SENES Consultants Limited
Specialists in Energy, Nuclear and Environmental Sciences

Post Mine Radiological Surveys

Addendum to Roca Honda Mine Reclamation Plan (Rev. 1)
Mine Permit No. MK025RN
McKinley County, New Mexico

Prepared for:

Roca Honda Resources, LLC
4001 Office Court, Suite 102
Santa Fe, NM 87505

Prepared by:

SENES Consultants Limited
8310 South Valley Highway, Suite 3016
Englewood, CO USA 80112

March, 2013

TABLE OF CONTENTS

1.0 INTRODUCTION

Roca Honda Resources, LLC ("RHR") has submitted a Mine Reclamation Plan (Revision 1) for the proposed Roca Honda underground uranium mine ("Site") in McKinley County, New Mexico (RHR, 2011a). As part of the agency review process, the New Mexico Mining and Minerals Division ("MMD") and New Mexico Environmental Department ("NMED") have indicated the need for a post mine radiological survey following removal of all structures, stockpiles and equipment from the site to "demonstrate that the operation has not resulted in radiological conditions that may impact human health and safety beyond the conditions existing prior to mining" (MMD, 2012). Pre-mining radiological baseline conditions were characterized with a radiological survey conducted in 2010 by DeNuke Contracting Services, Inc. ("DeNuke"). Results were presented in Section 13 of the Baseline Data Report (RHR, 2011b).

The purpose of this document is to provide:

- A radiological survey plan to identify, quantify and characterize the locations and spatial extent of post-mine radiological contamination that may exist once mining operations are complete and reclamation commences.
- A measurement protocol to help guide excavation and removal of contamination, as may be necessary, and to ensure that the post-reclamation radiological verification surveys confirm that reclamation objectives have been met.
- A post-reclamation radiological verification survey plan to verify and demonstrate that post-reclamation conditions are consistent with pre-mining baseline conditions and that the operation has not resulted in radiological conditions that may impact human health and safety beyond conditions existing prior to mining.
- Individual cost estimates (in current dollar amounts) for implementation of each of the radiological survey component plans.

The MMD and NMED have indicated that the procedures to be used and radiological parameters to be tested for this radiological survey should be consistent with the pre-mining baseline radiological survey. The intent is to ensure that comparisons are valid and that they can be used to demonstrate spatial and quantitative consistency between post-reclamation radiological conditions and pre-mining radiological baseline conditions. Achieving and demonstrating post-reclamation consistency with baseline radiological conditions will involve a three-stage radiological survey process, with each stage sequenced to occur at specific points in the Mine Reclamation Plan schedule (RHR, 2011a). The nomenclature, general descriptions, sequencing, and the corresponding sections of this document in which the detailed plans for each stage of the radiological survey process are provided are as follows:

1. <u>Post-mining, Pre-Remediation Radiological Survey</u> (Section 2.0): Once mining operations have been completed and primary structures and equipment have been removed from the Site [per sections

2.2.1 – 2.2.7 of the Mine Reclamation Plan (RHR, 2011a)], gamma surveys will be conducted across disturbed and accessible land areas to identify and characterize the extent of residual radiological contamination that may have been caused by the mining operations. This information will be used to determine the horizontal extent of remediation necessary to achieve consistency with baseline radiological conditions.

2. <u>Remedial Support Measurements</u> (Section 3.0): To guide remediation of areas identified to contain residual contamination as identified by step one above, real-time gamma measurements will be performed to determine when soil excavations have achieved consistency with baseline radiological conditions. These measurements will be used to guide excavations prior to any re-grading/contouring activities [per section 2.2.8 of the Mine Reclamation Plan (RHR, 2011a)].

3. <u>Post-Reclamation Verification Survey</u> (Section 4.0): A final "post-reclamation" verification survey will be performed after remediation is deemed complete and re-grading/contouring has been conducted [per sections 2.2.8-2.2.9 of the Mine Reclamation Plan (RHR, 2011a)], but prior to topdressing, seeding and mulching activities [per section 2.2.10 of the Mine Reclamation Plan (RHR, 2011a)] which could be negatively affected by radiological survey activities.

Individual cost estimates for implementation of each stage of the radiological survey process as indicated in items 1, 2, and 3 are provided in Section 5.0 of this document. Section 6.0 details the data quality assurance/quality control methods and protocols that will be used to help minimize and quantify data uncertainty. Information concerning the technical basis and scientific rationale for the approaches and methods that will be used for each stage of the radiological survey process, how these approaches/methods will produce radiological survey data that are compatible with the baseline data set provided in the Baseline Data Report (RHR, 2011b), and the technical basis for how these data will be evaluated to demonstrate consistency with baseline conditions, are provided in Section 7.0 of this document.

In addition, Section 7.0 provides information regarding additional radiological baseline measurements and sampling that will be performed onsite in the spring of 2013 in order to supplement and improve the overall future utility of the radiological baseline data set provided in the Baseline Data Report (RHR, 2011b). The supplemental onsite radiological survey data to be collected, and how these data will be used to update existing radiological baseline data, are detailed in Section 7.0. The results of these supplemental onsite radiological baseline survey data, and related revisions to existing radiological baseline data and/or respective data presentations, will be provided (anticipated summer 2013) as an addendum to Section 13 of the 2011 Baseline Data Report (RHR, 2011b).

It will also be necessary to supplement the Baseline Data Report (BDR) by collecting data along the portions of the proposed haul road corridors in Sections 11 and 17 that have changed, the utility corridor in Section 15, and the corridor of the mine dewatering pipeline that will convey treated water a distance of approximately 8 miles from the water treatment plant. Baseline radiological conditions will be established along these routes. This will include a gamma survey and representative soils sampling in accordance with the methods described in Sections 2.2.3, 4.2.3, 4.2.4 and 7.2 of this document. The results of the survey will also be included in the above referenced addendum to Section 13 of the 2011 Baseline Data Report (RHR, 2011b).

2.0 POST-MINING, PRE-REMEDIATION RADIOLOGICAL SURVEY

This section provides the technical basis, rationale and general approach, along with specific methods and procedures that will be used to identify and characterize the locations and spatial extent of radiological contamination upon final closure of the mine operations and removal of surface facilities, but prior to any remediation of disturbed land areas. Cost estimates are provided in Section 5.0. For the purposes of this plan, "contamination" refers to any area of significant horizontal extent where radiological conditions can be clearly identified to exceed pre-mining baseline conditions. This definition is based on MMD's requirement that RHR demonstrate that its mining operation has not resulted in conditions that may impact human health and safety beyond the conditions that existed prior to mining (MMD, 2012). The caveat of "significant horizontal extent" is important with respect to the above definition of contamination for a number of reasons as discussed below.

As indicated in Section 1.0, the overall radiological survey process is designed to help achieve, and ultimately to demonstrate, consistency with pre-mining baseline conditions. An important challenge when the remedial objective is essentially to remediate to pre-existing background levels, is to do so without causing unnecessary collateral damage to the environment and/or without creating new and unintended risks to human health and safety. Cleanup of very low levels of contamination can result in significant environmental degradation without corresponding reductions in human health risks (Whicker et al., 2004). Disturbing/mobilizing soils with low-level contamination can actually increase the potential for human exposures (via inhalation/ingestion pathways) and more generally, can negatively impact overall air and water quality in the vicinity of the site. Such remediation also unnecessarily increases the extent to which remediation workers are exposed to physical hazards.

Federal standards for radiation protection (e.g. 10 CFR 20, 40 CFR 192) are set at increments above background levels (e.g. 25 mrem/yr, 5 pCi/g radium-226, 20 μR/hr, etc.). These standards are based on recommendations from the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection (NCRP), and are respectively considered to be well below levels that could result in significant or measurable detriment to human health. Moreover, ICRP recommendations explicitly include the concept that any remedial action should do more "good than harm" (ICRP, 1990). In addition, many locations in the U.S. and abroad have levels of naturally occurring background radiation that are much higher than baseline levels at the Roca Honda Site, yet human health effects have never been demonstrated in epidemiological studies of populations living in such areas (Boice et al., 2010; Hall and Giaccia, 2006). The biological effects of exposure to radiation do not depend on whether the source is naturally occurring or a result of human activities. For all of the above reasons, a caveat concerning "significant horizontal extent" has been included in the definition of contamination for the purposes of this radiological survey plan. Remediating areas that are too small and/or too low level to realistically result in radiological impacts to human health could cause more harm than good.

The MMD and NMED have indicated that the post mine radiological surveys should, at minimum, include the footprint of the facility, areas around shafts and ore bays, beneath impoundments, the pipeline corridor, and the haulage routes within the permit area (MMD, 2012). These areas will be included in pre-remediation surveys, as well as in post-reclamation verification surveys (Section 4.0).

2.1 Technical Basis, Rationale and General Approach

As previously indicated, the stated objective for the radiological survey is to demonstrate that final radiological conditions at the Site will not impact human health and safety beyond conditions that existed prior to mining (MMD, 2012). General consistency with pre-mining baseline conditions is an achievable remedial goal that can be adequately demonstrated with radiological surveys. The primary remedial challenge is to achieve consistency with baseline conditions without creating unnecessary environmental degradation and/or new and unintended increases in risks to human health and safety.

Any radiological contamination due to mining operations at the Site will be limited to naturally occurring radioactive materials including uranium ore and proto-ore, or slightly mineralized non-economically mineralized mine development rock. In addition to uranium, these radioactive constituents can include variable amounts of natural thorium (Th-232) and potassium (K-40), all of which have associated gamma radiation emissions (primarily from decay series products).

As such, gamma surveys will be the primary method used to identify and characterize areas of contamination prior to any remediation that may be required to achieve consistency with baseline radiological conditions. The results of these gamma surveys will be compared against a baseline gamma survey map in corresponding areas (*see* Figure 10, Section 7.3) for evidence of contamination relative to pre-mining baseline conditions. Determination of "contamination" based on such comparisons requires consideration of uncertainty in gamma survey measurements. There are three basic sources of such uncertainty:

1. Instrument variability. This includes variations in response characteristics between different gamma detectors used for scanning, and temporal variability in the performance of individual detectors.

2. Natural temporal variability in gamma radiation at any given location. Radioactive decay is a random probabilistic process that follows a binomial distribution. As a result, gamma exposure rates at a given location will naturally vary somewhat from one second to the next. Across longer time scales, diurnal and seasonal fluctuations in the concentrations of gamma-emitting radon decay products in air near the ground surface can occur due to changes in air stability and/or changes in soil moisture, changes in soil moisture can affect shielding of terrestrial sources of gamma radiation, and changes in barometric pressure can affect atmospheric shielding of cosmic sources of radiation.

3. Spatial variability in terrestrial sources of gamma radiation (on both large and small spatial scales). Knowledge of the spatial variability in soil radionuclides and associated terrestrial gamma radiation

is primarily limited by the density of ground coverage attained by gamma surveys. Baseline gamma survey coverage at the Site was limited to about 2% of the land area within the permit area (RHR, 2011b). On smaller spatial scales, the accuracy of GPS readings is also limiting.

The most common way to help quantify the majority of combined data uncertainty due to instrument variability and natural temporal variability (items 1 and 2 above) is to perform data quality control (QC) measurements of ambient background radiation at a fixed onsite location every day throughout the duration of the gamma survey field work. During the course of baseline gamma surveys in 2010, daily instrument function checks were performed indoors at the Grants Field Office, including ambient background measurements at a consistent indoor location (Figure 1). The data in Figure 1 were reported in units of cpm (RHR, 2011b), but have been converted here into approximate units of exposure rate (μR/hr) based on the regression equation shown in Figure 7, Section 7.1. The amount of observed variability in Figure 1 is similar to that observed for static, fixed-location QC measurements at other sites having similar levels of ambient gamma radiation and general environmental characteristics[1].

