# 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 $1.1 \times 10^{-3}$ 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 $3.8 \times 10^{-3}$ and $6.8 \times 10^{-3}$, 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:

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

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:

$$\text{RfD} = \frac{\text{NOAEL or LOAEL}}{\text{UF1 x UF2... x MF}}$$

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):

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

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):

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

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 95th 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.