*Prepared for:*

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# FINAL

# REMOVAL SITE EVALUATION REPORT
# NORTHEAST CHURCH ROCK MINE SITE

*October 1, 2007*

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# ACRONYMS

| | |
|---|---|
| ATSDR | Agency for Toxic Substances and Disease Registry |
| bgs | below ground surface |
| Bi-214 | bismuth-214 |
| BIA | Bureau of Indian Affairs |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| COC | constituents of concern |
| C-O-C | chain-of-custody |
| COPC | constituent of potential concern |
| CSF | cancer slope factor |
| CSM | conceptual site model |
| cpm | counts per minute |
| CWA | Clean Water Act |
| DCGL | Derived Concentration Guideline Level |
| DGPS | differential global positional system |
| DQA | Data Quality Assurance |
| DQO | Data Quality Objective |
| EDD | electronic data deliverable |
| EPA | Environmental Protection Agency |
| EPC | exposure-point concentration |
| FSL | field screening level |
| HAS | historical site assessment |
| HHRA | human health risk assessment |
| HI | hazard index or hazard indices |
| HQ | hazard quotient |
| ILCR | incremental lifetime cancer risk |
| IDW | investigation derived waste |
| LOAEL | lowest observed adverse effect level |
| MARSSIM | Multi-Radiation Survey and Site Investigation Manual |
| MDC | minimum detectable concentration |
| MDL | method detection limit |
| Mf | modifying factor |
| MMD | New Mexico Mining and Mineral Division |
| NaI | sodium iodide |
| NCP | National Contingency Plan |
| NECR | Northeast Church Rock |
| NEMSA | non-economic material storage area |
| NFA | no further action |
| NMEID | New Mexico Environmental Improvement Division |
| NMED | New Mexico Environment Division |
| NMMA | New Mexico Mining Act |
| NNEPA | Navajo Nation Environmental Protection Agency |
| NOAEL | no observable adverse effect level |
| NOI | Notice of Intent |
| NPDES | National Pollutant Discharge Elimination System |
| NRC | Nuclear Regulatory Commission |
| ORNL | Oak Ridge National Laboratory |
| pCi/g | picoCurie per gram |
| PPE | personal protective equipment |
| PRG | preliminary remediation goal |
| QA/QC | quality assurance/quality control |
| Ra-226 | radium-226 |

| | |
|---|---|
| RAIS | Risk Assessment Information System |
| RfD | Reference Dose |
| RPM | Remedial Project Manager |
| RSE | removal site evaluation |
| SARA | Superfund Amendments and Reauthorization Act |
| SPLP | synthetic precipitation leaching procedure |
| SSL | soil screening level |
| SVOC | semi-volatile organic compound |
| TCLP | toxicity characteristic leaching procedure |
| UCL | upper confidence limit |
| UFn | uncertainty factor |
| UMTRCA | Uranium Mill Tailings Radiation Control Act |
| UNC | United Nuclear Corporation |
| USCS | Unified Soils Classification System |
| USEPA | United States Environmental Protection Agency |
| USGS | United States Geological Survey |
| VOC | volatile organic compound |
| VSP | Visual Sampling Plan |

# EXECUTIVE SUMMARY

A Removal Site Evaluation (RSE) was conducted at the Northeast Church Rock (NECR) Mine (the Site), and nearby areas between August 14, 2006 and December 5, 2006. The RSE consisted of investigating surface and subsurface soils and sediments at various areas within and near the Site. The Site is located approximately 16 miles northeast of Gallup, McKinley County, New Mexico. The RSE was conducted in accordance with the *Removal Site Evaluation Work Plan* (MWH, 2006a) (RSEWP).

The primary ore mineral that was mined at the Site was coffonite (U(SiO4)1-x(OH)4x), which was placed in small temporary stockpiles at NECR-1 and NECR-2 before transport to the Church Rock mill site. Ore and low-grade ore stockpiles were temporarily stored on the NECR-1 and NECR-2 pads prior to being transported off-site to the Church Rock mill. Following New Mexico's approval of a license amendment to permit placement of tailings in mine stopes for structural reinforcement in 1978, tailings material from ore processing at the mill was temporarily stored in three areas referred to as Sand Backfill Areas No. 1, No. 2 and No. 3 (see Figure 1-2) prior to placement in the mine stopes. The bulk of the tailings material from the sand backfill areas was placed in the mine stopes; the remaining tailings were removed and disposed of off-site during the 1986 NRC reclamation.

Stormwater and mine dewatering discharge were routed to three sediment ponds for treatment. Treated water was discharged to the Unnamed Arroyo pursuant to an NPDES permit. Sediment in these ponds was periodically removed and temporarily placed on the Sediment Pad prior to off-site transport to the mill site. Non-economic material (overburden and low-grade ore) was also placed in the Non Economic Material Storage Area(NEMSA). Refuse and other discarded equipment was placed in the Boneyard. Both the NEMSA and Boneyard were reclaimed in 1994 (UNC, 1994), which included placement of one foot of topsoil over the non-native materials and then seeding.

The Site was initially divided into eleven individual survey areas for the RSE, which included NECR-1, NECR-2, Ponds 1 and 2, Pond 3/3a, Sandfill 1, Sandfill 2, Sandfill 3, Sediment Pad, Boneyard, NEMSA, and the Unnamed Arroyo. Two additional areas were added during the field investigation based on preliminary radiological scans. These areas are Vent Hole 3/8 and the Trailer Park. Additionally, nine Home Sites located northeast of the Site were also investigated as part of the RSE and a soil removal action was subsequently carried out at five of these home sites (comprising three residences) based on the results of the RSE. These home sites are located between NECR and the Quivera mine and are situated on the Quivera mine lease. Potential impacts to the Home Sites may have occurred due to wind or water transport of materials stemming from historical operations at NECR, historical operations at the Quivera mine, or background conditions.

Several methods were employed in conducting this field investigation. Initially, static gamma measurements were conducted on random triangular grids. Equivalent Ra-226 concentrations were derived from the gamma survey results by developing correlations using regression analysis between the gamma survey results and co-located surface soil samples analyzed for Ra-226. Due to the presence of radiation containing materials on side-slopes or in a pile that can cause radiation shine (potentially causing an overestimation of Ra-226 soil concentrations), a lead collimator was used on the field detector to minimize interference.

Surface soil samples for laboratory analysis were collected at a minimum of 13 of the gamma measurement locations in each survey area. Subsurface samples were collected using a hollow-stem auger drill rig, test pits excavated with a backhoe, and a hand-auger.

Based on the constituents typically associated with uranium roll-front deposits, the following preliminary constituents of potential concern (COPCs) were evaluated:

- Ra-226
- Arsenic
- Molybdenum
- Selenium
- Uranium
- Vanadium

The metals not including Ra-226 were analyzed for screening purposes only and not for delineating the vertical and lateral extent of metals in soil. Progeny of Ra-226 were not analyzed during the investigation but were accounted for during the Site risk evaluation.

At the Boneyard, the full suite of volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) as well as analysis of the eight Resource Conservation and Recovery Act (RCRA) metals by Toxicity Characteristics Leaching Procedure (TCLP) were also analyzed. Samples from each survey area were also collected for analysis of leachate using the Synthetic Precipitation Leaching Procedure (SPLP) procedure and analyzing the leachate for the COPCs.

A Field Screening Level for Ra-226 was developed for the RSE. The FSL for Ra-226 was based on an acceptable risk range of $10^{-4}$ for residential scenarios, which results in a FSL of 2.24 pCi/g (1.24 pCi/g plus the mean of the Ra-226 background concentration 1.0 pCi/g].

The results of the gamma radiation surveys indicated that surface soils within the initial boundaries of each of the on-site areas contain surface soils with Ra-226 concentrations above the 2.24 pCi/g FSL over the majority of the areas surveyed. Only small fractions of the survey points within the initial boundaries areas were below the FSL. The locations of exceedances of Ra-226 from the gamma survey were frequent and closely spaced such that delineation of any smaller, clean areas within the interior of the areas is not practical, except possibly in Sandfill 1, where about 11 contiguous survey grid points were below the FSL.

The results of the static gamma radiation survey show that the average surface soil Ra-226 concentrations, as determined by correlation with the gamma survey results (CPM), range from approximately four to twenty times the 2.24 pCi/g FSL within each survey area. The surface soil Ra-226 concentration range is wide, with high standard deviations near or above the average concentrations indicating sporadic occurrences of elevated Ra-226 surface soil.

Based on the results, an outer boundary delineating the extent of exceedances of the FSL (i.e., locations below the Ra-226 FSL) based on the static gamma radiation survey for each area was interpreted and termed the FSL boundary. The FSL boundary was drawn outside of most exceedances of the FSL.

Initially, while in the field, the locations of the FSL boundaries were estimated based on the following:

- Undisturbed ground, such as in wooded areas with native soils.
- Roads, structures, and fences.
- Topographic limitations such as precipices, and steep hillsides.
- Boundaries of adjoining survey areas.
- Knowledge of historical operations.

The FSL boundaries were definitely determined based on the results of the gamma radiation surveys and analytical results from the soil sampling. The above listed features merely helped to guide the field investigation and to confirm the boundaries based on the survey and analytical results.

Surface soil samples were collected at 20% of the 80-foot triangular grid nodes (sample locations), or at least 13 locations within each survey area, as well as the five scan locations with the highest CPM readings at each of the nine Home Sites. Additionally, judgmental samples were collected in Vent Hole 3/8 and the Trailer Park, based on any gamma hotpots observed during the gamma survey scans conducted at those two areas. The results show that although there may be some variation between Ra-226 surface soil concentrations by soil sampling versus static gamma radiation survey at some locations, the averages are comparable. Ra-226 and uranium exceed the screening levels at some locations, while all results for molybedenum, selenium and vanadium were below their respective screening levels. Ra-226, uranium and arsenic concentrations in surface soil were as follows:

- Ra-226 values ranged from 0.8 to 875 pCi/g with 70% of the 268 surface soil samples analyzed for Ra-226 [includes stepouts] exceeding the FSL of 2.24 pCi/g.

- Uranium values ranged from 0.7 to 3,970 mg/kg with 9% of the 230 samples analyzed for uranium exceeding the screening level of 200 mg/kg.

- Arsenic values ranged from non-detect to 14.9 mg/kg with 60% of the 230 samples analyzed for arsenic exceeding the screening level of 3.7 mg/kg. The data do not show any correlation between arsenic and Ra-226 or uranium concentrations, and there does not appear to be any spatial pattern in concentrations within the survey areas.

Subsurface soil samples (>0.5 feet bgs) were collected from each of the (original) eleven on-site survey areas, which includes the Unnamed Arroyo. Samples were collected in test pits, soil borings, and hand auger holes and analyzed for the preliminary COPCs. The results show that Ra-226, uranium and arsenic exceed the screening levels at some locations, while all results for molybedenum, selenium and vanadium were below their respective screening levels. Ra-226, uranium and arsenic concentrations in surface soil were as follows:

- Ra-226 values ranged from 0.6 to 438 pCi/g; 66% of the 145 subsurface soil samples analyzed for Ra-226 exceeded the FSL of 2.24 mg/kg.

- Total uranium values ranged from 0.7 to 760 mg/kg; 12% of the 145 samples analyzed for uranium exceeded the screening level of 200 mg/kg.

- Arsenic values ranged from non-detect (<0.5) to 13.9 mg/kg; 52% of the 145 samples analyzed for arsenic exceeded the screening level of 3.7 mg/kg. The relative concentrations of asrsenic do not correlate with the concentrations of Ra-226 (e.g., high arsenic concentrations were not necessarily co-located with high Ra-226 concentrations).

Exeedances of the screening levels in subsurface soils was confined to the top 5 to 14 feet at all sample locations, except at NECR-1. At NECR-1, exceedances of the field screening levels were detected in one soil boring (SB-090) in all samples collected from 5 to 25 feet bgs.

The Ra-226 levels measured during the step-out static gamma radiation survey for the NECR-1 were above the FSL at the outermost locations in three primary areas: to the east within the parking area and across Red Water Pond Road, to the north towards and around the Home Sites, and in the IX Plant area. The area around the IX Plant consists of a near-vertical cliff that represents a natural, physiographic boundary, and does not warrant additional investigation. The areas to the north and east represent potential data gaps in the FSL boundary, however results to the north are increasingly likely to represent disturbances or impacts associated with historical mining or exploration activities on the Quivera Mining Company lease, and results to the east appear to be related to the construction or historical use of the former Quivera mine haul road.

A human health risk assessment (HHRA) was conducted for the Site based on the laboratory analysis results for surface soils (<0.5 feet bgs), and subsurface soils to a depth of 10 feet bgs. The HHRA for Home Sites 4, 6, 7, 8, and 9 where EPA conducted removal actions is based on the post-removal confirmation sampling at these Home Sites. The HHRA is a quantitative and qualitative evaluation of potential impacts of Site-derived contaminants on human health, in the absence of remediation or institutional controls. Results of the HHRA, along with other factors are used to determine whether residual levels of contaminants in Site media are protective of human health and may be left in place, or consideration of remedial alternatives are warranted. The HHRA results also provide the basis for the development of alternatives and risk-based cleanup goals for the Site, as appropriate.

The HHRA described herein was conducted in accordance with methods described in Section 6.0 of the approved *Removal Site Evaluation Work Plan* (MWH, 2006). In addition, at the request of EPA and the Navajo Nation, a HHRA was conducted for a hypothetical future on-site resident. This HHRA is comprised of a site-specific conceptual site model (CSM), screening-level HHRA, and baseline HHRA. Risk characterization results expressed as cancer ILCR and non-cancer HI estimates for on-site receptors (current/future maintenance personnel, hypothetical future livestock grazers and hypothetical future on-site residents) and for off-site receptors (current/future residents and hypothetical future livestock grazers) exposed to soils and sediments at the NECR Site are described below.

For each off-site and on-site area, two scenarios were evaluated: Scenario 1 summarizes risks to receptors when only direct soil exposure pathways are considered (i.e., incidental ingestion and inhalation of fugitive dust), while Scenario 2 includes six exposure pathways included in the USEPA risk models for non-radiological and radiological constituents (i.e., incidental soil ingestion, inhalation of fugitive dust, consumption of home-grown produce, consumption of locally grown meat, consumption of locally raised eggs, and external radiation) (USEPA, 2007). However, for a future site maintenance worker, Scenario 2 does not include consumption of home-grown plants or consumption of locally raised meat and eggs. Additionally, for the on-site livestock grazer, Scenario 2 does not include consumption of locally raised eggs or homegrown plants.

Additionally, the total combined risk for each area was calculated across all exposure pathways. Because the risk calculation methodology generated results that exceeded EPA's risk range even at background levels, incremental risk was also calculated, which is the result of the background risk subtracted from the total combined risk. The incremental risk is the risk attributable to each survey area above the background risk.

Located within the main NECR Site, there are 12 areas of concern which include: NECR-1, NECR-2 Ponds 1 & 2, Pond 3/3a, Sediment Pad, Sandfill 1, Sandfill 2, Sandfill 3, NEMSA, Boneyard, Vents 3 & 8, and the Trailer Park. Each on-site location was evaluated for both current/future maintenance personnel and the hypothetical future livestock grazer and hypothetical future on-site residents. The results of the assessment indicated the following:

- For current/future maintenance personnel, under Scenario 1, no surface or subsurface soils in the on-site areas have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1.

- For current/future maintenance personnel under Scenario 2, surface soils in eight of the areas, and subsurface soils in five of the areas have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. A surface soil Ra-226 concentration of 50 pCi/g would result in an estimated incremental risk or HQ within the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ < 1.

- For the hypothetical future on-site livestock grazer, under Scenario 1, no surface or subsurface soils in the on-site areas have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1.

- For the hypothetical future on-site livestock grazer, under Scenario 2, surface soils in all on-site areas, and subsurface soils in all but one of the areas have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. A surface soil Ra-226 concentration of 2.5 pCi/g would result in an estimated incremental risk or HQ within the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ < 1.

- For the hypothetical future on-site resident under Scenario 1, surface soils in all but three of the areas have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. Risk drivers under Scenario 1 were Ra-226 and uranium. A surface soil Ra-226 concentration of 110 pCi/g would result in an estimated incremental risk or HQ within the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ < 1. A surface soil uranium concentration of 48 mg/kg would result in an estimated incremental risk or HQ within the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ < 1.

- For the hypothetical future on-site resident under Scenario 2, surface soils in all of the areas have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. A surface soil Ra-226 concentration of 1.9 pCi/g would result in an estimated incremental risk or HQ within the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ <1. A surface soil uranium concentration of 48 mg/kg would result in an estimated incremental risk or HQ within the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ < 1.

For a resident under scenario 2, in order to achieve the EPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ <1, concentrations of Ra-226 in surface soil concentrations cannot exceed 1.9 pCi/g, which is below the naturally occurring average levels of Ra-226 levels on the Colorado Plateau.

Off-site areas include the nine Home Sites evaluated for residential receptors, the Unnamed Arroyo evaluated for the hypothetical future livestock grazer, and background data collected for the purpose of comparison to combined risk and hazard estimates for each area.

The results of the risk assessment, for residents of the Home Sites indicate the following:

- Scenario 1 - none of the Home Sites have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. Home Site #5 was associated with the highest ILCR (2E-05) estimated for any of the Home Sites under Scenario 1. However, the ILCR due to background soils under Scenario 1 was estimated as 1E-05.

- Scenario 2 – none of the Home Sites on the western side of the Unnamed Arroyo (Home Sites #1 through #5 have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1.

- Scenario 2 - none of the Home Sites on the eastern side of the Unnamed Arroyo (Home Sites #6, #7, #8 and #9) have incremental ILCR or HQ estimates above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1, based on EPA's post-removal confirmation sampling results. The total ILCR for all Home Sites on the eastern side of the Unnamed Arroyo were equal to 1E-04. For comparison, the total ILCR estimate for background soil was equal to 2E-04. Both the site-related and background risk estimates presented in this baseline ILCR are likely over-estimated as described in the Uncertainty Analysis (Section 4.4).

Incremental risk estimates greater than 1E-04 are attributable to the consumption of homegrown produce, the consumption of homegrown meat, and the external exposure pathways considered in Scenario 2. Actual exposures will be lower than those assumed if vegetable gardens are not used, livestock are not grazed in the area, and/or if a concrete slab is part of the foundation at these Home Sites. In addition, it may not be appropriate to consider the latter indirect exposure pathways given that the risk-based Soil Screening Levels (SSLs) for Ra-226 for external exposure, consumption of homegrown produce, and consumption of homegrown meat based on a risk level of 10-6 are 0.01 pCi/g, 0.069 pCi/g and 0.024 pCi/g, respectively, and are below the site-specific background level of 1.0 pCi/g. It should also be noted that the exposure and risk estimates described in this HHRA are biased high due to the soil sampling design. Field screening was used to identify biased locations for the collection of soil samples. In turn, the 95% UCL on the mean concentration of these biased soil samples was used to estimate exposure doses and risk estimates. In most cases, the concentrations observed at biased sample locations are representative of only a very minor portion of the entire home site.

However, as documented in USEPA's Home Site Investigation Trip Report September 11, 2007, ( E&E, 2007), EPA has carried out a soil removal action at three properties referred to in the RSEWP as Home Sites 4, 6, 7, 8, and 9. As stated in the Request for Time-Critical Removal Action at the Northeast Church Residential Site Memorandum dated April 18, 2007, the goal of EPA's removal action was to "reduc[e] the UCL 95% radium concentration in the excavation footprint to a concentration that is less than the Site screening level."

The field screening level (FSL) is 2.24 pCi/g, which is based on the sum of the Site-specific background mean (1.0 pCi/g) and a risk-based value representing the upper end of the risk range (i.e., the 1 in 10,000 excess cancer risk for radium in residential exposure scenarios) or 1.24 pCi/g. It should also be noted that the exposure and risk estimates described in this HHRA are biased high for the Home Sites due to the soil sampling design. Field screening was used to identify biased locations for the collection of soil samples. In turn, the 95% UCL on the mean concentration of these biased soil samples was used to estimate exposure doses and risk estimates. In most cases, the concentrations observed at biased sample locations are representative of only a very minor portion of the entire home site.

For the hypothetical future livestock grazer within the Unnamed Arroyo evaluated under Scenarios 1 and 2, neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1.

For the background data, only surface soil samples were collected. For Scenario 1, no soil concentrations of any COPC have a cumulative risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For Scenario 2, arsenic and Ra-226 contribute to incremental risk estimates above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 and/or HQ > 1 due to ingestion of soil, the consumption of homegrown produce and meat, and exposure to external radiation.

Different sources of uncertainty described in the report are incorporated into the risk estimate. Because the majority of these uncertainties err on the conservative side, the estimated risks presented in the HHRA for NECR most likely represent upper bound estimates; the actual risks are anticipated to be less. The protective nature of these assumptions is demonstrated by risk estimates associated with background concentrations of Ra-226 and non-radiological constituents in soil. The total ILCR for Ra-226 across all exposure pathways (i.e., Scenario 2) was estimated as 1E-04, and the total ILCR for measured concentrations of all constituents in background soil (assuming scenario 2) was estimated as 2E-04. Therefore, it is appropriate to consider both Scenario 1 and 2 in making risk management decisions.

# 1.0 INTRODUCTION

This Removal Site Evaluation Report describes the objectives, scope of work, and results of the Removal Site Evaluation (RSE) conducted at the Northeast Church Rock (NECR) Mine (the Site), and nearby areas between August 14, 2006 and December 5, 2006. The RSE consisted of investigating surface and subsurface soils and sediments at various areas within and near the Site. The Site is located approximately 16 miles northeast of Gallup, McKinley County, New Mexico, as shown on Figure 1-1, *Site Location.* The RSE was conducted in accordance with the *Removal Site Evaluation Work Plan* (MWH, 2006a) (RSEWP) and the modifications described herein.

This section summarizes the objectives, site history, land use and the regulatory history of the Site. References in this report to site history, past operations, and the title status are asserted by UNC to be correct, and are subject to verification by EPA and the Navajo Nation.

## 1.1 PROBLEM STATEMENT AND OBJECTIVES

The NECR Mine is an inactive uranium mine site. The bulk of the mining lease is located on Navajo surface trust lands that are administered by the Navajo Regional Office Bureau of Indian Affairs. UNC owns the remaining portion of the Site through a patented mining claim. The Mine is subject to the New Mexico Mining Act (NMMA), as well as other statutory and regulatory requirements detailed below. UNC had submitted a closeout plan to the New Mexico Mining and Mineral Division (MMD) on January 30, 2004, received comments from MMD on June 23, 2004, incorporated those comments and responded on July 30, 2004. On November 10, 2004 the MMD supplemented their closeout plan comments with a request for UNC to submit a Materials Characterization Work Plan. UNC submitted the plan in December 2004. On February 15, 2005, MMD conditionally-approved the plan along with some comments, which UNC responded to on March 11, 2005.

On March 22, 2005, the Navajo Nation Environmental Protection Agency (NNEPA) requested that EPA Region 9 assume primary oversight of the NECR Mine in coordination with the NNEPA, the State of New Mexico and the Bureau of Indian Affairs. On November 7, 2005, EPA Region 9 agreed to act as the lead regulatory agency for the Site. On December 16, 2005, MMD informed UNC that it would defer further permitting action at the mine pending successful completion of the EPA process.

EPA requested that UNC, the former operator of the mine, undertake an environmental evaluation of the Site for purposes of determining whether a CERCLA removal action is warranted. Based on prior radiological surveys conducted by the EPA Las Vegas Radiation Laboratory in coordination with NNEPA, EPA noted the potential that several residences located north of the Site may be impacted by hazardous substances that were transported there by wind or stormwater runoff, and requested that the removal evaluation encompass these areas. UNC representatives met with federal, state and tribal agencies on February 28, 2006, March 27-28, 2006, and May 23, 2006.

The final RSEWP was approved by the EPA on August 14, 2006. Collection of background and gamma level to soil concentration correlation samples (see Section 2.2.3) was conducted on August 17 and 18, 2006 and submitted to Energy Laboratories, Inc. (ELI) of Casper, Wyoming for chemical analysis. These data were reported in the *Results of the Background and Radium Correlation Sampling Technical Memorandum* (MWH, 2006b) and are presented here as well. The remaining field activities were conducted between November 6 and December 5, 2006.

The main objective of the investigation was to conduct an RSE that was consistent with the National Contingency Plan (NCP), Title 40, Code of Federal Regulation 300.410 – 415. The NCP lists several factors to be considered in determining the appropriateness of a removal action in 300.415 (b)(2), as discussed in the RSEWP.

In order to comply with the NCP (see the RSEWP, MWH, 2006a), the following RSE objectives were fulfilled:

- Conducted an RSE in conformance with the NCP;
- Characterized the nature and extent of releases of radionuclides in soil and sediment;
- Characterized the nature and concentrations of releases of metals in soil and sediment;
- Collected data to determine the appropriate response;
- Identified exposure pathways in accordance with the RSEWP;
- Evaluated baseline human health risks;
- Preliminarily defined survey areas and boundaries;
- Defined potential range of removal actions that are consistent with current and reasonably anticipated future land uses; and
- Evaluated soil for the reestablishment of a self sustaining ecosystem.

## 1.2 SITE HISTORY AND LAND USE

### 1.2.1 Ownership and Surrounding Land Use

Figure 1-2, *Local Land Use*, illustrates the property interests that encompass the Site and the surrounding lands that are of potential interest to the RSE. Surface ownership for Section 35 of T17N, R16W and Section 3 of T16N, R16W, which includes the majority of the NECR mine permit area, is held in trust by the Bureau of Indian Affairs for the Navajo Nation. The mineral rights are owned by Newmont USA, Ltd, successor to Santa Fe Pacific Gold Corporation. A small portion of the permit area is located on lands owned by UNC in the eastern part of Section 34, T17N, R16W. The remainder of Section 34 to the west of the NECR mine permit area is controlled by the Bureau of Land Management and is used for grazing, and potentially for mining. The NECR mine permit area encompasses approximately 125 acres.

UNC owns Section 36, T17N, R16W to the east, and Section 2, T16N, R16W to the southeast of the Site. These parcels are part of the Church Rock mill and tailings storage facility that is maintained under a Source Material License in compliance with Nuclear Regulatory Commission (NRC) requirements. Upon termination of the license, and to comply with Title II of the Uranium Mill Tailings Radiation Control Act (UMTRCA), these lands will be deeded to the Department of Energy, and will be held in perpetuity in the Legacy Monitoring Program. The Church Rock tailings storage facility is an EPA Region 6 National Priority List Site that is operated and maintained primarily through a NRC Source Materials License.

All lands to the north of the Site are part of the Navajo Indian Reservation. From the late 1960's into the early 1990's, the part of the reservation immediately adjacent to the Site was mined by Kerr-McGee Corporation (Quivera Mining Company) through a lease with the Navajo Nation (these mines were referred to as Church Rock I, IA and II). Kerr McGee's subsurface mining operations extended to near the underground workings of the Northeast Church Rock Mine. Based upon aerial photographs, by 1997 the Quivera Mine had been closed. In 1990, the Department of Interior, Bureau of Land Management (BLM) issued Quivera Mining Company a conditional approval letter of their Abandonment and Reclamation Plan for the Quivera Mine (BLM, 1990). One of the conditions imposed by the BLM was that the Quivera Mine surface be cleaned up so that gamma radiation as measured one meter above the ground surface does not exceed 50 uR/hr above background at roadways, fence lines, vent holes protore storage areas, and mine ponds and 57 uR/hr at mine spoils areas above background (see Abandonment and Reclamation Plan, Quivera, 1987). Between 1997 and 2004, it appears that between six and nine home sites had been developed on the land located south of the Quivera Mine. The area is also used for grazing. Historical aerial photographs reveal some prior disturbances surrounding the home sites that appear to be related to the mining activity at the Quivera Mine. Because natural water supplies are high in dissolved minerals content, potable and livestock water is supplied to the reservation via Navajo utilities. Two wells in the area, NR-1 and Friendship Well, are located northwest of the home sites. Both wells appear to have been unused for several years and the NR-1 well is locked by UNC.

The mine site is currently inactive and is fully fenced to prevent access by unauthorized visitors as well as livestock. However, there is a current grazing permit for the site issued by the Department of Interior Bureau of Indian Affairs (see Appendix A), and the Site was used for grazing previously prior to construction of the new property fence. The surrounding area is largely undeveloped land and is used primarily for livestock grazing. Wildlife are also present in the area. Adjacent to the northern permit boundary (north side of NECR-1) is Navajo Reservation Land. Approximately 800 feet to the north of NECR-1 are the home sites mentioned above; the land around the home sites used in connection with residential occupancy.

### 1.2.2 NECR Mining Practices

The majority of the NECR mine property (i.e., that part which lies on lands held in trust by the Bureau of Indian Affairs for the Navajo Nation) was operated by UNC under the terms of a mineral lease with the predecessors of what is now Newmont USA, Ltd. Active mine operations at the Site took place between 1968 and 1982 at which time the mine was placed on stand-by status. Mining was conducted by underground methods. The infrastructure included two main shafts (NECR-1 and NECR-2), several vent holes, support buildings, roads, and water treatment facilities, as shown on Figure 1-3, *Site Layout*. Reviews of historical aerial photographs and Site reconnaissance have indicated that portions of the Site are located within an arroyo.

Beginning in 1979 and ending when the mine went on standby status, pursuant to a permit from the New Mexico Environmental Improvement Division (NMEID), UNC used coarse tailings sands from the mill to provide roof support for critical mined-out portions of the NECR mine. The tailings sands were temporarily staged at the three locations shown on Figure 1-3 (see Sandfill areas), and then were pumped underground into specified areas using a sand slurry. Backfill preparation within the underground mine consisted of building bulkheads equipped with drains around the area to be backfilled. The entrained slurry water drained into the mine drainage system, where it mixed with mine water that was collected and pumped to the surface.

Dewatering operations continued into 1983. The water was treated in three constructed ponds to reduce suspended solids and radionuclide concentrations before being discharged into what is referred to as the Unnamed Arroyo. Upon passage of the Clean Water Act (CWA), discharges were released pursuant to a National Pollutant Discharge Elimination System (NPDES) permit. Treatment processes were added or changed over the years, principally to meet revisions to discharge requirements as dictated by the CWA. Even prior to the time that permitting requirements became effective ponds were used to settle suspended solids. Thus mine water was never directly discharged to the Unnamed Arroyo without some type of treatment.

The individual ponds were used as follows: Pond 1 functioned as a surge tank to allow for homogenization and sand settling. A flocculant was also added to remove suspended solids. The clarified water then flowed into Pond 2. Between Pond 2 and Pond 3a, sulfuric acid and barium chloride were added, resulting in the removal of radium through precipitation as radium sulfate in Pond 3/3a. Water from Pond 3 was fed to an ion exchange (IX) plant for the recovery of uranium and then discharged into the Unnamed Arroyo. The IX Plant was added to the Site's NRC license in 1977 and operated until dewatering operations ceased, at which point UNC closed the IX Plant, mine water treatment ponds, and tailings sand backfill areas in accordance with its NRC Source Materials License.

UNC undertook various closure activities at the NECR Mine between 1986 and 1994 pursuant to NRC requirements and the mining lease. In addition to removing the IX Plant and sludge-contaminated soils from the treatment ponds, closure actions included: removal of equipment and some buildings; backfilling and sealing the two shafts (NECR-1 and NECR-2) and associated vent holes with reinforced concrete caps; regrading, covering and revegetation of the non-economic materials storage area (NEMSA). The only remaining structural features include the main office, power poles, building foundations and other concrete platforms. The concrete pads were left standing at the request of the Pinedale Navajo Chapter house. A disposal area is located on that part of Section 34 owned by UNC (the Boneyard). The Boneyard was used to store old equipment, tires, wood pallets, and other miscellaneous materials. This material was either removed from the Site or buried at the Boneyard area. The area was covered with one foot of soil and reseeded as part of the closure activities.