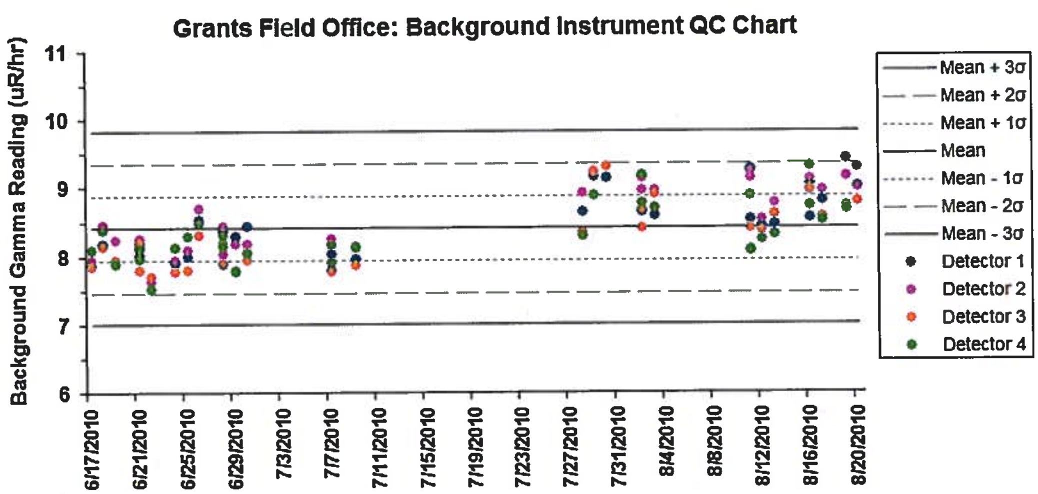

Figure 1: Variability in background QC measurements over time at the Grants Field Office for detectors used for gamma scanning at the Site (raw data extracted from RHR, 2011b, converted into units of approximate background exposure rate).

The data in Figure 1 provide a reasonable indication of the uncertainty likely to be present in the baseline gamma survey data set due to instrument variability, combined with natural fluctuations in background radiation, at any given location. The overall range of these measurements (approximately ± 2 μR/hr) suggests that any future measurements at the Site would need to exceed indicated baseline values in corresponding locations by more than 2 μR/hr in order to be considered evidence of potential contamination.

[1] This observation is based on numerous gamma surveys conducted by SENES personnel with the same type of instrument (Ludlum 44-10 detectors) at various sites in nearby western States (CO, UT, WY).

However, baseline scan data were obtained outdoors at the Site, were recorded while in motion, and the reproducibility of the exact location for each individual scan reading has some associated uncertainty. QC measurements repeated daily to test operational scan systems performance while actually scanning along a designated "field strip" (*see* Section 6.0) can demonstrate considerable additional variability due to small spatial differences in actual scan tracks, moving system performance, and temporal variations due to outdoor environmental factors[2] (Figure 2). The example field strip data in Figure 2 illustrate overall scan system variability in the field at a large site in Wyoming (approximately ± 6 µR/hr), which is about twice that which can be expected at the Roca Honda Site as average ambient background gamma radiation levels at the Roca Honda Site are about half that of the Wyoming site (numerical differences in readings between different detectors are generally proportional to the strength of the gamma field). Based on this observation, along with observations of scan system performance at other sites having relatively low levels of ambient background gamma radiation (e.g. less than 15 µR/hr), overall scan data uncertainty at a given location along any given scan transect at the Rocha Honda Site is expected to be about ± 3 µR/hr.

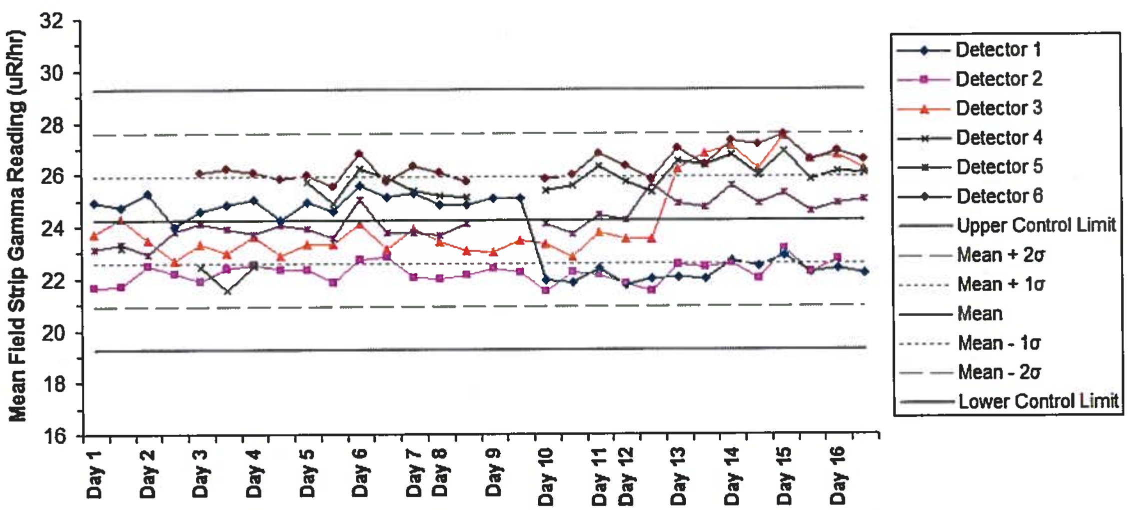

Figure 2: Example daily operational "field strip" scan system QC chart developed during the course of a large baseline gamma survey project in Wyoming. This particular example was chosen due to the unusually long duration of the project and greater amount of field strip data.

In addition to the above sources of data uncertainty, uncertainties associated with spatial variability in between scan transects must be also be considered. Because baseline gamma survey transects were spaced 50 meters apart, inferred (interpolated) baseline values in between these transects may not be accurate. Smaller-scale spatial variability in baseline values within these scan coverage gaps could potentially exceed interpolated estimates by more than 3 µR/hr, be mistakenly identified as

[2] On a diurnal basis, outdoor concentrations of gamma-emitting radon decay products in air are likely to be somewhat more variable versus indoor environments, particularly in the summer months, and outdoor temperature variations can slightly affect detector response.

contamination, and lead to cleanup of uncontaminated background soils. To help address spatial uncertainty when comparing future gamma measurements against baseline gamma survey data, a more generalized approach for evaluation of consistency with baseline will be used.

As previously indicated, a reasonable and achievable remedial objective is to excavate all clearly identifiable areas of contamination, yet to the greatest extent possible, avoid the potential to create unintended risks to human health and/or unwarranted environmental degradation by remediating low levels of contamination that may slightly exceed baseline readings at a given location, but do not exceed the degree of uncertainty associated with baseline gamma measurements at that location (the location itself will be somewhat uncertain as GPS data have some degree of associated error). Rather than attempting to draw conclusions about potential contamination based on individual measurements at any given location within the areas specified by MMD and NMED (MMD, 2012), recorded gamma surveys will be conducted across these areas and beyond[3] such that more generalized technical assessments can be performed using an approach that will help to minimize erroneous conclusions about contamination due to overall quantitative and spatial uncertainties in baseline gamma survey data.

Recorded gamma surveys will be conducted using modern technologies and methods that have become standard practice for characterization and remedial applications (e.g. Johnson et al., 2006; Meyer et al., 2005a and 2005b; Whicker et al., 2006 and 2008). This includes use of GPS-based gamma scanning systems with automated electronic data acquisition software and associated methods for data collection, mapping and interpretation. Scanning detectors will be mounted on all-terrain vehicles (ATVs) and/or backpacks at 3 feet above the ground surface (*see* Sections 2.2.3, 4.2.3 and 7.0).

The density of scan transects (Section 2.2.2) will be increased relative to that used for baseline gamma surveys to help reduce uncertainty related to spatial variability in between scan transects (the target scan transect width will be reduced to 20 meters, which at a 3-foot detector height, will increase the effective ground coverage to about 20%). The resulting data will be plotted in ArcGIS, and data interpolation by kriging will be performed (*see* Section 2.2.5) to produce a pre-remediation characterization map similar to the baseline gamma survey map (*see* Figure 10, Section 7.3). This will allow larger-scale spatial differences between pre-mining baseline conditions and pre-remediation conditions to be compared directly.

Interpolation by kriging tends to "smooth out" smaller-scale variability along scan transects and allows more effective interpretation of larger-scale spatial distributions of gamma radiation. Moreover, uncertainty in both baseline and post-mining gamma survey data due to unknown spatial variability between scan transects is somewhat "normalized" by kriging. Comparative use of kriged gamma survey maps to identify contamination will allow identification of contamination across any given area large

[3] A reasonable amount of margin (e.g. 50-100 meters) beyond these areas will also be scanned, with exact widths to be determined in the field based on potential for migration of contamination due to erosional transport mechanisms.

enough to be of potential radiological significance with respect to human health[4], yet will also minimize the potential to create new and unintended risks to human health and/or collateral environmental damage by avoiding unnecessary remediation. Larger-scale distributional differences between baseline and post-mining estimates of gamma exposure rates based on kriged scan data will be considered evidence of contamination if the numerical difference between corresponding averages across the area in question exceeds 3 μR/hr. This metric will be determined using spatial analysis tools in ArcGIS.

2.2 Method Specifications

Pre-remediation gamma surveys will consist of three basic elements: 1) gamma scans of areas potentially affected by mining operations, 2) instrument cross-calibration measurements for energy dependence corrections and related unit conversions to raw gamma scan data, 3) data mapping, interpolation with kriging, and spatial analysis. The technical details and relevant issues regarding these elements are described in the following sub-sections.

2.2.1 Gamma Survey Areas

Pre-remediation gamma scans will be performed across the footprint of the facility, areas around shafts and ore bays, beneath impoundments, the pipeline corridor, and the haulage routes within the permit area in accordance with MMD specifications (MMD, 2012). A reasonable amount of additional margin (e.g. 50-100 meters) will be scanned beyond these areas, with exact widths to be determined in the field based on potential for migration of contamination due to erosional transport mechanisms. For example, margins around open areas with potential for significant wind-blown migration of contamination will be wider (e.g. 100 meters) on the downwind sides of the area. Similarly, areas with potential for runoff-driven erosional transport will have wider scan margins on the hydrologically downgradient sides of the area.

2.2.2 Density of Gamma Scan Coverage

Sodium iodide (NaI) based detectors (with 2 × 2 inch NaI crystals) will be used for gamma scanning (*see* Section 2.2.3). All NaI detectors will be mounted on ATVs (for vehicle surveys) or backpacks (for walkover surveys) at approximately 3 feet above the ground surface during scanning. Based on previous observations and experience in the field, at this detector height, lateral NaI detector response to significantly elevated planar (non-point) gamma sources at the ground surface is estimated to be about 2 meters, giving each detector an estimated "field of view" of about 4 meters in diameter at the ground surface. This does not imply a system detector can register increased gamma readings from a small

[4] Areas smaller than the distance between gamma scan transects (e.g. < 50 meters in diameter) with exposure rates elevated by as little as 3 μR/hr above baseline will not realistically pose health risks beyond the existing range of baseline levels at the Site. Baseline variability across the Site is considerably greater than such small incremental changes. For comparison, a Federal gamma radiation cleanup standard for inactive uranium processing sites is 20 μR/hr above background levels (40 CFR 192, Part B). (*See Section 2.0 for additional relevant information*).

point source 2 meters away, but does indicate that scattered photons from larger, more radiologically significant, elevated source areas (e.g. 100 m^2) are likely to be detected at that distance.

