no pausing for stationary survey investigation needed in the field during the scan, and variability in the actual scan speed due to human inconsistencies in scan rate and detector height, a surveyor efficiency (p) of 0.8 is appropriate. For a dual component where a surveyor may pause during a scan survey for investigation, a surveyor efficiency of 0.5 will be used. The calculation below is an example for illustrative purposes and the scan MDC will be calculated in the field based on actual field conditions (based on the actual detector response factor, surveyor efficiency, field of view, scan rate to meet the scan MDC requirements, and background; d' is fixed as indicated below).

First calculate the Minimum Detectable Count Rate (MDCR) as follows:

MDCR = (d' x √bi) x (60/i)

Where:

d' = value for true positive and false positive proportion. A value of 1.38 (MARSSIM Table 6.5) will be used for 95% true and 60% false positive proportion.

bi = number of background counts in the interval i [(background rate in cpm/60 sec/min) x 2 for two second interval].

Example: For the bare 2x2 NaI detector background count of 10,000 cpm estimated from previous function checks at the site, the MDCR for two second observation interval (6.0 feet FOV/3.0 feet per second scan rate) would be:

bi (2 sec) = (10,000 cpm) x (1 min/60 sec) x (2 sec) = 333 counts

MDCR cpm = (1.38) x √[333 counts] x (60 sec/min)/(2 sec) = 756 cpm.

The MDCR $_{surveyor}$ using surveyor efficiency (p) of 0.8 would be:

MDCR $_{surveyor}$ = MDCR/√p = 756 cpm/√0.8 = 845 cpm.

From the MDCR $_{surveyor}$, calculate the scan MDC using the following:

Scan MDC = MDCR $_{surveyor}$, cpm x C, cpm/pCi/gm

Where: C = Detector response factor, 0.0005 pCi/g/cpm (from Section 7.2 above)

Scan MDC = 756 cpm x 0.0005 pCi/g/cpm = 0.42 pCi/gm

For the 0.5-inch lead collimated detector with a background of 3,000 cpm, C of 0.0015 pCi/g/cpm, observation interval of one second (3.0 feet FOV/3.0 feet per second scan rate), the scan MDC would be 0.98 pCi/g.

A daily function check must be performed prior to use. The scan rate for radiation scan survey may be changed to attain MDCs to required levels. The tolerable maximum instrument background count rate to attain a specified scan MDC can be calculated by solving the above equation using the other approved instrument and survey parameter values, such as survey sensitivity (d'); detector response factor; scan rate; observation interval; and surveyor efficiency. Likewise, maximum scan rate for scan survey to attain a specified scan MDCs can be calculated by solving the above equation with using other instrument and survey parameter values, such as survey sensitivity (d'); instrument background count rate; detector response factor; detector FOV for Ra-226; and surveyor efficiency factor.

Attachment A

Scaler/Ratemeter Calibration Form

Model____________________________ S/N ____________________

Calibration Source____

Threshold (input sensitivity), Found at________________ mV Left or Set at __________ mV

Window, In/Out__________ Window ________________ mV

Pulser Amplitude Set @_____________________________mV

Range/Mode	Calibration Point (Pulser Setting) cpm x multiplier	As Found Reading	Left or Set Reading

HV Set @________________ VDC

Date __________________________ Calibrated By ____

Attachment B

AVM Environmental Services Inc.
Scaler/Ratemeter - Detector Calibration Form

Scaler/Ratemeter : Ludlum 2221, SR #
Detector: 0.5 Inch Lead Collimated SPA-3, #

Source: ______________________________ Strength: _________________

Scaler/Ratemeter Threshhold set @ 100 (10mV); Window IN/OUT: OUT; Window: N/A mV

HV	Reading, CPM (Source)	Reading, CPM (Background)
500		
550		
600		
650		
700		
750		
800		
850		
900		
950		
1000		
1050		
1100		
1150		
1200		
1250		
1300		
1350		
1400		

at designated function check location in office.

Count #	Reading (CPM)
1	
2	
3	
4	
5	
Average	

Count Readings with 1 percent U_3O_8 can directly under collimated detector on designated function check location in office.

Count #	Reading (CPM)
1	
2	
3	
4	
5	
Average	

HV Set @ ________________________ VDC (Instrument) ___________________ VDC (DVM Fluke 8020B)

Input Sensitivity (THR), mV _________________

Function Check with 1 percent U_3O_8 ore in can. Can Directly under the detector.
Acceptable Function check range is: _______________________ to ____________________ CPM

Count Readings for Calibration Pad GPL (87.78 pCi/gm Ra-226)

#1 _______________ cpm
#2 _______________ cpm Average _______________ cpm
#3 _______________ cpm
#4 _______________ cpm Efficiency _______________ cpm/pCi/gm
#5 _______________ cpm Efficiency _______________ pCi/gm/cpm (1/cpm/pCi/gm)

Date ______________________________ By ____

SOP -2
AVM Environnemental Services, Inc.
Direct Gamma Radiation Level to Ra-226 Soil Concentration Correlation Update
St. Anthony Mine Closeout

1.0 Purpose

The purpose of this procedure is to update the Site specific Ra-226 concentrations in surface soil to direct gamma radiation level correlations for St. Anthony Mine Closeout. Site specific correlations were initially developed for both bare and collimated 2x2 NaI detectors during the 2018 Supplemental Radiologic Characterization as discussed in Attachment 1 to Appendix B.1. Although these correlations meet or exceed the appropriate acceptable statistical criteria (correlation coefficient, p-value and low MSEs), the correlations may be updated to improve the statistical parameters.