### 1.2.3 Regulatory History

The NECR Mine has been regulated under various permits during active and post-closure operations, as listed below.

- A NPDES permit for the treatment and discharge of mine water.
- An amendment to the radioactive materials license from the State of New Mexico for the operation of the IX Plant.
- A discharge permit and radioactive materials license from the State of New Mexico for backfilling coarse tailings sand into the mine.
- A source materials license with NRC following the June 1986 return of the State's licensing authority to the NRC for the closure of the sand backfill staging areas and the IX Plant and water treatment ponds.
- A mining permit issued by the State of New Mexico in 2004 to conduct additional mine closeout activities under the NMMA.
- A storm water discharge permit with EPA in 2005.

The NPDES permit covered the discharge of treated mine water into the arroyo downstream of NECR-1. The water was monitored for flow rate, pH, suspended solids, radionuclides, and trace metals; and was reported to the State of New Mexico and EPA in quarterly reports. The permit was inactive after mine dewatering ceased in 1983, and the permit was allowed to lapse at the end of 1993, at the same time that the mineral lease expired.

On June 23, 1977, UNC's State-issued radioactive materials license (UN-UNC-ML) was amended to allow for the operation of the IX Plant, and on January 29, 1979, the license was again amended to govern radiological aspects for the backfilling of coarse tailings sands into the mine workings for structural control. (During this period, New Mexico had agreement state status and was authorized to administer the license.) The NMEID issued discharge permit DP-63 to govern water quality aspects of the tailings sand backfill. As a basis for the permit, Battelle (1982) investigated potential impacts from the sand backfill areas on groundwater quality, and concluded that degradation would not occur. The permit required groundwater monitoring to verify the conclusions reached by Battelle.

In June 1986, the State of New Mexico returned its licensing authority for uranium recovery facilities to the NRC. UNC therefore closed the IX Plant, mine water treatment ponds, and tailings sand backfill areas in accordance with its NRC Source Materials License. This included the removal of radionuclide contaminated soils and process equipment, which were disposed of at the mill site in conjunction with mill decommissioning and reclamation activities. NRC certified the completion of the NECR cleanup activities in October 1989 in their letter to UNC dated October 1989. The letter stated: "Based on the equilibrium ration and the U-nat date provided by the licensee, the staff concludes that UNC has adequately removed remaining byproduct material from the mine site. Therefore no further action is necessary." (NRC, 1989).

UNC halted on-site activities at NECR in December 1993 after its lease expired. In September 2002, the New Mexico Appellate Court held that NECR was subject to the NMMA (New Mexico Mining Com'n v. United Nuclear, 133 NM 8, 57 P.3d 862, 2002). UNC submitted a mine permit application in July 2003 and a Closeout Plan in January 2004 (MWH, 2004a) to the MMD. UNC worked with MMD to complete work plans for site characterization and mine closure through March 2005. The State of New Mexico issued a letter in June 2004 for UNC to prepare a groundwater abatement plan. At roughly the same time that UNC received conditional approval to execute the Materials Characterization Work Plan (MWH, 2004b), the NNEPA requested that EPA assume jurisdiction for mine cleanup. On November 7, 2005, EPA agreed to the NNEPA's request, and in a December 16, 2005 letter from MMD to UNC, MMD deferred further permit action for NECR to EPA on the presumption that an EPA-led cleanup would result in compliance with the NMMA and address NMMA reclamation requirements. MMD reserved its right to make a determination of NMMA compliance following EPA's release of the mine site.

On May 13, 2005, UNC submitted a complete Notice of Intent (NOI) form seeking coverage under EPA's Multi-Sector General Permit for storm water discharges. There have been no discharge events to trigger any monitoring events since the permit has been in place, nor has there been continuous flow into the arroyos adjacent to the Site. UNC has implemented and maintains the best management practices that are contained in the Stormwater Pollution Prevention Plan (MWH, 2005).

### 1.2.4 Previous Work

Previous work that has been conducted at the Site is documented in serveral historical documents. These documents include those listed below.

- Closeout Plan (MWH, 2004a)
- Material Characterization Work Plan (MWH, 2004b)
- Groundwater Quality in the Westwater Canyon Member at the Northeast Church Rock Mine (MWH, 2004c)
- Northeast Church Rock Mine Site Assessment (MWH, 2003)
- Tailings Sand Backfill Cleanup Verification Report (UNC, 1989a)
- Kerr-McGee (Quivera Mine) Operations and Closure Report (date unknown)

Additionally, data concerning the results of the EPA field radiological scan that was conducted in 2005 (see Section 1.1) was conveyed to the project team by personal communication (EPA, personal communication, 2006).

## 1.3 PHYSICAL SETTING

### 1.3.1 Physiography

The Site is located in the southeastern part of the Colorado Plateau Physiographic Province, which is characterized by large regions of folding with broad uplifts and intervening basins. The site is located at the juncture of several of these major structures: the San Juan Basin, the Zuni Uplift, and the Defiance Uplift.

The NECR Mine site is located in an arroyo that drains to the northeast downstream of NECR-1 into another arroyo that drains to the east into Pipeline Canyon. For the purposes of the RSE, the arroyo that drains along the north side of the mine site and then between NECR-1 and Red Water Pond Road is hereafter referred to as the Unnamed Arroyo. Elevations at the Site range from 7,100 to 7,200 feet. Pipeline canyon is a northeast-southwest trending alluvial valley that drains intermittently to the southwest, eventually emptying into the Rio Puerco. Surface water flow from the Site discharges intermittently into the Unnamed Arroyo that empties into Pipeline Canyon via the other arroyo.

### 1.3.2 Climate

The average temperature in Gallup, 16 miles south of the Site, ranges between an average of 29 degrees Fahrenheit in January to an average of 68 degrees Fahrenheit in July. Gallup receives an average of 0.8 inches of precipitation in January and 2 inches in August, with a total annual average precipitation of 11 inches. Daily extremes reach as high as 100 degrees Fahrenheit in summer and as low as –34 degrees Fahrenheit in winter.

Potential evaporation in New Mexico is much greater than average precipitation. The average annual net pan evaporation is approximately 54 inches. Wind speeds over the state are usually moderate, although relatively strong winds often accompany occasional frontal activity during late winter and spring months. Blowing dust and serious soil erosion is a problem during dry spells. Based on data (1992-2002) from the Gallup airport, winds predominate from the west to southwest 11 months out of the year. A predominant direction from the south is reported for the month of August (http://www.wrcc.dri.edu).

### 1.3.3 Geology and Groundwater Quality

The surface of the Site, beneath the soil or colluvium layers (see Section 1.3.4) consists of alluvium along the axes of the drainages and bedrock in other areas. The alluvium present generally consists of clay, silt, sand, and gravel deposited in interfingering layers. The alluvium is very thin or absent at the mine, and is unsaturated. Approximately one mile southeast of the Site, in the valley bottom along the axis of Pipeline Canyon, the alluvium attains sufficient thickness and continuity to be a mappable geologic unit. Similarly, the alluvium becomes partially saturated only along the axis of Pipeline Canyon, in large part if not entirely due to infiltration of mine water discharge from the two upstream mines. Water levels in the alluvium have been gradually lowering ever since mine water discharges ceased.

The Site is underlain by the upper Cretaceous Crevasse Canyon Formation. The cliffs that rim the Site are comprised of white, medium- to coarse-grained sandstone of the Dalton Sandstone Member of the Crevasse Canyon Formation, while much of the Site permit area is underlain by unsaturated mudstones, sandstones, and coal beds of the Crevasse Canyon Formation. Underlying the Crevasse Canyon Formation are the Gallup and Mancos Shale formations, also of Cretaceous age. Groundwater is first encountered in the Gallup Formation; during the drilling of the NECR-1 area mine shaft an approximately 30 gpm yield was reported. The Mancos is a very effective confining layer being comprised of 500-800 feet of shale.

Underlying the Cretaceous sediments, are the Jurassic Morrison Formation and Dakota Formation. The primary uranium ore body mined at the Site is present within the Westwater Canyon Sandstone Member of the Morrison Formation. The NECR-1 and NECR-2 mine shafts at the Site extended to a depth of approximately 1,500 to 1,800 feet into the Westwater Canyon Sandstone Member. The Dakota and Morrison Formations may be hydraulically connected; together they constitute a productive aquifer, and produced about 1,500 gpm during mine dewatering operations.

A discussion of the background concentrations of COPCs is included in Section 2.5.

Groundwater quality data at the Site was presented in the document *Groundwater Quality in the Westwater Canyon Member at the Northeast Church Rock Mine* (MWH, 2004c). Maximum concentrations for background mine water quality exceeded NMED standards for iron, manganese, nitrate, and radium-226 (Ra-226). A sample collected from the NECR-1 area well on May 17, 2004 exceeded New Mexico Environment Division (NMED) standards for pH, total dissolved solids and boron.

### 1.3.4 Soils

Native soils at the Site boundary consist of well-drained silty sands and inorganic silts and clays, characteristic of a semi-arid pinyon-juniper region. Soils in the areas surrounding the nine home sites are expected to be similar. Coarser, poorly sorted alluvial deposits containing gravel and cobbles are found along the Unnamed Arroyo. The NECR-1 pad was constructed of non-economic mine materials consisting of sandstone and clay shale fragments, while the NECR-2 pad was constructed primarily of native soils. The NEMSA and the Boneyard were seeded in 1994, after being covered with one foot of native topsoil. Currently, areas of the Site have supported a variety of native vegetation, but revegetation of some areas has had little success due to livestock grazing.

The water treatment ponds (Pond 1, Pond 2, and Pond 3/3a) were originally filled with water and sediments settled in them from storm water runoff that drained the tailings sand backfill areas, as well as water from mine operations (see Section 1.2.2). The sediments were periodically removed and placed on the Sediment Pad for temporary storage prior to being transported off-site for processing at the mill. Residual tailings were removed from the ponds and the Sediment Pad as part of the 1986 cleanup pursuant to Condition 33 of NRC Permit License No. SUA-1475 (UNC, 1989a). Currently, the ponds and the Sediment Pad consist primarily of native materials.

As stated above, the sand backfill areas originally were used to store tailings from the mill. As discussed in Section 1.0, the tailings were removed and used to backfill the mine workings. The sand backfill areas were then included in the 1986 cleanup pursuant to Condition 33 of NRC Permit License No. SUA-1475 (UNC, 1989a). As such, the sand backfill areas now consist primarily of native materials.

# 2.0 FIELD INVESTIGATION METHODS

## 2.1 INTRODUCTION

This RSE investigation was conducted in a manner consistent with the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM, EPA, 2000a), as described below. MARSSIM is a comprehensive survey guidance for soils impacted by radionuclides. It is a performance-based approach for demonstrating compliance with a dose- or risk-based regulation. Consistent with MARSSIM, the RSE included processes to identify data quality needs and any limitations to conducting the survey. The survey design used in this RSE was developed and documented using the Data Quality Objectives (DQO) Process, as described in detail in Section 3.0 of the RSEWP, in accordance with MARSSIM. This represents the planning phase of MARSSIM. A quality assurance and quality control (QA/QC) plan was also include in the RSEWP, which incorporated the DQOs and integrated all technical and quality aspects for the life cycle of the project, including planning, implementation, and assessment.

The RSE was carried out in accordance with the SOPs and QAPP, and resulted in the generation of raw data (the Implementation Phase). The data collection techniques used were consistent with MARSSIM (see Chapters 6 and 7, and Appendix H of MARSSIM).

This report represents the Assessment Phase of the MARSSIM process. The data included were first verified to ensure that the SOPs specified in the QAPP were actually followed and that the measurement systems were performed in accordance with the criteria specified in the QAPP. Then the data were validated to ensure that the results of data collection activities support the objectives of the survey as documented in the QAPP, or permit a determination that these objectives should be modified. The data quality assessment (DQA) process was then applied using the validated data to determine if the quality of the data satisfied the intended use.

The Site was initially divided into eleven individual survey areas, which included NECR-1, NECR-2, Ponds 1 and 2, Pond 3/3a, Sandfill 1, Sandfill 2, Sandfill 3, Sediment Pad, Boneyard, NEMSA, and the Unnamed Arroyo. Two additional areas were added for limited investigation during the field work based on the results of preliminary radiological scans. These areas are Vent Hole 3/8 and Trailer Park. Additionally, nine home sites located northeast of the Site were also investigated as part of the RSE. These fourteen survey areas are shown on Figure 1-3, and Figure 1-4, *Locations of Home Sites*.

Several methods were employed in conducting this field investigation. Initially, static gamma measurements were conducted on random triangular grids. Surface soil samples were collected at several of the gamma measurement sites. Subsurface samples were collected using a hollow-stem auger drill rig, test pits excavated with a backhoe, and a hand-auger.

## 2.2 RADIOLOGICAL SURVEYS AND FIELD SCANS

The radiological characterization for the surface soil consisted of stationary (static) direct gamma radiation level measurements and radiation gamma scans for additional characterization of the survey area and boundaries. These two survey methods provided for detailed coverage of the aerial extent of Ra-226 within the top six inches of soil, which allowed for a more thorough characterization of the Site compared to relying on surface soil sampling and laboratory analysis alone. The field gamma radiation correlations, static measurements, and scans for the Ra-226 content in soil were performed using a Ratemeter/Scaler (Ludlum 2221) connected to a 2-inch by 2-inch sodium iodide (NaI) crystal scintillation detector (Eberline SPA-3), which detects all gamma radiation above a specific selected energy, including gamma radiation emitted from bismuth-214 (Bi-214), a decay product of Ra-226 in the soil. Prior to conducting the gamma radiation measurements, the operating high voltage levels of the NaI detectors were established in accordance with manufacturer instructions. The operating high voltage yielding the lowest noise, optimum efficiency and least sensitivity to voltage fluctuations in the field was established by determining the high voltage plateau of the detector.

The presence of radiation containing material on a side slope or in a pile can cause radiation shine at a location near that body of material (i.e., gamma rays are emitted in three dimensions and can impact areas laterally away from the source as well as vertically). Due to the elevated activity of materials at the Site, as discussed in Section 3.0, radiation shine could interfere with and cause an overestimation of Ra-226 soil concentrations at certain locations. A lead collimator was used to minimize this interference (it blocks lateral radiation shine), and a separate correlation calibration was performed for the collimated detector. This detector was held eighteen inches above the survey point to obtain a one-minute integrated count.

Static measurements were taken at all locations on a triangular grid, except at Vent Holes 3/8, the Trailer Park and the Home Sites. Vent Holes 3/8, the Trailer Park and the Home Sites were scanned first to locate elevated areas, and then static gamma measurements were taken at the highest readings to get more precise readings and locations for judgmental soil sample locations. The measurement results, field forms and function check forms are located in Appendix B.

### 2.2.1 Field Gamma Radiation Survey

The field radiation survey at the Site included the measurement of field gamma radiation levels to characterize the nature and lateral extent of Ra-226 concentration in surface soils. The field gamma radiation level measurements were performed using a 2x2 NaI scintillation detector coupled with a scaler/ratemeter as specified in the Standard Operating Procedures (SOPs) included in the RSEWP. The gamma radiation level measurement consisted of gamma radiation static (stationary) surveys and gamma radiation scan surveys for additional characterization of the survey areas and boundaries. These field gamma radiation surveys provided greater aerial extent of Ra-226 contamination for the top six inches of soil for the Site compared to relying on surface soil sampling alone.

Ra-226 is primarily an alpha emitting radionuclide with a gamma radiation emission of 186 KeV at about 4% intensity. This low energy and intensity of the Ra-226 gamma radiation emission makes direct determination of Ra-226 in the field a difficult task. However, bismuth-214 (Bi-214), a Ra-226 decay product, emits three high-energy (609 to 1764 KeV) gamma radiations at a total of approximately 80% intensity. The gamma radiation of Bi-214 can be readily and adequately measured in the field utilizing a NaI scintillation detector having high sensitivity. If soil geometry and other parameters such as moisture are consistent, the ratio of Bi-214 to Ra-226 would be consistent. This means there would be a direct relation (correlation) between Bi-214 gamma radiation levels and Ra-226 concentrations in the surface soil. The gamma radiation from other naturally occurring isotopes in soil, such as thorium-232 (Th-232) decay products and postassium-40 (K-40), may contribute to gross gamma radiation intensity. In addition, background gamma radiation from cosmic rays also contributes to gross gamma radiation intensity. However, the Th-232 decay products, K-40, and gamma radiation levels from cosmic rays are generally at a constant level. A linear regression would identify such a constant to correct for and minimize interference with the gamma radiation level and Ra-226 soil concentration correlation. Therefore, to calibrate the 2x2 NaI detector for Ra-226 measurement, a site-specific correlation between the gross gamma radiation level in counts per minute (CPM) and surface soil Ra-226 concentration (pCi/g) was performed in accordance with SOP-02 (see RSEWP) prior to the field survey.

The gamma radiation level instrumentation configuration consisted of an Eberline SPA-3, 2x2 NaI Scintillation detector connected to a Ludlum 2221 Scaler/Ratemeter. Minimum Detectable Concentration (MDC) is the activity level that the instrumentation is expected to detect 95% of the time. The RSEWP specified a gamma radiation survey instrument MDC of 50% of the Derived

Concentration Guideline Limit (DCGL). The $DCGL_W$ was specified in the RSEWP to be 1.24 pCi/g corresponding to the $10^{-4}$ risk criterion assuming a residential exposure scenario. Therefore, an instrumentation MDC of 0.61 pCi/g (50% of the 1.24 pCi/g) was specified for the static gamma radiation survey. Detailed descriptions of the instrumentation and the MDC calculations are included in Appendix B.

A correlation between the gamma radiation levels in CPM and surface soil Ra-226 concentrations was performed prior to the field gamma radiation survey for a site-specific calibration of the 2x2 NaI detectors. The results were provided in *Results of Background and Radium Correlation Sampling Northeast Church Rock Mine Site Technical Memorandum* (MWH, 2006b). The gamma radiation CPM equivalent to the Ra-226 field screening level (FSL) was necessary prior to conducting the actual surveys in order to identify area boundaries and identify locations above the FSL during the radiation survey. This required performing the necessary gamma radiation level measurements and soil sampling for Ra-226 to determine a correlation between gamma radiation level CPM and Ra-226 concentration in surface soils. A detailed discussion of the correlations that were developed is included in Appendix B.

The FSL (2.24 pCi/g) for Ra-226 was defined as the $DCGL_w$ (1.24 pCi/g) above the mean background Ra-226 concentration (1.0 pCi/g), as discussed in more detail in Section 2.4.

The field gamma radiation survey results and soil sampling results for the applicable correlations are provided in Table 2.2, *Gamma Radiation Levels Versus Surface Soil Ra-226 Concentrations Regression Data.* The summarized linear regression for <10,000 CPM and >10,000 CPM are shown on Figure A-5, *Gamma Radiation Levels vs Surface Soil Ra-226 Concentration Regression Data, NECR-1 Step Out Survey Points for <10K CPM Correlation with Collimated 2x2 NaI Detector,* and Figure A-6, *Gamma Radiation Level to Surface Soil Ra-226 Regression On-site Areas >10K Survey Points for >10K CPM Correlation with Collimated 2x2 NaI Detector*, respectively, included in Appendix B. All static gamma radiation survey readings were converted to surface soil Ra-226 concentration using the following equations, and are discussed in Section 3.1:

- Surface soil Ra-226 pCi/g = (0.0024 x CPM) – 11.608 ($R^2$ = 0.98) for collimated 2x2 NaI detectors (shown on Figure A-5 of Appendix B) with gamma radiation levels below 10,000 CPM. (2.24 pCi/g FSL equivalents to 5,770 CPM)

- Surface soil Ra-226 pCi/g = (0.0016 x CPM) – 13.909 ($R^2$ = 0.74) or collimated 2x2 NaI detectors (shown on Figure A-6 of Appendix B) with gamma radiation levels above 10,000 CPM. (2.24 pCi/g FSL equivalents to 10,093 CPM)

The first linear regression analysis shown above was used to estimate low levels of surface soil Ra-226 concentrations (i.e., near the FSL) in areas such as the step-outs where Ra-226 impacts were expected to be in surface soil only with gamma radiation levels generally below 10,000 CPM, yielded a regression with a low $R^2$ value significantly below the specified value of 0.80. This could be due to elevated variance and error associated with measurements at low levels. Therefore, two survey points collected from the step-out survey area (where Ra-226 contamination is in surface soil only) with Ra-226 concentrations above 10,000 CPM were included in the liner regression to improve the $R^2$ value. Although, this biased regression produced an $R^2$ value of 0.98, the data obtained by the field instrumentation was of estimated quality for field screening purposes.

The second linear regression analysis shown above which was used for correlation at locations with gamma radiation measurements above 10,000 CPM for the on-site areas, had an $R^2$ value of 0.74, lower than the 0.80 value specified in the RSEWP. A revision to the correlation was necessary to minimize interference and over estimation of surface soil Ra-226 from significantly elevated levels of subsurface Ra-226.

Despite the potential for over-estimation due to interference, the field gamma radiation survey measurements provided data of a quality sufficient for field screening. The data collected with field instruments have the potential for error and low accuracy and are considered to be estimated values, especially, in areas with different contamination distribution than the instrument calibration/correlation assumptions. This was the case for most of the on-site survey areas, where significantly elevated levels of Ra-226 are present in the subsurface. The initial correlation was developed prior to the field survey for Ra-226 in surface soils (less than six inches deep) with fairly homogeneous distribution. The initial correlation did not expect and account for the elevated gamma radiation shine from the subsurface Ra-226, and thus, the Ra-226 concentrations for surface soils determined by the gamma radiation survey using the initial correlations were higher compared to the single point soil sampling results. The correlations were revised and biased to account for the elevated gamma radiation levels in the subsurface, and to obtain more representative Ra-226 surface soil concentrations and improve the quality of the gamma radiation survey data. However, the revised correlation, which would account for subsurface Ra-226 interference, does not account for any variation in gamma radiation shine interference due to variation in subsurface Ra-226 concentrations at different on-site area locations. Therefore, the data obtained by field instrumentation with revised correlations is estimated data suitable for field screening purposes.

### 2.2.2 Field Direct Gamma Radiation Levels for Surface Soil Ra-226

The field gamma radiation survey for surface soil Ra-226 was performed between November 7 and December 1, 2006 in accordance with the RSEWP. The field gamma radiation survey included a static (stationary) survey and a scan survey. The static gamma radiation surveys were designed primarily to characterize the nature and extent of Ra-226 in surface soils. The gamma radiation scan survey was intended primarily to aid with investigation and characterization of the lateral extent of Ra-226 and to identify elevated areas in surface soils. The selected instrumentation for the gamma radiation survey provides gross gamma radiation levels in counts per unit time. As discussed above, the initial site-specific correlation for calibration of the instrumentation gamma radiation level in CPM to surface soil Ra-226 concentration, and the Ra-226 field screening level (2.24 pCi/g) equivalent gamma radiation level CPM were established.

#### 2.2.2.1 Static Gamma Radiation Survey

Static gamma radiation surveys were performed at specified grid nodes within the survey areas. The grid nodes were determined using Visual Sampling Plan (VSP) on an 80-foot triangular grid cast on a random origin. Initially, a total of 543 80-foot triangular grid nodes (sample locations) were generated that extended beyond the initial survey area boundaries to assist with the boundary delineation evaluation, as presented in Section 3.0. The locations of the static gamma measurements are shown on Figure 2-1, *Static Gamma Measurement Locations*. The following on-site survey areas were included in the survey:

- NECR-1 (156 grid points)
- NECR-2 (75 grid points)
- Pond 1/2 (85 grid points)
- Pond 3/3a (73 grid points)
- Sandfill 1 (76 grid points)
- Sandfill 2 (21 grid points)
- Sandfill 3 (28 grid points)
- Sediment Pad (29 grid points)

Colored flags were used in the field to indicate static gamma measurement and soil sample locations. Each of the grid points was located using a Differentially Corrected Global Positioning System (DGPS). The DGPS consisted of either the Trimble Geo XT or the Starlink Invicta GPS receiver with real time differential correction using OMNI STAR satellite, Tripod Data System (TDS) Ranger data logger with SOLO surveying software capable of navigating to a point. The differential correction provided submeter accuracy of point locations.

When the grid point was located where the survey would be difficult or inappropriate, such as a building foundation or pad, tree or big shrub, or unsafe terrain, the point was moved to the closest appropriate location and the new point location coordinates were obtained. The grid point was marked with a pin flag with survey area description and grid point number. A one-minute static gamma radiation level measurement was performed with a collimated SPA-3 2x2 NaI detector at each grid point as specified in Section 5.1 of SOP-03 (see RSEWP). The survey information, which included the point number and gamma radiation counts, was logged in the TDS data logger. The data logger automatically logged the corresponding date, time and coordinates. Also, the survey date, survey point ID and the gamma radiation reading in CPM, with any comment, were recorded in the Static Gamma Radiation Survey Field Forms, which are included in Appendix B. The survey information from the data logger files and the field forms are summarized and presented in Section 3.0.

Following completion of the static gamma radiation survey for all of the initial 543 grid points (see Figure 2-1) in the above specified survey areas on November 10, 2006, the gamma radiation counts for the grid point at or near the survey area boundaries were reviewed against the FSL of 4600 CPM for the survey area boundary evaluation. The survey area boundary delineation included the scan survey described in Section 5.2 of SOP-03 (see RSEWP) by walking along the 80-foot spaced transects perpendicular to the initial perimeter of each survey area. These transects were to be run between the most outer 80-foot static grid node with a gamma radiation level above the FSL to the next 80-foot grid node below the FSL outside the survey area boundary. However, the review indicated that the gamma radiation levels were above the 4,600 CPM FSL at most of the survey area boundary grid points. Therefore, a step-out static gamma radiation survey was started on November 13, 2006 beyond the survey area boundary grid points to locate points below the FSL readings for boundary delineation scan surveys.

The step-out static gamma radiation surveys for boundary delineation was performed along transects until the gamma radiation level counts were below the FSL, or other limiting features were encountered, such as a cliff or the boundary of another survey area. Additionally, features such as unimpacted ground (e.g., wooded areas with native soils), roads, structures, and fences were used to help estimate the locations of the FSL boundary. The results of the gamma radiation surveys and the soils sample analyses were used to confirm or adjust the FSL boundary subsequent to the field determination using more definitive data.
Gamma radiation readings at some of the outer step-out static survey points were slightly above the FSL. Nevertheless, the static survey for area boundary delineation was ceased after discussions and agreement with the EPA's on-site representatives based on the criteria listed above in conjunction with levels at or below the FSL. The surface soil sampling results were used in conjunction with the gamma radiation levels for final boundary delineation. A total of 238 step-out static gamma radiation surveys were performed for the area boundary delineations, as listed below.

- NECR-1: 149 step-out survey points
- NECR-2: 43 step-out survey points
- Pond 1 and Pond 2: 0 step-out survey points
- Pond 3/3a: 20 step-out survey points
- Sandfill 1: 0 step-out survey points
- Sandfill 2: 0 step-out survey points
- Sandfill 3: 15 step-out survey points
- Sediment Pad: 11 step-out survey points

A static gamma radiation survey with a collimated SPA-3 2x2 NaI detector was performed at 38 points along the banks of the Unnamed Arroyo, starting at the IX Plant (See Figure 1-2) and moving downstream. This area was not included originally in the RSEWP; however, discussions with the on-site EPA-representatives led to include this survey for boundary delineation along the banks of the Unnamed Arroyo, as documented in FCR#001 (see Appendix C).

Static gamma radiation surveys with a bare (uncollimated) SPA-3, 2x2 NaI detector were also performed at the nine home sites (total of 45 survey points), and the newly identified areas: Vent Hole 3/8 (35 survey points) and the Trailer Park (40 survey points). An uncollimated detector was selected for these areas to fully utilize the detector's lateral range for investigation purposes. A scan gamma radiation survey with uncollimated detector in these areas, as discussed in the following section, was performed to identify locations for further investigation.

Overall, static gamma radiation measurements were obtained at a total of 939 points from all areas at the Site between November 7 and December 1, 2006. All of the static survey readings recorded in the Static Gamma Radiation Survey Field Forms are included in Appendix B. The static gamma radiation reading counts were converted to surface soil Ra-226 concentrations using appropriate correlation linear regression equations, as discussed in Section 2.2.3. Results of the gamma radiation static survey are presented and discussed in Section 3.0.

#### 2.2.2.2 Gamma Radiation Scan Survey

Gamma radiation scan surveys were specified in the RSEWP to identify any hot spots (areas with elevated levels), and to delineate the lateral extent of contamination. The scan survey was conducted judgmentally around areas with elevated gamma readings from the static survey, and at site-specific locations. The gamma radiation scan surveys (walkthrough surveys) were performed as described in Section 5.2 of SOP-03 (see RSEWP) by walking at a rate of about one foot per second in serpentine shape along transects with a bare (uncollimated) 2x2 NaI detector at about 18 inches from the ground surface.

##### NECR On-Site Survey Areas

The RSEWP specified gamma radiation scan surveys at a coverage of up to 20% of the gamma radiation static surveys that exceeded the FSL to identify any hot spots. The RSEWP specified that if over 80% of the static survey within a survey area exceeded the FSL (equal to $DCGL_w$ plus background), there would be no scan survey in that area. Over 80% of the static gamma radiation survey measurements in all on-site survey areas exceeded the FSL, therefore no scan gamma radiation survey was performed in any of the original on-site survey areas.

##### NEMSA and Boneyard

The RSEWP specified that a gamma radiation scan survey be conducted at the NEMSA and Boneyard. Prior to implementing the survey, an inspection of these areas was conducted on November 11, 2006 by AVM, MWH and EPA representatives. The NEMSA appeared to contain a clean soil cover, however, the cover had been eroded at several locations and non-economic material was visible The gamma radiation exposure rates in the NEMSA ranged from about 25 μR/hr in areas with unimpacted cover to above 120 μR/hr where the soil cover was eroded and non-economic material was exposed. Elevated gamma exposure rates near 100 μR/hr were also observed at several locations in the Boneyard where subsidence and voids were present in the cover. A gamma radiation scan, which is meant to characterize surface soil, would not have provided any meaningful data as it would have been skewed by the deeper gamma radiation. Therefore, a decision was made to suspend the gamma radiation scan survey in these areas (see FCR#002 in Appendix C). Instead, characterization of these areas is based on surface and subsurface soil sampling, and visual observations made during the subsurface investigation.

### Home Sites

Gamma radiation scan surveying was performed on November 15, 2006 at the nine home sites. The four corners of the half-acre square area around each home were marked with pin flags. The scan survey was performed by walking at a rate of about one foot per second in a serpentine pattern along transects spaced 10 feet apart with an uncollimated 2x2 NaI detector (#408522-33) at about 18 inches from the ground surface. The scans were used to identify areas with gamma levels above the 16,600 CPM FSL. EPA on-site representatives provided oversight and assisted with the survey.

Locations with levels above the FSL, or a total of five locations with the highest readings, were identified and marked with pin flags at each home site. A gamma radiation static survey and soil sampling was then conducted at each of these locations. The gamma radiation static survey readings were recorded in the Field Data Forms, which are included in Appendix B; the results are discussed in Section 3.0.