The goal for ground scan coverage will be on the order of 20% for impact characterization surveys, meaning a distance between adjacent scan transects of about 20 meters. Practical considerations such as safety, terrain, and natural obstructions will dictate actual distances that can reasonably be maintained between adjacent scan transects. In terrain deemed unsafe for ATV scanning, efforts will be made to scan as closely as possible along the perimeters of such terrain, and/or walking surveys with a backpack mounted system will be performed. Scanning speeds will typically range between 1 and 5 mph depending on the roughness of the terrain and mode of scanning.

Scan data will be downloaded daily into a project database and plotted on preliminary maps to assess adequacy of scan coverage and screen the data for evidence of elevated gamma exposure rates. Wherever possible, areas identified to have notably higher levels of terrestrial gamma radiation will be re-scanned at higher density scan coverage (e.g. 5-10 meter transects) in order to better define the spatial distribution and horizontal extent of the elevated readings.

2.2.3 Scanning Protocols, Instrumentation and System Specifications

All NaI detectors will be mounted on ATVs (for vehicle scanning) or backpacks (for walkover scanning) at approximately 3 feet above the ground surface during scanning (*see* Section 4.2.3 for additional details, and Section 7.0 regarding the technical basis for these specifications). For ATV-mounted systems, detectors will be mounted as far as practicable away from the vehicle (e.g. 2-3 feet) to minimize any shielding effects from the ATV (potential for shielding effects is negligible for backpack scanning). The GPS receivers will be mounted with a clear view of the sky during scanning. Each scanning system will be coupled to a field computer with appropriate data acquisition software. The mounting system configuration may be modified to suit site conditions, but detector height will be maintained as specified and the functionality of the basic system will not change.

All detectors used for gamma surveys will be properly calibrated within a year prior to use in the field, and daily quality control (QC) measurements will be performed to document proper instrument function, temporal variability, variability between instruments, and to provide quantitative information on data precision and uncertainty (*see* Section 6.0). Base maps showing specified scan areas (Section 2.2.1) and relevant Site features should be loaded on field computers with GPS-based tracking software to help guide the scanning and ensure coverage across all intended survey areas. This will also help to minimize trajectory overlap and ensure adequate scan density coverage.

Ludlum Model 44-10 NaI detectors will be used for all gamma scanning. This instrument is the most commonly used NaI detector for large-area gamma surveys. The Ludlum 44-10 is a separate probe comprised of a 2"x2" NaI crystal and photomultiplier tube. This probe has proven to be a reliable and durable field instrument over many decades and has long been considered an industry standard. Each 44-10 detector will be paired with either a Ludlum Model 2350 rate meter, or a Model 2221 scaler/rate meter, equipped with RS232 data output capability. Each detector/rate meter system will be programmed to integrate gamma counts every one second and provide corresponding readings in units of µR/hr or cpm as data output through a RS232 serial port. Each detector/rate meter pairing will have been properly calibrated against a Cs-137 source within one year prior to use for the survey (digital copies of calibration certificates will be kept on file in the project records).

Each scanning system will utilize a WAAS enabled GPS receiver to provide GPS readings (latitude, longitude) every one second to pair with each individual gamma reading. Data acquisition will involve appropriate software installed on a portable field computer or on an appropriate alternate type of data logging device. Scan data will be downloaded daily into a project database and plotted on maps to assess adequacy of scan coverage on a daily basis and to help identify any problems that may have occurred with data acquisition.

2.2.4 Instrument Cross-Calibration Measurements

Gamma exposure rates measured by Ludlum 44-10 NaI detectors are only relative measurements as response characteristics of NaI detectors are energy dependent (Figure 3). True gamma exposure rates are best measured with a less energy dependent system that exhibits relatively "flat" response characteristics across the energy range of primary interest such as a Micro-Rem Meter or RadEye PRD from Thermo Scientific. For terrestrial radiation at uranium recovery sites, this range of interest is generally below the photon emission energy of Cs-137 [662 kilo-electron volts (keV)]. Cesium-137 is the most commonly used source for instrument calibrations. The majority of terrestrial gamma radiation at uranium recovery sites is comprised of scattered photons with kinetic energies well below 662 keV and as a result, Ludlum 44-10 NaI detectors will generally overestimate true gamma exposure rates (Figure 3).

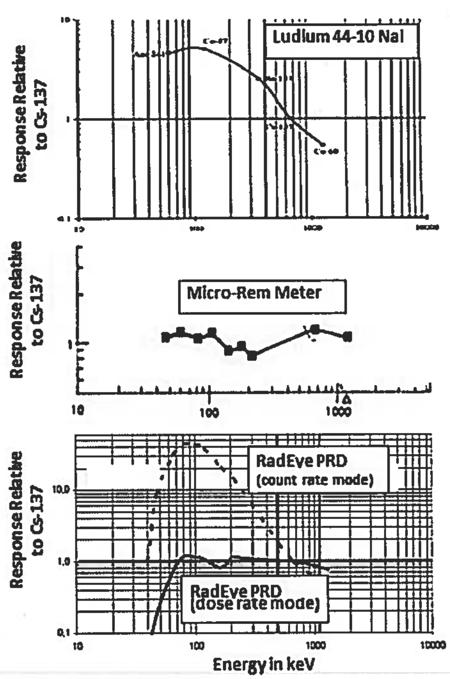

Figure 3: Energy response curves for Ludlum 44-10 NaI detector, a Micro-Rem meter, and a RadEye PRD (both count rate mode and energy-compensated dose rate mode).

NaI systems are useful for uranium recovery sites because they can quickly and effectively demonstrate relative differences in the spatial distribution of terrestrial gamma radiation before, during and after operational phases of the project. However, unless the same equipment and scanning geometry is used for all of these surveys, which can occur over project life spans on the order of decades, it is necessary to normalize the data to a common basis of comparison. This is the primary purpose of performing cross-calibration measurements, though as indicated in Sections 7.1 and 7.2.2, conversion of any data that are provided only in units of cpm into more generally useful units of exposure rate (µR/hr) is also important.

Cross-calibration ensures that the results of future gamma scans, which may use different NaI detectors, and perhaps different detector heights, detector models, or measurement technologies, can be meaningfully compared against the results of pre-operational baseline gamma surveys. When mining operations at the Site are completed years into the future, cross-calibration measurements will be necessary.

Either of two alternative instruments can be used for cross-calibrations at the Roca Honda Site as part of the post-mining impact characterization gamma survey. As indicated above, one is a Micro-Rem Meter (a "tissue equivalent" plastic scintillometer from Thermo Scientific), and the other is a RadEye PRD, a specialized NaI detector from Thermo Scientific that has energy compensated response characteristics when used in "dose rate mode". A comparison of energy response characteristics for the Ludlum 44-10 NaI detector, the Micro-Rem meter, and the RadEye PRD is provided in Figure 3.

For each cross-calibration instrument (Ludlum 44-10, Micro-Rem Meter and/or RadEye PRD), static measurements will be taken at 10-15 discrete locations covering a range of exposure rates representative of the site. These locations will be determined based on current and/or pre-mining baseline maps of gamma exposure rates across the Site. At each cross-calibration measurement location, 10-20 individual readings from each cross-calibration instrument will be recorded and averaged. Measurement geometry for collection of cross-calibration data will be 3 feet above the ground surface. Regression analyses will be performed on resulting values to determine statistical relationships between NaI detectors and Micro-Rem/RadEye-PRD[5] instruments. The resulting cross-calibration equations will be used to convert raw scan data (e.g. in units of cpm) into energy corrected units of dose rate (μrem/hr) or exposure rate (μR/hr). Though technically slightly different, for practical purposes the latter two units of measure are commonly considered essentially equivalent. Modified scan data resulting from these energy dependence corrections will be mapped and kriged to represent official gamma survey results for comparisons against similarly normalized and kriged baseline gamma survey maps.

2.2.5 Spatial Analysis of Gamma Survey Data

Once all individual gamma survey data have been collected, uploaded into the project database, and converted into energy-corrected units of μR/hr, they will be plotted in ArcGIS. Appropriate color-coded increments of exposure rate will be applied to allow visual interpretation and spatial analysis. The data will be reviewed initially to insure there are no "bad" data points that can on rare occasion result from small electrical surges or interruptions, for example due to unusually jarring vibrations during scanning, or upon initial start-up of data recording. Clear outliers will be discarded from the scan database.

[5] In addition to general low-energy dependence compensation, the RadEye PRD includes an energy discrimination algorithm to ignore the contribution of high-energy photons (> about 1.3 MeV, e.g., from cosmic sources of radiation) to the gamma field in order to measure only the exposure rate attributable to low-energy terrestrial sources of gamma radiation. As a result, two adjustments must be made to all RadEye measurement values that will be used for instrument cross calibration purposes. Technical details and formulas for these adjustments are provided in Appendix A.

Finalized gamma scan data will be mapped as individual discrete measurement points using a high quality base maps and/or aerial photos as base layers. In addition, the finalized gamma scan data will be interpolated by kriging to produce continuous estimates of gamma exposure rates across all scanned areas (consistent with the format shown in Figure 10, Section 7.3). Robust kriging software such as that included in the Spatial Analyst utility in ArcGIS will be used. Kriging is a geo-statistical interpolation procedure that fits a mathematical function to a specified number of nearest points within a defined radius to determine an output value for each location. A given "location" is represented by a cell of specified areal dimensions that may or may not include any measured data points. Values closer to the cell are given more weight than values further away and distances, directions, and overall variability in the data set are all considered in the predictive semivariogram model. Input parameters used for this application should be consistent with those used for the baseline survey data (*see* Figure 10, Section 7.3):

Cell size:	10 feet × 10 feet
Maximum search radius:	300 feet
Semivariogram model:	Exponential
Number of nearest data points:	10

As previously indicated, kriged maps of baseline gamma exposure rates will be compared against post-mining exposure rates to identify any significant areas of radiological contamination. To help illustrate the utility and visual effectiveness of such comparisons, example kriged gamma survey data from a site cleanup in Colorado are shown in Figure 4. In this example, the data on the left show gamma exposure rates and corresponding gamma-based estimates of soil Ra-226 concentrations prior to remediation, while the data on the right show interim changes for these radiological parameters in corresponding areas part way through the cleanup progress.

Detailed quantitative/spatial differences in radiological parameters due to cleanup progress are clearly apparent in Figure 4, even on relatively small spatial scales (e.g. to within about 10 meters in this particular example). This same approach to spatial analysis will be used not only to identify any contamination resulting from mining operations at the Roca Honda Site, but to also demonstrate consistency with baseline conditions after reclamation is complete (Section 4.0).

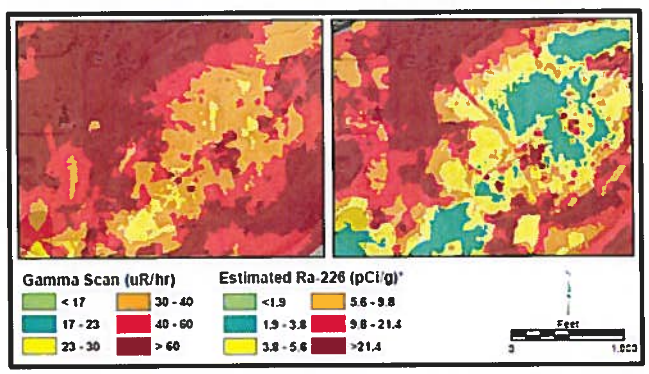

Figure 4: Example quantitative/spatial comparisons between kriged gamma survey data for a radiologically impacted site in Colorado. Left: pre-remediation gamma exposure rates and gamma-based estimates of soil Ra-226 concentrations* (e.g. *see* correlations, Sections 2.1 and 2.2.2). Right: corresponding interim radiological parameters part way through the cleanup.