2.0 Scope

The Ra-226 levels in soil could be measured as a surrogate by measuring Pb-214 and Bi-214 gamma radiation levels, as to the measurement described in Section 4.3.2 of the MARSSIM. Pb-214 and Bi-214 are decay products of Ra-226 through radon-222 (Rn-222), a gaseous form, some of which emanates from soil. This process results in activity disequilibrium between Ra-226 and PB-214/Bi-214 in the soil. The Rn-222 gas emanation fraction from the soil varies with different characteristics of a particular soil. Therefore, a site-specific calibration of the detector is necessary. Studies at the Site have shown that about 20 percent of the Rn-222 gas decayed from Ra-226 in soil emanates out of the surface soil, indicating that a significant percentage (about 80 percent) of Ra-226 will decay into Pb-214 and Bi-214 in the soil matrix. If the soil characteristics and other parameters (such as moisture, radon emanation fraction, contamination distribution profile, gamma ray shine from nearby sources, and land topography) are consistent, the ratio of Pb-214/Bi-214 to Ra-226 will be consistent. This results in a direct correlation between Pb-214/Bi-214 gross gamma radiation levels and Ra-226 concentrations in the soil. The gamma radiation from other naturally occurring isotopes in soil, such as Th-232 decay products and K^{40}, may contribute to gross gamma radiation intensity. In addition, background gamma radiation from cosmic rays also contributes to gross gamma radiation intensity. However, the gamma radiation level from such naturally occurring isotopes and sources are generally at a constant level. A linear regression would identify such a constant to correct for and minimize interference with the gamma radiation level and Ra-226 soil concentration correlation.

The site specific correlations for both the bare and collimated 2x2 NaI detectors were developed with primary assumption of contamination distribution in surface soil. Any lateral gamma radiation shine from the nearby elevated areas would skew gamma radiation level. A collimator detector mitigates the lateral shine interference. The collimated detector correlation was updated with sampling data from locations that fit this assumption during previous investigations and removal actions. A correlation with this assumption is most appropriate for excavation control and final status surveys during removal actions because the contamination distribution is expected to be fairly homogeneous and in surface soils following the removal action. Only gamma radiation level measurements and soil sample Ra-226 data from corresponding locations with this correlation assumption will be used to update the correlations.

3.0 Instrumentation

Instrumentation to collect gamma radiation level measurements will be the same as used during the development of previous correlations. A 2”x2” NaI Scintillation detector (an Eberline SPA-3 or Ludlum 44-10 detector) and a Scaler/Ratemeter, (Ludlum Model 2221 or 2241) will be used for field gamma radiation level measurements and to select sampling locations. A 2x2 NaI detector with 0.5-inch thick lead collimator will also be used for gamma radiation level measurement for the collimated detector correlation update.

The Scaler/Ratemeter will be calibrated consistent with SOP-1 to assure that it properly counts the electronic pulses generated and sent by the 2x2 NaI detector. An optimum operating high voltage for the detector will be established by performing a high voltage plateau on the detector using SOP -1a. The input sensitivity (threshold) of the Scaler/Ratemeter will be set @ 100 mV to avoid interference from low level background radiation. The pulses generated by the detector for Ra-226 gamma radiations (primarily from the Pb-124 and Bi-214 decay products) are significantly higher than 100 mV, as verified by using 1% uranium ore standard.

4.0 Gamma Radiation Level Measurements and Soil Sample Collection for Updating Correlation

If any surface soil sampling is performed during excavation control with a co-located static gamma radiation level measurement, the data may be used to update the correlation. One minute static gamma radiation level measurements will be performed consistent SOP-1. The co-located surface soil sample will be collected consistent with SOP-5, and will be analyzed for Ra-226 by an offsite vendor laboratory using EPA Method 901.1.

5.0 Linear Regression Analysis

The relationship between gamma radiations from Ra-226 to detector response is linear. To determine the correlation between gamma radiation level counts and corresponding Ra-226 concentration in surface soil, i.e. to determine a calibration equation, a liner regression analysis will be performed on the sample Ra-226 concentration in pCi/gm, Y, and the associated gamma radiation level count rate, cpm at X, from all the sample locations using a least-square liner regression and plotting the results. A linear regression is the only statistical approach determined to be appropriate because the 2x2 NaI detector response to gamma radiation detection is linear, specifically at the levels emanating from uranium ore and tailings impacted soil. The liner regression will be performed by augmenting the appropriate correlation data included in Attachment 1 of Appendix B.1. Prior to augmenting and updating the correlation, review the data to make sure that the data meets appropriate QA/QC requirements and the collected data fits the correlation assumption, i.e. fairly homogeneous Ra-226 distribution in only surface soil for bare detector, and in area with any lateral shine is mitigated with collimated detector.

Linear regression data will be summarized by the generalized equation:

$$Y = mX + b$$

where,

Y = soil concentration in pCi/gm,
m = slope, pCi/gm/cpm
X = count rate (the mean) in cpm
b = constant, y intercept

This correlation will provide a site specific calibration factor (m) in pCi/gm/cpm for the 2”x2” NaI detector, with a constant (b) to correct for any interference, specifically at lower range. The purpose of the update is to increase correlation sample numbers to improve statistical parameters (correlation coefficient, confidence level, p-value and low MSEs). If the update does not improve the statistical parameters, investigate the data to see if they meet the correlation assumptions or are outliers.

SOP-3
AVM Environnemental Services, Inc.
Field Gamma Radiation Survey for Ra-226 Concentration in Soil
St. Anthony Mine Closeout

1.0 SCOPE

1.1 Purpose

This procedure will be used for direct gamma radiation surveys to detect Ra-226 in surface soil for performing investigation surveys, excavation control (Remedial Action Support) surveys, and as a component of the Cleanup Verification Survey (CVS) at the St. Anthony Mine Site (site) site during closeout.

2.0 EQUIPMENT AND MATERIALS

2.1 A Ludlum model 2221 or 2241 Scaler/Ratemeter coupled with a Ludlum 44-10 or an Eberline SPA-3 2"x2" NaI crystal scintillation detector for direct gamma radiation detection. (SPA-3 and Ludlum 44-10 are both similar 2"x2" NaI crystal scintillation detectors).

2.2 A global positioning system (GPS) with real time differential correction and data logging capability

2.3 A 0.5 inch lead Collimator for use with 2"x2" NaI detectors, if needed to mitigate nearby lateral gamma-ray shine interference and focus on the area of interest under detector. The 0.5-inch thick collimator, which surrounds the NaI crystal, is contained within a protective marlex housing.

2.4 A vendor calibrated Exposure Rate (uR/hr) meter.

2.5 Map of survey areas with marked points, grid nodes and transects. Ink pen and appropriate Field Survey Forms to record survey readings and notes.

2.6 Measuring tape, pin flags, area markers and marking paint.

3.0 INSTRUMENT CONFIGURATION & OPERATIONS

Prior to any instrument function check or operation, the technician will read the Technical Manual for the instrument operations (Ludlum 2221) and the correlation Method (SOP-2) for the rationale behind the gamma radiation surveys.