Based on the preliminary results from this RSE investigation, the EPA conducted a soils removal action at Home Sites 4 and 6 through 9. Soils were excavated to a depth of three to 12 inches around these five Home Sites. Following excavation, EPA conducted confirmation sampling and analysis for Ra-226. A summary report was prepared by the EPA that included hand-sketch drawings showing the lateral extent of the soils removal, the locations of the post-excavation confirmation samples, and analytical results; a copy of the report is included in Appendix D. The EPA's removal boundaries showing the lateral extent of excavation are illustrated on Figure 2-1. It should be noted that these boundaries were surveyed and are of unknown accuracy. The results of the post-confirmation sampling were used in the risk assessment (Section 4), but are otherwise only included in Appendix D; Sections 2.0 and 3.0 of this report include the results of the RSE investigation only.

### Vent Hole 3/8 and Trailer Park

The EPA's on-site representative identified Vent Hole 3/8 and the Trailer Park during the field survey as additional areas requiring investigation and characterization. The addition of these two areas was documented in FCR#004 (see Appendix C). A scan survey was performed by walking at a rate of about one foot per second in serpentine pattern along transects spaced 10 feet apart with a bare (uncollimated) SPA-3 2x2 NaI detector (#408522-33) at about 18 inches from the ground surface. The scan survey was used to identify areas with elevated exposure rates, as specified in the RSEWP. Following the scan survey, a gamma radiation static survey was performed with the uncollimated detector at the areas with elevated gamma levels. The scan results (sketches and the Static Gamma Radiation Survey Field forms) are included in Appendix B. The results of the scan survey in these areas are summarized in Section 3.0

### Unnamed Arroyo

The RSEWP specified that a gamma radiation survey be conducted of the surface sediments in the channel of the Unnamed Arroyo. The RSEWP indicates that the scan be conducted with a collimated 2x2 NaI detector to identify areas with exceeding the 2.24 pCi/g Ra-226 FSL, equivalent to 5,200 CPM for the collimated SPAS-3 detector #408522-33. The 5,200 CPM FSL (detector 408522-33) was derived from the regression analysis performed for the Unnamed Arroyo gamma radiation survey correlation, as presented in Figure 7 of the document *Results of the Background and Radium Correlation Sampling Technical Memorandum* (MWH, 2006b), which included the Ra-226 correlation sampling results. The regression analysis indicated that 5,200 CPM is equivalent to 2.24 pCi/g of Ra-226. Due to the presence of radiation containing materials on side-slopes or in a pile that can cause radiation shine (potentially causing an overestimation of Ra-226 soil concentrations), a lead collimator was used on the field detector to minimize interference.

The correlation survey that was conducted revealed that all fifteen locations in the arroyo sediment bed had Ra-226 concentrations significantly above the FSL. The fifteen sampling locations extended from the edge of NECR-1 to the area around the home sites (see Technical Memorandum). The converted Ra-226 concentrations ranged from 9.7 pCi/g to 26.4 pCi/g. The survey results indicated that surface sediments along the entire length of the Unnamed Arroyo included in the RSEWP for surveying were likely to be above the FSL. Therefore, in consultation with the on-site EPA representatives, a decision (see FCR#001 in Appendix C) was made to eliminate the gamma radiation scan survey in the Unnamed Arroyo, and instead perform subsurface sediment sampling for laboratory analysis. As discussed in Section 2.2.4.1, a gamma radiation static survey at 80-foot grid transect locations along the arroyo bank was performed.

## 2.3 SURFACE SOIL FIELD INVESTIGATION

Surface soil sampling was initially performed at the individual survey areas listed below. Surface soils for the purpose of the RSE are defined as less than or equal to 0.5 feet below ground surface (feet bgs).

- NECR-1
- NECR-2
- Sandfill 1
- Sandfill 2
- Sandfill 3
- Ponds 1 and 2
- Pond 3/3a
- Sediment Pad
- NEMSA
- Boneyard

Surface soil sampling was also conducted at the nine home sites.

Two additional areas were added during the field investigation, because preliminary radiological scans yielded sufficiently high results. These areas are Vent Hole 3/8 and the Trailer Parks (See Figures 1-2 and 1-3). Sample locations at eight of the on-site survey areas were based on predetermined grids. Sample locations at the Boneyard, NEMSA, Trailer Park, Vent Hole 3/8, and the nine home sites were collected at judgmental locations, as described in this Section. Surface soil sample locations are shown on Figure 2-2, *Surface Soil Sample Locations Mine Site*. A tabular summary of the surface soil samples collected from each survey area is included in Table 2.3, *Summary of Soil Sampling Program*, and a more detailed summary of samples collected is included in Appendix B.

From eight of the on-site survey areas, surface soil samples were collected from 20% of the static gamma measurements or a minimum of 13 samples per area, whichever was greater. VSP was originally used to locate the surface soil samples on a triangular grid cast on a random origin. In order, to have the static gamma measurements and surface soil samples on the same grid, the surface soil locations were randomly co-located with the static gamma measurements that were cast on the 80-foot triangular grid. Surface soil samples were collected manually as grab samples from 0 to 0.5 feet and analyzed for the preliminary COPCs.

Initially, a total of 132 surface soil samples were co-located with static gamma measurements in eight of the on-site survey areas. The number of original surface soil samples for each area is summarized as follows (see also Appendix B):

- NECR-1 (31 surface soil samples)
- NECR-2 (15 surface soil samples)
- Sandfill 1 (15 surface soil samples)
- Sandfill 2 (13 surface soil samples)
- Sandfill 3 (13 surface soil samples)
- Pond 1 and No. Pond 2 (19 surface soil samples)
- Pond 3/3a (15 surface soil samples)
- Sediment Pad (14 surface soil samples)

As a result of FCR#003 (see Appendix C), 30 additional soil samples were collected at the step-out static gamma locations, as well as boundary confirmation samples. The numbers of step-out and boundary confirmation surface soil samples collected in each survey area were as follows:

- NECR-1 (16 step-out surface soil samples)
- NECR-2 (4 step-out surface soil samples
- Sandfill 1 (3 boundary confirmation surface soil samples)
- Sandfill 3 (2 boundary confirmation surface soil samples)
- Pond 1/2 (4 boundary confirmation surface soil samples)

Because the Boneyard and NEMSA were reclaimed in 1994 and covered with a one-foot layer of topsoil, they were unlikely to have preliminary COPCs at the surface. Therefore, only five judgmental surface samples were collected from each of these areas to evaluate if any impacts subsequent to reclamation have occurred. The sample locations were chosen based on field observations or evidence that impacts may have occurred (e.g., buried materials, stressed vegetation, eroded ground, areas with sediments deposited from storm water run-on). If no such evidence existed, the samples were collected randomly. Surface samples from the Boneyard and NEMSA were analyzed for preliminary COPCs and agronomic parameters.

The Trailer Park and Vent Hole 3/8 areas were added as per FCR#004 (see Appendix C). Five judgemental locations were selected from the Trailer Park and and five from Vent Hole 3/8 based on the gamma radiation scan survey and static gamma measurements. Surface soil samples were co-located with static gamma measurements, collected as grab samples from 0 to 0.5 feet bgs and analyzed for preliminary COPCs.

Sample locations at the nine home sites were developed judgmentally, based on the highest readings from the gamma radiation scan survey. Five samples were collected for the analysis of preliminary COPCs from each of the nine home sites (total of 45 samples) in a judgmental manner within approximately a one-half acre buffer around each home site, as shown on Figure 2-3, *Surface Soil Sample Locations, Home Sites*. The samples were located on native ground and were collected from the top three inches of soil. If grass was covering the soil, a small patch of grass was cleared down to the soil surface, as that would likely be the zone that wind borne particles from the Site would deposit if they were to make it to that location. The sample locations were biased to the five highest gamma measurements that resulted from the gamma radiation scan survey. The surface sample locations were refilled and leveled to grade after sampling with remaining soil.

Samples collected from the Unnamed Arroyo were initially planned to be taken as surface soil samples. However, as per FCR#001 (see Appendix C), subsurface soil samples were collected instead as discussed in Section 2.2.4.2. The collection methods for these samples are described in section 2.4.3.

Surface soil samples were also collected from the on-site survey areas for analysis of agronomic properties. Five samples were collected from each set of survey areas with similar characteristics, as follows:

- Five samples from the Pond 1/2, Pond 3/3a and the Sediment Pad;
- Five samples from Sandfill 1, Sandfill 2, and Sandfill 3;
- Five samples from NECR-1 and NECR-2; and
- Five samples from the Boneyard and the NEMSA.

This equated to a total of 20 samples. The samples collected in a judgmental manner from locations representative of the areas that may require reclamation, such as the application of top soil and/or reseeding. These data will be used to determine the suitability of the soils as growth media, including availability of nutrients and any potential toxicity.

Samples were also selected for the analysis of preliminary COPCs in leachate using the EPA Method 1213, Synthetic Precipitation Leaching Procedure (SPLP). Two samples were selected in a judgmental manner from each of the on-site survey areas that were not reclaimed (i.e., not including the NEMSA or the Boneyard). The sample locations were chosen at the surface or subsurface locations in each of the survey areas based on the highest total metal results. For each surface sample collected, the percent difference between the metal concentrations and the screening levels was determined. This percent difference was summed for each metal associated with the soil sample. Then the two samples from each survey area with the highest percent difference were selected for SPLP analysis. Of the 16 samples selected for SPLP analysis, 13 of the samples were selected from surface soil sample locations, and the other three were selected from subsurface soil sample locations. These survey areas and soil samples for SPLP are summarized below.

- NECR-1 (2 surface soil samples)
- NECR-2 (2 surface soil samples)
- Sandfill 1 (2 subsurface samples
- Sandfill 2 (2 surface soil samples)
- Sandfill 3 (1 surface soil sample, and 1 subsurface soil sample)
- Pond 1/2 (2 surface soil samples)
- Pond 3/3a (2 surface soil samples)
- Sediment Pad (2 surface soil samples)

Surface soil samples were collected, packaged, and handled according to the protocols in the RSEWP. All surface soil samples were collected using dedicated field equipment. Surface soils were sampled to a depth of 0.5 feet bgs in the on-site survey area and to depth of three inches at the nine home sites. The samples were collected using dedicated stainless steel teaspoons. These samples were placed in one-gallon Ziploc bags, and labeled with date, time, and sample identification. Field duplicates were collected at five percent of the sample locations, and the EPA took field duplicates at ten percent of the sample locations. Homogeneity was achieved by sampling twice the amount in one bag, then mixing and dividing into a separate bag. Additional sample volume was required for samples requiring agronomic analysis. Surface soil samples were submitted to ELI, Casper, Wyoming for analysis of preliminary COPCs, agronomic parameters, and SPLP analyses.

## 2.4 SUBSURFACE SOIL FIELD INVESTIGATION

Subsurface soil samples were collected from on-site survey areas specified in the RSEWP. In addition, subsurface samples were also collected from the Unnamed Arroyo as a result of FCR#001 (see Appendix C). Subsurface soil sample locations are shown one Figure 2-4, *Subsurface Soil Sample Locations*. A summary of the subsurface soil samples collected from each survey area is included in Table 2.3, *Summary of Soil Sampling Program* (See also Appendix B summary).

For the on-site areas, a total of five locations were selected judgmentally from each survey area and were co-located with surface soil sample locations. These subsurface soil sample locations were selected based on elevated surface gamma measurements, as well as the spatial distribution within the survey area (i.e., not clustered). Grab samples were collected from non-native materials every five feet until native soil was reached. At least one grab sample of the native soil was also attempted from each location. In several locations, the presence of sandstone bedrock made collection of a native soil sample not feasible. If the depth of non-native material was less than five feet at any location, one sample of non-native material was collected at approximately the middle of the vertical extent of non-native material, and one sample of the native soil was also collected, where possible. Subsurface soil samples collected at the Boneyard and NEMSA included one sample of the pre-cap material at each subsurface location.

Subsurface samples were collected using three methods. Locations where native soil was anticipated to be at depths greater than ten feet bgs were collected using a drilling rig fitted with hollow-stem augers. Locations where native soil was anticipated to be less than 10 feet and were accessible by heavy equipment were collected using test pits dug with a backhoe. A hand auger, the third method, was used in the Unnamed Arroyo. The sample collection methods are outlined in the sections below. A total of 146 subsurface soil samples were collected. A summary of the number of subsurface samples and subsurface sample intervals follows:

- NECR-1: six locations (28 samples); sample depths ranging from 4 to 45 feet bgs
- NECR-2: five locations (6 samples); sample depths ranging form 0.5 to 5 feet bgs
- Sandfill 1: five locations (9 samples); sample depths ranging from 0.5 to 4 feet bgs
- Sandfill 2: five locations (5 samples); sample depths ranging from 0.5 to 2 feet bgs
- Sandfill 3: five locations (7 samples); sample depths ranging from 0.5 to 2 feet bgs
- Pond 1/2: five locations (14 samples); sample depths ranging from 4.5 to 20 feet bgs
- Pond 3/3a: five locations (14 samples); sample depths ranging from 9 to 25 feet bgs
- Sediment Pad: five locations (9 samples); sample depths ranging from 1 to 10 feet bgs
- NEMSA: five locations (13 samples); sample depths ranging from 4 to 8.5 feet bgs
- Boneyard: five locations (11 samples); sample depths ranging from 1 to 9.5 feet bgs
- Unnamed Arroyo: 10 locations (30 samples); sample depths ranging from 0 to 3 feet bgs

Samples were also selected for the analysis of preliminary COPCs in leachate using the SPLP method, as discussed in Section 2.3. Of the total 16 samples selected for SPLP analysis, three were selected from subsurface soil sample locations, the remaining were selected from surface soil sample locations (see Section 2.3). The three subsurface soil samples were collected from Sandfill 1 (two samples) and Sandfill 3 (one sample).

During drilling at soil boring number SB-131, which was located along the northeastern edge of NECR-1, as shown on Figure 2-4, a dark gray clayey material was encountered that had a distinct petroleum odor to it. Consequently, one sample was collected from 22.0 to 23.5 feet bgs and submitted for analysis of Total Petroleum Hydrocarbons by EPA Method 8015B and VOCs by EPA Method 8260B.

Subsurface soils were visually classified in the field in accordance with the Unified Soil Classification System (USCS), and any soil horizons observed during the sample collection were noted in the field books and field logs located in Appendix C. Subsurface soil samples were collected, packaged, and handled according to the protocols in the RSEWP. Subsurface soil samples were placed in the appropriate container, and labeled with date, time, and sample identification. Field duplicates were collected at five percent of the sample locations. Homogeneity was achieved by sampling twice the amount in one bag, then mixing and separating into a separate bag. The EPA did not collect field splits from the subsurface sample locations.

Subsurface soil samples were sent to ELI in Casper, Wyoming for analysis of COPCs and SPLP. Soil samples for SVOC analysis were sent to ELI in Billings, Montana for analysis. The soil samples were analyzed for preliminary COPCs at nine of the on-site survey areas and the Unnamed Arroyo. At the Boneyard, samples for VOCs, SVOCs, and TCLP analysis were also collected.

### 2.4.1 Hollow-Stem Auger

At subsurface locations where native soil was anticipated to be greater than the depths achievable by a backhoe (greater than 10 ft bgs), sampling was conducted with a drill rig fitted with hollow-stem augers. The hollow-stem auger drill rig was used to collect samples at eight subsurface sample locations, as listed below:

- NECR-1 (five locations)
- Pond 1/2 (two locations)
- Pond 3 (one location)

Water Development Corporation (WDC) was the contractor hired to conduct the drilling. For each soil boring, the soil boring was advanced to the desired interval and an 18-inch split-spoon sampler was lowered into the bottom of the soil boring and driven with blows from a 140-pound hammer falling 30 inches in general accordance with ASTM D1586. The number of blow counts for each six-inch interval was recorded on the boring logs. Sampler refusal is generally indicated if more than 50 blows are required to advance the sampler six inches. This occurred several times, but only after native soil was reached, so there was no need to relocate any of the soil borings. Samples were collected every five feet to total depths from 14 feet to 45 ft bgs.

The split-spoon samplers were decontaminated between each sample interval using Alconox® and distilled water, as per the RSEWP (nitric acid was not used). This assured there would be no cross-contamination of the split-spoon samples. The augers were also decontaminated using a pressure washer and Alconox®.

### 2.4.2 Test Pits

Test pits were used where native soil was anticipated to be less than ten feet bgs. A total of 43 test pits were excavated, as listed below:

- NECR-1 (one test pit)
- NECR-2 (five test pits)
- Pond 1/2 (three test pits)
- Pond 3/3a (four test pits)
- Sandfill 1 (five test pits)
- Sandfill 2 (five test pits)
- Sandfill 3 (five test pits)
- Sediment Pad (five test pits)

The test pits were excavated using a rubber-tired backhoe that was capable of reaching a maximum depth of ten feet bgs. Dedicated stainless steel spoons were used to collect the soil samples. For test pits that were less than three feet in depth, soil samples were collected by multi-increment scoops along the test pit wall or bottom at the desired interval. For test pits greater than three feet in depth, soil samples were extracted using multi-increment scoops from the bucket of the backhoe. After samples were collected, the excavated soil was used as backfill and the backhoe was used to compact the area.

### 2.4.3 Hand Auger

A hand-auger was used to collect subsurface soil samples from the Unnamed Arroyo. Initially, only soil samples from zero to one foot bgs from ten transects (three locations per transect) were planned for collection, but as per FCR#001 (see Appendix C), a deeper subsurface investigation was required. As per FCR#001, samples were collected from ten transects oriented perpendicular to the arroyo, from the former NPDES discharge point to its confluence with the next downstream arroyo. The transects are shown schematically on Figure 2-4. One location from the midpoint of each transect was selected and samples were collected in one foot intervals from 0 to 3 feet, for a total of three samples at each of the ten locations.

The hand auger was decontaminated in between every sample interval. The decontamination was conducted in three stages using an Alconox® wash, nitric acid, and de-ionized water. A rinsate blank was also collected at the end of each day by pouring laboratory-grade de-ionized water on the hand auger in order to ensure thorough decontamination.

## 2.5 DEVELOPMENT OF FIELD SCREENING LEVELS

Screening levels for Ra-226 and arsenic were developed using the background concentrations of the COPCs, as presented in the Technical Memorandum (MWH, 2006). Soil samples for background determination were collected on August 17, 2006 and submitted to ELI of Casper, Wyoming for chemical analysis. The location of the background reference area and the sampling design were selected based on MARSSIM (EPA, 2000a). The area was located to the northwest of the Boneyard, as shown on Figure 2-5, *Surface Soil Sample Locations Background Refrence Area,* and was selected based on the following:

- Similar geology to the Site (Crevasse Canyon Formation);
- Upwind of the predominant wind direction (west to southwest);
- Distance from the Site (approximately one-half mile from permit boundary); and
- No evidence of impacts due to exploration or mining.

A total of 25 surface soil samples and two duplicate samples were collected from the background reference area. The samples were collected using the methods described in the Technical Memorandum. EPA representatives were present during sampling and confirmed background sample locations. Analytical results are summarized in Table 2.4, *Summary of Analytical Results from Background Sampling*; laboratory reports are included in the Appendix B. The concentrations of all analytes were less than the applicable Preliminary Remediation Goals (PRGs), except arsenic and Ra-226. Arsenic and Ra-226 concentrations exceeded both the industrial and residential PRGs in all samples (see Table 2.4). Table 2.4 also shows the mean and standard deviation for each of the COPCs. Screening levels were based on the EPA Superfund Preliminary Remediation Goals (PRGs) for radionuclides (EPA, 2004c) and the EPA Region 9 PRGs for metals and organic constituents (EPA, 2004a).

For Ra-226 plus daughters, the residential, agricultural, and outdoor worker PRGs for soil are 0.0124 pCi/g, 0.000632 pCi/g, and 0.0258 pCi/g, respectively. These values are not achievable by standard

EPA-approved analytical methods. The standard reporting limit (RL) of commercial laboratories using EPA Method 901.1, Ra-226 by gamma spectrometry, is 0.5 pCi/g.

Based on the technical limitations of Ra-226 analysis an alternate FSL was developed for Ra-226. As stated in the RSEWP, the FSL for Ra-226 was based on an acceptable risk range of $10^{-4}$ for residential scenarios, which results in a FSL of 2.24 pCi/g; (1.24 pCi/g plus the mean of the Ra-226 background concentration 1.0 pCi/g]. The background concentration was determined based on the results of background sampling conducted for the background determination (MWH, 2006b). The results for Ra-226 ranged from 0.6 to 1.3, with an average of 1.0 pCi/g. . However, it is important to note that at the nearby Church Rock I, IE and II Mines, the background gamma exposure rate is 9 uR/hr (Quivera, 1987), which is approximately equivalent to 4.5 pCi/g, as discussed in the following paragraph. Additionally, the average background concentration of Ra-226 throughout the Colorado Plateau is reportedly about 2 pCi/g (EPA, 2005).
Exposure rate levels above background levels at former uranium facilities are primarily from Ra-226 in soil. A linear regression between gamma exposure rate and Ra-226 soil concentration was performed to estimate the Ra-226 soil concentration at a gamma exposure rate of 57 uR/hr. The regression was based on exposure rate measurements collected around soil sampling locations obtained during the August 2006 correlation sampling activities at the Site. Based on this informal correlation, a location with 57 uR/hr would have approximately 27 pCi/gm Ra-226 in soil. However, the exposure rates were made at a reconnaissance level, and so were of the general area around each sampling location, not right above the location, which averages the concentration for that specific location. Also, a correlation between exposure rate and soil concentration can be affected by gamma shine related to the area geometry and contamination distribution.

The Site background value of 1.0 pCi/g appears to be on the low end of the range of concentrations seen in the region. The background value at the adjacent Quivera Mines is approximately 4.5 pCi/g (see discussion above). Other examples include: the NRC approved a Ra-226 soil background value for the Bluewater Mill Site (approximately 10 miles from Grants) of 1.9 pCi/g, and both the NRC and EPA approved a Ra-226 soil background value for the Homestake Mining Company Mill Site (approximately six miles from Grants) of 5.5 pCi/g (Nat Patel, personal communication). Additionally, the average background concentration of Ra-226 throughout the Colorado Plateau is about 2 pCi/g. (EPA Detailed Comments on EIS for Moab Uranium Mill Tailings Site). One possible explanation for the lower background value observed in the background reference area, is that the soils there are near an arroyo and may be largely of alluvial origin where the finer-grained material (silts and clays) may have been washed out. Radionuclides tend to adhere or bond to the finer grained particles, and so can be washed out of the coarser material.

Since all of the background arsenic concentrations exceeded the PRGs, the mean of the background arsenic concentrations (3.7 mg/kg) was used as the screening level for arsenic. The residential non-cancer PRG for arsenic is 22 mg/kg, and the industrial non-cancer PRG is 260 mg/kg. The screening levels for vanadium, molybdenum, and selenium were based on the EPA Region 9 PRGs, as shown on Table 2.4.

## 2.6 SITE RECONNAISSANCE

During the course of site reconnaissaince and site walk-overs, the following new survey areas were identified based on obvious mining-related activity or structures, as listed below.

- Vent Holes 3 and 8 – surficial disturbance and mounded soil.
- Trailer Park – surficial distubance

- NECR-2 Drainage - at less than two meters bgs, partially buried drums were observed on the ground surface.
- Magazine - at less than two meters bgs, construction debris and trash was observed.
- Fuel Oil Storage Area - at less than 2 meters bgs, no known material.

All of these areas were investigated during the RSE. Both the Vent Hole 3/8 area and the Trailer Park were investigated using gamma radiation scan surveys, judgmental gamma radiation static surveys, and judgmental surface soil sampling. The NECR-2 Drainage and the Magazine area were investigated coincidentally during the step-out investigation of NECR-2. Static gamma measurements were collected in both areas and step-out surface soil samples from NECR-2 were collected in the Magazine area. The Fuel Oil Storage Area was investigated coincidentally during the step-out investigation of NECR-1.

# 3.0 FINDINGS AND DISCUSSION

## 3.1 FIELD GAMMA RADIATION SURVEY DATA

The results of the field gamma radiation surveys presented herein were performed between August 15 and December 1, 2007 at the Site. The gamma radiation surveys consisted of static and scan gamma radiation surveys, as discussed in Section 2.2. The objective of the gamma radiation surveys was to characterize the nature and lateral extent of Ra-226 concentrations in surface soils at the Site. In addition to the surface soils at the Site impacted by past mining activities, impacts may have occurred to the northeast as a result of various transport mechanisms as discussed in the RSEWP. Due to these potential transport mechanisms, the objectives included characterization of radionuclides in surface soils outside the current survey area boundaries, along the Unnamed Arroyo and at the nine Home Sites.

As discussed in Section 2.2, static gamma radiation surveys were performed at on-site survey areas and the Home Site areas. The static gamma radiation level measurements obtained in CPM were recorded in the Static Gamma Radiation Survey Field Forms, which are included in Appendix B. The static gamma radiation reading counts were converted to surface soil Ra-226 concentrations using appropriate linear regression equations from the correlation study, as discussed in Section 2.2.3. All Ra-226 concentrations discussed in this section are the equivalent Ra-226 concentrations and not laboratory Ra-226 concentrations (laboratory Ra-226 concentrations are discussed in Section 3.2). The equivalent Ra-226 surface soil concentrations as determined from the gamma radiation surveys are presented graphically on Figure 3-1, *Results of Field Gamma Radiation Survey* and discussed in the following subsections.

### 3.1.1 NECR-1

The NECR-1 area was thought to contain non-economic materials and/or low-grade uranium ore, but was not expected to exceed the FSL, thus it was classified in the RSEWP as a potential Class 2 Area. Initially, one-minute static gamma radiation measurement was taken at a total of 156 grid nodes within and extending beyond the initial survey area boundary. The results of these static gamma survey measurements are summarized in Table 3.1, *NECR-1 Static Gamma Radiation Survey Results*. The results show that the surface soil Ra-226 concentrations within the initial survey boundary ranged from <0.6 to 218.8 pCi/g (averaged 29.8 pCi/g). The results show that the surface soil concentrations are above the FSL of 2.24 pCi/g at 153 of 156 locations (98% of the area). Gamma radiation readings exceeded the FSL of 4,600 CPM over 80% of the static survey points, therefore, no gamma radiation scan was performed to further identify hot spots within NECR-1.

The surface soil Ra-226 concentrations at grid points near the initial survey area boundary were above the FSL, as shown on Figure 3-1. A total of 149 step-out static gamma radiation survey measurements, as shown in Table 3.1 and Figure 3-1, were performed beyond the initial survey area boundary of NECR-1 to delineate the lateral extent of surface soil contamination. The levels measured during the step-out static gamma radiation survey for the NECR-1 were above the FSL at the outermost locations in three primary areas: to the east within the parking area and across Red Water Pond Road, to north towards and around the Home Sites, and in the IX Plant area. The area around the IX Plant consists of a near-vertical cliff that represents a natural, physiographic boundary, and does not warrant additional investigation. However, the areas to the north towards the Home Sites and to the east across Red Water Pond Road represent potential data gaps in definitively determining the FSL boundary, however results to the north are increasingly likely to represent disturbances or impacts associated with historical mining or exploration activities on the Quivera Mining Company lease, and results to the east appear to be related to the construction or historical use of the former Quivera mine haul road . The static gamma radiation survey was stopped for boundary delineation based on the criteria discussed in Section 2.2.4.1, and as follows:

- At the bank of the Unnamed Arroyo to the west and northwest.

- The Home Sites and wooded area with native soils to the north;

- The property fence, road and the Trailer Park area to the east and southeast.

- The boundary of Sandfill 1, Ponds 1 and 2, and Pond 3/3a to the southeast, south and southwest.

The gamma survey measurements and soil sample analytical results were then used to confirm or adjust the FSL boundary locations.

The gamma survey results at the 149 step-out locations from NECR-1 ranged from <0.6 to 85.8 pCi/g (averaged 8.9 pCi/g). The surface soil Ra-226 levels within the entire NECR-1 area including the step-out locations averaged 19.6 pCi/g.

### 3.1.2 NECR-2

The NECR-2 area, similar to NECR-1, was thought to contain non-economic materials and/or low grade uranium ore, but was not expected to exceed the FSL, therefore, it was also classified as a potential Class 2 survey area in the RSEWP. Initially, one-minute static gamma radiation measurements were obtained at a total of 75 grid nodes within, and extending beyond, the initial survey area boundary. The results of these static gamma survey measurements are summarized in Table 3.2, *NECR-2 Static Gamma Radiation Survey Results*. The results show that the surface soil Ra-226 concentrations ranged from <0.6 to 215.2 pCi/g (averaged 22.6 pCi/g); 64 out of the 75 (85%) exceeded the FSL. Gamma radiation readings exceeded the FSL of 4,600 CPM at over 80% of the static survey points; therefore, no scan gamma radiation survey was performed to delineate hot spots. Also, the surface soil Ra-226 concentrations at most of the grid points close to the initial survey area boundary were above the FSL, as shown on Figure 3-1.

Static gamma radiation measurements were made at 43 step-out locations around NECR-2 to delineate the lateral extent of Ra-226 in surface. The gamma radiation levels at the step-out locations were mostly above the FSL, except along the western boundary. Therefore, the static gamma radiation survey was stopped for boundary delineation based on the criteria discussed in Section 2.2.4.1, as follows:

- To the west until the readings were below the FSL.
- To the boundary of Sandfill 3 and Magazine area to the north.
- The wooded areas with native soils to the east.
- To the mesa cliff and Sandfill 2 to the southeast and south.

The gamma survey measurements and soil sample analytical results were then used to confirm or adjust the FSL boundary locations.

The gamma survey conducted at the 43 step-out locations indicated that Ra-226 ranged from <0.6 to 19.2 pCi/g (averaged at 3.4 pCi/g). The equivalent Ra-226 concentrations in surface soil within the entire NECR-2 area, including step-out locations and Magazine area averaged 15.6 pCi/g.

### 3.1.3 Sandfill 1

Sandfill 1 was previously remediated by UNC to remove mill tailings material (UNC, 1989). However, this area could contain residual ore material, and was expected to contain soils with Ra-226 in excess of the FSL. The area was therefore classified as a potential Class 1 Area in the RSEWP. A one-minute static gamma radiation survey was performed at 76 grid nodes within and just outside of the initial survey area boundary. The static gamma survey results are summarized in Table 3.3, *Sandfill 1 Static Gamma Radiation Survey Results*. The results show that the equivalent surface soil Ra-226 concentrations ranged from non-detect (<0.6) to 76.0 pCi/g (averaged 9.0 pCi/g); 45 of 76 (59%) exceeded the FSL of 2.24 pCi/g. The gamma radiation readings exceeded the FSL of 4,600 CPM at 62 of 73 (over 80%) static survey points; therefore, no scan gamma radiation survey was performed to delineate additional hot spots while in the field. Equivalent surface soil Ra-226 concentrations exceeded the FSL at some grid points around the area boundary, as shown on Figure 3-1. The Sandfill 1 survey was stopped for boundary delineation, based on the criteria discussed in Section 2.2.4.1, as follows:

- Pond 1 and 2 to the west.
- NECR-1 to the north.
- A road and cliff to the east.
- Concentrations below the FSL to the south.

The gamma survey measurements and soil sample analytical results were then used to confirm or adjust the FSL boundary locations.

Additional static and scan gamma radiation surveying was not performed for boundary delineation (i.e., step-outs) due to the physical limitations around the survey area. The survey did however provide sufficient data for establishing the area boundary. It is important to note that equivalent Ra-226 levels were below the FSL at 11 grid points (#16, 17, 20–22, 26-29, 35, and 36) within the interior of the area (see Figure 3-1).