Once a kriged map of pre-remediation gamma survey data is available for comparative spatial analysis against the kriged map of baseline gamma survey data (*see* Section 7.3, Figure 10), any areas of significant size, for example with horizontal dimensions greater than the range of gamma scan transect spacing (e.g. > 50 meters), that have differences in average kriged gamma data greater than about 3 µR/hr will be delineated on maps for remedial action. The averaging used to determine such contaminated areas will be performed using spatial analysis tools and techniques in ArcGIS, and for each individual delineated area, the sum of the average baseline gamma exposure rate, plus an added value of 3 µR/hr to account for data uncertainty, will be annotated on the pre-remediation map to serve as a remedial goal for use during remedial support surveys (Section 3.0)[6].

These spatial assessments will require some professional judgement, for example in the event that the data suggest only slight potential contamination in relatively small areas that are well removed from primary areas of contamination, and where considerations of environmental and ecological degradation must be weighed against potential remediation that would not realistically result in corresponding reductions in human health risks, and could actually increase such risks unintentionally. Costs associated with the pre remediation survey are provided in Section 5.0.

3.0 REMEDIAL SUPPORT MEASUREMENTS

Gamma measurements for remedial support purposes will involve unrecorded interim measurements to semi-quantitatively guide the horizontal/vertical extent of excavations necessary to achieve consistency with baseline conditions. As indicated in the previous section, a map showing areas of delineated contamination (> 3 µR/hr above average baseline in each delineated area) will be annotated such that each delineated area will show an area-specific numeric value that is equivalent to the sum of its respective average baseline value, plus an additional 3 µR/hr to account for data uncertainty. This annotated value will be used as an area-specific remedial goal for guiding excavations within the area in question based on the real-time gamma measurements being used to assess corresponding reductions in gamma radiation.

Because all official gamma survey krig maps will be based on energy-corrected scan values, it will be necessary to utilize the same instrument used to correct raw scan data based on instrument cross-calibration measurements. In other words, if a RadEye PRD instrument, reading out in energy compensated dose rate mode (Figure 3), is used for instrument cross-calibrations (Section 2.2.4), then a properly calibrated RadEye PRD instrument should be used for real-time field assessment of remedial reductions in gamma radiation relative to the remedial goal in each area delineated for remedial action. Once remedial excavations appear to have achieved compliance with the remedial action goal based on these measurements, excavations within the area in question will be terminated pending an official inspection by the project health physicist as described below. Soils removed from each radiologically

[6] If a RadEye PRD is used for remedial support measurements, the adjustments indicated in Appendix A should not be reflected in the remedial goal values annotated on this map. This will allow direct comparison of raw RadEye PRD readings against the remedial goal value without having to add estimated contributions from high-energy photons associated with K-40 and cosmic sources of radiation (see Appendix A).

contaminated area will be properly disposed of in accordance with the Roca Honda Mine Reclamation Plan (RHR, 2011a).

Guiding excavations based on remedial support gamma measurements is not a technically complicated activity, and can be performed by a properly trained environmental technician or remediation worker. However, a qualified and experienced environmental health physicist will oversee the project remotely, will be updated periodically throughout the cleanup regarding progress, and will provide technical advising should unusual circumstances or issues arise. Once excavations across all areas delineated for remedial action are believed to be complete based on remedial support gamma measurements, the overseeing health physicist will conduct a Site visit to perform independent measurements and develop a professional opinion as to whether post-reclamation radiological verification surveys (Section 4.0) are likely to quantitatively and spatially demonstrate consistency with baseline radiological conditions. If not, additional excavations will be performed until the project health physicist is confident that this remedial objective has been achieved. Costs for remedial support measurements are provided in Section 5.0.

4.0 POST-RECLAMATION VERIFICATION SURVEY

This section describes the radiological surveys that will be used to verify that after reclamation, radiological conditions across the site are consistent with pre-existing baseline conditions. Many of the technical bases, analytical approaches, methods and criteria described in detail for pre-remediation radiological surveys (Section 2.0) are applicable to post-reclamation verification surveys and are thus generally summarized or referenced rather than repeated in detail. Special considerations, differences or additions are discussed in this section, as is a plan for limited direct soil sampling for additional verification. Cost estimates are provided in Section 5.0.

4.1 Technical Basis, Rationale and General Approach

As previously indicated, the stated objective for post-reclamation radiological surveys is to demonstrate that final radiological conditions at the Site will not impact human health and safety beyond conditions that existed prior to mining (MMD, 2012). For the technical reasons detailed in Section 2.0, the general criterion against which post-reclamation survey data will be evaluated is "consistency with baseline conditions". This does not imply that every atom of radiological contamination generated by mining must have been identified and removed from the Site, but does require that any residuals due to mining are too low-level to be clearly distinguishable from baseline levels and/or are too small in areal extent to be of significance with respect to potential for human exposures and related impacts (*see* Section 2.1).

All of the radionuclides that could potentially be generated by mining at the Site occur naturally in all rocks and soils. Any residual radiological contamination that may remain after reclamation will have associated gamma radiation emissions (primarily from radioactive decay series products). As a result, gamma surveys will be the primary method used to verify that post-reclamation radiological conditions are consistent with pre-mining baseline conditions. Verification of this outcome will require evidence that residual sources of gamma radiation due to mining are not present at average levels that exceed average baseline conditions in a given area by more than the estimated amount of uncertainty inherent in gamma survey measurement data. The advantage of gamma surveys is that gamma emissions from soil radionuclides are easily detected in-situ in the field and thus, a much higher density of measurements is possible. Gamma scanning produces spatially comprehensive and reliable characterization with respect to evaluations of potential contamination from mining activities and/or consistency with baseline conditions.

The amount of uncertainty in baseline gamma scan data at any given measurement location is estimated to be about ± 3 μR/hr (Section 2.1). A similar amount of individual measurement uncertainty can be expected in post-reclamation verification gamma survey data. In addition, there is uncertainty associated with actual spatial variability in soil radionuclides and associated gamma radiation that exists between gamma scan transects. To help mitigate spatial sources of uncertainty, larger-scale distributional differences (e.g. differences across areas larger than 50 meters in diameter) between baseline and post-reclamation estimates of gamma exposure rates will be evaluated based on respective maps of kriged gamma scan data (*see* Section 2.2.5). In addition, the density of scan transects for post-reclamation gamma verification surveys (Section 4.2.2) will be increased relative to that used for baseline gamma surveys (increasing the effective ground coverage to about 20%) in order to better characterize small-scale spatial variability which can potentially be somewhat greater relative to baseline conditions once a contaminated area has been remediated.

Based on comparative spatial analysis between kriged baseline and post-reclamation gamma scan data, any areas of significant size, for example with horizontal dimensions greater than the range of gamma scan transect spacing (e.g. > 50 meters), where the average of post-reclamation krig data exceeds the corresponding average of baseline krig data by more than about 3 μR/hr will be considered inconsistent with (i.e. elevated relative to) baseline radiological conditions. In this circumstance, further remedial action may be required depending on the size of the area, the degree of exceedance, and whether a realistic potential exists for human health impacts beyond what can already be attributed to baseline radiological conditions across the Site[7]. Otherwise, the area in question will be considered consistent with corresponding radiological baseline conditions. This qualitative and quantitative spatial analysis process will be performed by a qualified environmental health physicist and professional GIS analyst using accepted health physics principles along with spatial analysis tools and techniques in ArcGIS.

In addition to comparisons of gamma exposure rates between baseline gamma surveys and post-reclamation gamma surveys, raw gamma scan data from both surveys will be converted into estimates of radionuclide concentrations in surface soils (e.g. Ra-226, U-nat) based on the results of the supplemental baseline gamma/soil radionuclide correlation study detailed in Section 7.2.2 (provided that any such correlations are shown to be statistically significant). In addition, a limited amount of direct soil sampling will be conducted in all areas potentially affected by mining operations for

[7] Baseline gamma exposure rates across the Site generally range from 6-14 μR/hr (*see* Figure 10), meaning that natural variability within the permit area is significantly greater than ± 3 μR/hr.

post-reclamation radiological verification surveys (Section 4.2.4), with samples to be analyzed at a qualified commercial laboratory. Results will be used for general Site-wide comparisons with direct soil sampling results from the supplemental gamma/soil radionuclide study (Section 7.2.2), with soil sampling results provided in the Radiological Baseline Report (RHR, 2011b), and with any gamma-based estimates of baseline radionuclide concentrations in surface soils generated as a result of the supplemental gamma/soil radionuclide study (Section 7.2.2).

All post-reclamation radiological verification survey results, including data, maps, evaluations and conclusions will be provided in a detailed technical report (Section 4.2.5).

4.2 Methods and Specifications

Post-reclamation radiological verification surveys will consist of three basic elements: 1) gamma scans of all areas potentially affected by mining operations (Section 4.2.1) which at minimum, will mimic the areas scanned for the pre-remediation surveys (Section 2.2.1); 2) limited soil sampling and laboratory analysis (Section 4.2.4); 3) data mapping, interpolation of gamma survey data by kriging, data analysis and reporting (Section 4.2.5).[8] The technical details and are described in the following sub-sections.

4.2.1 Gamma Survey Areas

Post-reclamation gamma verification scans will be performed across the footprint of the facility, areas around shafts and ore bays, beneath impoundments, the pipeline corridor, and the haulage routes within the permit area. As with pre-remediation gamma scans, a reasonable amount of additional margin (e.g. 50-100 meters) will be scanned beyond these areas (*see* Section 2.2.1). Depending on additional information and Site knowledge that may be acquired during the pre-remediation survey and remedial support measurement activities, additional areas may need to be scanned to ensure that the final post-reclamation radiological status of the Site can be verified as being consistent with baseline radiological conditions on a Site-wide scale (and beyond the permit area as applicable).

4.2.2 Density of Gamma Scan Coverage

As with pre-remediation surveys, the goal for ground scan coverage will be on the order of 20% for post-reclamation gamma verification surveys, meaning a distance between adjacent scan transects of about 20 meters. Considerations and limitations regarding scan coverage are discussed in Section 2.2.2. If

[8] Instrument cross-calibration measurements are not listed here as it is assumed that the amount of time elapsed between pre-remediation surveys (Section 2.0), remedial support activities (Section 3.0), and initiation of post-reclamation verification surveys (Section 4.0) will be relatively short (e.g. 1-2 years) and that the same gamma measurement instruments and scanning systems will be available for use during all of these radiological survey activities. If so, instrument cross-calibration measurements performed for pre-remediation surveys (Section 2.2.4) need not be repeated for verification gamma surveys, provided that the instruments are in current calibration during field use. If not, new cross-calibration measurements will be necessary for post-remediation gamma verification surveys (following the methods detailed in Section 2.2.4) to ensure proper data normalization for comparisons against baseline gamma survey data (Section 7.2.2).

additional area scans are performed, scan coverage may be increased to 50-meter scan transects. Modes of scanning will include ATV and/or backpack based systems (Section 4.2.3). Scan data will be downloaded daily into a project database and plotted on preliminary maps to assess adequacy of scan coverage.