The field gamma radiation level surveys for Ra-226 in surface soil will be performed using a Ludlum 2221 Scaler/Ratemeter connected to a 2"x2" NaI crystal scintillation detector (SPA-3 or Ludlum 44-10) which detects gamma radiation emitted from radium-226 decay products (primarily Pb-214 and Bi-214) in the soil. The detector will be held at approximately 12 inches from the ground surface. The bare (uncollimated) detector should be sensitive to an area at least six feet in diameter under the detector. The Model 2221 Scaler/Ratemeter with external RS232 or a Bluetooth connector can be coupled to a DGPS/data logger where the gamma radiation count rate in CPM would be logged with its corresponding location coordinates.

For gamma radiation surveys where significant shine interference is present from nearby areas, the 2”x2” NaI crystal scintillation detector will be installed in a 0.5 inch thick lead collimator to reduce gamma shine interference. During the survey, the detector will be held approximately 12 inches above ground level, which should focus and be most sensitive to an approximate 36 inch diameter area under the detector.

The instrumentation must be calibrated consistent with SOP-1 prior to use.

3.1 Instrument Function Check

An operational function check will be performed on the Scaler/Ratemeter (L2221) and the detector (SPA-3 or Ludlum 44-10) configuration each day prior to any field surveys. The operator will verify calibration validity for the Scaler/Ratemeter and the detector. The calibration date for the instruments must be within one year. If not, the instrument must be removed from service and calibrated with a certificate in file. The function check will be performed in the field office. The following function check procedures will be used and the pertinent information recorded on the Scaler/Ratemeter-Detector Function Check Form (Attachment A).

3.1.1 Visual Inspection

Perform a visual inspection checking for signs of any damage on the instrument, cables, detector and the shield. Test for possible electrical shorts in the cable with the instrument in the audio on mode, move the cable and note for any sudden increase in audible “clicks” and also and sudden increase in counts on the Scaler/Ratemeter display.

3.1.2 Calibration Due

Verify calibration validity for the Scaler/Ratemeter and the detector. Calibration date for the instruments must be within one year and have a current Calibration Certificate on file.

3.1.3 Battery Charge

Assure that the Scaler/Ratemeter battery is functional. For ESP Scaler/Ratemeter it should not be indicating a “Low BAT” signal. For Ludlum 2221, the battery voltage digital readout must be at least 5.3 volts.

3.1.4 High Voltage

The detector high voltage must match that determined during high voltage calibration (HV Plateau) for that detector.

3.1.5 Threshold (input sensitivity)

Check and make sure that the Scaler/Ratemeter threshold is set at 10.0 mV. If not, set the threshold to 10.0 as all gross gamma measurements are performed with 10 mV (equivalent to 100 setting on instrument) threshold. Ludlum 2221 Threshold can be set by the instrument digital read out display.

3.1.6 Window

If Ludlum 2221 Scaler/Ratemeter is used for instrument configuration, the WIN (window) toggle switch must be in the OUT position for gross gamma measurements.

3.1.7 Background Counts

The background counts will be determined for the same time interval as the field static survey count time, generally one minute. The background counts will be performed at the designated location in the field office. A location will be designated in the field office for obtaining the required daily background counts. Keep all beta/gamma radiation sources away from the detector while performing the background check. The background function check counts at the field office must be within 20% or lower than the background counts obtained during the detector high voltage calibration.

3.1.8 Source Function Counts

Obtain the gamma radiation function check source, (1% U_3O_8 ore standard sealed in a can marked "Function Check Source”). The 1% ore standard was used to determine the acceptable count range for the detector following calibration. Place the source at the same location on the detector used to obtain the source function check counts during calibration. Count the source for one minute and note the counts in CPM. The source function check counts must be within 20% of the source counts obtained during the detector and Scaler/Ratemeter calibration.

3.1.9 Instrument Tolerance

The Scaler/Ratemeter and detector counting and detecting tolerance are expressed as percent deviation from the mean of the acceptable count range. The background counts and the source function check counts must be within 20% of the mean established following instrument calibration. If the source count is outside this range, pull the instrument from service. The instrument must be repaired and/or re-calibrated prior to use.

3.1.10 Technician

After completing the function check, initial in the column marked TECH of the function check form.

3.2 Instrument Minimum Detectable Concentration Calculation

When required, calculate Minimum Detectable Concentration (MDC) for the instrumentation using the function check background readings as described in SOP-1 (Instrument MDC Calculation). Acceptable MDCs are below the specified investigation or Action Levels. The acceptable Ra-226 MDC limit for the site soil cleanup action for static gamma survey is 3.3 pCi/g (50% of the 6.6 pCi/g CAL) and scan MDC limit for scan gamma survey is 3.4 pCi/g (50% of the 6.84 pCi/g CALemc). Calculate MDC for appropriate survey, i.e. Direct Measurement MDC for static (stationary) gamma radiation survey and scan MDC for scan or walkthrough gamma radiation survey instrument background information. Record in the Function Check Form (Attachment A) if the instrument MDC is less than the acceptable limit.

The integration count time for static measurement and the scan rate for scan survey may be changed to attain MDCs at acceptable levels

4.0 FIELD GAMMA RADIATION SURVEYS

The direct gamma radiation level survey for Ra-226 in surface soil will be conducted as either scan survey (walkthrough) or static survey (stationary) measurements.

4.1 Scan Gamma Radiation Survey

Scan gamma radiation surveys (walkthrough surveys) will be performed by walking with the detector at about 12 inches from the ground surface with the scaler/Ratemeter in count RATE MODE. Scan surveys will be performed to identify and locate any hot spots and contaminated area boundaries for investigations and excavation control during the site cleanup action. Scan surveys will also be performed as a component of the CVS. A 0.5 inch lead collimator for 2”x2” NaI detectors will be used if needed to reduce lateral gamma-ray shine interference and focus on an area of interest under the detector. The scan rate and walking speed depends on the desired scan MDC for the survey. For this instrument configuration, a scan walking rate of 3 feet per second (fps) results in a Ra-226 scan MDC of 1.52 pCi/g. For a different san MDC, the scan walking rate may be modified.