### 3.1.4 Sandfill 2

Sandfill 2 was also remediated previously by UNC to remove mill tailings material (UNC, 1989). However, this area could contain residual ore material, and was expected to contain soils with Ra-226 in excess of the FSL. The area was therefore classified as a potential Class 1 Area in the RSEWP. A one-minute static gamma radiation survey was performed at 21 grid nodes. The static gamma survey results are summarized in Table 3.4, *Sandfill 2 Static Gamma Radiation Survey Results*. The results show that the surface soil Ra-226 levels ranged from non-detect (<0.6) to 26.0 pCi/g (averaged 5.6 pCi/g); 12 of 21 (57%) exceeded the FSL of 2.24 pCi/g. Gamma radiation measurements exceeded the FSL of 4600 CPM at over 80% of the static survey points; therefore, no scan gamma radiation survey was performed to delineate hot spots.

Equivalent Ra-226 levels around the area boundary were near or below the FSL along the west, south and east boundary, as shown on Figure 3-1. Sandfill 2 was therefore bounded based on the criteria discussed in Section 2.2.4.1, as follows:

- By NECR-2 to the north.
- By a mesa cliff and Ra-226 levels below the FSL to the east.
- By Ra-226 levels below the FSL to the west and south.

The gamma survey measurements and soil sample analytical results were then used to confirm or adjust the FSL boundary locations. No step-out gamma survey was necessary for boundary delineation. The revised boundary is shown on Figure 3-1.

### 3.1.5 Sandfill 3

Sandfill 3 was also remediated previously by UNC to remove mill tailings material (UNC, 1989). However, this area could contain residual ore material, and was expected to contain soils with Ra-226 in excess of the FSL. The area was therefore classified as a potential Class 1 Area in the RSEWP. A one-minute static gamma radiation survey was performed at the 28 grid nodes. The static gamma survey results are summarized in Table 3.5, *Sandfill 3 Static Gamma Radiation Survey Results*. The surface soil concentrations within the initial area boundary ranged from non-detect (<0.6) to 133.6 pCi/g (averaged 20.9 pCi/g); 25 of 28 (89%) exceeded the FSL. Gamma radiation readings exceeded the FSL of 4,600 CPM at over 80% of the static survey points; therefore, no scan gamma radiation survey was performed to delineate hot spots. A step-out static gamma survey was performed at 15 grid points for boundary delineation. The survey area boundary was confirmed based on the criteria discussed in Section 2.2.4.1, as follows:

- Gamma readings below the FSL and wooded hills with undisturbed, native soils to the west.
- The boundary of NECR-2 to the south and east.
- The boundary of the Sediment Pad to the north.

The gamma survey measurements and soil sample analytical results were then used to confirm or adjust the FSL boundary locations. As shown in Table 3.5, equivalent Ra-226 levels at the step-out locations ranged from non-detect to 14.9 pCi/g (averaged 3.1 pCi/g).

### 3.1.6 Ponds 1 and 2

Ponds 1 and 2 were considered as one area during the RSE due to their proximity and similarity in mining process and operations. The ponds could contain sediments from the historical mine water treatment that have Ra-226 concentrations in excess of the FSL, and the area was therefore classified as potential Class 1. Results of the static gamma radiation survey at 85 grid points within this area are shown in Table 3.6, *Pond 1 and Pond 2 Static Gamma Radiation Survey Results* and Figure 3-1. Ra-226 concentrations ranged from non-detect (<0.6) to 498.3 pCi/g (averaged 45.8 pCi/g); 76 of 85 (89%) locations exceeded the FSL. Gamma radiation readings exceeded the FSL of 4,600 CPM at over 80% of the static survey points; therefore, no scan gamma radiation survey was performed in this area to delineate hot spots. The survey area boundary was confirmed based on the criteria discussed in Section 2.2.4.1, as follows:

- By the steep pond bank and Pond 3/3a boundary to the north.
- Steep cliffs and Sandfill 1 to the east.
- Steep cliffs and wooded areas with undisturbed native soils to the south and west.

The gamma survey measurements and soil sample analytical results were then used to confirm or adjust the FSL boundary locations. No step-out gamma survey was necessary for boundary delineation.

### 3.1.7 Pond 3/3a

Ponds 3 and 3a were considered as one area (Pond 3/3a) during the RSE due to their proximity and similarity of mine water treatment operations. Both ponds contained radium sulfate precipitated mine discharge water during mine operations, and may contain residual radium sulfate in the pond sediments. Due to the potential for exceedances of the FSL, the area was classified as a potential Class 1 Area in the RSEWP. Results of the static gamma radiation survey at the initial 69 grid nodes in the Pond 3/3a are summarized in Table 3.7, *Pond 3/3a Static Gamma Radiation Survey Results*. Four of the planned grid points were located under water and were therefore eliminated from the survey. The results show that the surface soil Ra-226 concentrations ranged from <0.6 to 293.6 pCi/g (averaged 25.5 pCi/g) within the initial area boundary. Ra-226 concentrations exceeded the FSL at 67 of 69 locations (97% of the area), as shown on Figure 3-1. Gamma radiation readings exceeded the FSL of 4,600 CPM at over 80% of the static survey points; therefore, no gamma survey was performed to delineate hot spots within Pond 3/3a.

Pond 3/3a was bounded based on the criteria discussed in Section 2.2.4.1, including the Sediment Pad to the west and NECR-1 to the east. A step-out static gamma radiation survey was performed at a total of 20 grid points along transects beyond the initial south boundary to the base of the Ponds 1 and Pond 2 embankments, and beyond the northern boundary to the base of the mesa cliff to adequately delineate the south and north portions of the area boundary. Results of this step-out static gamma radiation survey are included in Table 3.7; Ra-226 concentrations ranged from non-detect to 11.5 pCi/g (averaged 4.0 pCi/g). As shown on Figure 3-1, the northern boundary is bounded by concentrations below the FSL, while the southern boundary is bounded by a road as well as the Ponds 1 and 2 survey area.

### 3.1.8 Sediment Pad

The Sediment Pad was used to store sediments removed from the mine water radium precipitation treatment. Therefore, since it was known that the Sediment Pad could contain sediments with Ra-226 in excess of the FSL, the area was classified as a potential Class 1 Area. The one-minute static gamma radiation survey results at the initial 29 grid nodes are included in Table 3.8 *Sediment Pad Static Gamma Radiation Survey Results*. Surface soil Ra-226 concentrations within the initial area boundary ranged from 2.9 to 210.7 pCi/g (averaged 46.3 pCi/g); the FSL was exceeded at all of the initial 29 grid locations (see Figure 3-1). Gamma radiation readings exceeded the FSL of 4,600 CPM at over 80% of the static survey points; therefore no scan gamma radiation survey was performed to delineate hot spots. As shown on Figure 3-1, the Sediment Pad is bounded based on the criteria discussed in Section 2.2.4.1, as follows:

- By the Sandfill 3 to the west and southwest.
- A road and steep wooded hill to the south and southeast.
- By Pond 3/3a to the east.

The gamma survey measurements and soil sample analytical results were then used to confirm or adjust the FSL boundary locations. A step-out static gamma radiation survey for delineation of the northern boundary was performed at 11 points only beyond the northern boundary to the base of the mesa cliff. These results are included in Table 3.8 and summarized on Figure 3-1, and show that step-out surface soil Ra-226 concentration ranged from non-detect to 5.4 pCi/g (averaged 1.6 pCi/g). The northern boundary is therefore bounded by Ra-226 concentrations below the FSL.

### 3.1.9 Non-Economic Material Storage Area

An investigation by scan gamma radiation survey was specified in the RSEWP for characterization of the NEMSA. The NEMSA contains non-economic materials and/or low-grade ore with a clean soil cover. Ra-226 concentrations were expected to be below the FSL, thus it was classified as a potential Class 2 Area in the RSEWP. However, as a decision was made to suspend the scan survey and collect surface and subsurface soil samples for laboratory analysis instead. This decision was based on site reconnaissance that showed non-economic materials at or near the surface beneath thinner areas of the cap and elevated gamma exposure rate measurements collected at various locations within the NEMSA and the Boneyard Area by EPA and UNC representatives.

### 3.1.10 Vent Holes 3 and 8

Characterization of the Vent Hole 3 and 8 area was not specified in the RSEWP. This area was included in the RSE because it was identified by the on-site EPA representatives during the field survey. This area consists of areas around Vent Holes 3 and 8, as shown on Figure 3-1. As discussed in Section 2.2, a scan gamma radiation survey was performed with the bare (uncollimated) 2x2 NaI detector #805522-33 within the overall area boundary shown on Figure 3-1 to identify any hot spots above the FSL. The area boundary was determined based on inspection of the ground surface conditions, suspect ore materials, and gamma exposure rate levels around the vent holes.

The scan gamma survey, which was conducted along transects spaced approximately 10 feet apart, identified three locations (small isolated areas of about two to five feet diameter) around Vent Hole 3, and 32 locations around the Vent Hole 8. A static gamma radiation survey was then performed with the bare 2x2 NaI detector at these elevated locations. The results of the static gamma radiation survey are included in Table 3.9, *Vent Hole No. 3 and No. 8 Static Gamma Radiation Survey Results,* and shown on Figure 3-1. Ra-226 surface soil concentrations at the three locations around Vent Hole 3 identified by the scan survey ranged from 4.3 to 15.0 pCi/g. Ra-226 concentrations at the 32 locations identified by the scan survey around Vent Hole 8 ranged from non-detect to 71.6 pCi/g (averaged 19.5 pCi/g); only two locations were below the FSL within the identified hotspots. The scan gamma radiation survey indicated that Ra-226 was below the FSL at all locations outside of the identified hot spots.

Eight or so of the isolated small areas northwest of the Vent Hole 3 and 8 structure are on a mound (see field sketch in Appendix B), where unidentified earthen material was observed; the elevated concentrations could be deeper than 0.5 feet bgs on this mounded area. An apparent sump was also observed in the southwest part of the Vent Hole 3 and 8 structure (see field sketches in Appendix B), where the surface soil concentrations were slightly above the FSL.

### 3.1.11 Trailer Park Area

The Trailer Park area was also not specified in the RSEWP, but was included in the survey after being identified as potentially impacted area during the field activities. As discussed in Section 2.2, a scan gamma radiation survey was performed in the Trailer Park Area within the area boundary, as shown on Figure 3-1, to identify hot spots above the FSL. The area boundary was determined based on an inspection of the ground surface, visible evidence of mine-related materials, features such as structure foundation pads and fills, and the base of wooded area and hills with undisturbed native soil. The scan survey identified a total of 39 locations (small isolated areas of about 2 to 50 square feet each) within the Trailer Park. Results of the one-minute static gamma radiation survey at these locations are included in Table 3.10, *Trailer Park Area Static Gamma Radiation Survey Results* and shown on Figure 3-1. The results show that surface soil Ra-226 concentrations ranged from 2.5 to 108.7 pCi/g (averaged 16.5 pCi/g). The static survey confirmed all 39 locations within the hotspots identified by the scan survey to be above the FSL. At locations #2, #7, #9, #13, #40, and #41, visible mine-related materials was observed, which could extend deeper than 0.5 feet bgs. The scan gamma radiation survey indicated that Ra-226 was below the FSL at all locations outside of the identified hot spots.

### 3.1.12 Home Sites

Due to potential wind or storm water, and to a lesser extent human and animal activity, transport of ore material still present at the Site, there was a concern about potential impacts to the nine Home Sites near the downstream end of the of the Unnamed Arroyo where it intersects with the unnamed dirt road that runs east-west along the northern side of the Home Sites, as shown in Figure 2-3. . The Home Sites were classified as potential Class 3 Areas in the RSEWP, and a scan gamma radiation survey was specified to identify any locations above the FSL. As discussed in Section 2.2, a scan gamma radiation survey with a bare (uncollimated) 2x2 NaI detector was performed within a half-acre area around each of the nine Home Sites. The scan survey results showed the gamma radiation levels at or slightly above the background level, but below the FSL (16,600 CPM or 2.24 pCi/g Ra-226 in surface soil) at Home Sites 1 through 5, as shown in field forms in Appendix B. These low levels were confirmed by the results of the one-minute static gamma radiation survey, the results of which are included in Table 3.11, *Home Site Static Gamma Radiation Survey Results*.

At Home Sites 6 through 9, the scan survey results indicated gamma radiation levels from 13,000 CPM (background) to about 34,000 CPM. Results of the static gamma radiation survey, included in Table 3.11, at five elevated locations identified by the scan survey at each of the Home Sites, indicated surface soil Ra-226 concentrations above the FSL. Maximum equivalent Ra-226 concentrations were:

- 4.2 pCi/g at Home Site 6
- 11.0 pCi/g at Home Site 7
- 3.5 pCi/g at Home Site 8
- 3.2 pCi/g at Home Site 9

These results are shown on Figure 3-2, *Results of Gamma Survey and Soil Sampling at the Home Sites*. There are several potential mechanisms that could have contributed to the elevated levels detected at the Home Sites, including transport of windblown material from the NECR on-site areas and the Quivera Mine, historic disturbed areas from Quivera operations in the immediate vicinity of the Home Sites, and transport of eroded sediments from NECR-1 in storm water run off, and transport of windblown materials from the former Quivera haul road. During the NECR-1 step-out survey conducted north of NECR-1 (south of Home Sites #6 and #7), eroded sediment trails from the north slope of the NECR-1 pad were observed.

### 3.1.13 Unnamed Arroyo

A gamma radiation survey was specified in the RSEWP as a part of the characterization survey for the surface sediments within the Unnamed Arroyo bed. However, a scan gamma radiation survey was not performed, as discussed in Section 2.2, because the August 17, 2006 correlation gamma radiation level measurements and soil sampling data showed that gamma levels and Ra-226 concentrations are above the FSL (>80%) the entire length of the sediment bed from NECR-1 down to the Home Sites (the survey was extended to the unnamed dirt road that runs east-west on the northern side of the Home Sites, as shown on Figure 2-3). Therefore, in consultation with the on-site EPA representatives, a decision was made to eliminate the scan gamma radiation survey, and perform subsurface sediment sampling for laboratory analysis instead to evaluate the vertical extent of Ra-226.

As discussed in Section 2.2, a static gamma radiation static survey was performed at 33 transect locations along the north plus five transect locations on the south bank (downstream end) of the Unnamed Arroyo about two to three feet from the edge of the bank. The results, which are summarized in Table 3.12, *Arroyo Bank Static Gamma Radiation Survey Results,* and on Figure 3-2, indicated that surface soil Ra-226 concentrations ranged from <0.6 to 12.2 pCi/g (averaged 2.7 pCi/g). As can be seen on Figures 3-1 and 3-2, concentrations exceeded the FSL at most locations within 200 feet of NECR-1, but not farther to the northeast of NECR-1, except at two sample locations on the south side of the arroyo bank (3.2 and 12.2 pCi/g). The two farther samples are located approximately 1,100 feet northeast of NECR-1 along the south bank of the Unnamed Arroyo (see Figure 3-2).

The 33 samples collected along the north side of the Unnamed Arroyo included eleven samples collected from within the boundaries of the former IX Plant (see Figures 1-2 and 3-1). The results (see Table 3.12) indicated that equivalent surface soil Ra-226 concentrations in the area of the former IX Plant ranged from 1.3 to 9.5 pCi/g (averaged 4.3 pCi/g). Ra-226 concentrations were above the FSL at all but one of the locations within the boundaries of the former IX Plant. The FSL boundary in that area was based on the results of the static gamma survey and the presence of a near vertical cliff over 40 feet high on the north side of the IX Plant, as shown on Figures 1-2, 1-3 and 3-1.

### 3.1.14 Gamma Radiation Survey Results Summary

As discussed in the above subsections, the gamma radiation surveys indicated that surface soils within the initial boundaries of each of the on-site areas specified in the RSEWP, contain surface soils with Ra-226 concentrations above the 2.24 pCi/g FSL, as shown on Figure 3-1. A small fraction of the survey points within the initial boundaries areas are below the FSL. The locations of exceedances of Ra-226 (equivalent) are frequent and closely spaced such that delineation of any smaller, clean areas within the interior of the areas was not practical. About 11 survey grid points below the FSL are contiguous enough to isolate a potential, small clean area within Sandfill 1. The results of the static gamma radiation survey discussed above for all areas are further summarized in Table 3.13, *Gamma Radiation Results Summary*. The results show that the average surface soil Ra-226 concentrations, as determined by correlation with the gamma survey results (CPM), within the survey areas are significantly above the 2.24 pCi/g FSL, from approximately four to twenty times the FSL. As shown in Table 3.13, the surface soil Ra-226 concentration range is wide, with high standard deviations near or above the average concentrations indicating sporadic Ra-226 contamination in surface soil.

Based on the static survey level results (i.e., locations below the FSL), an outer boundary for each area was interpreted and is shown on Figure 3-1 as the "FSL Boundary". This boundary was drawn outside of most exceedances of the FSL. Where the results were inconclusive, the FSL Boundary was determined based on:

- Undisturbed ground, such as in wooded areas with native soils.
- Roads, structures, and fences.
- Topographic limitations such as precipices and steep hillsides.
- Boundaries of adjoining survey areas.

The RSEWP also specified one-point surface soil sampling for laboratory analysis at 20% of the 80-foot triangular grid nodes (sample locations), or at least 13 grid nodes within an area, and five from each of the nine Home Sites as discussed in Section 3.2. The FSL Boundary was confirmed and slightly revised based on the results of the surface soil sampling, as discussed in Section 3.2. Comparisons of surface soil Ra-226 concentrations by soil sampling and by static gamma radiation surveying at 218 points are shown in Table 3.14, *Gamma Radiation Survey and Surface Soil Ra-226 Results Comparison*. The results show that although there may be some variation between Ra-226 surface soil concentrations by soil sampling versus static gamma radiation survey at some locations, the averages are comparable. The average Ra-226 surface soil sampling results at 218 locations is 31.4 pCi/g with a standard deviation of 83.2 pCi/g whereas the static gamma radiation survey results at co-locations showed an average of 28.3 pCi/g with a standard deviation of 55.8 pCi/g. The static gamma radiation survey provided surface soil Ra-226 levels at over 750 additional on-site area locations and enhanced the completeness of surface soil Ra-226 characterization compared to soil sampling for laboratory analysis would have alone.

## 3.2 SURFACE SOILS METALS DATA

Surface soil samples (≤0.5 feet bgs) were collected from each of the survey areas, and analyzed for the preliminary COPCs (Ra-226, As, Mo, Se, U, and V), except those collected in August 2006 for the initial gamma versus Ra-226 correlation, which were only analyzed for Ra-226. The locations of each of the surface soil sample locations are shown on Figures 2-2 and 2-3, and the analytical results are presented on Figure 3-2, and Figure 3-3, *Surface Soil Analytical Results*. The analytical results are tabulated in Table 3.15, *Summary of Surface Soil Analyical Results, Metals*. These results include the initial correlation samples, the primary surface soil samples, step-out and boundary confirmation samples, and any additional surface soil samples that were collected at subsurface sampling locations. The surface soil validated analytical data are presented in Appendix B, *Laboratory Analytical Data*.

The results show that Ra-226, arsenic, and uranium exceed the screening levels at some locations, while all results for molybedenum, selenium and vanadium were below their respective screening levels (see Table 3.15). Only the surface soil analytical results for Ra-226, total uranium and arsenic are discussed, by survey area, in the following sections. The surface soil analytical results were compared to the Ra-226 FSL and EPA Region 9 industrial PRGs for arsenic and uranium, except the Home Sites, which were compared to EPA Region 9 residential PRGs.

### 3.2.1 NECR-1

A total of 49 surface soil samples were collected from NECR-1 (see Table 3.15). Of these 49 samples, 31 were primary samples, 17 were step-out samples outside the original area boundary, and one sample was a correlation sample. On-site (within the NECR-1 boundary) concentrations of Ra-226 ranged from 7.0 to 93.3 pCi/g (averaged 39.3 pCi/g); all exceeded the FSL of 2.24 pCi/g. Most of the step-out samples were collected north, northeast, and southeast of NECR-1, as shown on Figure 3-3. To the north of NECR-1, concentrations of Ra-226 exceeded the FSL close to the boundary and then dropped off below the FSL within 100 to 300 feet from the boundary. To the northeast, there are Ra-226 concentrations above the FSL (e.g., locations NECR1-281, -293 and -307). The locations of these samples are shown on Figure 2-3, and the results are shown on Figure 3-3 (sheet 1) NECR1-307 is located adjacent to Red Water Pond Road, which was formerly used as the haul road for the nearby Quivera mine. The results of three samples collected between NECR-1 and Sandfill 1 ranged from 1.3 to 5.2 mg/kg. These results confirmed the gamma survey results, and it was not necessary to revise the FSL Boundary based on the gamma survey results (see Figure 3-3).

Only four out of 49 soil samples collected from NECR-1 exceeded the uranium screening level of 200 mg/kg (See Figure 3-3). Concentrations ranged between 209 and 758 mg/kg. All four of those samples were collected from on-site locations at disparate locations within the area.

On-site arsenic concentrations ranged from non-detect to 8.3 mg/kg (average 3.9 mg/kg), while step-out arsenic concentrations ranged from 2.7 to 14.9 mg/kg (average 6.0 mg/kg). These data indicate that there is no significant difference between on-site and step-out arsenic concentrations. There also does not appear to be a spatial pattern to the arsenic concentrations, or a correlation with Ra-226 concentrations.

### 3.2.2 NECR-2

Twenty-four surface soil samples were collected from NECR-2 (see Table 3.15). Of these 24 samples, 15 were primary samples, four were step-out samples, and five were correlation samples On-site concentrations of Ra-226 ranged from 1.2 to 160 pCi/g (averaged 27.7), and all but one of the step-out samples exceeded the FSL. The one step-out sample that exceeded the FSL was located northeast of NECR-2, within the Magazine Area. These results confirmed the gamma survey results, and it was not necessary to revise the FSL Boundary (see Figure 3-3).

Only one out of a total of 24 soil samples from NECR-2 exceeded the uranium screening level of 200 mg/kg. That one sample was collected from an on-site location (see Figure 3-3) and was reported to be 370 mg/kg.

On-site arsenic concentrations ranged from 1.3 to 6.4 mg/kg (averaged 3.5 mg/kg), while step-out arsenic concentrations ranged from 3.3 to 8.1 (averaged 5.7 mg/kg). These data indicate that there is no significant difference between on-site and step-out arsenic concentrations. Three of the highest arsenic concentrations were from the three step-out locations samples near the Magazine area. There is no apparent pattern to the spatial distribution of arsenic concentrations, no a correlation with Ra-226.

### 3.2.3 Sandfill 1

Eighteen surface soil samples were collected from Sandfill 1 (see Table 3.15), three of which were collected at boundary confirmation locations. On-site concentrations of Ra-226 ranged from 0.8 to 47.3 pCi/g (averaged 10.2 pCi/g); 72% exceeded the FSL. All three boundary samples were located to the east of Sandfill 1 and all three exceeded the FSL, but ranged from 3.8 and 5.4 pCi/g (averaged 4.5 pCi/g). These results were used to slightly modify the FSL Boundary (see Figure 3-3).

No results exceeded the uranium screening level of 200 mg/kg.

Arsenic concentrations at Sandfill 1 ranged from 2.0 to 6.7 (average 3.9 mg/kg); 60% exceeded the screening level. All three boundary confirmation samples exceeded the arsenic screening level.

### 3.2.4 Sandfill 2

Thirteen surface soil samples were collected from Sandfill 2; no step-out samples were required. Ra-226 concentrations ranged from 0.8 to 36.0 pCi/g (average 10.2 mg/kg); 77% exceeded the FSL. These results confirmed the gamma survey results, and it was not necessary to revise the FSL Boundary (see Figure 3-3).

No sample results exceeded the uranium screening level of 200 mg/kg.

Arsenic concentrations ranged from 3.2 to 9.0 mg/kg (average 5.2 mg/kg); 60% exceeded the screening level. The five highest concentrations (above 5.0 mg/kg) were located to the west of the original Sandfill 2 boundary (See Figure 3-3).

### 3.2.5 Sandfill 3

Sixteen surface soil samples were collected from Sandfill 3. Two were collected at boundary confirmation locations and one sample was collected at a correlation point. Ra-226 concentrations ranged from 1.0 to 123.0 pCi/g (averaged 28.7 mg/kg); all samples but the three on-site samples and the correlation sample exceeded the FSL. The boundary samples were below the FSL. These results confirmed the gamma survey results, and it was not necessary to revise the FSL Boundary (see Figure 3-3).

An additional 10 surface soil samples were collected 50 to 400 feet northwest of Sandfill 3 for the initial gamma versus Ra-226 correlation (see Table 3.15) and were analyzed for Ra-226 only. These samples were collected between the Unnamed Arroyo, the Sediment Pad, Sandfill 3 and the NEMSA, as shown on Figure 3-3. Ra-226 concentrations in these samples ranged from 1.1 to 6.6 pCi/g (average 3.1 pCi/g); 50% exceeded the FSL.

Only one out of 17 samples exceeded the uranium screening level of 200 mg/kg; this sample, at 396 mg/kg, was located in the middle of the survey area.

Arsenic concentrations ranged from 1.5 to 5.3 mg/kg (averaged 3.5 mg/kg); 35% exceeded the screening level.

### 3.2.6 Ponds 1 and 2

Twenty-five surface soil samples were collected from Ponds 1 and 2 (see Table 3.15). Four of the locations were boundary confirmation samples; three samples resulted from subsurface locations that were not paired with a primary surface sample; and one was a correlation sample. On-site concentrations of Ra-226 ranged from 1.0 to 655 pCi/g (averaged 105.9 pCi/g); 81% exceeded the FSL. Concentrations of Ra-226 were below the FSL at all four boundary confirmation locations. These results confirmed the gamma survey results, and it was not necessary to revise the FSL Boundary (see Figure 3-3).

Only three (on-site) out of 25 soil samples from Ponds 1 and 2 exceeded the uranium screening level of 200 mg/kg. The concentrations of these three samples ranged from 339 to 1,080 mg/kg. Two of these samples were located in the northeast corner of Pond 1, and the third in the northwest corner of Pond 1 (ore material was noted here). These samples coincided with the highest Ra-226 results.

On-site arsenic concentrations ranged from 2.5 to 8.8 mg/kg (average 4.5 mg/kg), while boundary confirmation arsenic concentrations ranged from 2.2 to 4.5 (average 3.0 mg/kg). There does not appear to be a distinct spatial pattern in arsenic concentrations, nor a clear correlation with Ra-226 concentrations.

### 3.2.7 Pond 3/3a

Sixteen surface soil samples were collected from Pond 3/3a (see Table 3.15); no step-out locations were required. Of the 16 samples, 13 were primary samples, two were from subsurface sample locations, and one was a correlation sample. Concentrations of Ra-226 ranged from 1.4 to 875 pCi/g (averaged 102.1 pCi/g) and all but one exceeded the FSL. These results confirmed the gamma survey results, and it was not necessary to revise the FSL Boundary (see Figure 3-3).

Three out of 16 soil samples from Pond 3/3a exceeded the uranium screening level of 200 mg/kg, corresponding to the three highest Ra-226 concentrations. These three exceedances ranged from 1,020 to 3,970 mg/kg). All three of these samples were collected within the original area boundary from the central and southwest portion of Pond 3.

Arsenic concentrations ranged from 2.7 to 8.1 mg/kg (averaged 5.3 mg/kg); all but two exceeded the screening level. There does not appear to be a spatial pattern in arsenic concentrations, nor a correlation with Ra-226 concentrations.

### 3.2.8 Sediment Pad

Thirteen primary surface soil samples and one additional sample paired with a subsurface location were collected from the Sediment Pad (see Table 3.15); no step-out locations were required. Concentrations of Ra-226 ranged from 1.5 to 236 pCi/g (averaged 60.5 pCi/g); all but one exceeded the FSL. These results confirmed the gamma survey results, and it was not necessary to revise the FSL Boundary (see Figure 3-3).

Three out of 14 soil samples collected from the Sediment Pad exceeded the uranium screening level of 200 mg/kg. The concentrations were reported to be 363 mg/kg, 366 mg/kg and 1,640 mg/kg. All three exceedances were located in the central portion of the area.

Arsenic concentrations ranged from non-detect to 11.6 mg/kg (average 2.9 mg/kg); only two exceeded the screening level. The two samples exceeding the screening level came from disparate locations.

### 3.2.9 Non-Economic Materials Storage Area

Five surface soil samples were collected from the NEMSA and were coincident with five judgmental test pit locations. Ra-226 concentrations ranged from 0.9 to 2.6 pCi/g (averaged 1.5 pCi/g) with only one sample slightly exceeding the FSL.

Uranium results were all below the screening level.

Arsenic concentrations ranged from 0.7 to 4.3 mg/kg (averaged 3.4 mg/kg) and three of the samples were just above the arsenic screening level.

### 3.2.10 Boneyard

Five surface soil samples were collected from the Boneyard and were coincident with five judgmental test pit locations. Ra-226 concentrations exceeded the FSL in only one sample (45.9 pCi/g), located at the southern end of the Boneyard.

Uranium concentrations were all below the screening level.

Arsenic concentrations ranged from 1.3 to 5.5 mg/kg (averaged 3.9 mg/kg). Three of the five samples were above the screening level and one sample was equal to the screening level.

### 3.2.11 Vent Holes 3 and 8

Five judgmental soil samples were collected from the Vent Hole 3/8 area. This area was not included in the RSEWP, but was added during the field investigation according to FCR#004 (see Appendix C). Ra-226 concentrations ranged from 1.4 to 137 pCi/g (averaged 31.5 pCi/g); all but one sample exceeded the FSL. Uranium concentrations exceeded the screening level at only one location, corresponding to the location with the highest Ra-226 concentration, located in the central portion of the Vent Hole 8 area near the Vent Hole 8 structure. Arsenic concentrations were above the screening level at only one location (5.1 mg/kg), located in the Vent Hole 8 area.

### 3.2.12 Trailer Park

Five judgmental soil samples were collected from the Trailer Park. This area was not included in the RSEWP, but was added during the field investigation according to FCR#004 (see Appendix C). Ra-226 concentrations ranged from 2.1 to 33.2 pCi/g (averaged 4.2 pCi/g); three of the samples exceeded the FSL. These three samples were all located at the northern end of the area (see Figure 3-3). Uranium concentrations were all less than the screening level. Arsenic concentrations ranged from non-detect (<0.5 mg/kg) to 6.1 mg/kg (averaged 4.2 mg/kg), with no apparent spatial pattern and no correlation with Ra-226..

### 3.2.13 Home Sites

Five surface soil samples were collected from each of the nine Home Sites in the areas where the highest readings were obtained from the gamma radiation scan survey. Overall, Ra-226 concentrations ranged from 0.9 to 29.6 pCi/g (averaged 16.6 mg/kg). All results were below the FSL for Home Sites 1, 2, 3 and 5 (see Figure 3-2). Ra-226 exceeded the FSL in 100% of the samples collected around Home Sites 6, 7, 8 and 9 and in two of the five samples from around Home Site 4. A summary of the surface soil results for these five Home Sites is as follows:

- Home Site 4 – Ra-226 ranged from 1.3 to 3.6 pCi/g and two samples exceeded the FSL.
- Home Site 6 – Ra-226 ranged from 5.6 to 14.9 pCi/g and all five samples exceeded the FSL.
- Home Site 7 – Ra-226 ranged from 3.4 to 29.6 pCi/g. Removing the highest value in the range decreased to 3.4 to 9.4 pCi/g.
- Home Site 8 – Ra-226 ranged from 2.3 to 5.6 pCi/g. All five samples exceeded the FSL; however, two samples (2.3 and 2.5 pCi/g) were just above the FSL.
- Home Site 9 – Ra-226 ranged from 2.6 to 6.7 pCi/g and all five samples exceeded the FSL.