4.2.3 Scanning Protocols, Instrumentation and System Specifications

As indicated in Section 2.2.3, all NaI detectors will be mounted on ATVs (for vehicle scanning) or backpacks (for walkover scanning) at approximately 3 feet above the ground surface during scanning (*see* Section 7.0 regarding the technical basis for these specifications). Example detector mounting configurations are shown in Figure 5. The specifications for scan data acquisition indicated in Section 2.2.3 are applicable to post-remediation gamma verification surveys and will be observed accordingly. All detectors used for gamma surveys will be properly calibrated within a year prior to use in the field, and daily quality control (QC) measurements will be performed to document proper instrument function, temporal and instrument variability, and to provide quantitative information on data uncertainty (*see* Section 6.0). As with pre-remediation surveys, base map shape files of specified scan areas (Section 4.2.1) and relevant Site features should be loaded on field computers with GPS-based tracking software to help guide the scanning and ensure coverage across all intended survey areas. Scanning speeds will range between 1 and 5 mph depending on the terrain and mode of scanning.

As previously indicated, Ludlum Model 44-10 NaI detectors will be used for all gamma scanning activities. Each 44-10 detector will be paired with either a Ludlum Model 2350 rate meter, or a Model 2221 scaler/rate meter, equipped with RS232 data output capability. Each detector/rate meter system will be programmed to integrate gamma counts every one second and provide corresponding readings in units of μR/hr or cpm as data output through a RS232 serial port. Each detector/rate meter pairing will have been properly calibrated against a Cs-137 source within one year prior to use for the survey (digital copies of calibration certificates will be kept on file in the project records).

Figure 5: Example detector mounting configurations for backpack and ATV gamma scanning systems.

Each scanning system will utilize a WAAS enabled GPS receiver to provide GPS readings (latitude, longitude) every one second to pair with each individual gamma reading. GPS receivers will be mounted above each detector with a clear view of the sky. Data acquisition will involve appropriate software installed on a portable field computer or on an appropriate alternate type of data logging device. Scan data will be downloaded at the end of each day of survey field work into a project database and plotted on maps to assess adequacy of scan coverage on a daily basis and to help identify any problems that may have occurred with data acquisition.

4.2.4 Soil Sampling

One or more composite samples of surface soils will be collected to a depth of 15 cm in each area specified by the MMD for post-reclamation radiological verification surveys (MMD, 2012). This includes the footprint of the facility, areas around shafts and ore bays, beneath impoundments, the pipeline corridor, and haulage routes within the permit area. At each location, soil sampling and compositing will be conducted in accordance with the protocols indicated in Section 7.2.2 for the supplementary baseline gamma/soil radionuclide correlation study. All soil samples will be analyzed for U-nat, Ra-226, Th-232 and K-40 in accordance with the protocols indicated in Section 7.2.2.

4.2.5 Data Analysis, Presentation and Reporting

Once all individual gamma survey data have been collected, uploaded into the project database, and converted into energy-corrected units of µR/hr, they will be plotted in ArcGIS. Appropriate color-coded increments of exposure rate will be applied to allow visual interpretation and spatial analysis. The data will be reviewed for quality control and any clearly identified outliers will be discarded from the scan database. Mapping and kriging will be performed in the same manner described for pre-remediation surveys (Section 2.2.5).

Kriged maps of post-reclamation gamma survey data will be compared against baseline gamma survey data to identify any significant spatial/quantitative differences. Any areas of significant size (e.g. greater than the 20-50 meter spacing for scan transects), and where the average of post-reclamation krig data exceeds the average baseline krig data by more than about 3 µR/hr, will be considered inconsistent with baseline radiological conditions (i.e. "elevated") and additional remediation may be necessary. Otherwise, the area in question will be considered to be confirmed as consistent with pre-mining radiological baseline conditions. This qualitative and quantitative spatial analysis process will be performed by a qualified environmental health physicist and professional GIS analyst using accepted health physics principles along with standard spatial analysis tools and techniques in ArcGIS.

Raw gamma scan data from both baseline and post-reclamation gamma surveys will be converted into estimates of radionuclide concentrations in surface soils based on the results of the supplemental baseline gamma/soil radionuclide correlation study as detailed in Section 7.2.2 (provided that any such correlations are shown to be statistically significant). In addition, a limited amount of direct soil sampling will be collected in all areas specified by the MMD for post-reclamation radiological verification surveys (Section 4.2.4) and analyzed at a qualified commercial laboratory. Results will be used for general Site-wide comparisons with direct soil sampling results from the supplemental baseline gamma/soil radionuclide study (Section 7.2.2), with soil sampling results provided in the Radiological Baseline Report (RHR, 2011b), and with any gamma-based estimates of baseline radionuclide concentrations in surface soils generated as a result of the supplemental gamma/soil radionuclide study (Section 7.2.2). All post-reclamation radiological verification survey results, including data, maps, evaluations and conclusions will be provided in a detailed technical report.

5.0 ESTIMATED COSTS

Estimated costs for the pre-remediation gamma survey (Section 2.0), remedial support gamma measurements (Section 3.0), and the post-reclamation verification survey (Section 4.0), are provided in the following tables.

Cost estimate for Pre-Remediation Gamma Survey:

Task / Cost Category	Cost Item	Quantity	Unit[1]	Cost[2]	Task Cost
Gamma Surveys & Associated Measurements					
Environmental Health Physicist	Rad Survey Lead[3]	6	DY	$6,000	
Field Technician	Rad Tech[3]	6	DY	$4,320	
Gamma Survey Systems (ATVs, detectors, etc.)	Scan equipment[3]	6	DY	$2,790	
Transportation	Truck useage, fuel[3]	6	DY	$585	
Lodging & Per Diem	Lodging & per diem	12	Staff-DY	$2,040	
Miscellaneous (field supplies, etc.)	Field supplies	6	DY	$120	$15,855
Data Analysis					
Data Analysis to Delineate Contamination	Rad Survey Lead	15	Hr	$1,875	
Mapping	GIS Analyst	15	Hr	$1,500	$3,375
				Total[2] =	**$19,230**

Assumptions

[1]DY = 8-hour workday

[1]Staff-DY = Combined daily lodging and per diem for field staff for duration of field work

[2]Based on current (2013) dollar amounts

[3]Technical resources based out of Albuquerque, NM

Cost estimate for Remedial Support Gamma Measurements:

Task / Cost Category	Cost Item	Quantity	Unit[1]	Cost[2]	Task Cost
Gamma Surveys & Associated Measurements					
Environmental Health Physicist	Technical Oversight	4	DY	$4,000	
Field Measurement Personnel[3]	Reclamation Worker	30	DY	$4,800	
Gamma Measurement Instrument[4]	Instrument Rental	90	DY	$1,350	
Transportation[5]	Truck useage, fuel	2	DY	$345	
Lodging & Per Diem[5]	Lodging & per diem	2	DY	$340	$10,835
				Total[2] =	**$10,835**

Assumptions

[1]DY = 8-hour workday

[2]Based on current (2013) dollar amounts

[3]Cleanup takes three months, cleanup worker spends 1/3 of each day taking measurements to help guide excavations

[4]Rental of RadEye PRD or Micro-Rem Meter for duration of cleanup

[5]Travel/lodging expenses for reclamation worker covered under general Reclamation Plan, technical oversight based out of Albuquerque, NM

Cost estimate for Post-Reclamation Radiological Verification Surveys:

Task / Cost Category	Cost Item	Quantity	Unit[1]	Cost[2]	Task Cost
Radiological Surveys & Associated Measurements/Sampling					
Environmental Health Physicist	Rad Survey Lead[3]	7	DY	$7,000	
Field Technician	Rad Tech[3]	7	DY	$5,040	
Gamma Survey Systems (ATVs, detectors, etc.)	Scan equipment[3]	7	DY	$3,255	
Transportation	Truck useage, fuel[3]	7	DY	$645	
Lodging & Per Diem	Lodging & per diem	14	Staff-DY	$2,380	
Miscellaneous (field supplies, etc.)	Field supplies	7	DY	$140	$18,460
Outside Services					
Soil Sample Radionuclide Analysis	Laboratory Analysis	15	Samples	$3,300	$3,300
Data Analysis and Reporting					
Data Analysis, Verification Reporting	Rad Survey Lead	50	Hr	$6,250	
Mapping	GIS Analyst	20	Hr	$2,000	$8,250
				Total[2] =	**$30,010**

Assumptions

[1]DY = 8-hour workday

[1]Staff-DY = Combined daily lodging and per diem for field staff for duration of field work

[2]Based on current (2013) dollar amounts

[3]Technical resources based out of Albuquerque, NM

6.0 DATA QUALITY ASSURANCE / QUALITY CONTROL

All gamma surveys, supporting radiological measurements and soil sampling will include a data QA/QC program to provide confidence in the results and ensure that the data generated are reliable, with a minimal amount of uncertainty introduced by variability in instruments and field survey methods. The program is designed to help quantify data uncertainty due to these sources of variability as well as those associated with natural environmental factors (e.g. changes in soil moisture, barometric pressure, etc.). In general, quality assurance (QA) includes qualitative factors that provide confidence in the results, while quality control (QC) includes quantitative evidence that enables estimation of data uncertainty (accuracy and precision).

Data QA protocols/factors include the following:

- Documentation of field activities and any relevant observations regarding environmental or equipment related conditions that could affect survey data.
- Daily review of scan data for general consistency with scan data from other systems and/or adjacent scan tracks.
- The radiological survey designs contained in this plan were developed by qualified environmental health physics professionals with highly specialized experience and expertise in radiological surveys and spatial analysis techniques for uranium recovery site applications.
- Implementation of radiological surveys and data assessments will be conducted by qualified professionals with specialized experience and expertise with these types of surveys based on

education/experience in environmental health physics, preferably with specific experience regarding uranium recovery site applications.

- Technical information regarding the methods used, including supporting references to relevant regulatory guidance, scientific research journal articles or other peer-reviewed technical literature are provided in this document.

Data QC protocols/factors will include the following:

- Technical information on survey instrument calibrations to help quantify accuracy.
- Routine QC measurements will be performed in the field to ensure proper instrument performance and to quantify data precision/reproducibility.

6.1 Quality Control Protocols for Gamma Survey Data

All recorded gamma surveys and interim supporting gamma measurements at the Site will include instrument QC measurements performed at a designated location for each NaI detector that may be used. Preferably this location will be onsite and outdoors, but regardless must always be at the precise same location and positioned in the exact same measurement geometry each day. The purpose is to quantify the consistency of readings between detectors before, during and after the project at a precisely controlled location. Prior to initiation of field work, the mean of 10-20 individual readings of ambient background radiation, as well as radiation from a gamma check-source (e.g. a Cs-137 button source), will be recorded for each detector at the same location and under identical counting geometries. Under these circumstances, all data from any given set of properly calibrated and correctly functioning NaI scanning detectors should approximate a normal (Gaussian) distribution (Figure 6).

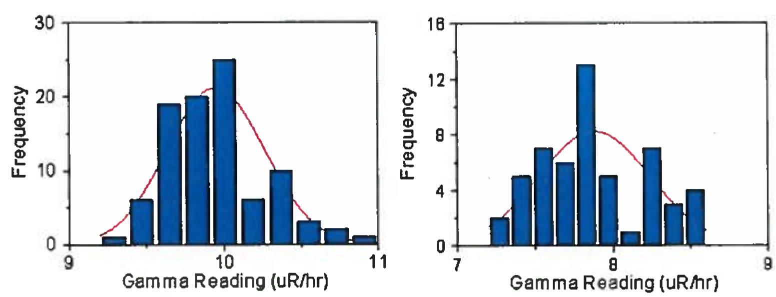

Figure 6: Example frequency histograms for several series of QC measurements from different NaI detector sets used for two separate gamma survey projects. The red lines represent theoretical normal distributions.