A GPS based gamma radiation scan survey can be performed to log a gamma radiation rate with corresponding point location coordinates in a data logger. A GPS based scan survey paired with a scaler/ratemeter and a bare 2”x2” detector will be used for CVS scan surveys. This scan survey can be performed by walking along the specified transects in the areas using a 2x2 NaI detector with a ratemeter coupled with a DGPS/data logger unit. The GPS-gamma scan survey system will consist of a Ludlum 2221 Scaler/Ratemeter/ with SPA-3 2x2 NaI Detector coupled to a DGPS/data logger system. Where terrain allows, the CVS scan survey may also be performed using an all terrain vehicle (ATV) mounted scan survey system. The Ludlum 2221 will be operated in Ratemeter 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 based on the scan coverage rate and the detector FOV for Ra-226 will be used for this survey, as discussed in SOP-1.

The logging process can be partially automated by logging points by interval. You can log points after a specified time period has elapsed. The procedure for using the Log By Interval function in SoloField mapping software is described below:

1. Select **Log** > **Log by Interval**, or tap the **Log by Interval** button in the Mode Toolbar. This will open the **Select Feature to Log** screen.
2. You will be prompted to select a feature and to complete the attribute entry. When you tap on the **OK** button in the **Attributes** screen, the **Log by Interval** screen will be displayed.
3. Select between **Log by TIME interval.**
4. Enter the **2.00 Seconds** log interval in the **Log every** field.
5. Tap the **Start** button to begin logging by interval.

The first point will be logged at your current position. Once you have waited the specified time another point will be logged. This will continue until you tap the **Pause** button or close the screen. At the end of each survey day, the field data will be downloaded into a computer and processed for tabularization and mapping. Download the survey file as follow:

Select **File** > **More** > **Export** to open the **File Export** screen.

You may select the **Export Format** by tapping on the down arrow to the right of the selection box. choose Text, All exported files are stored in \My\Documents\SOLO\Export by default, otherwise. If **Prompt for filename** is selected, you can customize the names as each file is created.

Depending upon the export format selected, you may choose to export your features in two ways; a unique file for each feature layer, or one file.

With **Text *.txt** selected as the **Export Format**, tap **Options** to display the text options. You may turn these options on/off using the checkbox next to each option.

When you are satisfied with your selections, tap the **Export** button to create the file(s) in the selected format

4.2 Static Gamma Radiation Survey

Static gamma radiation surveys will be performed at any point or location of interest during surface soil investigation surveys, excavation control surveys, and at specified grid nodes within survey units for the CVS. The detector will be held at about 12 inches from the ground surface. The Scaler/Ratemeter will be set in the count SCALER MODE. A one-minute integrated count (CPM) of gamma radiation level will be obtained at each location for a static gamma radiation survey. A DGPS integrated with a data logger may be used to log the gamma counts and location for static surveys. A 0.5 inch lead collimator for the 2”x2” NaI detectors will be used if needed to reduce lateral gamma-ray shine interference and focus on the area of interest under detector. Static surveys for the CVS will be conducted using a collimated detector. For this instrument configuration, a one-minute integrated count results into a Ra-226 MDC of about 0.3 pCi/g for bare detectors and 0.4 pCi/g for collimated detectors. For a different MDC, the integrated count period may be modified.

4.3 Remedial Action Support (Excavation Control) Survey

Excavation control surveys will be performed to guide the excavation of contaminated soil exceeding the Ra-226 CAL of 6.6 pCi/g during the site soil cleanup action. Obtain field action level in CPM (for either bare or collimated detector) for the site soil cleanup level concentration (pCi/g) based on the site specific correlation. This direct radiation cleanup level may change as cleanup progresses and the correlation is updated; therefore, contact the Radiation Safety Officer (RSO) to obtain the current direct radiation cleanup level. Excavation control surveys will be performed using a combination of scan gamma radiation surveys and static radiation level measurements as follow:

IT IS IMPORTANT TO COORDINATE WITH THE EXCAVATION CREW THE EXCAVATION AND SURVEY SEQUENCE FOR YOUR SAFETY. ESTABLISH NECESSARY SAFETY COORDINATION WITH THE EXCAVATION CREW. ALWAYS WEAR AN ORANGE SAFETY VEST WHILE PERFORMING SURVEY IN THE FIELD.

1. Perform the function check as indicated in Section 4.1 of this procedure. In area where gamma radiation shine is expected, use the collimated detector.

2. Insure that the Scaler/Ratemeter is set in RATE mode. Turn the Scaler/Ratemeter audio

speaker to the ON position. For Ludlum 2221 Scaler/Ratemeter, set the RESP (response) toggle switch to F (fast) position. Set the audio rate toggle switch to x1, x10 or x100 position based on radiation level of the area and familiarize yourself to the audio rate at the action level count rate. The audio toggle rate set at x10 or x100 is appropriate for the field survey.

3. Using appropriate maps, area boundary location coordinates and a DGPS if needed, field locate and mark any area exceeding the cleanup level with pin flags. Radiation scanning may be necessary to delineate the contaminated area boundaries. Coordinate the marked area with the excavation crew. The area may be divided into smaller subareas such as about 100 square meter areas, or 10 feet strips to help efficiently control excavation based on the type of excavation equipment used for excavation. The excavation fleet will remove the contaminated soil in necessary thickness lifts initially based on vertical extent of contamination.

4. Following the initial excavation lift, assure that the excavation equipment is out of the way and the area is clear and safe, perform a radiation scan with the detector at approximately 12 inches from the ground surface by walking in a serpentine pattern along a transect or within the subdivided areas with the audio speaker ON to identify any locations that exceed the site action level count rate by audio response and digital count rate display. The scan survey for the excavation control will be performed for 100% coverage within the area. Note that the collimated detector at about 12 inches from ground is most sensitive within an area of about three feet diameter under the detector, and about six feet diameter under the bare detector. The scan gamma radiation survey form (Attachment B) may be used to note any comments.

   If no point or a location exceeding the action level is identified within the area by the scan, the removal action in the area would be considered complete, and the area will be ready for the final status survey.

5. If the radiation scan following the initial soil excavation lift shows portions the area above the cleanup level, or any static measurement point is above the cleanup level, mark out those areas with pin flags or marking paint and coordinate with the excavation crew for the additional excavation of contaminated soil as necessary until the scan survey shows no points or locations above the cleanup action level, and repeat step 5 at those locations.