The results of the post-excavation soils removal confirmation sampling and analysis conducted by the EPA subsequent to the RSE investigation are included in Appendix D.

Uranium concentrations ranged from 0.7 to 20.5 mg/kg (averaged 4.5 mg/kg). The residential PRG of 16 mg/kg for uranium was exceeded at two sample locations; one from around Home Site 7 (20.5 mg/kg) and the other from around Home Site 9 (19.1 mg/kg).

Arsenic concentrations ranged from 2.8 to 5.5 mg/kg (averaged 4.2 mg/kg); 60% exceeded the screening level. There does not appear to be a correlation between arsenic concentrations and Ra-226 concentrations in surface soils collected around the Home Sites.

Molybdenum results were all non-detect (<5.0 mg/kg).

Selenium concentrations ranged from non-detect to 6.3 mg/kg and were all below the screening level of 5,100 mg/kg, as well as the residential PRG of 390 mg/kg.

Vanadium concentrations ranged from 21.5 to 49.7 mg/kg and were all below the screening level of 1,000 mg/kg, as well as the residential PRG of 78 mg/kg.

### 3.2.14 Unnamed Arroyo

Fifteen surface soil samples were collected from the Unnamed Arroyo during the correlation sampling in August 2006, and analyzed for Ra-226. Ra-226 ranged from 9.7 to 26.4 pCi/g (averaged 16.8 pCi/g); 100% exceeded the FSL. Because of these results, additional surface soil samples were not collected as planned in the RSEWP, and instead subsurface soil samples were collected according to FCR#001 (see Appendix C). The results of the subsurface soil sampling are discussed in Section 3.3.

### 3.2.15 Surface Soil Analytical Results Summary

Table 3.15 includes a statistical summary of the surface soils, which shows the following:

- Ra-226 values ranged from 0.8 to 875 pCi/g (averaged 30.6 pCi/g); 70% of the 263 surface soil samples analyzed for Ra-226 [includes stepouts] exceeded the FSL of 2.24 pCi/g.
- Toal uranium values ranged from 0.7 to 3,970 mg/kg (averaged 79.7 mg/kg); 7% of the 229 samples analyzed for total uranium exceeded the screening level of 200 mg/kg (industrial

PRG). Two samples from the forty-five samples collected from around the Home Sites exceeded the residential screening level of 16 mg/kg.

- Arsenic values ranged from non-detect (<0.5 mg/kg) to 14.9 mg/kg (averaged 4.2 mg/kg); 54% of the 229 samples analyzed for arsenic exceeded the screening level of 3.7 mg/kg. There did not appear to be a pattern to the spatial distribution of arsenic. The presence, absence or range of concentrations of arsenic do not consistently correlate with higher or lower Ra-226 or uranium concentrations.

- Molybdenuym values ranged from non-detect (<5.0 mg/kg) to 214.0 mg/kg (averaged 3.8 mg/kg); all results were below the screening level of 5,100 mg/kg (industrial PRG).

- Selenium values ranged from non-detect (<0.2 mg/kg) to 159 mg/kg (averaged 9.5 mg/kg); all results were below the screening level of 5,100 mg/kg (industrial PRG), and all samples from the Home Sites were below the residential PRG.

- Vanadium values ranged from 9.0 to 502 mg/kg (averaged 40.2 mg/kg); all results were below the screening level of 1,000 mg/kg (industrial PRG), and all samples from the Home Sites were below the residential PRG.

## 3.3 SUBSURFACE SOILS METALS DATA

Subsurface soil samples (>0.5 feet bgs) were collected from each of the original on-site survey areas, and the Unnamed Arroyo. Samples were collected from test pits, drill holes, and hand auger borings (Unnamed Arroyo). All subsurface soil samples were analyzed for the preliminary COPCs (Ra-226, As, Mo, Se, U, and V). The locations of each of the test pits, soil borings and auger holes are shown on Figure 2-4, and the analytical results for Ra-226, uranium and arsenic are shown on Figure 3-4, *Subsurface Soil Analytical Results*. The results of these analyses are also tabulated in Table 3.16, *Summary of Subsurface Soil Analyical Results, Preliminary COPCs*. All validated subsurface data is located in Appendix B.

The subsurface data from the on-site survey areas were compared to the FSL for Ra-226 and the EPA Region 9 industrial PRGs for uranium and arsenic. The use of the FSL is not strictly valid in comparison to subsurface metals results, but was used as a rough comparison to surface soil concentrations. Subsurface soil concentrations were primarily used to evaluate the vertical extent of impacts from mining, and to determine the depths to native soils. Soils sample results to depths of 10 feet bgs were used in the HHRA, as discussed in Section 4.0. The analytical results of the subsurface soil samples show that Ra-226, uranium and arsenic exceed the screening levels at some locations, while all results for molybedenum, selenium and vanadium were below their respective screening levels (see Table 3.16).

### 3.3.1 NECR-1

Twenty-eight subsurface soil samples were collected from five soil borings and one test pit at NECR-1. Total depths of the soil borings ranged from 14 to 45 feet bgs, and were extended into native ground. Ra-226 concentrations ranged from 1.0 to 103.0 pCi/g (averaged 21.4 pCi/g). In all drill holes, Ra-226 exceeded the FSL in the top two samples (5 and 10 feet bgs), except SB-131 on the north edge of NECR-1 (less than the FSL at 10 feet bgs). Ra-226 concentrations exceeded the FSL at depths greater than 10 to 16.5 feet at only one location (SB-090), where it exceeded the FSL in all samples down to 25 feet bgs.

Based on a comparison of pre-mine topography with post-mine topography and observations made during drilling, the approximate depths of the NECR-1 survey area are known. Ra-226 did not exceed the FSL in any samples deeper than the maximum depths of the NECR survey area, as summarized below.

| Loc ID | Estimated Depth to Native | Observed Depth to Native | Max Depth of Screening Level Exceedance |
|---|---|---|---|
| SB-016 | 15-20 | 18 | 15 |
| SB-046 | 25-30 | 25 | 10 |
| SB-095 | 10-15 | 12 | 10 |
| SB-090 | 35-40 | 28 | 25 |
| SB-131 | 15-20 | 22 | 5 |

The estimated depths to native material shown above were based on a comparison of pre-mine to post-mine topography, and the observed depths were based on observations made during the drilling. The maximum depth of the screening level exceedances was based on the depth of the last sample with Ra-226 greater then the screening level; the next sample in each case was collected 5 feet deeper. Non-native material with a distinct petroleum odor was observed at approximately 22 feet bgs in SB-131.

In boring SB-016, native material was observed at 18 feet bgs and the Ra-226 data supported this observation. The first five sampling intervals (starting at 5 feet bgs) reported Ra-226 concentrations of 21.1, 64.6, and 63.1 feet bgs, respectively; Ra-226 decreased to 1.4 pCi/g at 20 feet.

This sharp decrease in Ra-226 concentrations was observed in all five the soil borings. In some instances the decrease coincided with the observed depth in native material such as in SB-016, SB-090 and SB-095. In borings SB-046 and SB-131, it appears that the decrease in Ra-226 concentrations was due to encountering either native soils or reworked native materials. In the impacted fill materials, Ra-226 concentrations ranged between 4.2 and 103 pCi/g, while in native or re-worked native materials, Ra-226 concentrations ranged between 1.0 and 1.9 pCi/g.

The one test pit advanced at NECR-1 was located at the eastern end of the area, outside the main entrance gate, where the NECR survey area is only about five feet thick. The test pit (TP-138) was excavated to 4 feet bgs (native bedrock encountered) and sampled from 3.5 to 4 feet bgs. The FSL for Ra-226 was exceeded (24.2 pCi/g) in this one sample.
Uranium concentrations exceeded the screening level in only five samples from two soil borings (SB-046 and SB-090). In SB-090, uranium concentration exceedances ranged from 218 to 331 mg/kg. The shallowest uranium exceedance was reported at 25 feet bgs and corresponded with a Ra-226 concentration of 48.9 pCi/g. The three subsequent (deeper) uranium exceedances were 313, 331, and 240 mg/kg at 30, 35, and 40 feet bgs, respectively, corresponding to Ra-226 concentrations between 1.2 and 1.7 pCi/g. At 45 feet bgs, the uranium concentration decreased to 165 mg/kg and the Ra-226 concentration at this depth was 1.3 pCi/g. The only exceedance of uranium in SB-046 (337 mg/kg) was reported at a depth of 15 feet bgs and the Ra-226 concentration in this sample was 1.3 mg/kg.

The concentrations of uranium and Ra-226 in the next sample (20 feet bgs) were 3.4 mg/kg and 1.0 pCi/g, respectively.

Arsenic concentrations ranged from non-detect (<0.5 mg/kg) to 7.9 mg/kg (averaged 6.9 mg/kg). In all five soil borings, arsenic exceeded the screening level. Many of the exceedances were within the native material, coincident with Ra-226 concentrations less than the FSL, but not in all cases (see Table 3.16).

These results indicate that impacted materials generally extend to 10 to 15 feet bgs, except for the area around SB-090, where it extends to approximately 25 feet bgs. Soil boring SB-090 is located near the northwestern edge of NECR, and near an erosional gulley on the sideslope of the NECR-1 where the depth of NECR-1 is greatest.

### 3.3.2 NECR-2

Six subsurface soil samples were collected from five test pits at NECR-2. Ra-226 concentrations ranged from 1.2 to 12.6 mg/kg (averaged 5.9 pCi/g); all but one sample exceeded the FSL. The maximum depth of the test pits was from 1.0 to 5.0 feet bgs. Most areas of NECR-2 contain less than five feet of non-native or re-worked native materials. The eastern portion of the area appeared to have been cut, as the soils observed appeared to be primarily native. In the northwestern corner, around TP-052, the area appeared to have been filled in, possibly with the soil removed from the eastern portion of the area. Based on a comparison of pre-mine to post-mine topography, the northwestern corner of the area appears to be 15 to 20 feet deep, consisting primarily of native material.

At test pit location TP-015 in the southwestern corner of NECR-2, sandstone bedrock was observed at one foot bgs and excavating could not proceed any deeper. A sample was collected from 0.5 to 1.0 feet bgs and the Ra-226 concentration was 2.5 pCi/g, just above the FSL. Similarly, sandstone bedrock was observed at 1.5 feet bgs in TP-020 and excavating could not proceed any deeper. The Ra-226 concentration in the sample collected from 1.0 to 1.5 feet bgs was 1.2 pCi/g.

Native soils were logged in TP-035 (middle of area) from the ground surface to bedrock at 1.5 feet. The concentration of Ra-226 in the sample collected from 1.0 to 1.5 feet bgs was 10.4 pCi/g. This was also the case at TP-039 (eastern edge of area) where native soils were observed to bedrock at 1.5 bgs, and the sample collected from 1.0 to 1.5 ft bgs had a Ra-226 concentration of 5.5 pCi/g. Test pit TP-052 , located in the northwestern corner of NECR-2 contained non-native and reworked native materials to at least 4.0 feet bgs. The soil sampled collected from 1.5 to 2.0 bgs contained Ra-226 at 12.6 pCi/g, the highest in NECR-2. In what appeared to be native soils, the concentration of Ra-226 decreased to 2.9 pCi/g, just above the FSL.

Uranium and arsenic concentrations were all below the screening levels in the subsurface samples collected from NECR-2.

### 3.3.3 Sandfill 1

Nine subsurface soil samples were collected from five test pits in Sandfill 1. Ra-226 concentrations ranged from 0.6 to 113.0 pCi/g (averaged 39.4); all but one sample exceeded the FSL. Maximum sample depths ranged from 1.0 to 4.0 feet bgs. During test pitting, non-native material was observed to be as much as approximately 3.5 feet deep.

Native soils were observed starting at the surface of TP-043 to competent bedrock at 1.5 feet bgs. The one sample collected from this test pit from 1.0 to 1.5 feet bgs confirmed the presence of native soil. The concentration of Ra-226 in the sample was 0.6 pCi/g.

Non-native materials were observed to 3.5 feet bgs in TP-030. A shallow sample collected from 1.0 to 1.5 feet bgs reported a Ra-226 concentration of 113 pCi/g. A sample collected from observed native materials from 3.5 to 4.0 feet bgs showed a decrease in Ra-226 concentration to 4.8 pCi/g. Competent sandstone bedrock was encountered at 4.0 feet bgs.

Samples collected from test pits TP-049, TP-063, and TP-068, were similar to TP-030. Non-native materials were observed at depths ranging from 1.5 to 3.5 ft bgs. In all three test pits, sandstone bedrock was encountered at the bottom of the test pit. The samples collected above the bedrock reported a decrease in Ra-226 and usually uranium concentrations when compared to the samples collected in the non-native materials. The concentration of Ra-226 in the non-native materials from these three test pits ranged from 57.4 to 75.8 pCi/g, whereas, the Ra-226 concentration above the bedrock ranged from 6.4 to 8.8 pCi/g.

Uranium concentrations were all below the screening level in the subsurface samples collected from Sandfill 1.

Arsenic concentrations ranged from 1.1 to 13.9 mg/kg (average 5.3 mg/kg); four of the samples that exceeded the arsenic background screening level were at locations coincident with Ra-226 FSL exceedances. However, the arsenic exceedances were all reported in the deeper sample collected above the sandstone bedrock. The shallow samples collected in the non-native materials did not report any exceedance of arsenic above background.

### 3.3.4 Sandfill 2

Five subsurface soil samples were collected from five test pits in Sandfill 2, which shares its northern boundary with NECR-2. Ra-226 concentrations ranged from 1.1 to 3.8 pCi/g (averaged 2.2 pCi/g); only two of the samples were slightly above the FSL (see Figure 3-4). Both of the samples with FSL exceedances were located in the southern portion of Sandfill 2 and the Ra-226 concentrations were 2.4 and 3.8 pCi/g in TP-008 and TP-012, respectively. Native materials were observed starting from the ground surface until bedrock was encountered at depths ranging from 1.0 to 3.0 feet bgs. Samples were collected approximately at the midpoint between the ground surface and sandstone bedrock.

Uranium concentrations were all below the screening level in the subsurface samples collected from Sandfill 2.

Arsenic concentrations ranged from 3.1 to 5.3 mg/kg (averaged 3.9 mg/kg). Except for one sample, the arsenic concentrations ranged from 3.1 to 3.8 mg/kg very close to the mean background concentration of 3.7 mg/kg.

### 3.3.5 Sandfill 3

Seven subsurface soil samples were collected from five test pits in Sandfill 3. Ra-226 concentrations ranged from 1.2 to 84.1 pCi/g (averaged 27.8 pCi/g); all but one sample exceeded the FSL. Maximum sample depths ranged from 1.0 to 2.0 feet bgs. During test pitting, non-native material was observed to approximately 1.5 feet deep. At test pit locations TP-006, TP-009, and TP-025, native soil was logged starting at the surface to sandstone bedrock at a depth of 1.0 foot. The concentrations of Ra-226 in the soil samples from 0.5 to 1.0 feet bgs above the bedrock ranged from 5.1 to 27.8 pCi/g.

Non-native fill materials were observed in TP-005 and TP-014 to a depth of approximately 1.0 to 1.5 feet bgs. The concentration of Ra-226 in TP-005 decreased from 40.8 to 28.1 pCi/g between the fill and native intervals. Sandstone bedrock was encountered at 2.0 feet bgs. The concentrations of Ra-226 in TP-014 were reported as 1.2 pCi/g and 84.1 pCi/g for the 0.5 to 1.0 feet bgs and the 1.0 to 1.5 feet bgs sample intervals, respectively. Since the log for this test pit reports the fill/native soil interface as 1.0 feet bgs, there is a possibility that the sample labels were inadvertently switched for this location.

Uranium concentrations ranged from 21.1 to 488 mg/kg (averaged 162.6 mg/kg). The two samples that exceeded the uranium screening level (227 and 488 mg/kg) were the two samples collected from TP-014.

Arsenic concentrations ranged from 0.8 to 6.9 mg/kg (averaged 3.9 mg/kg); all but two of the samples exceeded the screening level.

### 3.3.6 Ponds 1 and 2

Fourteen subsurface soil samples were collected from two soil borings and three test pits in Ponds 1 and 2. The soil borings extended to 15 and 20 feet bgs. The maximum sample depths collected from the test pits were between 5.0 and 9.5 feet bgs. Ra-226 concentrations ranged from 0.7 to 438 pCi/g (averaged 71.2 pCi/g). No exceedances of the FSL occurred in samples from SB-071, which was located in the Pond 1 berm along the road on the north side of the ponds (see Figures 2-3 and 3-4). The FSL was exceeded in the 5 and 10 foot samples only from SB-082, which was sampled to 20 feet bgs. Native material was observed at a depth of 15 feet bgs at SB-082. The concentration of Ra-226 decreased from 12.2 to 1.1 pCi/g between the 10 - and 15 -foot bgs samples in this boring.

The highest Ra-226 concentrations detected in Ponds 1 and 2 were 417 and 438 pCi/g. These two samples were collected in Pond 1 at 1.5 and 5.0 feet bgs from test pits TP-035 and TP-058, respectively. These two test pits are located on the western side of Pond 1 with TP-035 near the lowest point in the pond. The Ra-226 concentration decreased to 1.3 pCi/g in the 8.5 to 9.0-foot bgs sample interval in TP-058; however, bedrock sandstone was not reached in this test pit. A decreasing trend in Ra-226 concentrations was also observed in TP-035 with Ra-226 concentrations reported in the 2.0 to 2.5 feet bgs and 9.0 to 9.5 feet bgs sample intervals as 41.5 and 19.6 pCi/g, respectively. It did not appear that native soil was reached in TP-035 and the depth of impacted pond sediments appears to be greater than 10 feet bgs.

The only subsurface samples collected from Pond 2 were from TP-030 near the center of the pond. The lowest location in the pond was not accessible due to soft, muddy ground conditions. The Ra-226 concentration in non-native pond materials was reported as 41.3 pCi/g in the 2.0 - to 3.0-foot bgs sample interval. Native materials were observed starting at 4.0 feet bgs to the depth of the test pit at 7.0 feet bgs. The sample collected from 4.0 to 5.0 feet bgs in the logged native materials reported a decreased Ra-226 concentration of 6.2 pCi/g.

The maximum depths of non-native material within Pond 1 and Pond 2 are 5 and 15 feet, respectively, based on a comparison of pre-mine to post-mine topography. This assumes no excavation into native ground was conducted during pond construction. Pond 1, based on test pit observations, contains over three meters of construction debris and pond sediments.

Uranium concentrations ranged from 1.3 to 760 mg/kg (averaged 116.7 mg/kg). The screening level was exceeded in three samples (206 to 760 mg/kg), collected from test pits TP-035 and TP-058, where the two highest Ra-226 concentrations were detected.

Arsenic concentrations ranged from 1.4 to 6.8 mg/kg (averaged 4.9 mg/kg); all but two samples exceeded the screening level, including locations where Ra-226 was below the FSL.

### 3.3.7 Pond 3/3a

Fourteen subsurface soil samples were collected from one soil boring and four test pits in Pond 3/3a. The soil boring was sampled every five feet to 25 feet bgs. The maximum sample depths collected from the test pits were from 9.0 to 9.5 feet bgs. Ra-226 concentrations ranged from 0.7 to 15.7 pCi/g (averaged 3.4 pCi/g). There were no exceedances of the FSL from SB-061, which was located on the berm road between NECR-1 and Pond 3 on the east side of Pond 3 (see Figures 2-3 and 3-4). Ra-226 exceeded the FSL in only three of the test pit samples.

The concentration of Ra-226 in TP-007, located between Ponds 3 and 3a, was 4.5 pCi/g in the 5.0 to 5.5-foot bgs sample. The Ra-226 concentration at 9.0 to 9.5 feet bgs was 0.7 pCi/g and this sample appeared to be in native or re-worked native material. No exceedance of the FSL was reported in TP-014 and TP-037 at depths greater than 5.0 feet bgs. However, it was difficult to tell if the materials were pond sediments or native materials at these locations. No samples between 0.5 and 5.0 feet bgs were collected in these two locations; therefore, Ra-226 concentrations greater than the FSL could exist between the surface and 5.0 feet bgs. This observation is supported by the Ra-226 results from TP-029 located between TP-014 and TP-037. In TP-029, Ra-226 concentrations exceeded the FSL in the 3.0 to 3.5 foot bgs and 6.0 to 6.5 foot bgs sample intervals. The Ra-226 concentrations were reported to be 14.3 and 15.7 pCi/g, respectively. However, the Ra-226 concentration (2.1 pCi/g) decreased to below the FSL in the 9.0 to 9.5 foot bgs interval in the bottom of TP-029.

The maximum depth of non-native material within Pond 3/3a is 10 feet, based on a comparison of pre-mine to post-mine topography; this assumes no excavation into native ground was conducted during pond construction.

Uranium concentrations were all well below the screening level in the subsurface samples collected from Pond 3/3a.

Arsenic concentrations ranged from 2.9 to 6.7 mg/kg (average 4.7 mg/kg); all but three samples exceeded the screening level, at locations with Ra-226 both above and below the FSL.

### 3.3.8 Sediment Pad

Nine subsurface soil samples were collected from five test pits at the Sediment Pad. Ra-226 concentrations ranged from 2.8 to 165 pCi/g (averaged 70.0 pCi/g); all of the samples exceeded the FSL. Maximum sample depths ranged from 1.0 to 10.5 feet bgs.

Non-native fill materials were observed to a depth of 3.0 feet in TP-006, located on the west side of the Sediment Pad. The Ra-226 concentration reported from the fill sample (1.5 to 2.0 feet bgs) was 92.9 pCi/g. The sample collected from the observed native soil (3.0 to 3.5 feet bgs) showed a decrease in Ra-226 concentration to 2.8 pCi/g, just slightly above the FSL. This same trend was observed at TP-012 and TP-014. However, the depths of fill materials at these locations were between 1.0 and 1.5 feet bgs and the native soil Ra-226 concentrations were 2.9 and 9.8 pCi/g at TP-012 and TP-014, respectively.

The location investigated on the east side of the Sediment Pad, TP-021, appeared to be located over a historic pond. Both fill samples from this test pit exceeded the FSL (99.7 and 86.3 pCi/g) and the depth of fill materials exceeded the depth of the excavator (10.5 bgs).

Only one sample was collected from TP-026 where bedrock was encountered at 3.0 feet bgs. The test pit logs reported that the sample was collected in what appeared to native soils; however, the concentration of Ra-226 was 86.6 pCi/g, greater than the FSL.

The maximum depth of non-native material within the Sediment Pad is 10 feet, based on a comparison of pre-mine to post-mine topography. This assumes no excavation into native ground was conducted during pad construction.

Uranium concentrations ranged from 68.6 to 357 mg/kg (averaged 161 mg/kg). Three of the samples exceeded the screening level, at locations coincident with higher Ra-226 concentrations.

Arsenic concentrations ranged from non-detect to 5.5 mg/kg (averaged 2.7 mg/kg); four of the samples exceeded the screening level, generally at locations coincident with the lowest Ra-226 concentrations.

### 3.3.9 Non-Economic Materials Storage Area

Thirteen subsurface soil samples were collected from five test pits at the NEMSA. Ra-226 concentrations ranged from 0.8 to 140 pCi/g (averaged 45.4 pCi/g). Maximum sample depths ranged from 4.5 to 9.0 feet bgs. As specified in the RSEWP, one sample of the pre-cap material was to be collected at each test pit. In the case of TP-002, the pre-cap surface was located at 0.25 feet bgs. Therefore, this sample collected in non-economic material from 0.25 to 0.75 bgs is considered a subsurface sample. Based on test pit observations, the depths to native material ranged from around 2 feet along its southern boundary with the Boneyard, to greater than 10 feet at its northern end (based on visual observations). A comparison of pre-mine to post-mine topography suggested the maximum depth at the northern end is approximately 12 feet. Concentrations of Ra-226 in the non-economic materials ranged from 8.4 pCi/g to 140 pCi/g. The four Ra-226 concentrations below the FSL were all located in native materials and ranged between 0.8 and 1.3 pCi/g.

Uranium concentrations ranged from 1.4 to 390 mg/kg (averaged 124.9 mg/kg). Two of the exceedances (227 and 311 mg/kg) were coincident with native soil samples collected from TP-001 and TP-002. The uranium concentrations in the other two native sample from TP-003 and TP-005 were 49.3 and 1.4 mg/kg, respectively. Native soil was not reached in TP-004 as the depth to native soil exceeded the depth of the excavator. The third exceedance of uranium (390 mg/kg) was collected in non-economic material from TP-004.

Arsenic concentrations ranged from non-detect to 4.9 mg/kg (averaged 2.2 mg/kg); three of the samples exceeded the screening level, and two of these samples were collected in native soil.

### 3.3.10 Boneyard

Eleven subsurface soil samples were collected from five test pits in the Boneyard. Ra-226 concentrations ranged from 1.1 to 50.7 pCi/g (averaged 11 pCi/g). However, only three samples exceeded the FSL; all three of which were collected from test pit TP-004, which was located near northern boundary with the NEMSA. This test pit contained trash, scrap metals and gray fill materials. The Ra-226 concentrations in the three other test pits ranged from 1.1 to 1.9 pCi/g. This indicates that some mine materials were placed near TP-004 in addition to the scrap metal and other debris, but mine materials do not appear to be prevalent throughout the Boneyard

As specified in the RSEWP, one sample of the pre-cap material was to be collected at each test pit in the Boneyard. However, unlike NEMSA, there was not a visual distinction between the cap soil material and the re-worked native soil material mixed with debris. Therefore, no pre-cap samples were collected from the Boneyard; samples were collected approximately every five feet to native soil plus one sample of native soil.

Maximum sample depths ranged from 1.5 to 10.0 feet bgs. Based on test pit observations, the depths to native material ranged from at the surface at its southern end, to approximately 9 to 10 feet along the western lobe near TP-004 and TP-005. A comparison of pre-mine to post-mine topography suggested that depths were zero along its entire eastern lobe, 5 to 7 feet along its western lobe, and 8 feet or so in its northwestern corner.

No debris was noted in TP-001. Both TP-002 and TP-003 observed partially buried cables but no other debris. Both TP-004 and TP-005 contained large amounts of buried debris including scrap metal and plastic debris.

Uranium concentrations ranged from 0.8 to 240 mg/kg (average 46.2 mg/kg). Only two of the samples exceeded the FSL, both were from TP-004 and were coincident with two of the higher Ra-226 concentrations.

Arsenic concentrations ranged from 0.8 to 5.2 mg/kg (averaged 3.8 mg/kg). Seven of the samples exceeded the FSL; the four that did not were collected from test pit TP-004 in the northwestern corner.

### 3.3.11 Unnamed Arroyo

Ten hand auger holes were advanced each to 3 feet bgs from the edge of NECR-1 to near the confluence with the next arroyo (see Figure 3-4). Three composite subsurface soil samples were collected from each auger hole at 0-1 foot bgs, 1-2 feet bgs, and 2-3 feet bgs, for a total of 30 subsurface soil samples from the Unnamed Arroyo. Ra-226 concentrations ranged from 8.4 to 35.7 pCi/g (average 16.4 pCi/g); all 30 samples exceeded the FSL. The vertical distribution of concentrations does not suggest a downward decreasing trend from 0 to 3 feet bgs; in four of the holes, the highest concentrations were detected in the deepest samples. There also does not appear to be a spatial trend with the highest Ra-226 concentration located at SB-005 in between NECR-1 and the next arroyo.

Uranium concentrations were all below the screening level of 200 pCi/g.

Arsenic concentrations ranged from 1.2 to 8.2 mg/kg (averaged 3.4 mg/kg); the screening level was exceeded in only nine of the samples, seven from the deepest samples from each hole, and two from 1 to 2 feet bgs.

### 3.3.12 Subsurface Soil Analytical Results Summary

Table 3.16 includes a statistical summary of the analytical results, which shows the following, site wide:

- Ra-226 values ranged from 0.6 to 438 pCi/g (averaged 30.9 pCi/g); 66% of the 146 subsurface soil samples analyzed for Ra-226 exceeded the FSL of 2.24 mg/kg.
- Total uranium values ranged from 0.7 to 760 mg/kg (averaged 86.4 mg/kg); 12% of the 146 samples analyzed for uranium exceeded the screening level of 200 mg/kg.
- Arsenic values ranged from non-detect (<0.5) to 13.9 mg/kg (averaged 4.0 mg/kg); 52% of the 146 samples analyzed for arsenic exceeded the screening level of 3.7 mg/kg.
- Vanadium values ranged from 10.4 to 173 mg/kg (averaged 40.1 mg/kg); all results were below the screening level of 1,000 mg/kg.
- Selenium values ranged from non-detect (<0.2 mg/kg) to 227 mg/kg (averaged 16.0 mg/kg); all results were below the screening level of 5,100 mg/kg.
- Molybdenuym values were all non-detect (<5.0 mg/kg).

## 3.4 SOIL LEACHATE ANALYSES

### 3.4.1 Soils Synthetic Precipitation Leachate Procedure

A total of 16 surface and subsurface samples were collected for analysis by the SPLP method, as described in Section 2.3. Two samples were collected from each of the following areas.

- NECR-1
- NECR-2
- Ponds 1 and 2
- Pond 3/3a
- Sandfill 1, 2 and 3
- Sediment Pad

The leachate was analyzed for the preliminary COPCs (Ra-226, uranium, arsenic, selenium, and vanadium), the results of which are presented in Table 3.17, *Summary of Synthetic Precipitation Leaching Procedure Analytical Results*. Laboratory analytical reports are included in Appendix B. The results of the SPLP analyses indicated the following:

- Ra-226 ranged from non-detect to 27.1 pCi/L (averaged 5.6 pCi/L).

- Uranium concentrations ranged from 0.00096 to 4.4 mg/L.

- Arsenic concentrations ranged from 0.0013 to 0.0084 mg/L.

- Molybdenum results were all non-detect (<0.1 mg/L).

- Selenium concentrations ranged from non-detect (<0.0029 mg/L) to 0.94 mg/L.

Available analytical data for Site mine water are presented in the groundwater technical memorandum titled *Groundwater Quality in the Westwater Canyon Member at the Northeast Church Rock Mine* (MWH, 2004c). These data represent the ambient groundwater quality in the Westwater Canyon Member at the Site. These data indicated the following:

- Concentrations of Ra-226 ranged from 0.6 to 490 pCi/L (averaged 97.6 pCi/L), compared to the New Mexico Human Health Standard of 30 pCi/L (Ra-226 and Ra-228 combined).

- Concentrations of uranium ranged from 0.725 to 3.71 mg/kg (averaged 2.08 mg/kg), compared to the New Mexico Human Health Standard of 5.0 mg/kg.

- Concentrations of arsenic ranged from 0.0100 to 0.0118 mg/kg (averaged 0.0102 mg/kg), compared to the New Mexico Human Health Standard of 0.1 mg/kg.

- Concentrations of molybdenum ranged from 0.001 to 0.04 mg/kg (averaged 0.012 mg/kg), compared to the New Mexico Human Health Standard of 1.0 mg/kg.

- Concentrations of selenium ranged from 0.0.004 to 0.05 mg/kg (averaged 0.031 mg/kg), compared to the New Mexico Human Health Standard of 0.05 mg/kg.