This information will be used to construct instrument control charts (*see* Figure 1, Section 2.1), the limits of which will be periodically updated throughout the duration of the field work as appropriate based on cumulative data from all daily QC measurements. This protocol will help account for natural temporal variability in ambient gamma radiation due to fluctuations in atmospheric or other conditions (e.g. changes in barometric pressure, soil moisture, radon decay products, etc.). For normally distributed data, over 99% of measurements are expected to fall within ± 3 standard deviations from the mean. Any instrument with a QC measurement result falling outside ± 3 standard deviations from the mean of all previous QC measurements warrants investigation. If a detector exceeds control limits on both background and check-source control charts, it will be replaced with a factory-calibrated spare detector and sent back to the manufacturer for repair and recalibration. An example of an instrument "background" QC chart for NaI detector readings is shown in Figure 1 (Section 2.1).

In addition to daily static QC measurements for any gamma instrument to be used in the field, an additional form of daily data QC protocols will be specifically employed for all recorded gamma surveys (i.e. for both post-mining impact characterization surveys, and post-reclamation gamma verification surveys). The actual operational field performance of each scanning system to be used will be tested onsite each day by obtaining average scan readings along a designated "field strip" (see Figure 2, Section 2.1 for an example of a field strip QC chart). The field strip will be in the range of 20-40 meters in length, and ideally will be located in an area that has relatively uniform gamma readings on all sides. Field strip scans will be conducted before and after each day's scanning activities in order to evaluate overall system performance and to provide quantitative information regarding the combined amount of data uncertainty attributable to variations in instrument readings (detectors/scanning systems), temporal variations in ambient gamma radiation in the field due to changes in atmospheric or other environmental conditions (e.g. barometric pressure, soil moisture, etc.), and small differences in detector locations and geometry when attempting to replicate measurements along a given scan track. Field strip data for each scanning system must remain within acceptable QC limits throughout the project. In cases where a scan system develops suspect performance during the day's scanning (e.g. later identified by an unacceptable evening field strip result), the subject data file(s) will be eliminated from the project data base and the system (or detector) in question will be not be used again until repaired or replaced with properly performing spare equipment (also subject to routine field strip QC measurements).

6.2 Data QA/QC for Soil Sampling

A consistent methodology as described in Section 7.2.2 will be followed for all composite soil sampling. At each composite sampling location, the amount of soil collected at each sub-sampling location within the sampling plot will be as equal as possible. Location ID numbers, date, and GPS coordinates for each sampling location will be recorded in the field log book, along with notes of any observations that could potentially affect the data. After samples have been collected, they will be maintained under proper chain-of-custody (COC) protocols. Field sampling personnel will complete a COC form for each shipping container of soil samples to be delivered to the laboratory for analysis. COC/analytical request forms will be provided by the laboratory.

On the COC/analytical request form, the laboratory will be specifically advised as to the crucial importance of thorough homogenization of each soil sample in accordance with the lab's standard sample preparation protocols. For samples analyzed for Ra-226 by HPGe gamma spectroscopy, aliquots of homogenized samples will be weighed and placed into counting tins, then sealed for a minimum of 21 days prior to counting to allow ingrowth of short-lived Ra-226 progeny and approximate equilibrium conditions to become established. Separate aliquots of the homogenized samples will be used for analyses requiring wet radiochemical methods.

The contract laboratory will have fully qualified radiochemistry capabilities that include appropriate accreditations (e.g. NLAP, EPA, etc.). Each batch of laboratory analyses will include QC measurements (e.g. sample spikes, method blanks, duplicate analyses, etc.) and QC results will be provided with each data report to provide indications of measurement accuracy. The laboratory will use NIST certified standards for instrument calibrations, and for gamma spectroscopy, will utilize NIST or EPA certified soil Ra-226 reference material standards for such calibrations. Laboratory QC data will be reviewed for data quality verification purposes.

The analytical results for Ra-226 concentrations in surface soil samples will be compared against the gamma survey map, as well as a map of estimated Ra-226 concentrations in surface soils across the Site based on gamma/soil radionuclide correlations. Any unusual or dramatic spatial/quantitative discrepancies will be investigated to determine if the subject data can be considered valid results.

7.0 RADIOLOGICAL BASELINE DATA REVIEW AND SUPPLEMENTAL SURVEYS

7.1 Review of Existing Radiological Baseline Data

The radiological baseline data collected by DeNuke in connection with the proposed Roca Honda Mine Site are technically rigorous and spatially comprehensive. While appropriately focused primarily on gamma radiation surveys, certain aspects of the gamma survey methodologies, and how the data are presented in the Baseline Data Report, have practical limitations with respect to direct comparative use for operational purposes (e.g. relative to routine gamma exposure rate measurements for radiation safety evaluations, worker dose assessments, and related Site inspections), and also with respect to the efficiency and timeliness with which data can be collected and analyzed for pre-remediation surveys, remedial support measurements, and post-reclamation verification surveys. It is important to be able to readily evaluate any above-background gamma measurements in terms of doses to humans, and also to maximize the effectiveness, practicality, and efficiency of the gamma survey methodology such that it will be cost-effective over the lifespan of the project. There are also some relatively minor issues related to baseline soil sampling that have been identified in terms of maximizing the future utility of the overall radiological baseline data set. The above considerations are detailed as follows:

1. Based on information provided by DeNuke in the Baseline Data Report (RHR, 2011b), the gamma detectors used to perform baseline gamma surveys were positioned at a detector height of about 10 inches above the ground surface. The Radiological Baseline Report (RHR, 2011b) provides no direct reference to the detector height used for gamma scanning, but shows pictures of DeNuke field personnel scanning with detectors positioned at about 10 inches above the ground surface, and also cites from a table in MARSSIM (NRC, 2000) a value of 2.9 pCi/g as the minimum detectable Ra-226 concentration for the scanning technique used (i.e. the "scan MDC"). This cited value is based on a

detector height of 10 inches above the ground surface. Use of a 10-inch detector height is an unconventional approach for conducting baseline gamma surveys across large areas, yet is appropriate for helping to detect small amounts of contamination that could potentially exist at historic exploratory drilling locations, which was an additional baseline survey objective. A lower detector height has greater sensitivity for detecting small amounts of contamination. However, for general baseline or final verification gamma surveys, a 3-foot detector height is a more standard practice as this height is more representative of whole-body exposure rates, and is also more practical and efficient in terms large-scale field use as it allows sufficient clearance above most vegetation or other types of obstacles when mounted on backpacks or all-terrain vehicles (ATVs). Moreover, the primary data quality objective (DQO) for large-area baseline gamma surveys is to provide characterization of larger-scale spatial distributions across the site, rather than to detect very small and/or subtle anomalies that have little importance in terms of human health risks, or in terms of practical relevance with respect to the likely scope of future remediation needed to achieve consistency with baseline conditions on a site-wide scale.

2. Gamma survey data in the original Radiological Baseline Report were presented in units of counts per minute (cpm) (RHR, 2011b). For comparative assessments with operational and post-remediation gamma surveys, where potential radiological doses to humans are typically of interest, it is appropriate and useful to present baseline gamma survey data in units of exposure rate [micro-roentgens per hour (µR/hr)] or dose rate [micro-rem per hour (µrem/hr)]. Instrument cross-calibration measurements necessary to convert raw energy-dependent gamma scan data (in units of cpm) into estimates of true exposure rate (in µR/hr) were performed by DeNuke field personnel. Although a linear trend in the data provided in the report is apparent, the statistical relationship is not significant (Figure 7). In addition, the scan data presented in the original report were plotted in smaller sub-sections of the Site and legend color scale increments represent a range of values much greater than the range of values actually present. A more useful data presentation will resolve variability in gamma radiation on a more applicable scale, and respectively illustrate both quantitative and spatial distributions simultaneously across the Site on quality aerial imagery to facilitate interpretation of quantitative/spatial relationships relative to planned facilities areas and relevant land features. This is important for identifying contamination, guiding remedial efforts, and demonstrating that post-reclamation gamma survey data are spatially consistent with pre-mining baseline data in corresponding areas.

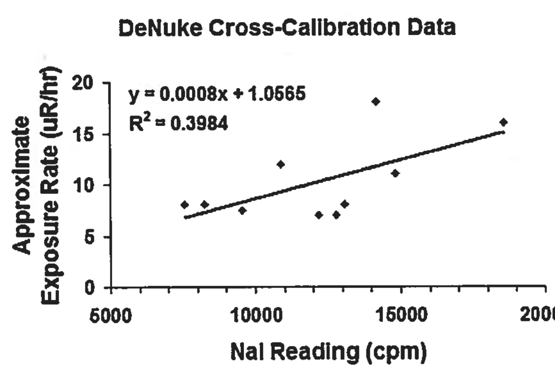

Figure 7: Relationship between energy dependent readings from a NaI-based scanning detector (in cpm) versus approximate gamma exposure rates (in µR/hr) based on readings from a less energy dependent micro-rem meter.

3. Characterization of Soil Ra-226 concentrations is a particularly important aspect of radiological baseline studies because it is the immediate long-lived parent of a number of short-lived radionuclides, including radon gas and gamma-emitting decay products which are responsible for a vast majority of the potential for radiation doses to humans. For this reason, Ra-226 is typically a key constituent in terms of remedial objectives. Direct soil sampling is an inherently limited approach for characterizing the spatial distributions of Ra-226 concentrations in surface soils, particularly when the study area is large and spatial variability is relatively high (a fairly common occurrence when geology, soils and land features are variable). A well-established, effective and widely-used analytical approach for spatially comprehensive characterization of Ra-226 concentrations in surface soils involves gamma/soil Ra-226 correlations (NRC, 2003; Johnson et al., 2006; Meyer et al., 2005a and 2005b; Whicker et al., 2006 and 2008). If a gamma/Ra-226 correlation is statistically significant, Ra-226 concentrations in surface soils can be estimated indirectly with reasonable accuracy based on gamma readings across all scanned areas. As part of the 2010 radiological baseline study at the Site, 10 discrete soil samples were collected by DeNuke and analyzed for Ra-226 at a commercial laboratory. At each soil sampling location, discrete gamma measurements were also taken at detector height of 1 meter. Linear regression analysis of the resulting data suggests essentially no statistical relationship (R^2 = 0.15) between gamma readings and soil Ra-226 concentrations (Figure 8, top). Part of the reason for this result may be due to the methodology. A discrete measurement and sampling approach is typically less effective versus composite measurements and sampling across larger, more generally representative areas at each correlation assessment location (e.g. across 10 × 10 meter plots). In addition, note that the statistical linear relationship between gamma readings and U-238 concentrations at these same soil sampling locations is significantly stronger (R^2 = 0.67) (Figure 8, bottom). Although U-238 is not a gamma emitter like Ra-226 and its short-lived decay products, both should be expected to display a similar, and reasonably significant, linear relationship with gamma readings as in nature Ra-226 normally exists in a state of approximate radiological equilibrium with its U-238 parent (i.e. respective radioactivity concentrations are approximately equal). The implication of this observation is that there appears to be considerable analytical error associated with Ra-226 results. Potential reasons for such error are discussed in bullet point number 4 below. In order to supplement and further characterize baseline

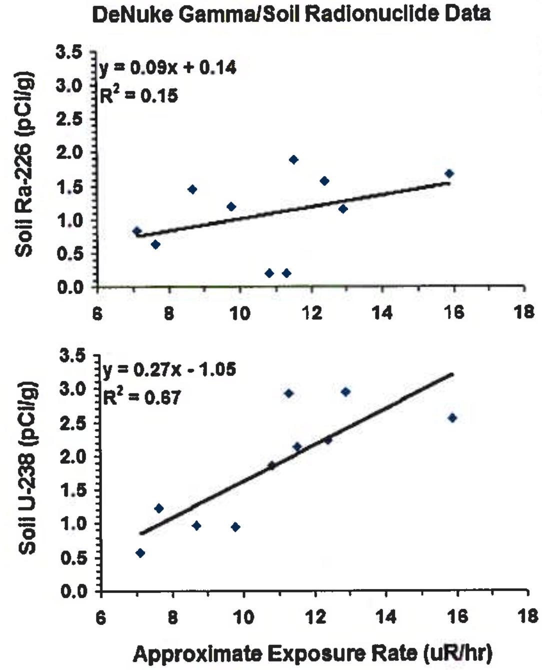

Figure 8: Relationships between approximate gamma exposure rate versus soil Ra-226 concentration (top) and U-238 concentration (bottom) based on data provided in the Radiological Baseline Report (RHR, 2011b).

concentrations of Ra-226 in surface soils across the Roca Honda permit area, additional gamma measurements and soil sampling will be conducted using a methodology specifically designed to establish a more robust gamma/soil Ra-226 correlation that can be used to estimate soil Ra-226 concentrations based on gamma survey data (*see* Section 7.2.2).