6. If the radiation scan following the initial soil excavation lift still shows most or all of the area above the cleanup level, the contamination in entire area is deeper than the initial lift. Coordinate with the excavation crew for additional soil excavation and repeat steps 5 and 6 until the area is clean.

4.4 Investigation Survey

Gamma radiation surveys for Ra-226 contamination investigations will be used to identify hot spots and contamination boundaries. Static gamma radiation surveys will be conducted at any points of interest that are above the appropriate investigation level of an area. Obtain appropriate investigation level in CPM since they are different for different type of areas as described in the CVSS Plan. Follow the scan and static survey procedure as described in Section 4.1 and 4.2 above. Scan gamma radiation surveys will be performed by walking around with the detector at about 12 inches from the ground surface with the scaler/ratemeter in count RATE MODE. Scan surveys will be performed at necessary coverage rates, as specified in the CVS Plan for investigations, within areas of interest in a serpentine shape along transects. The investigation scan and static gamma survey data may be recorded in the DGPS/data logger and/or in field forms that are included in Attachments B and C.

4.5 Cleanup Verification Survey

The final Status Survey will be implemented following excavation control surveys indicating that the contaminated soil an area or a survey unit exceeding the RAL has been removed and is ready for CVS. Both, the scan and static gamma radiation surveys are components of the CVS. The scan gamma radiation survey would have already been performed at very dense coverage during the excavation control survey for cleanup action support. This information will be used for the scan gamma radiation survey requirements for the status survey.

CVS Scan gamma radiation survey

Systematic CVS scan gamma radiation surveys will be conducted prior to the static gamma radiation survey in survey units. The technician will perform the static gamma radiation survey as follows:

1. The scan survey coverage in each class survey unit is different. Obtain appropriate scan coverage for the survey unit from the CVS Plan.

2. Calculate Transect spacing for the CVS systematic gamma scan using the detector field of view (FOV) for the Ra-226 gamma radiations:

   transect spacing = FOV**/**Required % scan coverage.

   For example, for FOV of 6.0 feet for 2x2 NaI detectors, a 20 percent scan coverage requires a transect spacing of 30 feet.

3. Field locate and mark the specified transects in a survey unit using a GPS and appropriate marking material.

4. Conduct the CVS scan survey along transects as described in Section 4.1

5. Download the scan survey data as described in Section 4.1.

A QA/QC review of the scan data will be performed. The scan data will be reviewed to determine if the survey unit is ready for the static gamma survey.

CVS Static gamma radiation survey

The static gamma radiation survey will be implemented following the CVS scan gamma survey. One minute static direct gamma radiation survey will be performed using a 0.5 inch lead collimated detector at triangular grid nodes in each survey unit casted on a random origin. The technician will perform the static gamma radiation survey as follows:

1. Place the detector in the 0.5 inch lead collimator. Perform the function check as indicated in Section 4.2 of this procedure.

2. Verify that the Scaler/Ratemeter (Ludlum 2221) is set in scaler (integration) mode and that

the count time is set for one minute. Turn the Scaler/Ratemeter audio speaker to the ON position.

3. Obtain coordinates of each grid node in the survey unit.

4. Locate CVS static points (grid node) using the static survey point coordinate data, and a DGPS system.

5. Hold the detector at approximately 12 inches from the ground surface above the survey point. Obtain a one minute integrated count.

6. Log the survey point ID, coordinates and counts in the DGPS/data logger. The technician may also record the counts in CPM and appropriate corresponding survey point information (location ID and/or coordinates etc) on the Static Gamma Radiation Survey Field Form (Attachment C).

7. If any of the measurement is above the counts for CAL or CALemc based on the correlation, mark the survey point with a pin flag for investigation.

8. Repeat steps 4 to 6 for additional static radiation measurements.

9. The Ra-226 concentration in the soil will be calculated from the gamma radiation survey counts (CPM) using the linear regression equation established from the correlation for that detector. The static gamma survey data will be reviewed for QA/QC. The results from the static gamma survey will be used for demonstrating compliance with CAL.

5.0 ATTACHMENTS

Attachment A	Scaler/Ratemeter-Detector Function Check Form
Attachment B	Scan/Walkthrough Gamma Radiation Survey Field Form
Attachment C	Static Gamma Radiation Survey Field Form

Attachment A, SOP-03
Scaler/Ratemeter - 2" x 2" NaI Detector Function Check

Scaler/Ratemeter ID:____________________________________

Function Check Source ID: 1% U_3O_8 Ore in Sealed can

2" x 2" Detector ID:______________________________________

Acceptable background Count (cpm) Range (20%) ______________________ to ______________________

Acceptable Source Count (cpm) Range (20%) ______________________ to ________________________

Date	Physical Check	Cal Due	Battery[1] Volts or OK	HV Volts	Threshhold mV [2]	Window In or OUT[3]	C.C.[4]	BKG Counts cpm	Source Counrts cpm	Within Acceptable Range Y or N	MDC pCi/gm	Tech

Note: (1) Battery Voltage for Ludlum 2221 must be >5.3 volts; (2) Threshhold must be at 100 mV; (3) Window Position must be OUT; (4)

Attachment B, SOP-03
Scan/Walkthrough Gamma Radiation Survey Field Form

Instrumentation : Scaler/Ratemeter_________________________________, Detector____

Instrument Calibration Date: ______________________________, Instrument Daily Function Check Performed: __________

2"x2" NaI Detector Collimated ______ Yes or ______ No.

Survey Area/Unit Decsription ____

Survey Date/Time	Survey Area-Transect ID/Description	Gamma Radiation Reading Range CPM	Comments/Notes

Technician Signature __________________________________, Reviewed by _____________________________________

Attachment C, SOP-03
Static Gamma Radiation Survey Field Form

Instrumentation : Scaler/Ratemeter___________________________, Detector _______________________________________

Instrument Calibration Date: ______________________________, Instrument Daily Function Check Performed: __________

2"x2" NaI Detector Collimated ______ Yes or ______ No.