The laboratory results from the SPLP leachate analyses suggested that if the materials within the areas listed in Table 3.17 were subjected to sufficient infiltration by rainwater or snowmelt, they could generate a leachate that contains Ra-226, uranium, selenium and/or arsenic. While the SPLP leachate results were primarily below the New Mexico Human Health Standards for groundwater (NMAC 20.6.2.3103) or the Federal Maximum Contaminant Levels (MCLs), there were exceedances of one or the other of these standards for Ra-226, uranium and selenium, as shown in Table 3.17. Ra-226 exceeded the MCL of 5 pCi/L in five samples from Ponds 1/2, Pond 3 and Sandfill 1, but did not exceed the New Mexico standard of 30 pCi/L. Both selenium and uranium exceeded the MCL and New Mexico standard of 0.03 mg/L in two samples from Ponds 1/2 and one sample from Pond 3/3a. However, the concentrations of these constituents are all within the range of concentrations detected in the Westwater Canyon Member, with the exception of selenium. Selenium concentrations in the SPLP leachate exceeded the maximum concentrations detected in the Westwater Canyon Member in samples collected from Ponds 1 and 2 and Pond 3/3a. Additionally, it should be noted that as a practical matter, rainfall does not impact groundwater in the Westwater Canyon Member as a result of a combination of arid climate, depth to groundwater and the number and thickness of intervening confining layers.

### 3.4.2 Soils Toxicity Characteristic Leaching Procedure

Eleven subsurface soil samples were collected from the Boneyard and analyzed using the TCLP method, which is designed to determine the mobility of potential inorganic analytes, specifically the RCRA priority pollutant metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver). The results of these analyses are presented in Table 3.18, *Summary of Toxicity Characteristic Leaching Procedure Analytical Results*. Laboratory analytical reports are included in Appendix B. All results were non-detect, indicating that there are no materials in the Boneyard capable of generating a poor quality leachate of metals.

## 3.5 SOILS ORGANICS DATA

### 3.5.1 Boneyard

Eleven surface soil samples were collected between one and ten feet bgs from test pits in the Boneyard. The samples were analyzed for VOCs by EPA Method 8260B and for SVOCs by EPA Method 8270C. Laboratory analytical reports are included in Appendix B. The results of these analyses were non-detect for all VOC and SVOC parameters.

### 3.5.2 NECR-1

One subsurface soil sample was also collected from the north edge of NECR-1 for analysis of organic compounds. During drilling at soil boring SB-131 in NECR-1, which was located along the northeastern edge of NECR-1 (see Figure 3-4), a dark gray clayey material was encountered that had a distinct petroleum odor to it. Consequently, one soil sample was collected between 22.5 and 24 feet bgs and submitted for analysis of Total Petroleum Hydrocarbons (TPH) by EPA Method 8015B and VOCs by EPA Method 8260B. Laboratory analytical reports are include in Appendix B. All VOC parameters were non-detect, except for the parameters sec-Butylbenzene (0.24 mg/kg) and 1,2,3-trichlorobenzene (0.53 mg/kg). The results for these two compounds were both significantly below their respective EPA Region 9 PRGs. The results of the TPH analysis revealed the following:

- Diesel range organics at 1,400 mg/kg
- TPH $C_8$-$C_{40}$ at 1,900 mg/kg
- Oil range organics at 460 mg/kg

These results suggest that the material sampled contained primarily diesel or fuel oil range organic compounds.

## 3.6 SOILS AGRONOMIC DATA

Fifteen surface soil samples and five subsurface soil samples (test pits) were collected from analysis of agronomic parameters, and other constituents that could have an impact on plant growth. The samples were analyzed for: pH, calcium, magnesium, potassium, sodium, Sodium Absorption Ratio (SAR), chlorine, arsenic, molybdenum, radium-226, selenium, uranium, and vanadium. The results of analyses for agronomic parameters are presented in Table 3.19, *Summary of Surface Soil Analytical Results, Agronomic Parameters*. The results of metals analyses in surface soils are shown in Table 3.15. The purpose of the analyses was to identify the potential risks to plant establishment based on the levels of constituents present. Results from the laboratory analysis were used to evaluate the impact of constituent levels on direct revegetation success at the Site and to determine if additional soil cover may be necessary in some areas to provide a suitable medium for root growth and plant establishment. Although toxicity thresholds of plants for each constituent will vary by individual species and life form (e.g. grasses, forbs, shrubs, trees), general toxicity guidelines and potential impacts on plant establishment at the Site are outlined below.

The level of arsenic that plants tolerate varies by plant species and life form. Although some species of grass are extremely tolerant of high levels of arsenic and maintain normal growth at very high levels, most plants will begin to exhibit symptoms of toxicity (reduction in plant biomass, decreased root growth, deceased germination) when arsenic levels in the soils reach 50 to 100 mg/kg. Studies evaluating the effect of arsenic toxicity on ryegrass, reported lowest observable effective concentration (LOEC) for arsenic in soils at 50 mg/kg, with substantial reductions in plant growth occurring at 250 mg/kg (Jiang and Singh, 1994). Concentrations of arsenic in surface soils ranged from non-detect (<0.5 mg/kg) to 13.9 mg/kg, well below the toxicity threshold of 50 mg/kg. Based on toxicity thresholds in the literature, arsenic concentrations in the soil would not negatively impact plant establishment at the Site.

Molybdenum is a microelement that is least soluble in an acid environment and more readily available in alkaline soils. When elevated levels of molybdenum occur in soils plant toxicity can occur. The level of molybdenum that plants tolerate varies by plant species and life form. Ducsay and Kovacik (2001) reported sensitive agronomic species displayed signs of molybdenum toxicity at 90 mg/kg, where native grasses and shrubs tend to have higher tolerances to molybdenum in soils, exhibiting toxic effects of molybdenum at much higher concentrations, around 150 mg/kg. As a general guide, molybdenum levels in soils are considered safe to native plants at levels below 150 mg/kg. Results from the laboratory analysis report molybdenum surface and sub-surface concentrations at all locations below laboratory detectable levels, with one exception, NECR-1. NECR-1 had four surface soil samples with detectable levels of molybdenum, with only one sample exceeding the molybdenum toxicity threshold of 150 mg/kg. Based on toxicity thresholds in the literature, the extent of molybdenum in NECR-1 would have negligible impact on vegetation establishment.

Radium-226 is the most abundant and stable radionuclide in the biosphere, with increased mobility and solubility in soils under extremely acidic conditions (Kabata-Pendias, 2000). Although results from the laboratory analysis report concentrations of Ra-226 at the Site ranged from non-detect (<0.6 mg/kg) to 438 mg/kg, the impact of these levels on vegetation establishment cannot be determined. No information was uncovered in the literature that would provide an adequate way to measure the phytotoxicity of Ra-226; therefore the impact of Ra-226 on plant establishment cannot be evaluated. However, due to the slightly basic pH of the soils at the Site and low mobility of Ra-226 in solution, it is probable that the amount of Ra-226 in solution available for plant uptake would be limited, lowering the potential for plant toxicity to occur.

Selenium is a naturally occurring element found in rocks, soil and water. Selenium enters the soil profile through the weathering of Selenium-rich rocks, moving through the soil until adsorbed on clay particles, iron hydroxides or organic particles. Selenite and selenates are produced in the soil by microorganisms from the less soluble forms of selenium. When selenium occurs in alkaline soils and becomes oxidized as selenate, the selenium becomes water-soluble. This form is highly toxic and easily leached from the soil, thus facilitating uptake of selenium by certain plants. Although some

studies have shown sensitive species of ryegrass exhibiting selenium toxicity in sandy soils with selenate concentrations as low as 2 mg/kg (Smith, 1984), symptoms of selenium toxicity for most plants occur when selenium levels in the soils range from 10 to 20 mg/kg. Results from the laboratory analysis at the site report selenium levels in NECR-1, Sediment Pad, NEMSA, Boneyard, Sandfill 1, Sandfill 3, and Ponds 1 and 2 exceeding the toxicity threshold of 10 to 20 mg/kg for plants. Based on information in the literature, direct revegetation at the site will be impaired in locations exhibiting elevated selenium concentrations in the soils, suggesting additional topsoil may be needed for successful plant establishment.
Uranium is a naturally occurring element found in low levels within all rock, soil, and water, existing in +4 and +6 oxidation states in most geologic environments (Kabata-Pendias, 2000). Through the process of weathering, uranium forms mainly organic complexes in the soil that are easily soluble and mobile, with the distribution of uranium highly controlled by the oxidation state and Eh-pH of the system. Although few studies have been done to evaluate the toxicity of uranium on plants, one study conducted in 1995 found no adverse effect of uranium on native plant species at uranium levels of 5,000 mg/kg in soil. All areas of the Site were well below the no observable effective concentration (NOEC) of 5,000 mg/kg, indicating uranium concentrations in the soil would not negatively impact plant establishment at the Site.

Vanadium is a natural element in the earth, forming compounds with other elements such as oxygen, sodium, sulfur, or chloride. Although small amounts of vanadium have been found to stimulate plant growth, present in large amounts vanadium is toxic to plants, with pentavalent vanadium being the most toxic form (Irwin, 1997). Vanadium toxicity to plants varies with soil type due to the differences in phytoavailablity associated with soil colloids and organic matter. For example, studies have shown vanadium toxicity occurring in sandy soils at 80 mg/kg, where vanadium concentrations of 100 mg/kg in loamy soils had no effect on plant growth (Kabata-Pendias, 2000). As a general guide, vanadium levels in soils are considered safe to plants at levels below 100 mg/kg. Although results from this RSE indicated a few samples with vanadium concentrations greater than 100 mg/kg, nearly all of the samples collected at the Site had vanadium concentrations below the phytotoxicity level of 100 mg/kg. Impacts to plant growth from vanadium concentrations in the soil will be limited to NECR-2 where elevated levels of selenium are already present, suggesting additional topsoil may be needed in this location to provide an adequate medium for plant growth.

Soluble salts, Sodium Absorption Ratio (SAR) and pH are important soil properties and can impact the success of plant growth and establishment. When high amounts of soluble salts (calcium, magnesium, potassium) are present, severe plant growth problems can occur. In addition, soils high in sodium or elevated SAR can present physical restrictions in the soil for plant growth. When high levels of sodium are present, exchange sites on the soil particles become saturated with sodium, creating dense layers, restricting root development and plant growth.

Soil pH controls the solubility of ions and impacts plant growth under extreme alkaline or acidic conditions. Under acidic conditions, many soil minerals dissolve, increasing the concentration of metal ions in solution to toxic levels, inhibiting plant growth. Under alkaline conditions, the solubility of minerals can decrease to the point that nutrient deficiencies can occur, reducing plant biomass.

Results from this RSE indicated consistently neutral or slightly basic pH at the Site, with low soluble salts and SAR, with one exception. Samples taken from the Sediment Pad had extremely high levels of salts and an elevated SAR at the surface (EC = 11.70 and SAR of 20.90). Although pH for the Sediment Pad is neutral and would not impact plant establishment at the Site, elevated salts and sodium levels will limit direct revegetation success on the Sediment Pad, indicating additional soil cover will be needed for plant establishment.

Overall, constituent concentrations at the site are relatively low and the quality of the soil high, suggesting some areas within the Site would be able to support plant communities without additional soil cover. However, elevated selenium, vanadium or salts occurring in NECR-1, Sediment Pad, NEMSA, Boneyard, Sandfill 1, Sandfill 3, and Ponds 1 and 2 suggest that direct revegetation at these locations would be challenging in some areas and that additional soil cover would be advised to provide an adequate growth medium for vegetation establishment. The amount and total area of soil cover needed should be determined by the levels of constituents present at each location.

# 4.0 HUMAN HEALTH RISK ASSESSMENT

This section documents the methods used in, and results of, a human health risk assessment (HHRA) conducted for the Site. The HHRA is a quantitative and qualitative evaluation of potential impacts of Site-derived contaminants on human health, in the absence of remediation or institutional controls. Results of the HHRA are used to determine whether residual levels of contaminants in Site media are protective of human health and may be left in place, or consideration of remedial alternatives are warranted. As such, results of this HHRA will be used to evaluate the need for potential remediation at the Site, and will provide the basis for the development of alternative, risk-based cleanup goals for the Site, as appropriate.

The HHRA described herein was conducted in accordance with methods described in Section 6.0 of the approved *Removal Site Evaluation Work Plan* (MWH, 2006). This HHRA is comprised of a site-specific conceptual site model (CSM), screening-level HHRA, and baseline HHRA, as described in the following subsections.

## 4.1 CONCEPTUAL SITE MODEL

The CSM is a descriptive and graphical presentation of the physical, chemical, and biological relationships between sources of contaminants and potentially exposed populations. As such, the CSM describes and integrates information on the following (EPA, 1989):

- Contaminant sources, contaminated media and COPCs;
- Contaminant fate and transport pathways;
- Potentially exposed populations under current and future scenarios; and
- Potentially complete exposure pathways between contaminated media and receptors.

Each of these components of the CSM for the Site are described below.

### 4.1.1 Contaminated Media and COPCs

Sources of contamination and potentially impacted media associated with the Site, and downgradient off-site areas, are described in this subsection.

As described in Section 3.1.1 of the *Removal Site Evaluation Work Plan* (MWH, 2006), the primary ore mineral that was mined at the Site was coffonite (U(SiO4)1-x(OH)4x), which was placed in small temporary stockpiles at NECR-1 and NECR-2 before transport to the Church Rock mill site. A level pad was created at NECR-1, and fill material consisting of non-economic material was placed to a depth of approximately 20 to 30 feet in the northwestern corner of NECR-1. The pad for NECR-2 was made of native material and did not require material from processing of the ore at the Church Rock mill. Ore and low-grade ore stockpiles were temporarily stored on the NECR-1 and NECR-2 pads prior to off-site transport to, and processing at, the Church Rock mill. Following New Mexico's approval of a license amendment to permit placement of tailings in mine stopes for structural reinforcement in 1978, tailings material from ore processing at the mill was stored in three areas referred to as Sand Backfill Areas No. 1, No. 2 and No. 3 (see Figure 1-2). The bulk of the tailings material from the sand backfill areas was placed in the mine stopes; the remaining tailings were removed and disposed of off-site during the 1986 NRC reclamation. In addition, rainfall runoff from the sand backfill areas and water from the mine dewatering operations (see Section 1.2.2) was routed to three sediment ponds. Sediment in these ponds was periodically removed and temporarily placed on the Sediment Pad prior to off-site transport to the mill. The water in these ponds was treated and then discharged down the Unnamed Arroyo pursuant to an NPDES permit.

Residual tailings material in the three sand backfill areas and in the sediments in the ponds and Sediment Pad were removed and taken off-site in 1986, pursuant to NRC License No. SUA-1475, Condition 33 (UNC, 1989b), as discussed in Section 1.2.2. The tailings material was identified based on the ratio of natural uranium to Ra-226, which was less than 0.75 for tailings. Low-grade ore and non-economic material had a ratio of greater than 0.75 and native ground had low concentrations of all radionuclides. The bulk of the tailings material from the sand backfill areas was placed in the mine stopes pursuant to State approval. The sandfill areas were further cleaned up using NRC approved reclamation criteria for NECR based on foreseeable future uses of the site as grazing land and wildlife habitat. Because the NRC reclamation focused on tailings removal, the RSE focused on the potential that material with elevated levels of radionuclides may still be present in areas of NECR as suggested by the verification results shown in the *Tailings Sand Backfill Cleanup Verification Report* (UNC, 1989a).
Non-economic material was also placed in the NEMSA. Refuse and other discarded equipment was placed in the Boneyard. Both of these sites were reclaimed in 1994 (UNC, 1994), which included placement of one foot of topsoil over the non-native materials and then seeding.
Groundwater from the mine workings was pumped to the surface and treated in three ponds to reduce suspended solids and radionuclide concentrations and then sent through the IX unit (see Section 1.2.2). The spent water was then discharged to the northeast along the Unnamed Arroyo, in accordance with a NPDES permit, which restricted the discharge of COPCs into the Unnamed Arroyo.

Due to the potential for transport of site soils or sediment by wind or rainwater, and to a lesser extent by human and animal activity, potential impacts to nine Home Sites near the mouth of the Unnamed Arroyo were investigated. Potential sources of any such impacts include historical site operations, operations at the Kerr McGee mine, or background conditions. [The Bureau of Land Management, in their conditional approval letter (BLM, 1990) of Quivera's Abandonment and Reclamation Plan, instructed Quivera Mining Company to reclaim the surface of roadways, fence lines, vent holes protore storage areas, and mine ponds so that gamma radiation levels would be reduced to 50 uR/hr above background and reclaim the surface of the mine spoils area so that gamma radiation levels would be reduced to below 57 uR/hr above background (BLM, 1990). Values of 50 uR/hr and 57 uR/hr are approximately equivalent to 23.7 pCi/g and 27 pCi/g, respectively, as discussed in Section 2.5.

### 4.1.2 Contaminant Fate and Transport Pathways

As described in Section 3.0, the chemicals detected at the Site during the 2006 field investigation include several metals (i.e., arsenic, molybdenum, selenium, uranium, vanadium and zinc), and one radionuclide (i.e., Ra-226). These metals and radionuclide are naturally occurring elements in the Earth's crust. Radium is naturally-occurring and is almost ubiquitous in soil, water, geologic materials, plants and foods at low concentrations (ATSDR, 1990). Radium is only moderately soluble in water and can enter surface water or groundwater by desorption from rock surfaces, dissolution of geologic materials, and by ejection from minerals during radioactive decay (USGS, 1998). However, radium solubility is controlled by adsorption to, or co-precipitation within, sulfate minerals (e.g., barite and gypsum). In experiments on radium bioavailability in contaminated soils and sediment, leaching of radium from waste pit materials was observed to be low (DeLaune et al., 1994). The adsorptive behavior of radium is similar to that of other divalent cations including barium, calcium and strontium, and solubility in water generally increases with increasing pH (ATSDR, 1990). Consequently, radium is not a very mobile constituent in the environment (ATSDR, 1990). For radionuclides including radium, radioactive decay is the only degradation process that results in conversion of a radioisotope to more or less harmful daughter products. The radioactive half-life of Ra-226 is 1,602 years, and the decay products include radon-222 and alpha/gamma emissions (ATSDR, 1990).

For the stable metals, weathering of metal-containing ore and/or anthropogenic metals, dissolution of weathered metal ions and particulates in storm water, and transport of dissolved ions or particulates in storm water runoff to surface water (including the Unnamed Arroyo) represent a potential fate and transport pathway. This potential migration pathway is also applicable to radionuclides. Dissolution of radionuclides or metals in storm water, and infiltration/percolation is a method for transporting surficial contaminants to subsurface soil and groundwater. As described above, however, radium is resistant to significant transport via this pathway except under conditions of elevated pH. Entrainment of dust that contains radionuclides or metals adsorbed to the surface, or contained within soil particles may be a method for off-site transport. Dust generation and wind transport and human and animal activity may possibly have resulted in the unexpected transport of COPCs to off-site areas.

Finally, uptake of radionuclides or metals into plants, and subsequent transfer to human and wildlife receptors through the food chain is another potential fate and transport mechanism. Uptake of radium by plants is dependent upon soil and plant type (ATSDR, 1990). Soil-to-plant transfer coefficients are reported to range from 1.1 x $10^{-3}$ to 6.5 (Watson et. al., 1984, as cited in ATSDR, 1990). A partition coefficient for Ra-226 in forage and hay was estimated as 0.1. Because radionuclides including radium may be absorbed by plants, there is the potential for human exposure through consumption of meat, eggs or milk derived from animals that graze on forage grown in soils containing these substances. Mean ratios of radium-226 in milk and beef to that in the animals' diet has been estimated to be 3.8 x $10^{-3}$ and 6.8 x $10^{-3}$, respectively (Watson et. al., 1984, as cited in ATSDR, 1990). Once ingested, radium tends to partition into bone due to its similarity to calcium, and may bioaccumulate in humans and animals (USGS, 1998).

### 4.1.3 Land Uses and Potentially Exposed Populations

The Site is the former location of an underground uranium mine. The Site is currently inactive, and human receptors at the Site are limited to facility oversight, security personnel, and UNC representatives. The Site is fully fenced preventing access by unauthorized visitors, livestock or wildlife, as has happened historically. The Site was used for agricultural grazing under a grazing permit issued by the BIA until December 2006 when GE/UTC installed a fence. The planned future land use of the Site is grazing within the mine permit area. With cooperation of the NNEPA, access to the Site will be secured and limited for a period of at least twelve years after site reclamation is complete, as required by the New Mexico Mining Act (NMMA) so that revegetation programs have sufficient time to restore a self-sustaining ecosystem. Past uses of the NECR mine permit area included grazing and a reasonably anticipated future use for reclaimed surface areas at mines such as NECR would typically be limited to grazing or wildlife habitat (as is the case with the nearby Quivera Mine). At the request of EPA and the Navajo Nation, the risk assessment has been revised to include calculations for unrestricted use for the site survey areas. All lands to the north of the Site, with the exception of Quivera Mine, are part of the Navajo Indian Reservation and, with the exception of Quivera Mine, which is fenced and is not used for residential purposes, land use is unrestricted. These lands include home sites (with the exception of the reclaimed Quivera mine spoils and ponds area), and are also used for livestock grazing and hunting. The former United Nuclear Corporation mill is located southeast of the Site, and the former Kerr-McGee Quivera Mine Permit Area is located immediately northeast of the Site.

### 4.1.4 Potentially Complete Exposure Pathways

Based on future land uses for the Site, human receptors may be exposed to COPCs through ambient air, soil, surface water, sediment, and biota (i.e., plants and animals). Exposures to COPCs in ambient air may occur through inhalation of dust entrained in air, as well as deposition onto plant surfaces and subsequent consumption of plant parts by humans. Potentially complete soil exposure pathways include external radiation, incidental ingestion of soil particles, dermal contact with soil particles, root uptake and translocation of COPCs to above-ground plant parts and subsequent consumption; and uptake by livestock (e.g., cattle, sheep and poultry) and wildlife that are subsequently harvested and consumed by humans. Sediment exposure pathways for human receptors are similar to soil pathways, because the Unnamed Arroyo is dry for the majority of the year. Potentially complete surface water exposure pathways include incidental ingestion and dermal contact of surface water by off-site residents, and potential uptake of COPCs in surface water by plants or animals that are subsequently harvested and consumed by humans.

Currently, there are no potable or non-potable uses of groundwater beneath the Site. In addition, there are no plans to install wells on-site during the foreseeable future, or to use groundwater beneath the Site for potable or other uses. It is possible that off-site groundwater may be used for potable or agricultural uses (e.g., irrigation of plants or watering livestock). Groundwater associated with the Westwater Canyon sandstone member of the Morrison Formation is present at a depth of 1,500 to 1,800 feet bgs, and is separated from alluvial, non-potable groundwater by an aquitard, as discussed in Section 1.3.3. Therefore, potential domestic and agricultural groundwater exposure pathways are considered incomplete.

Diagrams of the CSMs for each scenario graphically depict the relationship between potential sources of contamination, exposure media, and human receptors for the Site are presented in Figure 4-1, *Human Health Conceptual Site Model (Scenario 1)*, and Figure 4-2, *Human Health Conceptual Site Model (Scenario 2).* It should be noted that unrestricted (i.e., residential) land use only applies to areas north of the Mine permit, excluding the Quivera Mine site (refer to Section 4.1.3). Hypothetical future on-site residents are included in the CSMs for on-site (i.e., Mine permit) areas for evaluation of the potential need for future deed restrictions.

## 4.2 SCREENING-LEVEL HHRA

A screening-level HHRA was conducted to evaluate whether detected concentrations of chemicals of potential concern (COPCs) identified for each investigation area may pose a current or potential future risk or hazard to public health based on protective, screening-level assumptions. Results of the screening level HHRA were used to identify those investigation areas and media that are appropriate for no further action (NFA), and those investigation areas and media for which further evaluation is warranted.

Methods used in the screening-level HHRA are described in Section 4.2.1, and results of the screening HHRA are presented in Section 4.2.2.

### 4.2.1 Screening HHRA Methods

The general approach to the screening-level HHRA was to compare detected concentrations of radionuclides and metals/organics to EPA PRGs for Radiologicals (EPA, 2004c) and EPA Region 9 PRGs (EPA, 2004a), respectively. Screening-level, cumulative cancer risk estimates and non-cancer hazard indices (HIs) were calculated under both residential and industrial scenarios, in order to evaluate the need for potential future institutional controls at the Site.

Screening risk assessment methods and procedures for radionuclides and metals, respectively, are documented in *Soil Screening Guidance for Radionuclides: Technical Background Document* (EPA, 2000b) and *EPA Region 9 PRGs – 2004 Update* (EPA, 2004a), respectively. The general framework for conducting HHRAs under CERCLA is provided in *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Part A. Baseline Risk Assessment* (EPA, 1989).

Human Health COPC screening for soil and sediment was based on comparison of maximum detected concentrations in surface and subsurface soil to residential and industrial USEPA Region 9

Preliminary Remediation Goals (PRGs). A complete data summary for each site is presented in Section 3.2 for soil analytes and Section 3.3 for sediment analytes. Based on this comparison (Tables 3.15 and 3.16), the following COPCs were identified for soil: one radionuclide (Ra-226); five metals (i.e., arsenic, molybdenum, selenium, uranium, and zinc). Ra-226, arsenic and uranium were the immediate chemicals of concern due to their exceedance of PRG values, however the screening-level cumulative carcinogenic risk and non-carcinogenic hazard index (HI) for all detected chemicals was calculated in accordance with USEPA guidance as described below.

According to USEPA Region 9 (2004), when more than one chemical is present, it is appropriate to calculate the screening-level, cumulative carcinogenic risk and non-carcinogenic HI for all detected chemicals in soil. The underlying basis for this calculation is that a chemical may be present at a maximum concentration that is lower than its respective PRG, but still contribute to a cumulative carcinogenic risk or non-carcinogenic HI.

Briefly, chemical-specific cancer risk estimates, the "probability of an individual developing cancer as a result of a lifetime of exposure to a particular level of a potential carcinogen" (EPA, 1989), were calculated for each COPC, in each medium, at each investigation area. Next, chemical-specific cancer risk estimates were summed across exposure pathways to estimate medium-specific cumulative cancer risk estimates. Total cumulative cancer risk estimates were calculated by adding medium-specific cancer risk estimates. A similar procedure was used to estimate total non-cancer HIs. Total HIs, which represent the cumulative hazard from "multiple substances and/or multiple exposure pathways" (EPA, 1989), were calculated by summing medium-specific HIs.

Results of the screening-level HHRA were used to evaluate whether detected concentrations of COPCs in a given investigation area represent no significant risk to human receptors and the area is appropriate for NFA in regard to human health, or the Site requires further risk evaluation.

### 4.2.2 Screening HHRA Results

Results of the screening-level HHRA for the Site are presented in Tables 4-1 through 4-4. For all on-site investigation areas, screening-level cumulative carcinogenic risk and/or non-carcinogenic HI estimates for residential receptors exposed to surface soil exceeded the USEPA screening-level cancer risk criterion of 1 x 10-6 or HI equal to 1 (Table 4-1). For residential receptors exposed to subsurface soils at on-site investigations areas, screening-level cumulative carcinogenic risk and/or non-carcinogenic HI estimates also exceeded the USEPA screening-level cancer risk criterion of 1 x 10-6 or HI equal to 1 (Table 4-2). Exceedances of screening-level risk and/or HI criteria were generally attributable to arsenic and Ra-226.

For all on-site investigation areas, screening-level cumulative carcinogenic risk and/or non-carcinogenic HI estimates for industrial receptors exposed to surface soil exceeded the USEPA screening-level cancer risk criterion of 1 x 10-6 or HI equal to 1 (Table 4-3). For industrial receptors exposed to subsurface soils at on-site investigations areas, screening-level cumulative carcinogenic risk and/or non-carcinogenic HI estimates also exceeded the USEPA screening-level cancer risk criterion of 1 x 10-6 or HI equal to 1 (Table 4-4). Again, exceedances of screening-level risk and/or HI criteria were generally attributable to arsenic and Ra-226.

Because concentrations of arsenic and Ra-226 in sediments or surface soils along the Unnamed Arroyo and at the Home Sites were above residential PRGs, and the Home Sites require evaluation of residential exposures anyway, these locations were automatically carried through to the baseline HHRA without performing a screening-level HHRA analysis (see Section 4.3).

It should be noted that the screening-level carcinogenic risk and non-carcinogenic HI estimates described above were based on conservative assumptions regarding land use (e.g., residential land use for all portions of the Site), default exposure assumptions, and do not take into account the contribution to risk of background concentrations of metals and Ra-226. As such, screening-level risk estimates tend to be over-estimated. Based on the above results, however, all investigation areas at the Site were further evaluated in a baseline HHRA, using more appropriate considerations regarding land uses and exposures, as described in Section 4.3.

## 4.3 BASELINE HHRA

This section describes methods and results of a baseline HHRA conducted for the Site. A detailed discussion of the methods used in the baseline HHRA is presented in Section 4.3.1, and results of the baseline HHRA are presented in Section 4.3.2.

### 4.3.1 Baseline HHRA Methods

Risks to public health and the environment were evaluated in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Remedial Response process, as amended by the Superfund Amendments and Reauthorization Act (SARA), and in consideration of State of New Mexico risk assessment guidance (NMED, 2005). The HHRA evaluates potential public health risks associated with contaminants present at the Site, as well as potential historic releases of contaminants from the Site to the surrounding environment. Potential public health risks associated with current levels of radionuclides and metals present in Site media were evaluated assuming external radiation exposure, direct exposure to contaminated media, and indirect exposures through the food chain, as applicable, as described below.

A site-specific, baseline evaluation of risk was conducted for all COPCs, media and investigation areas identified during the screening-level risk evaluation (refer to Section 4.2). The baseline HHRA includes refinements to the screening-level risk evaluation approach including, but not limited to, use of dose modeling based on site-specific exposure scenarios and pathways, and statistically-derived media concentrations. The baseline risk evaluation includes the calculation of "total" risk and hazard estimates based on site-related contamination and background levels of radionuclides and metals, as well as risk and hazard estimates excluding background. Risk and hazard estimates in excess of background are termed "incremental" risks or hazards. Results of the baseline risk evaluation will be used to identify constituents of concern (COCs) for applicable Site media. Radionuclides or metals that contributed to an incremental risk or hazard in excess of EPA's risk management range of $1 \times 10^{-6}$ to $1 \times 10^{-4}$ and HI of 1 will be identified as Site COCs, in accordance with EPA (1991a). The final step of the risk assessment process involved the calculation of site-specific and media-specific cleanup goals for any COCs identified for the Site.

Specific guidance considered during preparation of the baseline HHRA for the Site includes, but was not limited to, the following documents and reference materials:

- *Risk Assessment Guidance for Superfund. Volume I: Human Health Evaluation Manual, Part A. Baseline Risk Assessment* (EPA, 1989).
- *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors* (EPA, 1991a).
- *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decision* (EPA, 1991b).
- *Exposure Factors Handbook, Volume I: General Factors* (EPA, 1997a).
- *Exposure Factors Handbook, Volume III: Activity Factors* (EPA, 1997b).

- *Soil Screening Guidance for Radionuclides: User's Guide* (EPA, 2000b).

- *Soil Screening Guidance for Radionuclides: Technical Background Document (*EPA, 2000c).

- *EPA Region 9 PRGs – 2004 Update* (EPA, 2004a).

- *Risk Assessment Guidance for Superfund (RAGS), Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment)* (EPA, 2004b).

- *New Mexico Environmental Department Technical Background Document for Development of Soil Screening Levels – Final Report. Revision 3* (NMED, 2005).

#### 4.3.1.1 Exposure Assessment

The exposure assessment begins with development of a site-specific CSM. The human health CSM for the Site was described in Section 4.1.