4. EPA Method 907.0, a wet radiochemical separation method, was used by DeNuke for analysis of Ra-226 concentrations in radiological baseline soil samples. Radiochemical separation methods are known to have a tendency to underestimate Ra-226 concentrations relative to direct gamma spectroscopy on an unaltered bulk soil sample using a high-purity germanium (HPGe) detector (EPA Method 901.1, modified for soil samples). Several baseline soil samples collected at the Site were reported by the laboratory to have concentrations of Ra-226 that are exceptionally low for natural soils (e.g. approximately 0.2 pCi/g). In general, there is poor analytical agreement between Ra-226 results and U-238 results at corresponding locations (Figure 8) which as previously mentioned, is a potential indication of analytical uncertainty given the expectation of radiological equilibrium between these radionuclides in natural soils.

   Use of the radiochemical separation methodology for Ra-226 analysis has limitations including:

   - The sample size is very small (e.g. < 1 gram) raising issues of representativeness,
   - There can be self-absorption of alpha emissions from sample precipitate mounting filters,
   - It is not possible to dissolve 100% of the radium present in the crystalline soil mineral matrix without the use of expensive and difficult chemical fusion methods or highly aggressive acid digestion techniques, and;
   - Radiotracer techniques can introduce analytical errors with respect to estimating the overall chemical yield of Ra-226 resulting from the chemical separation and filter mounting process.

   With gamma spectroscopy, these potential sources of data uncertainty are avoided as the radioactivity associated with short-lived decay products of Ra-226 (Pb-214 and Bi-214) from a much larger sample can be measured directly[9]. The use of gamma spectroscopy is appropriate for analysis of Ra-226 in soils, particularly when attempting to correlate gamma survey readings in the field with soil Ra-226 concentrations. Additional soil sampling will be conducted as part of the supplemental gamma/Ra-226 correlation study (as indicated above in bullet point number 3), and these soil samples will be analyzed for Ra-226 using gamma spectroscopy (EPA Method 901.1, modified)[10].

[9] Once radiological equilibrium between Ra-226 and its short-lived decay products is attained (about 21 days after sealing the soil sample in a counting tin), gamma energy peaks associated with Pb-214 and Bi-214, which are unique and lack major interferences from other radionuclide emissions, can be easily and directly measured and the resulting radioactivity concentration will be equivalent to the parent Ra-226 concentration. Because a large sample is used (e.g. 200 grams), the signal to noise ratio is typically high and data uncertainty is minimized.

[10] These samples will also be analyzed for natural thorium (Th-232) and uranium (U-nat), as well as K-40 (see Section 7.2.2)

5. The 2010 Radiological Baseline Surveys at the Site included analysis of isotopic uranium (U-238, U-235 and U-234). A radiological rationale is not apparent for analysis of isotopic uranium at a uranium mine site. The relative abundances of U-238, U-235, and U-234 contained in uranium as it exists in natural soils and rocks, as well as in uranium ore is essentially constant[11]. Future soils analysis for uranium at the Site will be performed for natural (total) uranium (U-nat). The analytical method should be EPA Method 200.8 (ICP-MS) or equivalent, preferably with soil matrix digestion using EPA Method 3052 (microwave assisted acid digestion) or equivalent (EPA Method 3050B or equivalent may alternatively be used, recognizing that digestion will not be as complete). With respect to earlier baseline soil analysis results for isotopic uranium, total uranium (U-nat) concentrations will be estimated by summing the isotopic results.

7.2 Supplemental Radiological Baseline Surveys

7.2.1 Reuse Water Pipeline, Access Routes and Utility Corridor

A gamma survey will be conducted along the modified access and utility corridors and the mine water pipeline corridor using gamma scanning equipment specifications and methodologies described in Sections 2.2.3 and 4.2.3 of this document. A backpack or ATV-mounted scanning system will be used while traveling along the corridors in order to accomplish this scanning in an efficient manner. If the ATV-mounted scanning is not appropriate or possible, a backpack-mounted walking or bicycle survey methodology will be used where necessary (e.g. in rough terrain or across areas of limited access). Regardless of the mode of scanning used, the detector will be positioned at approximately 3 feet above the ground surface, with scanning speeds of 1-5 mph depending on the terrain encountered.

Based on initial field review of corridor gamma survey data, 5-10 representative locations will be selected along the corridor for composite sampling of surface soils (to a depth of 15 cm) and analysis for U-nat, Ra-226, Th-232 and K-40 concentrations in accordance with the protocols/methods described in Section 7.2.2 (*see* Correlation Study) and Section 4.2.4.

7.2.2 Supplemental Onsite Measurements/Sampling

Within the permit area, 10-15 representative locations will be selected for supplementary onsite radiological baseline measurements and soil sampling. Supplemental measurement/sampling locations will be selected based on the range of known gamma survey readings across the Site (*see* Figure 10, Section 7.3). At each location, the following measurement/sampling will be performed:

[11] The total amount of radioactivity contained in natural uranium is partitioned according to the following isotopic percentages: 48.6% is due to U-238, 49.2% is due to U-234, and 2.2% is due to U-235 (cited percentages in health physics literature can vary slightly, but all are close to these values).

Normalization of Gamma Survey Detector Heights:

1. At each location, 10-20 individual readings (cpm) from a properly calibrated Ludlum 44-10/2221 instrument pairing will be recorded at two different detector heights: 10 inches and 3 feet above the exact same point on the ground surface. The average gamma reading (cpm) for each set of individual detector readings for each detector height at each location will be calculated and recorded.

2. Regression analysis will be performed on resulting values to determine the Site-wide statistical relationship between gamma readings at 10 inches versus 3 feet above the ground surface. The resulting statistical relationship, if apparent and statistically significant, will be used to normalize all raw gamma survey data from the original 2010 radiological baseline survey (RHR, 2011b) to approximately equivalent readings at a detector height of 3 feet above the ground surface.

Instrument Cross-Calibration Measurements:

1. At each location, 10-20 individual readings from a properly calibrated Ludlum 44-10/2221 instrument pairing (in units of cpm), along with 10-20 individual readings from a properly calibrated Thermo Scientific Micro-Rem meter (in units of µrem/hr) and/or a RadEye PRD (used in energy-compensated dose rate mode with units of µR/hr), will be recorded and averaged. Measurement geometry for collection of instrument cross-calibration data will be 3 feet above the ground surface.

2. Regression analyses will be performed on resulting paired values to determine statistical relationships between NaI detectors and Micro Rem and/or RadEye-PRD[12] instruments. The resulting cross-calibration equations will be used to convert 3-foot normalized original scan data (cpm) into energy-corrected units of dose rate (µrem/hr) and/or exposure rate (µR/hr).

Gamma/Soil Radionuclide Correlation Study:

1. At each location, a 100 m^2 plot for correlation measurements and soil sampling will be established with pin flags. A gamma scan will be performed across each correlation plot (100% scan coverage at a detector height of 3 feet). The average gamma reading (cpm) from scan data across each correlation plot will be calculated and recorded in the field logbook.

2. Within each correlation plot, 9 sub-samples of surface soils will be collected across the plot (to a depth of 15 cm) and composited into a single sample to represent average soil radionuclide characteristics across the plot. Composite surface soil samples from each correlation plot will be submitted to a qualified commercial laboratory for analysis of Ra-226, U-nat, Th-232 and K-40. The correlation plot scanning/sampling design for each location is illustrated in Figure 9.

[12] Adjustments must be made to all RadEye PRD measurements for cross-calibration purposes (*see* Footnote 5, Section 2.2.4 and Appendix A).

3. The laboratory chain of custody/analysis request form to be submitted with composite correlation plot soil samples will specify the following requirements:

    a. Thorough homogenization of each sample at the laboratory.

    b. Ra-226 analysis by EPA method 901.1 (modified for soil samples) with sample counting to be performed at least 21 days after sealing in the counting tin to ensure full ingrowth of Rn-222 and its decay products. Analysis of K-40 will also be conducted with EPA method 901.1, as will analysis of Ra-228 (to determine Th-232 concentrations under the assumption of radiological equilibrium).

    c. U-nat analysis by EPA Method 200.8 (ICP-MS) or equivalent, preferably with soil matrix digestion using EPA Method 3052 (microwave assisted acid digestion) or equivalent (EPA Method 3050B may alternatively be used, recognizing that digestion will not be as complete).

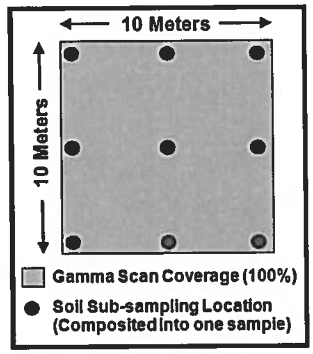

Figure 9: Correlation plot soil sampling and gamma scanning design.

4. Upon receiving soil analysis results from the laboratory, regression analysis will be performed to determine if a significant statistical correlation exists between average gamma readings and soil Ra-226, U-nat, Th-232 and K-40 concentrations based on paired data from all correlation plots.

Based on the results of the above supplemental baseline survey elements, modified gamma scan data resulting from 3-foot detector height normalizations and energy dependence corrections will represent additional final results for the baseline gamma survey. In addition, if any of the gamma/radionuclide correlations are statistically significant, existing gamma survey data from the 2010 radiological baseline survey will be converted into estimates of applicable radionuclides in the top 15 cm of the soil profile across the entire Site (after normalization of raw gamma scan data to a 3-foot detector height).

7.3 Updated Radiological Baseline Data Presentations

In order to better understand the quantitative and spatial distributions of ambient gamma radiation across the Site, raw scan data from the 2010 baseline gamma survey (RHR, 2011b) were converted to estimates of approximate exposure rate using the linear equation from Figure 7, and the results were kriged (a geo-statistical interpolation procedure) using Spatial Analyst (an ArcGIS program) (Figure 10). The exposure rates shown in Figure 10 represent only approximate interim estimates for temporary use (e.g. for selecting supplemental radiological measurement/sampling locations) and are subject to change pending normalization of raw gamma scan data to a 3-foot detector measurement height and energy/unit-basis conversions based on supplemental instrument cross-calibration measurements (Section 7.2.2). Once these data adjustments are accomplished, the updated gamma survey data set will be considered finalized and ready for mapping on aerial imagery as shown in Figure 10. Final baseline maps of individual gamma point data as well as gamma krig data will be developed for inclusion in the supplemental report to be submitted to the MMD as an addendum to Section 13 of the 2011 Baseline Data Report (RHR, 2011b).