Survey Area/Unit Decsription ____

Survey Date/Time	Survey Point ID/Description	Survey Point Coordinate		Gamma Radiation Reading, CPM	Comments/Notes
		Northing	Easting		

Technician Signature ___________________________________, Reviewed by ______________________________________

AVM SOP-4
AVM Environmental Services, Inc.
Field Soil Gamma Radiation Screening Procedure
St. Anthony Mine Closeout

1.0 Introduction

This field soil screening procedure for Ra-226 consists of measuring 609 KeV gamma radiations of Bi-214, a decay product of Ra-226 through Rn-222. The 609 KeV gamma radiation counts of the sample soil is compared to a reference soil from the site with a known Ra-226 concentration for field screening. Although the Rn-222 is a gas and the soil is not sealed, the soil retains over 80 % of Rn-222 gas within the soil matrix, resulting in a significant amount of Bi-214 decay product and its gamma radiations. Bi-214 609 KeV gamma radiation is at fairly high intensity (46%) and isolated, which mitigates interference from other energy gamma radiations. A single channel analyzer (SCA), such as Ludlum L221 integrated with Ludlum 44-20 3x3 NaI scintillation detector will be used to measure radiation of a particular energy of Bi-214. The heavily shielded counting chamber lowers the background counts without lowering the counting efficiency for that geometry and sample size, thus lowers the detectable concentration. For a quick estimate of Ra-226 in soil, a reference soil with a known Ra-226 concentration (similar to screening level), which is not previously sealed, the 609 KeV gamma radiation level of Bi-214 can be measured (pulse height analysis) for field screening. The sample in a plastic bag is placed in a counting chamber (1.5 inch thick x 7.5 Inch ID x 12 inch tall lead ring collimator with a 1.5 inch thick lead bottom shield) around the 3x3 NaI detector and 609 KeV gamma radiation counts are obtained and compared to the reference soil and sample soil for field screening. The soil screening results are estimated for confirmation of gamma survey results during excavation control, and are not used for CVS confirmation of removal actions at specified limits. If the soil screening result is used for confirmation of CVS survey and indicate that the sample concentration is at or below the CAL, the sample must be sent off site vendor laboratory analysis for confirmation.

2.0 L2221/44-20 Window Operation and Energy Calibration Procedure

The following procedure calibrates threshold directly in keV.

1. Setup the counting chamber shield system with L 44-20 detector inside the chamber and connected to L2221 scaler/ratemeter. The L44-20 3x3 NaI detector is situated in the shielded counting chamber with the detector crystal facing up.

2. Place RATEMETER multiplier switch to LOG position.

3. Unscrew and remove instrument calibration cover.

4. Press HV pushbutton. The HV should read out on the display directly in volts. While depressing the HV pushbutton, turn HV potentiometer maximum counterclockwise. The HV should be less than 50 volts.

5. Depress the THR pushbutton. Turn the THR potentiometer clockwise until 652 displays.

6. With WIN IN/OUT switch IN, depress the WIN pushbutton. Turn the WIN potentiometer until 20 appears on the display.

7. Switch WIN IN/OUT to OUT.

8. Connect the detector (Ludlum 44-20) and expose to Cs-137 source.

9. Increase HV (if HV potentiometer is at minimum, it will take approximately 3 turns before any change is indicated). While increasing the HV, observe the log scale of the ratemeter. Increase HV until ratemeter indication occurs.

10. Switch WIN IN/OUT switch to IN.

11. Turn the HV control until maximum reading occurs on the log scale. Increase HV until reading starts to drop off, and then decrease the HV for maximum reading.

12. Turn RATEMETER selector switch to the X1K position.

13. Press ZERO pushbutton and release. If meter does not read, switch to a lower range until a reading occurs.

14. Carefully adjust HV potentiometer until maximum reading is achieved on the range scale. The instrument is now peaked for Cs137 on both the LOG and Linear scales. Record HV for energy calibration.

    NOTE: When the THR control is adjusted, the effective window width remains constant. As an example, if the THR is set at 559, the WIN at 100, a 609 KeV peak +559 (100 divided by 2) will be centered in the window. Then the threshold point is equivalent to 559 KeV with a 100 KeV window and calibrated for 100 KeV per turn. Now if the thresh hold is reduced to 250, the threshold is equivalent to 250 KeV, but the window (100) is still equal to 100 KeV. Proportionally, this represents a broader window.

15. Set THR at 559 and window at 100 for Bi-214 609 KeV (559 to 669 KeV ROI) gamma radiation measurement. Expose the detector with a 1% Uranium ore function check source and obtain a one minute counts. Remove the function check source and obtain a one minute background counts.

16. Record the energy calibration data in the L2221SCA/L44-20 Energy Calibration Form (Attachment A).

3.0 Minimum Detectable Concentration

The calculation below is an example for illustrative purposes for minimum detectable concentration (MDC), and the actual MDC will be calculated in the field based on actual field background measurements from function checks. The MDC, for 0.05 probability for both false positive and false negative errors, is calculated using equation 6-7 in Section 6.7.1 of the MARSSIM Guidance,

$$MDC = C \times [3 + 4.65.\sqrt{B}]$$

Where,

C = Detector response factor, pCi/g/cpm

B = Background count rate in cpm.

Example:

For the 3x3 NaI detector of the soil screening system, estimated background count rate of 80 cpm from previous function checks and the detector response during 2018 Characterization of about 86 cpm/pCi/gm (570 net cpm for 3,000 gm reference soil @ 6.6 pCi/g of Ra-226) sample , then the Ra-226 MDC for a 3,000 gm screening sample for a one minute measurement is calculated to be:

$$MDC = (0.0116\ \text{pCi/g/cpm}) \times [3 + 4.65 \cdot \sqrt{(80\ \text{cpm})}] = 0.79\ \text{pCi/gm}$$

The required MDC for the St. Anthony Mine Closeout is <3.3 pCi/g (50% of the 6.6 pCi/g CAL). The soil screening counting system will meet the required MDC limit of with one minute background counts of less than about 1000 cpm

Note: The MDC calculation assumes the weight of reference soil and screening soil to be same, 3000 grams, and the background and sample counting time be the same, least one minute. The measurement (integration) time of background and sample may be changed to attain desired MDC.

4.0 Field Soil Screening Procedure

1. Setup the L2221 parameters (HV, Threshold and Window) obtained during energy calibration above and connect the 44-20 detector. Make sure the window toggle switch is in the IN position.