Upon request of the EPA and Navajo Nation, the following potential current and future human receptors were considered for the Site:

- Current and future on-site maintenance personnel;
- Hypothetical future livestock grazer;
- Hypothetical future on-site residential receptors; and
- Current and future off-site residential receptors.

Relevant exposure pathways for the above receptors are visually presented in Figures 4-1 and 4-2. Potentially complete and incomplete exposure pathways for human receptors are described in more detail below.

#### Soil Exposure Pathways

Contaminants may be released to surface and subsurface soil through the unexpected release of COPCs via fugitive dust, via permitted discharge of treated mine waters to the Unnamed Arroyo, and potential metals disposal in the Boneyard. Potential human exposure pathways to COPCs in surface or subsurface soils include the following:

- Incidental ingestion of soil particulates by current/future on-site maintenance personnel, hypothetical future livestock grazers, hypothetical future on-site residential receptors, and current/future off-site residential receptors.

- Ingestion of homegrown produce by hypothetical future on-site residential receptors and current/future off-site residential receptors.

- Ingestion of locally-raised meat by hypothetical future on-site residential receptors, current/future off-site residential receptors, and on-site livestock grazer receptors.

- Ingestion of locally-raised eggs by hypothetical future on-site residential receptors and current/future off-site residential receptors.

- Inhalation of soil particulates (e.g., dust) by current/future on-site maintenance personnel, hypothetical future livestock grazers, hypothetical future on-site residential receptors, and current/future off-site residential receptors.

- External exposure of radiation from soil particulates by current/future on-site maintenance personnel, hypothetical future livestock grazers, hypothetical future on-site residential receptors, and current/future off-site residential receptors.

Incidental ingestion of soil particles in the form of dust, dermal contact with dust, and inhalation of dust are potentially complete exposure pathways for current/future on-site maintenance personnel, hypothetical future on-site residential receptors, current/future off-site residential receptors, and hypothetical future on-site livestock grazers (Figure 4-1**)**. Additionally, ingestion of produce grown in potentially contaminated soil, ingestion of meat from livestock (e.g., cattle or sheep) grazing in potentially contaminated areas, ingestion of eggs from poultry raised in potentially contaminated areas, and external exposure to radiation from soil are potentially complete exposure pathways for hypothetical future on-site residential receptors and current/future off-site residents (Figure 4-2). Ingestion of potentially contaminated soil, ingestion of meat from livestock (e.g., cattle or sheep) grazing in potentially contaminated areas, and external exposure to radiation from soil are potentially complete pathways for the on-site livestock grazer (Figure 4-2).

### Sediment Exposure Pathways

Contaminants may be released to sediment from water treatment ponds (Pond No. 1, Pond No. 2, and Pond No. 3/3a) which were originally filled with water and sediments settled in them from storm water runoff that drained the tailings sand backfill areas, as well as water from mine operations (see Section 1.2.2). The sediments were placed on the Sediment Pad for temporary storage prior to being transported off-site for processing at the mill, and so contaminants may be released from unexpected fugitive dust from the Sediment Pad, as well as fugitive dust from sediment present in the Unnamed Arroyo. Potential human exposure pathways include:

- Incidental ingestion of sediment particulates by current/future on-site maintenance personnel, hypothetical future on-site industrial workers, hypothetical future on-site residential receptors, current/future off-site residential receptors, or hypothetical future livestock grazers, and.

- Ingestion of homegrown produce by hypothetical future on-site residential receptors or current/future off-site residential receptors.

- Inhalation of sediment particulates (e.g., dust) by current/future on-site maintenance personnel, hypothetical future on-site industrial workers, hypothetical future on-site residential receptors, current/future off-site residential receptors, or hypothetical future livestock grazers

- External exposure of radiation from sediment particulates by current/future on-site maintenance personnel, hypothetical future on-site industrial workers, hypothetical future on-site residential receptors, current/future off-site residential receptors, or hypothetical future livestock grazers.

Incidental ingestion of sediment particles in the form of dust, dermal contact with dust, and inhalation of dust are potentially complete exposure pathways for current/future maintenance personnel, hypothetical future on-site residential receptors, current/future off-site residential receptors, and hypothetical future on-site livestock grazers (Figure 4-1). Additionally, external exposure, ingestion of homegrown produce, ingestion of locally-raised meat, and ingestion of locally-raised eggs are potentially complete exposure pathways for hypothetical future on-site residential receptors and current/future off-site residents (Figure 4-2). Ingestion of potentially contaminated sediment, ingestion of meat from livestock (e.g., cattle or sheep) grazing in potentially contaminated areas, and external exposure to radiation from sediment are potentially complete pathways for the on-site livestock grazer (Figure 4-2).

#### 4.3.1.2 Exposure Quantification

Potential exposures and risks associated with the complete exposure pathways identified above were quantified in the baseline HHRA conducted for the Site. Methods used in the derivation of media exposure point concentrations (EPCs), and procedures for quantifying exposure doses for current and future human receptors, are described in the following subsections.

#### Deriving Exposure-Point Concentrations

For purposes of quantifying exposure doses in the baseline HHRA, exposure-point concentrations (EPCs) were derived as the 95 percent upper confidence limit (95% UCL) on the arithmetic mean concentration. The 95% UCL of the mean concentration was calculated consistent with methods described in EPA (2002b). First, sampling results for individual COPCs detected within a given medium were evaluated to identify whether the data population is representative of an underlying normal or lognormal distribution. The Shapiro-Wilks W test for normality and the coefficient of variation statistic (Gilbert, 1987) were used, as necessary, to test the underlying data distribution (see Appendix D). For data sets that are best represented by a normal distribution, the 95% UCL is typically calculated based on the Student t-statistic (USEPA, 2002b).
It should be noted that the EPCs derived herein reflect the nature of the sampling design. For on-site source areas, EPCs are derived from soil sampling results collected on a random grid. For the Home Sites, EPCs developed prior to EPA conducting removal actions at Home Sites 4, 6, 7, 8, and 9 are based on biased soil sample locations selected using field screening measurements. Field screening was used to identify biased locations for the collection of soil samples. In turn, the 95% UCL on the mean concentration of these biased soil samples was used to estimate EPCs. In most cases, the concentrations observed at biased sample locations are representative of only a very minor portion of the entire Home Site. Therefore, the 95% UCL on the mean for biased soil sample results represents a significant over-estimate of actual exposures for home site residents. Following removal of contaminated surficial soils at Home Sites 4, 6, 7, 8, and 9, EPA conducted post-removal confirmation sampling at these Home Sites. EPCs for Ra-226 based on post-removal confirmation sampling results for the Home Sites are presented in Appendix D. For comparison, EPCs and risk estimates based on the original, pre-removal action COPC concentrations are presented in Appendix E.

The equation for calculating the UCL for a normal distribution (USEPA, 2002b) is:

$$UCL = x(bar) + t\,(s/\sqrt{n})$$

Where:

| | | |
|---|---|---|
| UCL | = | Upper confidence limit |
| x(bar) | = | Mean of the untransformed data |
| s | = | Standard deviation of the untransformed data |
| t | = | Student t-statistic (from table published in Gilbert, 1987) |
| n | = | Number of samples |

For data sets that are best represented by a lognormal distribution, 95% UCL concentrations may be calculated using the Land method (i.e., H-statistic), Chebyshev inequality method, or Student t-statistic based on the natural log-transformed data (USEPA, 2002b).

Alternative methods of deriving 95% UCL concentrations are available for other distribution types (e.g., the gamma distribution), or when the shape of the underlying distribution of concentrations is unknown. Nonparametric, or distribution-free, methods require no assumptions about the shape of the data distribution, and are applicable to a variety of situations. Examples of nonparametric methods include the jackknife procedure, bootstrap re-sampling procedures, and the Chebyshev inequality method (USEPA, 2002b). Automated approaches to calculating the 95% UCL concentration have been developed, including USEPA's ProUCL software.

USEPA's ProUCL software, along with other statistical methods cited in USEPA (2002b), were used to estimate potential 95% UCL on the mean EPCs for soil and sediment data sets at the Site. For the HHRA described herein, the EPC recommended by ProUCL was used to quantify potential human health risks. EPCs and summary statistics for each site, medium, and COPC are summarized in Appendix D.

EPCs were identified based on the following:

- Potential exposure. Soil and sediment EPCs were selected from samples collected from between zero and 10 feet bgs (inclusive). Data from soil samples collected from below 10 feet bgs were excluded, as it is assumed that potential on-site maintenance activities would not extend below this depth. Specific sample depths that were used to determine surface EPC versus subsurface EPCs were 0 to 0.5 ft bgs and >0.5 to 10 ft bgs, respectively.

- Qualified data. Only validated, qualified data were reviewed in the EPC selection process. All data with "B" (analytes detected in an associated field or laboratory blank) or "R" (result unusable because quality control criteria were not met) qualifiers were eliminated.

- Naturally occurring metals. Concentrations of all COPCs detected in soil or sediments were included in the risk assessment, regardless of whether or not they represent background conditions (i.e., are naturally occurring). Attribution of risk to background or source-related contamination was evaluated during the risk characterization phase, as described below.

### Calculating Exposure Doses

This section describes HHRA methods for quantifying exposure doses for human receptors. As described in Section 4.3.1.1, complete and potentially significant exposure pathways between human receptors and site-related COPCs are limited to direct soil and sediment contact pathways (i.e., incidental ingestion, and inhalation of particulates), and indirect exposure pathways (i.e., ingestion of homegrown produce, ingestion of locally-raised meat, ingestion of locally-raised eggs, and external exposure to radiation). Potential exposures and risks related to other pathways and media were qualitatively evaluated in the HHRA. The dose equations used in the quantification of direct exposure pathways for soil and sediment are consistent with USEPA guidance for conducting exposure assessments (USEPA, 1989a).

Equations for quantifying direct exposure pathways (i.e., incidental ingestion, and inhalation of COPCs in dust derived from sediment) are presented below.

**Incidental Ingestion:**

$$\text{Ingestion Intake for Soil/Dust (mg/Kg-day)} = \frac{CS \times IR \times CF \times EF \times ED}{BW \times AT}$$

Where:

CS = Concentration in soil (mg/Kg)
IR = Ingestion rate (milligrams [mg] soil/day)
CF = Conversion factor ($10^{-6}$ kilogram [Kg]/mg)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (Kg)
AT = Averaging time (period over which exposure is averaged – days)

**Inhalation:**

$$\text{Inhalation Intake for Soil/Sediment (mg/Kg-day)} = \frac{CS \times (1/PEF) \times InhR \times EF \times ED}{BW \times AT}$$

Where:

CS = Concentration in soil/sediment (mg/Kg)
PEF = Particulate emission factor (cubic meters [$m^3$]/Kg)
InhR = Inhalation rate ($m^3$/day)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (Kg)
AT = Averaging time (period over which exposure is averaged – days)

As described further in Section 4.3.1.4, dose modeling and baseline cancer risk and non-cancer hazard estimates were calculated for direct and indirect exposure pathways using EPA's PRG Calculator for Radiologicals (EPA, 2006a) for Ra-226, EPA's PRG Calculator for Non-radiologicals for metals (EPA, 2006b), and the Oak Ridge National Laboratory (ORNL) Risk Assessment Information System (RAIS) PRG Calculator (ORNL, 2007) for ingestion of meat. The algorithms for evaluation of the ingestion of homegrown produce and external radiation exposure are described in EPA (2006a, 2006b).

Specific assumptions to be used in quantifying exposures for human receptors are provided in Tables 4-5 through 4-7 of this HHRA Report.

#### 4.3.1.3 Toxicity Assessment

This section describes the toxicity assessment methodology used in the evaluation of public health risks described herein. Human health toxicity assessment methods were developed in accordance with USEPA (1989a) guidance.

Toxicity assessment involves a critical review and interpretation of toxicology data from epidemiological, clinical, animal, and in vitro studies. A review of toxicology data ideally determines both the nature of health effects associated with a particular chemical and the probability that a given dose of a chemical could result in an adverse health effect. Following are the primary sources of toxicity values that were used in the baseline HHRA for the Site:

- IRIS Database (USEPA, 2007a).
- HEAST (USEPA, 1995a).

- National Center for Environmental Assessment (USEPA, 2007b).
- Agency for Toxic Substances and Disease Registry Toxicology Profiles (various dates)

Toxicology information important for quantitative risk assessment of long-term health effects is generally divided into the following two categories:

- Potential for carcinogenic health effects
- Potential for chronic non-carcinogenic, adverse health effects

Table 4-8 presents the list of toxicity values used in the HHRA presented herein.

**Carcinogenic Effects of COPCs**

The cancer slope factor (CSF) is the toxicity value used to quantitatively express the carcinogenic potential of cancer-causing constituents. The slope factor is expressed in units of milligrams per kilogram per day (mg/Kg-day)-1 and represents the cancer risk per unit daily intake of a carcinogenic chemical (refer to Table 4-8). The CSF represents the upper 95 percent confidence interval of the slope of the dose response curve. The 95 percent upper confidence interval value assures a safety factor to protect the most sensitive receptors.

In cases where available carcinogenic toxicity values are presented as inhalation unit risks (expressed as the inverse of micrograms per cubic meter [$\mu g/m^3]^{-1}$), the following conversion method will be used:

$$\text{Inhalation Slope Factor (mg/Kg-day)}^{-1} = \frac{\text{Air Unit Risk } (\mu g/m3)\ \text{-1 X 70 Kg X 103 } \mu g/mg}{\text{20 m3/day}}$$

The following default assumptions (USEPA, 1991a) are incorporated as parameters for this equation:

- Body weight of 70 Kg
- Inhalation rate of 20 $m^3$/day

When an absorption fraction of less than 1.0 is applied in deriving the unit risk, an additional conversion factor is necessary so that the slope factor is based on an administered dose. The standardized duration assumption for slope factors is continuous lifetime exposure.

**Non-Carcinogenic Effects of COPCs**

The reference dose (RfD) is the toxicity value used to quantitatively express the potential for a chemical to produce chronic non-carcinogenic effects. The RfD is expressed in units of mg/Kg-day and represents a daily intake of contaminant per kilogram of body weight that is not sufficient to cause the threshold effect of concern for the contaminant (refer to Table 4-8). Exposure doses that are above the RfD, the threshold dose for non-carcinogens, could potentially cause adverse health effects. Confidence in the RfD is subjective, based on USEPA review groups and quality of the supporting database. Chemical-specific RfDs do not account for the potential effects of chemical mixtures.

RfDs are generally based on no observable adverse effect levels (NOAELs) derived from animal studies. When NOAEL values are unavailable, a lowest observable adverse effect level (LOAEL) is generally used. An uncertainty factor (UF) is typically incorporated into the RfD to reduce the numerical value, resulting in a more conservative toxicity value.

In addition to UFs, modifying factors (MFs) are often used in calculating RfDs. A MF ranging from 0 to 10 can be included to reflect a qualitative professional assessment of additional uncertainties in critical studies and available databases.

The equation for calculating an RfD is:

$$RfD = \frac{NOAEL \text{ or } LOAEL}{UF1 \times UF2 \ldots \times MF}$$

Where:

RfD = Reference dose (mg/Kg-day)
NOAEL = No observed adverse effect level (mg/Kg-day)
LOAEL = Lowest observed adverse effect level (mg/Kg-day)
UFn = Uncertainty factor
MF = Modifying factor

#### 4.3.1.4 Risk Characterization

Baseline human health risk characterizations for the Site integrate the results of exposure and toxicity assessments described in Sections 4.3.1.2 and 4.3.1.3 to derive a quantitative and qualitative evaluation of potential risks to current and potential future human receptors. Methods used in the characterization of baseline human health risks are described below.

Calculated exposure doses for each identified COPC were used to estimate chemical-specific and cumulative cancer risks; and non-cancer hazard quotients (HQ) and HIs.

Risk of developing cancer from exposure to a carcinogenic chemical is estimated by multiplying the CSF by the exposure dose (USEPA, 1989a):

$$ILCR \text{ (unitless)} = CSF \times Dose$$

Where:

ILCR = Incremental lifetime cancer risk (unitless)
CSF = Cancer slope factor (mg/Kg-day)-1
Dose = Exposure dose (mg/Kg-day)

Cancer risks from multiple COPCs are assumed to be additive and are summed to estimate a cumulative ILCR for all carcinogenic site contaminants.

The HQ describes the potential for site COPCs to produce non-carcinogenic effects. HQ is defined as the ratio of the exposure dose to the RfD (USEPA, 1989a):

$$HQ \text{ (unitless)} = \frac{Dose}{RfD}$$

Where:

Dose = Exposure dose (mg/Kg-day)
RfD = Reference dose (mg/Kg-day)

An HQ greater than 1.0 indicates that the estimated exposure dose for that COPC may not be protective of non-carcinogenic health effects. An HQ of less than 1.0 suggests that non-carcinogenic health effects should not occur. Individual HQs for site COPCs are summed to produce a cumulative hazard estimate, termed the HI. In cases where the cumulative HI exceeds 1.0, the HI may be re-evaluated based on target organ effects (USEPA, 1989a).

According to the USEPA (USEPA, 1991b), sites with a cumulative cancer risk estimate between 1.0 x 10-6 and 1.0 x 10-4, and a non-cancer HI of less than 1.0, may be appropriate for NFA. Alternatively, sites with a cumulative cancer risk estimate or non-cancer HI in excess of these criteria are appropriate for further evaluation or consideration of remedial alternatives. Any future decisions regarding the need for remedial action will consider in an evaluation of Site-specific issues related to future land uses, the technical feasibility of remediation, and related considerations.

For identified radiological COPCs, the baseline HHRA involved refinement of EPA's screening-level PRGs for Radiologicals (EPA, 2004b). EPA PRGs for Radiologicals (EPA, 2004b) are available for both residential and industrial exposure scenarios. As described in Section 4.1.3, reasonably anticipated future land use of the Site is grazing within the mine permit area, following a period of undisturbed land use to allow for revegetation after restoration activities are completed. Therefore, refinements to EPA PRGs for Radiologicals (EPA, 2004b), such as Ra-226 and daughters, was made to consider this site-specific scenario and applicable exposure assumptions. Refined PRGs for radionuclides were developed using EPA's PRG Calculator (EPA, 2006b) and the RAIS PRG Calculator (ORNL, 2007), with site-specific input variables. In addition, hypothetical future on-site residential land use is evaluated in the baseline HHRA to determine the potential need for future deed restrictions.

For identified non-radiological COPCs, the baseline HHRA involved a refined evaluation of risk consistent with methods published in EPA's *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Part A. Baseline Risk Assessment* (EPA, 1989). Cumulative carcinogenic risk and non-carcinogenic HI estimates were calculated across non-radiological metals and exposure media, and compared to EPA's risk management range of $1 \times 10^{-6}$ to $1 \times 10^{-4}$ for carcinogenic risk and non-carcinogenic HI of 1 (EPA, 1991b). Again, total and incremental cancer risk and non-cancer HI estimates were calculated and reported concurrently.

Radionuclides, metals, and organic constituents in excess of EPA's risk management range (EPA, 1991b) were identified as COCs for potential evaluation of remedial alternatives.

### 4.3.2 Baseline HHRA Results

Risk characterization results expressed as cancer ILCR and non-cancer HI estimates for on-site receptors (current/future maintenance personnel, hypothetical future livestock grazers, and hypothetical future on-site residents) and for off-site receptors (current/future residents and hypothetical future livestock grazers) exposed to soils and sediments at the NECR Site are described in this section and summarized in Tables 4-9 through 4-24.

For each off-site and on-site area, two scenarios were evaluated: Scenario 1 summarizes risks to receptors when only direct soil exposure pathways are considered (i.e., incidental ingestion and inhalation of fugitive dust), while Scenario 2 potentially includes six exposure pathways (i.e., incidental soil ingestion, inhalation of fugitive dust, consumption of homegrown produce, consumption of locally-raised meat, consumption of locally-raised eggs, and external radiation), as applicable to individual receptors. Individual exposure pathways described above for Scenario 2 are only applied to appropriate individual receptors. For example, maintenance personnel were not evaluated for consumption of homegrown produce, or locally-raised meat and eggs. Livestock grazers were not evaluated for consumption of homegrown produce or eggs, but were evaluated for consumption of locally-raised meat, as indicated in Tables 4-10 and 4-14, respectively. On-site residents were evaluated for all six exposure pathways, including consumption of homegrown produce, locally-raised meat, and locally-raised eggs. Scenario 2 presents the more conservative exposure scenario for each receptor.

Additionally, the total combined risk for each area was calculated across all exposure pathways, for each area and for background. In order to distinguish the contribution of background in accordance with EPA's Policy Statement on the Role of Background in the CERCLA Decision Process (OSWER 9265.6-07P, EPA 2002) the results are discussed in terms of incremental risk, which is the result of the background risk subtracted from the total combined risk. Because background soils exceeded EPA's risk range the risk characterization focuses on the incremental risk or the risk attributable to each survey area above the background risk.

#### 4.3.2.1 On-Site Areas

Located within the main NECR Site, there are 12 areas of concern which include: NECR-1, NECR-2 Ponds 1 & 2, Pond 3/3a, Sediment Pad, Sandfill 1, Sandfill 2, Sandfill 3, NEMSA, Boneyard, Vents 3 & 8, and the Trailer Park (See Figures 1-3 and 2-1). Each on-site location was evaluated for current/future maintenance personnel, the hypothetical future on-site resident, and the hypothetical future livestock grazer.

**NECR-1**

For current/future maintenance personnel within NECR-1 evaluated under Scenario 1 (Tables 4-9 and 4-11), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of NECR-1 for maintenance personnel under Scenario 2 (Tables 4-10 and 4-12), only subsurface soil has an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. This is attributable to the presence of Ra-226 at an EPC of 46 pCi/g in subsurface soil, and the external exposure pathway.

For the hypothetical future livestock grazer within NECR-1 evaluated under Scenario 1 (Tables 4-13 and 4-15), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of NECR-1 for the livestock grazer under Scenario 2 (Tables 4-14 and 4-16), both surface and subsurface soil have an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. This is attributable to the presence of Ra-226 in surface soil at an EPC of 39 pCi/g, in subsurface soil with a Ra-226 EPC of 46 pCi/g, and both the meat consumption and external exposure pathways.

For the hypothetical future on-site resident within NECR-1 evaluated under Scenario 1 (Table 4-17), none of the COPCs has an incremental risk above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04. Uranium has an incremental HQ > 1, which is attributable to soil ingestion. For evaluation of NECR-1 for hypothetical future on-site residents both for the national average and for Native Americans under Scenario 2 (Tables 4-18 and 4-19), surface soil has an incremental risk greater than 1E-06 to 1E-04 and an HQ > 1. Incremental risk estimates greater than 1E-04 are attributable to the consumption of homegrown produce and/or meat, and the external exposure pathways. The only exposure pathway with an HQ > 1 is soil ingestion. Actual exposures may be lower than those estimated if vegetable gardens are not used, if livestock do not graze in the area, or if these levels are reduced through future reclamation activities at the site. Also, it should be noted that it may not be appropriate to consider the latter indirect exposure pathways given that the risk-based Soil Screening Levels (SSLs) calculated for Ra-226 for external exposure, consumption of homegrown produce, and consumption of homegrown meat based on a risk level of $10^{-6}$ are 0.01 pCi/g, 0.069 pCi/g, and 0.024 pCi/g, respectively, and are all well below the site-specific background level of 1.0 pCi/g.

**NECR-2**

For current/future maintenance personnel within NECR-2 evaluated under Scenario 1 (Tables 4-9 and 4-11), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ

> 1. For evaluation of NECR-2 for maintenance personnel under Scenario 2 (Tables 4-10 and 4-12), neither surface soil or subsurface soil concentrations of any COPC have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1.

For the hypothetical future livestock grazer within NECR-2 evaluated under Scenario 1 (Tables 4-13 and 4-15), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of NECR-2 for the future livestock grazer under Scenario 2 (Tables 4-14 and 4-16), both surface and subsurface soil has an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. This is attributable to the presence of Ra-226 in surface soil at an EPC of 39 pCi/g, in subsurface soil with a Ra-226 EPC of 10 pCi/g, and the meat consumption pathway.

For the hypothetical future on-site resident within NECR-2 evaluated under Scenario 1 (Table 4-17), none of the COPCs has an incremental risk above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04. Uranium has an incremental HQ > 1, which is attributable to soil ingestion. For evaluation of NECR-2 for hypothetical future on-site residents both for the national average and for Native Americans under Scenario 2 (Tables 4-18 and 4-19), surface soil has an incremental risk greater than 1E-06 to 1E-04 and an HQ > 1. Incremental risk estimates greater than 1E-04 are attributable to the consumption of homegrown produce and/or meat, and the external exposure pathways. The only exposure pathway with an HQ > 1 is soil ingestion. As discussed above for NECR-1, actual exposures may be lower than those estimated and it may not be appropriate to consider the latter indirect exposure pathways.

**Ponds 1 & 2**

For current/future maintenance personnel at Ponds 1 & 2 evaluated under Scenario 1 (Tables 4-9 and 4-11), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of Ponds 1 & 2 for maintenance personnel under Scenario 2 (Tables 4-10 and 4-12), both surface and subsurface soil have an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. This is attributable to the presence of Ra-226 in surface soil at an EPC of 179 pCi/g and in subsurface soil with a Ra-226 EPC of 352 pCi/g.

For the hypothetical future livestock grazer at Ponds 1 & 2 evaluated under Scenario 1 (Tables 4-13 and 4-15), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of Ponds 1 & 2 for the future livestock grazer under Scenario 2 (Tables 4-14 and 4-16), both surface and subsurface soil have an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. This is attributable to the presence of Ra-226 in surface soil at an EPC of 179 pCi/g, in subsurface soil with a Ra-226 EPC of 352 pCi/g, and both the meat consumption and external exposure pathways.

For the hypothetical future on-site resident at Ponds 1 & 2 evaluated under Scenario 1 (Table 4-17), surface soil concentrations of Ra-226 have an incremental risk above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04, and uranium has an incremental HQ > 1. These risks are attributable to soil ingestion. For evaluation of Ponds 1 & 2 for hypothetical future on-site residents both for the national average and for Native Americans under Scenario 2 (Tables 4-18 and 4-19), surface soil has an incremental risk greater than 1E-06 to 1E-04 and an HQ > 1. Incremental risk estimates greater than 1E-04 are attributable to soil ingestion, the consumption of homegrown produce, the consumption of locally raised meat and/or locally raised eggs, and the external exposure pathways. The only exposure pathway with an HQ > 1 is soil ingestion. As discussed above for NECR-1, actual exposures may be lower than those estimated and it may not be appropriate to consider the latter indirect exposure pathways.

**Pond 3/3a**

For current/future maintenance personnel at Pond 3/3a evaluated under Scenario 1 (Tables 4-9 and 4-11), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of Pond 3/3a for maintenance personnel under Scenario 2 (Tables 4-10 and 4-12), both surface and subsurface soil have an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. This is attributable to the presence of Ra-226 in surface soil at an EPC of 253 pCi/g and in subsurface soil with a Ra-226 EPC of 11 pCi/g.

For the hypothetical future livestock grazer at Pond 3/3a evaluated under Scenario 1 (Tables 4-13 and 4-15), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of Ponds 3/3a for the future livestock grazer under Scenario 2 (Tables 4-14 and 4-16), both surface and subsurface soil has an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. This is attributable to the presence of Ra-226 in surface soil at an EPC of 253 pCi/g and both the meat consumption and external exposure pathways. This is also attributable to the presence of Ra-226 in subsurface soil at an EPC of 11 pCi/g and the meat consumption pathway.

For the hypothetical future on-site resident at Pond 3/3a evaluated under Scenario 1 (Table 4-17), surface soil concentrations of Ra-226 have an incremental risk above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04, and uranium has an incremental HQ > 1. These risks are attributable to soil ingestion. For evaluation of Pond 3/3a for hypothetical future on-site residents both for the national average and for Native Americans under Scenario 2 (Tables 4-18 and 4-19), surface soil has an incremental risk greater than 1E-06 to 1E-04 and an HQ > 1. Incremental risk estimates greater than 1E-04 are attributable to soil ingestion, the consumption of homegrown produce, the consumption of locally raised meat and/or locally raised eggs, and the external exposure pathways. The only exposure pathway with an HQ > 1 is soil ingestion. As discussed above for NECR-1, actual exposures may be lower than those estimated and it may not be appropriate to consider the latter indirect exposure pathways.

**Sediment Pad**

For current/future maintenance personnel within the Sediment Pad area evaluated under Scenario 1 (Tables 4-9 and 4-11), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of the Sediment Pad for maintenance personnel under Scenario 2 (Tables 4-10 and 4-12), both surface and subsurface soil have an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. This is attributable to the presence of Ra-226 in surface soil at an EPC of 109 pCi/g and in subsurface soil with a Ra-226 EPC of 104 pCi/g.

For the hypothetical future livestock grazer within the Sediment Pad area evaluated under Scenario 1 (Tables 4-13 and 4-15), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of the Sediment Pad for the future livestock grazer under Scenario 2 (Tables 4-14 and 4-16), both surface and subsurface soil have an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. This is attributable to the presence of Ra-226 in surface soil at an EPC of 109 pCi/g, and in subsurface soil with a Ra-226 EPC of 104 pCi/g, and both the meat consumption and external exposure pathways.

For the hypothetical future on-site resident within the Sediment Pad area evaluated under Scenario 1 (Table 4-17), none of the COPCs has an incremental risk above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04. Uranium has an incremental HQ > 1, which is attributable to soil ingestion. For evaluation of Sediment Pad area for hypothetical future on-site residents both for the national average and for Native Americans under Scenario 2 (Tables 4-18 and 4-19), surface soil has an incremental risk greater than 1E-06 to 1E-04 and an HQ > 1. Incremental risk estimates greater than 1E-04 are attributable to the consumption of homegrown produce and/or meat, and the external exposure pathways. The only exposure pathway with an HQ > 1 is soil ingestion. As discussed above for NECR-1, actual exposures may be lower than those estimated and it may not be appropriate to consider the latter indirect exposure pathways.

**Sandfill 1**

For current/future maintenance personnel at the Sandfill 1 area evaluated under Scenario 1 (Tables 4-9 and 4-11), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of the Sandfill 1 for maintenance personnel under Scenario 2 (Tables 4-10 and 4-12), only surface soil has an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. This is attributable to the presence of Ra-226 in surface soil at an EPC of 106 pCi/g.

For the hypothetical future livestock grazer at the Sandfill 1 area evaluated under Scenario 1 (Tables 4-13 and 4-15), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of the Sandfill 1 for the future livestock grazer under Scenario 2 (Tables 4-14 and 4-16), both surface soil and subsurface soil have an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. This is attributable to the presence of Ra-226 in surface soil at an EPC of 15 pCi/g, the presence of Ra-226 in subsurface soil at an EPC of 106 pCi/g, and both the meat consumption and external exposure pathways.

For the hypothetical future on-site resident at the Sandfill 1 area evaluated under Scenario 1 (Table 4-17), none of the COPCs has an incremental risk above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or an HQ > 1. For evaluation of the Sandfill 1 area for hypothetical future on-site residents both for the national average and for Native Americans under Scenario 2 (Tables 4-18 and 4-19), surface soil has an incremental risk greater than 1E-06 to 1E-04. Incremental risk estimates greater than 1E-04 are attributable to the consumption of homegrown produce and/or meat, and the external exposure pathways. As discussed above for NECR-1, actual exposures may be lower than those estimated and it may not be appropriate to consider the latter indirect exposure pathways.