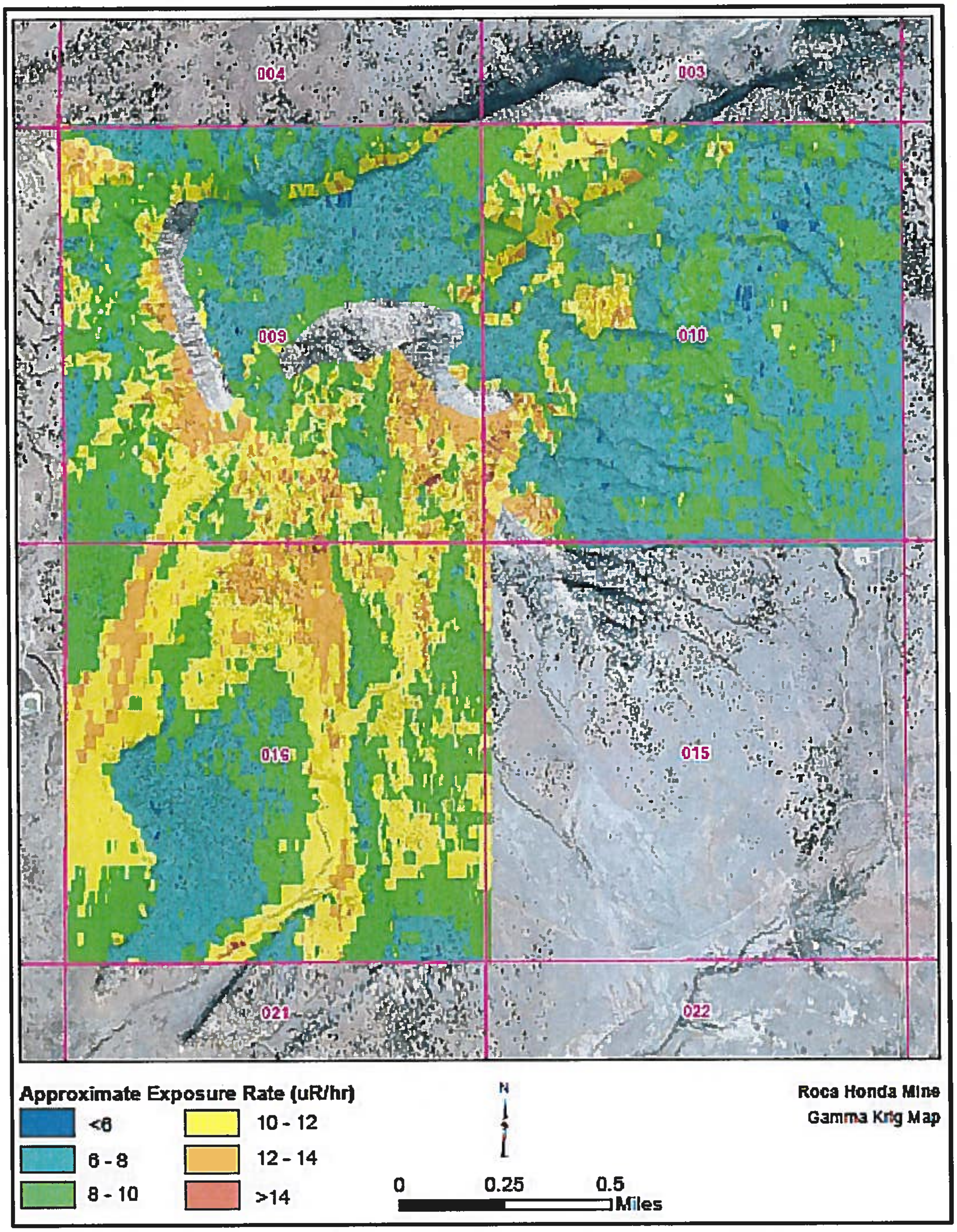

Figure 10: Interim estimates of the spatial distribution of baseline gamma exposure rates across the permit area. A final baseline data set and respective version of this map requires normalization of raw gamma scan data to a 3-foot detector height and energy/unit-basis conversions based on formal instrument cross-calibration measurements (*see* Section 2.2.2).

8.0 REFERENCES

Boice JD, Jr., Hendry JH, Nakamura N, Niwa O, Nakamura S, Yoshida K. 2010. Low-dose-rate epidemiology of high background radiation areas. Radiation Research, 173:849-854.

Hall EJ, Giaccia AJ. 2006. Radiobiology for the Radiobiologist. 6 ed. Philadelphia, PA: Lippincott Williams & Wilkins.

Johnson, J.A. Meyer, H.R., and Vidyasagar, M. 2006. Characterization of Surface Soils at a Former Uranium Mill. Operational Radiation Safety. Supplement to Health Physics, Vol. 90, February, 2006.

International Commission on Radiological Protection (ICRP). 1990. Recommendations of the International Commission on Radiological Protection, ICRP Publication 60. Annals of the ICRP ICRP, Pergamon Press, Oxford.

Meyer, R.; Shields, M.; Green, S. 2005a. A GPS-based system for preliminary or remedial action gamma scanning. American Nuclear Society Topical Meeting on Decommissioning, Decontamination, & Reutilization. Denver, Colorado, August 7-11, 2005.

Meyer, R.; Shields, M.; Green, S.; Johnson, J. 2005b. A GPS-based system for radium/uranium contamination gamma scanning. Uranium Mining and Hydrogeology IV. Broder J. Merkel, Andrea Hasche-Berger (Editors). Uranium in the Environment, conference proceedings, Freiberg, September 2005.

New Mexico Mining and Minerals Division (MMD). 2012. Agency Comments, Roca Honda Mine Reclamation Plan – Revision 1, and Biological Survey of the Reuse Pipeline Route, Permit Application No. MK025RN. October 4, 2012.

Roca Honda Resources, LLC (RHR). 2011a. Reclamation Plan for Roca Honda Mine, Revision 1, August, 2011, as further revised, May 2012.

Roca Honda Resources, LLC (RHR). 2011b. Baseline Data Report, Section 13.0, Radiological Survey. January, 2011.

U.S. Nuclear Regulatory Commission (NRC). 2000. Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), Revision 1. NUREG 1575. Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 2003. Standard Review Plan for In Situ Leach Uranium Extraction License Applications. NUREG-1569. Final Report. U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards. Washington, D.C.

Whicker, F.W.; Hinton, T.G.; MacDonell, M.M.; Pinder III, J.E.; Habegger, L.J.. 2004. Avoiding Destructive Remediation at DOE Sites. Science, Volume 303. March 12, 2004.

Whicker, R.; Cartier, P.; Cain, J.; Milmine, K.; Griffin, M. 2008. Radiological Site Characterizations: Gamma Surveys, Gamma/Ra-226 Correlations and Related Spatial Analysis Techniques. Operational Radiation Safety, Health Physics, Vol. 95 (Supplement 5): S180-S189; November, 2008.

Whicker, R.; Whicker, M.; Johnson, J.; and Meyer, H. 2006. Mobile Soils Lab: On-site Radiological Analysis Supporting Remedial Activities. Health Physics. Operational Radiation Safety. 91(2) Supplement 1:S24-S31, August.

APPENDIX A: RadEye PRD Measurement Adjustments for Instrument Cross-Calibrations

The RadEye PRD instrument is a specialized NaI detector from Thermo Scientific that includes multi-channel energy discrimination for low-energy terrestrial radiation and respective algorithms to provide respective energy compensated response characteristics when used in "dose rate mode". The manufacturer's "dose rate" terminology as applied to this NaI detector is based on a commonly used rule-of-thumb that dose rate to tissue is approximately equivalent to exposure rate in air (the detector actually reads out in units of μR/hr which are generally used in reference to the gamma exposure rate in air, though this radiological unit is technically defined in terms of an absorbed dose rate to air). In addition to general low-energy dependence compensation, the RadEye PRD includes an energy discrimination algorithm to ignore the contribution of high-energy photons (> about 1.3 MeV) to the background gamma radiation field in order to measure only the exposure rate attributable to low-energy terrestrial sources of gamma radiation. As a result, two adjustments must be made to all RadEye measurement values that will be used for instrument cross calibration purposes.

When the RadEye PRD instrument is first turned on in dose rate mode, it will go through a "learning" procedure that takes about 20-30 seconds to complete. During this start-up procedure, the instrument will calculate the exposure rate attributable to interactions in the NaI crystal from ambient background photons with energies greater than about 1.3 mega-electron volts (MeV). This high-energy component of the background radiation field is ignored for all subsequent measurements while low-energy dependence compensation algorithms are applied to the remaining gamma energy spectra to measure the "true" exposure rate associated only with lower-energy photons from terrestrial sources. Essentially, this procedure "strips out" instrument response due to high-energy cosmic sources of background radiation, as well as that due to high-energy terrestrial radiation from K-40 (which emits a 1.46 MeV photon). To correct for this background "stripping" of the portion of the total gamma field attributable to cosmic and K-40 photons, the following calculations and adjustments must be made when RadEye measurement data are to be used for instrument cross-calibration purposes:

ADJUSTMENT FOR COSMIC RADIATION:

1. Elevations at Site range from about 7,135 to 7,800 feet. The estimated approximate average elevation of the site is about 7,400 feet (2,255 meters).

2. Based on the average elevation (2,255 meters) as estimated above, the approximate average exposure rate from cosmic sources at the Site is calculated to be 6.9 μR/hr, using the following relationship as provided in Stone et al. (1999):

$$D_c = \left(7\times10^{-6}(E)^2 - 1.2\times10^{-3}(E) + 27.38\right)0.114$$

<u>Where</u>:
D_c = Cosmic component of total exposure rate (μR/hr)
E = Average elevation in meters (from Step 1 above)

0.114 = Unit conversion factor from nGy/hr to μR/hr

3. For each average RadEye PRD reading obtained at each cross-calibration measurement location, add 6.9 μR/hr as calculated in Step 2 above to account for the cosmic component of the total exposure rate (note: the cosmic component of exposure rates at the Site will vary only slightly due to differences in elevation, e.g. ranging from about 6.6 to 7.3 μR/hr).

ADJUSTMENT FOR TERRESTRIAL GAMMA RADIATION FROM K-40:

1. For each cross-calibration measurement location at the site, determine the corresponding local concentration of K-40 in surface soil based on the composite surface soil sample collected across the corresponding gamma/soil radionuclide correlation plot (in pCi/g) (see Section 2.5).
2. Multiply the result in Step 1 above by 0.184 (μR/hr)/(pCi/g) (a conversion factor for an infinite plane as indicated in NCRP, 1987) to determine approximate average exposure rate due to K-40 in surface soil at each cross-calibration measurement location.
3. For each average RadEye PRD reading obtained at each cross-calibration measurement location, add the corresponding terrestrial exposure rate value for K-40 as calculated in Step 2 above.

Once the contributions of cosmic sources and terrestrial K-40 sources to the total "true" exposure rate at each cross-calibration location have been added to the average RadEye PRD reading at each location, perform a linear regression of average NaI detector reading (x axis) versus average "adjusted" RadEye PRD reading (y axis). The resulting linear regression equation will be used to convert all raw NaI-based gamma survey data into estimates of "true" exposure rate.

REFERENCES:

Stone, J.M.; Whicker, R.D. Ibrahim, S.A.; Whicker, F.W. 1999. Spatial Variations in Natural Background Radiation: Absorbed Dose Rates in Air in Colorado. Health Physics, Vol. 9(5), May, 1999.

NCRP (National Council on Radiation Protection and Measurements). 1987. Exposure of the Population in the United States and Canada from Natural Background Radiation. NCRP Report No. 94. NCRP, 7910 Woodmont Avenue, Bethesda, MD 20814.