2. Setup the counting chamber shield system in back of pick-up truck.

3. The L44-20 3x3 NaI detector is situated in the shielded counting chamber with the detector crystal facing up.

4. Perform background and source (1% Uranium ore) function checks and record in the Function Check Form (Attachment B).

5. Insert a clean plastic bag in the counting chamber for lining detector and counting chamber to avoid cross contamination.. Obtain 3,000 grams of appropriate reference soil, not previously sealed, and place in the plastic bag so that the sample is around the detector without any void, similar to the Marinelli Beaker geometry to provide the best counting efficiency. Cover the chamber opening with lead lid.

6. Obtain an integrated count for specified time period, generally one minute, with L2221 in Scaler mode and record in the soil screening Field Form (Attachment C). The reference soil counts may be used for efficiency calculation (pCi/g/com) for MDC calculation.

7. Remove the plastic bag with soil. Insert new plastic bag in the chamber for liner. Homogenize sample in stainless steel bowl and weigh 3000 grams of sample. Repeat step 5 and 6 for next soil sample. Change counting chamber liner between every sample.

8. Compare the reference soil counts to the sample soil counts to determine the sample Ra-226 concentration at above or below the reference soil concentration.

9. Following completion of soil screening, split a sample aliquot if needed for confirmatory analysis using EPA Method 901.1 by vendor laboratory. Return the unused sample at the location collected from.

QA/QC Procedure

1. The instrumentation, L2221 must be calibrated at least annually. Although the operating HV for the 3x3 NaI detector for soil screening is established during energy calibration discussed above, an HV plateau should be performed at least annually to verify proper detector operation throughout the HV range.
2. The background and source (with uranium ore check source to verify 609 KeV ROI calibration) function checks must be performed daily prior to use.
3. The reference soil material concentration must be determined from vendor laboratory analysis, or prepared using a certified reference material.
4. Duplicate measurement will be performed for 5% of the samples.
5. For cleanup verification survey soil screening, any soil sample screening result less than CAL will be sent to a vendor laboratory for confirmation.

Attachment A

AVM Environmental Services Inc.
L2221 SCA/L44-20 Energy Calibration Form

SCA: L2221, SR #68782 Detector: Ludlum 44-20 (3x3 NaI Scintillator)

Calibration Source: Cs-137 Check Source, 5 uCi (August 2008) For 662 KeV Peak Cal

Threshold (input sensitiv **652**

Window, In/Ou___**IN**___ Window ______**20**______

HV Initial ___________, At Peak _____________

Maximum CPM: ________________________ Background CPM: _________________

HV Set @______________ VDC

For Bi-214 609.2 KeV Peak (559 - 659 KeV ROI), Set Threshold @ 559, Window @ 100

CBi-214 609 KeV ROI Calibration Check: 1% U3O8 Ore Check Source: _______________ CPM
Background count (empty chamber) ____________ CPM

Date _______________________ Calibrated By ____________________________________

Attachment B

AVM Environmental Services, Inc.
Ludlum SCA L2221 - 44-20 3x3 NaI Detector Function Check
559 - 659 KeV Gamma Radiation Soil Screening

L2221 #68782

Function Check Source ID: 1% U_3O_8 Ore in Sealed can

Ludlum 44-20 3x3 NaI Detector, #PR295573

Acceptable background Count (cpm) Range (20%) ______________________ to ____________________

Acceptable Source Count (cpm) Range (20%) ______________________ to _______________________

Date	Physical Check	Cal Date	Battery[1] Volts or OK	HV Volts	Threshhold mV [2]	Window mV	Window In/Out	BKG Counts cpm	Source Counrts cpm	Within Acceptable Range Y or N	MDC pCi/gm	Tech

Note: (1) Battery Voltage for Ludlum 2221 must be >5.3 volts; (2) Threshhold must be at 220 mV; (3) Window @ 440, must be IN

Attachment C

AVM Environmental Services, Inc.
Field Soil Sample Gamma Radiation Screening Form

Instrumentation : Scaler/Ratemeter_________________________, Detector ___________________________________

Instrument Calibration Date: ___________________________, Instrument Function Check Performed: _________

Survey Area/Unit Decsription ____

Date/Time	Soil Sample ID	Sample Weight Grams	609 (559-669) Kev Gross Counts	Weight Corrected Counts	CPM	Estimated Ra-226 pCi/g	Comments

Technician Signature _______________________________, Reviewed by __________________________________

AVM SOP-5
AVM Environnemental Services, Inc.
Surface Soil Sampling
St. Anthony Mine Closeout

1.0 Introduction

This standard operating procedure (SOP) describes methods and equipment commonly used for collecting environmental surface soil samples for radiologic analyses during the soil cleanup action at the St. Anthony Mine Site (Site). The information presented in this SOP is generally applicable to the collection of all surface soil samples, except where the analyte(s) may interact with the sampling equipment. This SOP defines sample collection procedures using hand augers and shovels/trowels samplers. This document focuses on methods and equipment that are readily available and typically applied in collecting surface soil samples. It is not intended to provide an all-inclusive discussion of sample collection methods.

The objective of surface soil sampling is to characterize radiologic and chemical properties of the soil. Details pertaining to sample locations, number of samples, and type of analyses required, are presented in the Excavation Control (Appendix B.1) and Cleanup Verification Survey Plan (Appendix B.2).

2.0 Scope

This SOP describes procedures for surface soil sampling using hand tools for Ra-226, total uranium and metals analysis as required during the St. Anthony Mine Closeout.

3.0 Sample Type

Surface soil samples are typically collected from the ground surface to 6 inches below ground surface. Samples collected from greater than 6 inches below ground surface are referred to as subsurface soil samples. Soil sampling includes samples for confirmation of in-situ gamma radiation level and ex-situ gamma radiation soil screening, and for site-specific correlation Surface soil samples may be collected as grab samples or as composite samples. The sample method is determined based on the physical characteristics of the sample location and soil matrix.

- Grab sample: A sample taken from a particular location. Grab samples are useful in determining discrete concentrations, but also provide spatial variability when multiple samples are collected. Grab samples will be collected from sampling locations for the final status survey and during excavation control.

- Composite sample: A number of samples that are individually collected then combined (homogenized) into a single sample for subsequent analysis. Composite samples are useful when averaged or normalized concentration estimates of a waste stream or an area are desired. Also, multi-point composite samples may be collected for correlation sampling location.