**Sandfill 2**

For current/future maintenance personnel at the Sandfill 2 area evaluated under Scenario 1 (Tables 4-9 and 4-11), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of the Sandfill 2 for maintenance personnel under Scenario 2 (Tables 4-10 and 4-12), neither surface soil nor subsurface soil concentrations of any COPC have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1.

For the hypothetical future livestock grazer at the Sandfill 2 area evaluated under Scenario 1 (Tables 4-13 and 4-15), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of the Sandfill 2 for the future livestock grazer under Scenario 2 (Tables 4-14 and 4-16), only surface soil had an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. This is attributable to the presence of Ra-226 in surface soil at an EPC of 19 pCi/g and the meat consumption pathway.

For the hypothetical future on-site resident at the Sandfill 2 area evaluated under Scenario 1 (Table 4-17), none of the COPCs has an incremental risk above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or an HQ > 1. For evaluation of the Sandfill 2 area for hypothetical future on-site residents both for the national average and for Native Americans under Scenario 2 (Tables 4-18 and 4-19), surface soil has an incremental risk greater than 1E-06 to 1E-04. Incremental risk estimates greater than 1E-04 are attributable to the consumption of homegrown produce and/or meat, and the external exposure pathways. As discussed above for NECR-1, actual exposures may be lower than those estimated and it may not be appropriate to consider the latter indirect exposure pathways.

**Sandfill 3**

For current/future maintenance personnel at the Sandfill 3 area evaluated under Scenario 1 (Tables 4-9 and 4-11), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of Sandfill 3 for maintenance personnel under Scenario 2 (Tables 4-10 and 4-12), neither surface nor subsurface soil have an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. Surface soil has a total cancer risk of 2E-4. This is attributable to the presence of Ra-226 in surface soil at an EPC of 69 pCi/g.

For the hypothetical future livestock grazer at the Sandfill 3 area evaluated under Scenario 1 (Tables 4-13 and 4-15), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of Sandfill 3 for the future livestock grazer under Scenario 2 (Tables 4-14 and 4-16), both surface and subsurface soil have an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. This is attributable to the presence of Ra-226 in surface soil at an EPC of 69 pCi/g, in subsurface soil with a Ra-226 EPC of 49 pCi/g, and both the meat consumption and external exposure pathways.

For the hypothetical future on-site resident at the Sandfill 3 area evaluated under Scenario 1 (Table 4-17), none of the COPCs has an incremental risk above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04. Uranium has an incremental HQ > 1, which is attributable to soil ingestion. For evaluation of the Sandfill 3 area for hypothetical future on-site residents both for the national average and for Native Americans under Scenario 2 (Tables 4-18 and 4-19), surface soil has an incremental risk greater than 1E-06 to 1E-04 and an HQ > 1. Incremental risk estimates greater than 1E-04 are attributable to the consumption of homegrown produce and/or meat, and the external exposure pathways. The only exposure pathway with an HQ > 1 is soil ingestion. As discussed above for NECR-1, actual exposures may be lower than those estimated and it may not be appropriate to consider the latter indirect exposure pathways

**NEMSA**

For current/future maintenance personnel within the NEMSA area evaluated under Scenario 1 (Tables 4-9 and 4-11), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of the NEMSA area for maintenance personnel under Scenario 2 (Tables 4-10 and 4-12), only subsurface soil has an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. This is attributable to the presence of Ra-226 in subsurface soil at an EPC of 69 pCi/g.

For the hypothetical future livestock grazer within the NEMSA area evaluated under Scenario 1 (Tables 4-13 and 4-15), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of the NEMSA area for the future livestock grazer under Scenario 2 (Tables 4-14 and 4-16), both surface and subsurface soil have an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. This is attributable to the presence of Ra-226 in surface soil at an EPC of 42 pCi/g, in subsurface soil with a Ra-226 EPC of 69 pCi/g, and both the meat consumption and external exposure pathways.

For the hypothetical future on-site resident within the NEMSA area evaluated under Scenario 1 (Table 4-17), none of the COPCs has an incremental risk above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04. Uranium has an incremental HQ > 1, which is attributable to soil ingestion. For evaluation of the NEMSA area for hypothetical future on-site residents both for the national average and for Native Americans under Scenario 2 (Tables 4-18 and 4-19), surface soil has an incremental risk greater than 1E-06 to 1E-04 and an HQ > 1. Incremental risk estimates greater than 1E-04 are attributable to the consumption of homegrown produce and/or meat, and the external exposure pathways. The only exposure pathway with an HQ > 1 is soil ingestion. As discussed above for NECR-1, actual exposures may be lower than those estimated and it may not be appropriate to consider the latter indirect exposure pathways.

**Boneyard**

For current/future maintenance personnel within the Boneyard area evaluated under Scenario 1 (Tables 4-9 and 4-11), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of the Boneyard area for maintenance personnel under Scenario 2 (Tables 4-10 and 4-12), neither surface or subsurface soil have an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. This is attributable to the presence of Ra-226 in surface soil at an EPC of 36 pCi/g.

For the hypothetical future livestock grazer within the Boneyard area evaluated under Scenario 1 (Tables 4-13 and 4-15), neither surface soil nor subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of the Boneyard area for the future livestock grazer under Scenario 2 (Tables 4-14 and 4-16), both surface and subsurface soil have an incremental risk greater than 1E-06 to 1E-04 or an HQ >1. This is attributable to the presence of Ra-226 in surface soil at an EPC of 46 pCi/g, in subsurface soil with a Ra-226 EPC of 36 pCi/g, and both the meat consumption and external exposure pathways.

For the hypothetical future on-site resident within the Boneyard area evaluated under Scenario 1 (Table 4-17), none of the COPCs has an incremental risk above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or an HQ > 1. For evaluation of the Boneyard area for hypothetical future on-site residents both for the national average and for Native Americans under Scenario 2 (Tables 4-18 and 4-19), surface soil has an incremental risk greater than 1E-06 to 1E-04. Incremental risk estimates greater than 1E-04 are attributable to the consumption of homegrown produce and/or meat, and the external exposure pathways. As discussed above for NECR-1, actual exposures may be lower than those estimated and it may not be appropriate to consider the latter indirect exposure pathways.

**Vents 3 & 8**

The Vents 3 & 8 area was added on during the RSE and therefore only surface soil samples were taken from this area.

For current/future maintenance personnel within the Vents 3 & 8 area evaluated under Scenario 1 (Table 4-9), no surface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of the Vents 3 & 8 area for maintenance personnel under Scenario 2 (Tables 4-10), surface soil has an incremental risk greater than 1E-06 to 1E-04. This is attributable to the presence of Ra-226 in surface soil at an EPC of 92 pCi/g.

For the hypothetical future livestock grazer within the Vents 3 & 8 evaluated under Scenario 1 (Tables 4-13 and 4-15), no surface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of the Vents 3 & 8 for the future livestock grazer under Scenario 2 (Tables 4-14), surface soil has an incremental risk greater than 1E-06 to 1E-04. This is attributable to the presence of Ra-226 via the external exposure pathway at an EPC of 92 pCi/g, and both the meat consumption and external exposure pathways.

For the hypothetical future on-site resident within the Vents 3 & 8 area evaluated under Scenario 1 (Table 4-17), none of the COPCs has an incremental risk above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04. Uranium has an incremental HQ > 1, which is attributable to soil ingestion. For evaluation of the Vents 3 & 8 area for hypothetical future on-site residents both for the national average and for Native Americans under Scenario 2 (Tables 4-18 and 4-19), surface soil has an incremental risk greater than 1E-06 to 1E-04 and an HQ > 1. Incremental risk estimates greater than 1E-04 are attributable to the consumption of homegrown produce and/or meat, and the external exposure pathways. Exposure pathways with an HQ > 1 include soil ingestion. As discussed above for NECR-1, actual exposures may be lower than those estimated and it may not be appropriate to consider the latter indirect exposure pathways.

**Trailer Park**

The Trailer Park area was added on during the RSE and therefore only surface soil samples were taken from this area.

For current/future maintenance personnel within the Trailer Park area evaluated under Scenario 1 (Table 4-9), no surface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of the Trailer Park area for maintenance personnel under Scenario 2 (Table 4-10), no surface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1.

For the hypothetical future livestock grazer within the Trailer Park area evaluated under Scenario 1 (Table 4-13), no surface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For evaluation of the Trailer Park area for the future livestock grazer under Scenario 2 (Table 4-14), surface soil has an incremental risk greater than 1E-06 to 1E-04. This is attributable to the presence of Ra-226 in surface soil at an EPC of 32 pCi/g, and both the meat consumption and external exposure pathways.

For the hypothetical future on-site resident within the Trailer Park area evaluated under Scenario 1 (Table 4-17), none of the COPCs has an incremental risk above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04. Uranium has an incremental HQ > 1, which is attributable to soil ingestion. For evaluation of the Trailer Park area for hypothetical future on-site residents both for the national average and for Native Americans under Scenario 2 (Tables 4-18 and 4-19), surface soil has an incremental risk greater than 1E-06 to 1E-04 and an HQ > 1. Incremental risk estimates greater than 1E-04 are attributable to the consumption of homegrown produce and/or meat, and the external exposure pathways. Exposure pathways with an HQ > 1 include soil ingestion. As discussed above for NECR-1, actual exposures may be lower than those estimated and it may not be appropriate to consider the latter indirect exposure pathways.

#### 4.3.2.2 Off-Site Areas

Off-site areas include the nine Home Sites evaluated for residential receptors (Figure 2-3), the Unnamed Arroyo (Figure 2-4) evaluated for the hypothetical future livestock grazer, and background data collected for the purpose of comparison to combined risk and hazard estimates for each area (Figure 2-5). The Home Sites were divided into a western and eastern group based on potential levels of impact and the geography of the two areas. The two areas are separated by the unnamed arroyo. The five eastern home sites are closer to the Site. Two of the four western home sites are located near the Unnamed Arroyo; the other two western home sites are located near the former Kerr McGee haul road. As a result of EPA's removal action within Home Sites #4, #6, #7, #8, and #9, the incremental risks and hazards associated with pre-soil removal results (Appendix E) are no longer representative of current conditions for those Home Sites. Following the removal action, EPA collected post-removal confirmation sampling results for Ra-226, but not for other analytes. Consequently, post-removal data for Ra-226 were used to evaluate current incremental risks and hazards associated with these Home Sites.

**Western Home Sites (#1 through #5)**

For residents of the western Home Sites evaluated under Scenario 1 (Table 4-20), none of the Home Sites have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For residents of the western Home Sites evaluated under Scenario 2, none of the Home Sites have an incremental risk or HQ above the USEPA risk management range of 1E-06 to 1E-04 or HQ > 1 (Tables 4-21 and 4-22).

**Eastern Home Sites (#6 through #9)**

For residents of the eastern Home Sites evaluated under Scenario 1 (Table 4-23), none of the incremental risk or HQ for any of the Home Sites exceeds the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For residents of the eastern Home Sites evaluated under Scenario 2 (Table 4-24 and 4-25), none of the Home Sites have incremental ILCR or HQ estimates above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1, based on EPA's post-removal confirmation sampling results. The total ILCR for all Home Sites on the eastern side of the Unnamed Arroyo were equal to 1E-04. For comparison, the total ILCR estimate for background soil was equal to 2E-04. Both the site-related and background risk estimates presented in this baseline ILCR are likely over-estimated as described in the Uncertainty Analysis included in Section 4.4.

**Unnamed Arroyo**

For the hypothetical future livestock grazer within the Unnamed Arroyo evaluated under Scenario 1 (Table 4-26), neither surface soil or subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. This is also true for the evaluation of the livestock grazer within the Unnamed Arroyo under Scenario 2 (Table 4-27).

**Background Data**

For the background data, only surface soil samples were collected. For Scenario 1, no soil concentrations of any COPC have a cumulative risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For Scenario 2, the total cumulative risk is 2E-04, and is above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04. This excess risk estimate for background soil is attributable to arsenic and Ra-226 by the soil ingestion, consumption of homegrown produce, consumption of locally-raised meat, and external radiation pathways.

## 4.4 UNCERTAINTY ANALYSIS

Following is a brief summary of potential uncertainties associated with the HHRA conducted for NECR. The following uncertainties have been identified based on limitations in the available information, methods, or assumptions described in this HHRA.

### 4.4.1 Contaminant Source Characterization

Environmental investigations conducted at the Site were based on site histories, known or suspected releases, and observed physical characteristics (e.g., the presence of waste materials or topographic anomalies) for non-radiological constituents. In addition, areas of the Site not known to be contaminated were investigated using a field gamma radiation survey for surface soil Ra-226. The field gamma radiation survey for surface soil Ra-226 was performed between November 7 and December 1, 2006 in accordance with the RSEWP. The field gamma radiation survey included a static (stationary) survey and a scan survey. The static gamma radiation surveys were designed primarily to characterize the nature and extent of Ra-226 in surface soils. The gamma radiation scan survey was intended primarily to aid with investigation and characterization of the lateral extent of Ra-226 and to identify elevated areas in surface soils. Areas of the site with significant detections of gamma radiation were targeted for additional, biased sampling. Based on the investigation methods employed, it is unlikely that locations within the 0.5-acre Home Site survey areas that were not specifically sampled contain significant levels of Site-related contaminants.

### 4.4.2 Site COPC Identification

The process used in the selection of site COPCs may introduce a degree of uncertainty in the HHRA. However, protective methods and assumptions were used to select site COPCs, in accordance with EPA (1989; 1991a). Protective assumptions used in the COPC screening procedure included comparison of maximum detected chemical concentrations of Ra-226 to EPA Soil Screening Levels (EPA, 2000b), and non-radiological analytes to residential and industrial PRGs (USEPA, 2004a). It should be noted, however, that these screening levels are based on conservative assumptions regarding land use (e.g., residential land use for all portions of the Site), default exposure assumptions, and do not take into account the contribution to risk of background concentrations of metals and Ra-226. As such, screening-level risk estimates tend to be over-estimated. Based on results of the screening HHRA, all investigation areas at the Site were further evaluated in a baseline HHRA

### 4.4.3 Exposure Assessment

Exposure assessment describes the processes used to identify potentially important receptors, exposure media, exposure pathways, and methods used to quantify exposure of human receptors to site contaminants. Potential uncertainties in the exposure assessment include, but are not limited to, the receptors, exposure pathways, exposure assumptions, and EPCs that are quantitatively and/or qualitatively evaluated in the HHRA. Receptors that were quantitatively evaluated in the HHRA for the NECR Site include residents for on-site, as well as off-site areas. As described in Sections 4.1.3 and 4.1.4, however, land use restrictions are in place for the Mine permit area by virtue of the NMMA, the current deed which allows the mineral rights owner to use as much of the surface as is necessary and convenient in connection with mining activities on the property, and the mine permit that allows mining and grazing activities. Unrestricted (i.e., residential) land use only applies to areas north of the Mine permit, excluding the Quivera Mine site, which is fenced and not used for residential purposes. Hypothetical future on-site residents were included in the baseline HHRA for evaluation of the potential need for future deed restrictions.

Exposure assumptions included the consumption of homegrown produce, and meat and eggs obtained from livestock raised in both on-site and off-site areas of the Mine permit. Exposure of human receptors to COPCs through the food chain is typically associated with substantial uncertainty due to the methods and assumptions used in modeling food chain exposures. Consequently, food uptake factors and exposure assumptions tend to err on the protective side. For example, the consumption rate of locally raised meat was based on the 95$^{th}$ percentile meat consumption rate for Native Americans equal to 5.09 grams per kilogram per day (g/kg-d), or 124.95 kilograms per year (kg/yr), published in EPA's *Exposure Factors Handbook* (USEPA, 1997b). The mean consumption rate for Native Americans, as cited in EPA (1997b), is less than half this amount, or 1.87 g/kg-d (51.45 kg/yr). In addition, information provided to GE/UTC by EPA indicates that the diet of local Navajo members includes a significant portion of mutton from sheep. The mean per capita intake rate for mutton in the U.S. is 0.0125 g-kg-d (0.31 kg/yr), while that for beef is 1.16 g/kg-d (28.4 kg/yr). While ranchers tend to have higher intake rates of locally-grown meat than average U.S. citizens, these comparisons suggest that the assumption regarding meat intake rate used in this baseline HHRA is protective. As a result, the carcinogenic risk estimate for ingestion of meat based on background levels of Ra-226 measured in soils at the Site was equal to 4E-05.

Finally, medium-specific EPCs used to quantify exposures for human receptors may result in uncertainty in exposure dose estimates. To address this potential uncertainty, maximum or 95 % UCL concentrations were used to estimate exposure doses for human receptors exposed to Site-related media, consistent with EPA (1989, 1992) guidelines. Based on the above considerations, the exposure doses presented in the HHRA for NECR are believed to represent protective, upper bound estimates of exposure.

### 4.4.4 Toxicity Assessment

The toxicity values (CSFs and RfDs) that were used in estimating carcinogenic risks and noncarcinogenic hazards also represent a potential source of uncertainty. The toxicity values used in the HHRA for NECR were derived from EPA sources, as described in Section 4.3.1.3. Toxicity values that are developed by the EPA generally represent upper bound estimates of toxicity, and incorporate uncertainty factors for extrapolation from animal data to humans, differences in individual sensitivity within populations, and the overall confidence in the data set. Because the toxicity values established by EPA are based on NOAEL concentrations and incorporate uncertainty factors, they are generally considered to be protective. The use of conservative toxicity values in the risk estimate tends to overestimate actual risks.

Route-to-route extrapolations were used when toxicity values were not available for a given route of exposure. The most frequent route-to-route extrapolations were performed to derive dermal CSFs or RfDs from oral values, because dermal CSFs and RfDs are not typically available. However, route-to-route extrapolations were also performed when inhalation CSFs or RfDs were not available, and the toxicological information supports such extrapolation. Route-to-route extrapolations were performed as described in USEPA (2002c). Route-to-route extrapolation results in potential uncertainty in the toxicological and risk evaluations for chemicals where this practice was employed, because some chemicals may be more or less toxic, or exhibit a different mechanism of toxicity, by the dermal versus oral route of exposure.

### 4.4.5 Risk Characterization

The different sources of uncertainty described above are incorporated into the risk estimate. Because the majority of these uncertainties err on the conservative side, the estimated risks presented in the HHRA for NECR most likely represent upper bound estimates; the actual risks are anticipated to be less. The protective nature of these assumptions is demonstrated by risk estimates associated with background concentrations of Ra-226 and non-radiological constituents in soil. The total ILCR for measured concentrations of all constituents in background soil (assuming scenario 2) was estimated as 2E-04. In other words, the uncertainty assumptions built into the risk calculation methodology are such that the HHRA results indicate that local residents are exposed to risks above EPA's target risk range based solely on background (pre-existing) conditions.

# 5.0 SUMMARY AND CONCLUSIONS

This Report describes the results of the RSE conducted at the Site and adjacent properties between August 14, 2006 and December 5, 2006. The RSE consisted of investigating surface and subsurface soils and sediments at various areas within and near the Site, in accordance with the RSEWP.

The Site was initially divided into eleven individual survey areas, which included NECR-1, NECR-2, Ponds 1 and 2, Pond 3/3a, Sandfill 1, Sandfill 2, Sandfill 3, Sediment Pad, Boneyard, NEMSA, and the Unnamed Arroyo. Two additional areas were added during the field investigation based on preliminary radiological scans; these areas were investigated in a judgmental manner only. These areas are Vent Hole 3/8 and the Trailer Park. Additionally, nine Home Sites located northeast of the Site were also investigated as part of the RSE and a soil removal action was subsequently carried out at five of the Home Sites (consisting of three properties) based on the results of the RSE. These home sites are located between NECR and the Quivera mine and are situated on the Quivera mine lease. Potential impacts to the Home Sites may have occurred due to wind or water transport of materials stemming from historical operations at NECR, historical operations at the Quivera mine, or background conditions.

Field investigation methods included scan and static gamma surveying, surface soil sampling, and subsurface soil sampling. The gamma radiation surveys indicated that surface soils within the initial boundaries of each of the on-site areas contain surface soils with Ra-226 concentrations above the 2.24 pCi/g FSL. The FSL for Ra-226 was derived from the residential PRG and mean background concentration of Ra-226, as described in Section 2.5. Small fractions of the survey points within the initial boundaries areas are below the FSL. The locations of exceedances of Ra-226 (equivalent) are frequent and closely spaced such that delineation of any smaller, clean areas within the interior of the areas is not practical, except possibly in Sandfill 1, where about 11 contiguous survey grid points are below the FSL.

The results of the static gamma radiation survey show that the average surface soil Ra-226 concentrations, as determined by correlation with the gamma survey results (CPM), range from approximately four to twenty times the 2.24 pCi/g FSL within each survey area. The surface soil Ra-226 concentration range is wide, with high standard deviations near or above the average concentrations indicating sporadic occurrence of elevated Ra-226 in surface soil.

Based on the static survey level results (i.e., locations below the Ra-226 FSL), an outer boundary for each area was interpreted and is shown on Figures 3-1 and 3-3 as the "FSL Boundary". This boundary was drawn outside of most Ra-226 exceedances of the FSL. The FSL Boundary was confirmed and slightly revised based on the results of the surface soil sampling. In many cases, the edge of impacted ground was established in the field, based on the following:

- Undisturbed ground, such as in wooded areas with native soils.
- Roads, structures, and fences.
- Topographic limitations such as precipices, and steep hillsides.
- Boundaries of adjoining survey areas.

The RSEWP also specified one-point surface soil sampling at 20% of the 80-foot triangular grid nodes (sample locations), or at least 13 grid nodes within an area, as well as from the five scan locations with the highest CPM readings at each of the nine Home Sites. The results show that although there may be some variation between Ra-226 surface soil concentrations by soil sampling versus static gamma radiation survey at some locations, the averages are comparable.

Surface soil samples (≤0.5 feet bgs) were collected from each of the fourteen survey areas, and analyzed for the preliminary COPCs (Ra-226, As, Mo, Se, U, and V). The results show that Ra-226 and uranium exceed the field screening levels at some locations, while all results for molybedenum, selenium and vanadium were below their respective field screening levels. Screening levels for As, Mo, Se, U, and V were based on the mean background concentrations, or in the case of arsenic, the published EPA Region 9 PRG, as described in Section 2.5. Ra-226, uranium and arsenic concentrations in surface soil were as follows:

- Ra-226 values ranged from 0.8 to 875 pCi/g with 70% of the 268 surface soil samples analyzed for Ra-226 [includes stepouts] exceeding the FSL of 2.24 pCi/g.

- Uranium values ranged from 0.7 to 3,970 mg/kg with 9% of the 230 samples analyzed for uranium exceeding the field screening level of 200 mg/kg.

- Arsenic values ranged from non-detect to 14.9 mg/kg with 60% of the 230 samples analyzed for arsenic exceeding the field screening level of 3.7 mg/kg. The data do not show any correlation between arsenic and Ra-226 or uranium concentrations, and there does not appear to be any spatial pattern in concentrations within the survey areas.

Subsurface soil samples (>0.5 feet bgs) were collected from each of the (original) eleven on-site survey areas, which includes the Unnamed Arroyo. Samples were collected in test pits, soil borings, and hand auger holes and analyzed for the preliminary COPCs. The results show that Ra-226, uranium and arsenic exceed the field screening levels at some locations, while all results for molybedenum, selenium and vanadium were below their respective field screening levels. Ra-226, uranium and arsenic concentrations in surface soil were as follows:

- Ra-226 values ranged from 0.6 to 438 pCi/g; 66% of the 145 subsurface soil samples analyzed for Ra-226 exceeded the FSL of 2.24 mg/kg.

- Total uranium values ranged from 0.7 to 760 mg/kg; 12% of the 145 samples analyzed for uranium exceeded the field screening level of 200 mg/kg.

Arsenic values ranged from non-detect (<0.5) to 13.9 mg/kg; 52% of the 145 samples analyzed for arsenic exceeded the field screening level of 3.7 mg/kg. The arsenic concentrations do not correlate with Ra-226 concentrations (e.g., locations of high aresenic concentrations are not necessarily co-located with high uranium concentrations) and there does not appear to be any spatial pattern in concentrations within the survey areas. Exeedances of the field screening levels is subsurface soils was confined to the top 5 to 14 feet at all sample locations, except at NECR-1. At NECR-1, exceedances of the field screening levels were detected in one soil boring (SB-090) in all samples collected from 5 to 25 feet bgs.

An evaluation of the the ratio of U-nat to Ra-226 concentrations in soils at the Home Sites was conducted. The average ratio of soils from around the Home Sites sampled for the RSE was 1.14. This is compared to an average ratio for background soils of 1.11, indicating that the Home Site soils are similar in nature to the background soils.

The HHRA that was conducted for the Site was based on the laboratory analysis results for surface soils (<0.5 feet bgs), and subsurface soils to a depth of 10 feet bgs. The HHRA is a quantitative and qualitative evaluation of potential impacts of Site-derived contaminants on human health, in the absence of remediation or institutional controls. Results of the HHRA are used to determine whether residual levels of contaminants in Site media are protective of human health and may be left in place, or consideration of remedial alternatives are warranted. The HHRA results also provide the basis for the development of alternatives and risk-based cleanup goals for the Site, as appropriate.

The HHRA described herein was conducted in accordance with methods described in Section 6.0 of the approved *Removal Site Evaluation Work Plan* (MWH, 2006). This HHRA is comprised of a site-specific conceptual site model (CSM), screening-level HHRA, and baseline HHRA. Risk characterization results expressed as cancer ILCR and non-cancer HI estimates for on-site receptors (current/future maintenance personnel, hypothetical future livestock grazers, and hypothetical future on-site residents) and for off-site receptors (current/future residents and hypothetical future livestock grazers) exposed to soils and sediments at the NECR Site are described below.

For each off-site and on-site area, two scenarios were evaluated: Scenario 1 summarizes risks to receptors when only direct soil exposure pathways are considered (i.e., incidental ingestion and inhalation of fugitive dust), while Scenario 2 includes five exposure pathways (i.e., incidental ingestion, inhalation of fugitive dust, consumption of homegrown produce, consumption of homegrown meat/eggs, and external radiation) (USEPA, 2007).

Additionally, the total combined risk for each area was calculated across all exposure pathways. Because the results of the risk calculations indicate that even naturally occurring (background) conditions exceed EPA's target risk range, incremental risk, which is the result of the background risk subtracted from the total combined risk, was also calculated for each survey area, as well as the Home Sites.

Located within the main NECR Site, there are 12 areas of concern which include: NECR-1, NECR-2 Ponds 1 & 2, Pond 3/3a, Sediment Pad, Sandfill 1, Sandfill 2, Sandfill 3, NEMSA, Boneyard, Vents 3 & 8, and the Trailer Park. Each on-site location was evaluated for current/future maintenance personnel, the hypothetical future livestock grazer, and hypothetical future on-site residents. The results of the assessment indicated the following:

- For current/future maintenance personnel under Scenario 1, no surface or subsurface soils in the on-site areas have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1.

- For current/future maintenance personnel under Scenario 2, surface soils in eight of the areas, and subsurface soils in five of the areas have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. A surface soil Ra-226 concentration of 50 pCi/g would result in an estimated incremental risk or HQ within the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ < 1.

- For the hypothetical future livestock grazer, under Scenario 1, no surface or subsurface soils in the on-site areas have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1.

- For the hypothetical future livestock grazer, under Scenario 2, surface soils in all but one of the areas, and subsurface soils in all but three of the areas have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. A surface soil Ra-226 concentration of 2.5 pCi/g would result in an estimated incremental risk or HQ within the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ < 1.

- For the hypothetical future on-site resident under Scenario 1, surface soils in all but three of the areas have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. Risk drivers under Scenario 1 were Ra-226 and uranium. A surface soil Ra-226 concentration of 110 pCi/g would result in an estimated incremental risk or HQ within the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ < 1. A surface soil uranium concentration of 48 mg/kg would result in an estimated incremental risk or HQ within the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ < 1.

- For the hypothetical future on-site resident under Scenario 2, surface soils in all of the areas have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. A surface soil Ra-226 concentration of 1.9 pCi/g would result in an estimated incremental risk or HQ within the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ < 1. A surface soil uranium concentration of 48 mg/kg would result in an estimated incremental risk or HQ within the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ < 1.

For a resident under scenario 2, in order to achieve the EPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ <1, concentrations of Ra-226 in surface soil concentrations cannot exceed 1.9 pCi/g, which is below the naturally occurring average levels of Ra-226 levels on the Colorado Plateau.

Off-site areas include the nine Home Sites evaluated for residential receptors, the Unnamed Arroyo evaluated for the hypothetical future livestock grazer, and background data collected for the purpose of comparison to combined risk and hazard estimates for each area.

The results of the risk assessment for residents of the Home Sites indicate the following:

- Scenario 1 - none of the Home Sites have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. Home Site #5 was associated with the highest ILCR (2E-05) estimated for any of the home sites. However, the ILCR due to background soils under scenario 1 was estimated as 1E-05.

- Scenario 2 – none of the Home Sites on the western side of the Unnamed Arroyo (Home Sites #1 through #5) have an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1.

- Scenario 2 - none of the Home Sites on the eastern side of the Unnamed Arroyo (Home Sites #6, #7, #8 and #9) have incremental ILCR or HQ estimates above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1, based on EPA's post-removal confirmation sampling results. The total ILCR for all Home Sites on the eastern side of the Unnamed Arroyo were equal to 1E-04. For comparison, the total ILCR estimate for background soil was equal to 2E-04. Both the site-related and background risk estimates presented in this baseline ILCR are likely over-estimated as described in the Uncertainty Analysis (Section 4.4).

Incremental risk estimates greater than 1E-04 are attributable to the consumption of homegrown produce, the consumption of homegrown meat, and the external exposure pathways considered in Scenario 2. Actual exposures will be lower than those assumed if vegetable gardens are not used, if livestock do not graze in the area, and/or if a concrete slab is part of the foundation at these Home Sites. In addition, it may not be appropriate to consider the latter indirect exposure pathways given that the risk-based Soil Screening Levels (SSLs) for Ra-226 for external exposure, consumption of homegrown produce, and consumption of homegrown meat based on a risk level of 10-6 are 0.01 pCi/g, 0.069 pCi/g and 0.024 pCi/g, respectively, and are below the site-specific background level of 1.0 pCi/g. It should also be noted that the exposure and risk estimates described in this HHRA are biased high due to the soil sampling design. Field screening was used to identify biased locations for the collection of soil samples. In turn, the 95% UCL on the mean concentration of these biased soil samples was used to estimate exposure doses and risk estimates. In most cases, the concentrations observed at biased sample locations are representative of only a very minor portion of the entire home site.

For the hypothetical future livestock grazer within the Unnamed Arroyo evaluated under Scenario 1 and 2, neither surface soil or subsurface soil concentrations of any COPC has an incremental risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1.

For the background data, only surface soil samples were collected. For Scenario 1, no soil concentrations of any COPC have a cumulative risk or HQ above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 or HQ > 1. For Scenario 2, arsenic and Ra-226 contribute to incremental risks above the USEPA risk management range of cancer risk equal to 1E-06 to 1E-04 and/or HQ > 1 due to soil ingestion, the consumption of homegrown produce and meat and exposure to external radiation.

Different sources of uncertainty described in the report are incorporated into the risk estimate. Because the majority of these uncertainties err on the conservative side, the estimated risks presented in the HHRA for NECR most likely represent upper bound estimates; the actual risks are anticipated to be less. The protective nature of these assumptions is demonstrated by risk estimates associated with background concentrations of Ra-226 and non-radiological constituents in soil. The total ILCR for measured concentrations of all constituents in background soil (assuming scenario 2) was estimated as 2E-04. Therefore, it is appropriate to consider both Scenario 1 and 2 in making risk management decisions.

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