4.0 Sampling Equipment and Technique

The following materials will be available, as required, during soil sampling activities:

- Personal protective equipment (PPE), as specified by the site HASP
- Stainless steel bowls
- Stainless steel spoons
- Stainless steel spatulas
- Stainless steel trowel
- Stainless steel spades
- Stainless steel hand augers
- Rock pick
- Permanent Indelible ink pens
- Tape measure or a ruler
- Sealable plastic bags (e.g., Ziploc®)
- Appropriate sample location coordinates and/or area maps or figures
- Equipment decontamination materials
- Transport container such as cooler (if sampling for laboratory analysis)
- Appropriate Field Sampling Data forms

A grab surface soil sample may consist of a single scoop or core, or the sample may be a composite of several individual samples. Surface soil samples shall be obtained using hand augers, shovels/trowels, or soil core samplers.

Hand Auger: A hand auger consists of a stainless steel tube with two sharpened spiral wings at the tip. The auger typically cuts a 2-inch to 3-inch diameter boring and works better in consolidated or slightly moist soils. Because the auger is hand-driven, penetration in dense or rocky/gravelly soil may be difficult. For surface soil sample collection, the procedures outlined below shall be followed.

1. Advance the auger by hand into the soil, to the desired depth (6 inches or less for surface soil samples), by turning in a clockwise direction with down force applied.

2. Retrieve the auger by pulling straight up until completely out of the hole, preferably without any rotation.

3. Fill the sample container, generally a Ziploc bag for Ra-226 and/or other container, using clean stainless steel spatulas or spoons. Repeat step 1 and 2 until a sufficient amount of sample is collected for specified analysis. For Ra-226 analysis by Method 901.1, about 400 grams in a quart size Ziploc bag is sufficient. For on-site ex-situ soil screening, about 3000 grams in a gallon size Ziploc bag will be required. Affix label on the sample container with appropriate sample information.

Shovel/Trowel: Various shovel/trowel designs and sizes are commercially available for a variety of sampling applications. These devices are hand-driven and are typically used for sampling relatively soft, unconsolidated surface soils. Some designs (e.g., the sharpshooterTM) can be driven into hard, rocky soil by opening a deep, narrow hole. All shovels or trowels used for soil sampling shall be made of stainless steel. The procedures outlined below shall be followed while collecting samples with shovels or trowels.

1. Drive the shovel/trowel into the soil six inches deep.

2. Retrieve the shovel/trowel being careful to not spill sample.

3. Fill the sample container, generally a Ziploc bag for Ra-226 and/or other type sample container for metals using clean stainless steel spatulas or spoons. Repeat step 1 and 2 until sufficient amount of sample is collected for specified analysis. For Ra-226 analysis by Method 901.1, about 400 grams in a quart size Ziploc bag is sufficient. For on-site ex-situ soil screening, about 3000 grams in a gallon size Ziploc bag will be required. Affix label on the sample container with appropriate sample information.

This procedure can also be used for collecting soil samples collected for ex-situ gamma radiation soil screening for subsurface soil investigation from the base of shallow test holes, pits or trenches excavated by hand tool such as a shovel or by a backhoe. Any soil sample collected for on-site ex-situ gamma screening may require sending to off-site vendor laboratory for Ra-226 analysis based on the ex-situ soil screening results. Split an aliquot for the off-site vendor laboratory from the ex-situ sample, which would had been already homogenized and of ample quantity.

5.0 Sample Equipment Decontamination

All sampling tool and equipment used for soil sampling will be clean prior to any soil sample collection. Sampling tools and equipment that are reusable will be decontaminated in between sample collection at different locations to avoid sample cross contamination. Hand tools, such as trowels, shovels, spoons, mixing bowls, etc. will be decontaminated at the sample locations. Any large equipment may be decontaminated at the designated decontamination area at the Site to for appropriate disposal of residual soil and rinsate. Since the sampling involves soil that may be potentially impacted by the COCs, Ra-226, uranium, and the COPC metals from uranium ore, which are mostly insoluble, the following procedure will be used to decontaminate soil sampling tools and equipment:

1. Brush off any loose soil from the sampling tool.
2. Wash the sampling tool with water and a residue free detergent, such as Alconox, in a bucket using a brush.
3. Rinse the sampling tool in a bucket with fresh water.
4. Rinse the sample tool with de-ionized water.

6.0 Investigation Derived Waste

The surface soil sampling is not expected to generate any Investigation Derived Waste (IDW) other than PPE (disposable gloves) and paper towels. Any excess soil from soil sample will be backfilled into the hole created from sample collection. Sampling tool decontamination rinse water will be poured on top of the backfilled sample hole for compaction. This method does not create any additional contamination or waste. If it is not feasible to put the excess sample back in the sample location, the excess soil will be contained and placed in the Pit which already contains elevated level of material, and will eventually be remediated.

7.0 Sampling Data Recording, Handling and

Field sampling documentation will be completed to provide sample information. Fill out sample information in the Field Soil Sample Log Form, included in Attachment A. Any additional information may be included in the log book. Sample handling requirements, such as storage, shipping and chain of custody, are specified in the Excavation Control (Appendix B.1) and Cleanup Verification Survey Plan (Appendix B.2). The soil samples collected for the COCs and CPOC metals do not require any specific preservatives. Complete sample chain of custody provided by laboratory. The field supervisor will retain all site documentation while in the field and add to project files when the field mobilization is complete.

8.0 QA/QC Requirements

Quality assurance quality control (QA/QC) includes following the SOP as discussed above, which includes proper decontamination to avoid cross contamination and sampling data recording and handling. Field QA/QC samples will be collected at the frequency specified in the work plan as listed below:

- Sampling equipment rinsate sample as discussed above in the section 5.0.
- Field QA/QC soil sample duplicate at a frequency of 10% of the samples collected.

Other applicable QA/QC requirements for laboratory, such as blanks, duplicate analyses, matrix spike are specified in the Cleanup Verification Survey Plan (Appendix B.2).

Attachment A
Field Soil Sample Log Form
St. Anthony Mine Closeout

Sample ID	Sample Date and Time	Sample Location (Coordinates)	Sample collection method/container/preservative	Analyses	Sample Type/Description	Comments/Notes	Sample Tech

Please include other applicable information, such as sampling activity/event, COC#, sampling depth, soil description, sample sub-location, etc in sample description or comments/notes