# Human Health Risk Assessment

# Homestake Mining Co. Superfund Site

# Cibola County, New Mexico

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## ACRONYMS

| | |
|---|---|
| AMCL | Alternative Maximum Contaminant Level. |
| ARAR | Applicable Relevant and Appropriate Requirement. |
| ASPECT | Airborne Spectrophotometric Environmental Collection Technology. |
| BEIR | Biological Effect of Ionizing Radiation |
| CDI | Chronic Daily Intake |
| CERCLA | Comprehensive Environmental Resource and Compensation and Liability Act |
| COPC | Chemical of Potential Concern |
| CPM | Counts per Minute |
| DCGL | Derived Concentration Guideline Level |
| EPA | Environmental Protection Agency |
| ERG | Environmental Restoration Group |
| HEAST | Health Effects Assessment Summary Table |
| HI | Hazard Index |
| HMC | Homestake Mining Company |
| HQ | Hazard Quotient |
| HVAC | Heating, Ventilating and Air Conditioning |
| IRIS | Integrated Risk Information System |
| LADI | Lifetime Average Daily Intake |
| MARSSIM | Multi-Agency Radiation Survey and Site Investigation Manual. |
| MCL | Maximum Contaminant Level |
| MDC | Minimum Detectable Concentration |
| Mg/kg | Milligram per Kilogram |

| | |
|---|---|
| MMM | Multi Media Mitigation |
| NaI | Sodium Iodide |
| NAREL | National Air and Radiation Environmental Laboratory |
| NAS | National Academy of Sciences |
| NRC | Nuclear Regulatory Commission |
| ORIA | Office of Radiation and Indoor Air |
| OSL | Optically Stimulated Luminescence |
| pCi/L | Pico Curie per Liter |
| $pCi/m^2$-s | Pico Curie per Meter Square per Second |
| QASP | Quality Assurance Sampling Plan |
| R&IE | Radiation and Indoor Environmental National Laboratory |
| RfC | Reference Concentration |
| RfD | Reference Dose |
| RME | Reasonable Maximum Exposed |
| ROPC | Radionuclides of Potential Concern |
| RSL | Regional Screening Level |
| SF | Slope Factor |
| START | Superfund Technical Assessment and Response Team |
| STP | Small Tailings Pile |
| TEDE | Total Effective Dose Equivalent |
| UMTRCA | Uranium Mill Tailings Radiation Control Act |
| WL | Working Level |

# 1 Executive Summary

In 1958, the Homestake Mining Company (HMC) uranium mill opened and began milling operations. The Homestake site is located 5.5 miles north of the Village of Milan in northwest New Mexico.

Primarily because of groundwater contamination, the USEPA placed the Homestake site on the National Priorities List (NPL) in September 1983. In 1990, the mill ceased operations and the mill operating facilities were decommissioned and demolished between 1993 and 1995. During that time, the NRC was the lead regulatory agency for site reclamation and closure activities. The soil cleanup and mill reclamation activities were completed in 1995 and approved by the Nuclear Regulatory Commission (NRC) in 1999.

Although the mill has ceased its operations, two tailings piles, a groundwater treatment facility using reverse osmosis, and two existing evaporation ponds and a third recently constructed pond remain on site . Currently, the primary activity at the site is the containment and treatment of contaminated groundwater through a groundwater restoration program that the NRC is overseeing. The restoration effort is expected to continue through 2020, with final evaporation and site closure and decommissioning continuing through 2022.

The major land use south and southwest of the Site consist of residential developments located in the Pleasant Valley Estates, Murray Acres, Broadview Acres, Valle Verde and Felice Acres residential subdivisions. Over the years, permanent residential homes, modular homes and mobile homes have been established in the subdivision areas and immediate adjacent areas. As of early 2013, based on HMC's annual survey of the residential areas, all domestic water supply connections were completed with the exception of one Valle Verde resident who elected not to connect to the Milan water supply system. Private domestic wells that use the underlying shallow alluvial ground water were found unsuitable for drinking and other domestic uses.

Residents in the Five Subdivision communities raised several health concerns regarding the HMC site. They alleged that the site is polluting their air, soil and private well waters. This Human Health Risk Assessment (HHRA) responds to the residents' concerns in addition to being

a part of the remediation investigation for the site. The Risk Assessment identified chemicals and radionuclides that are potentially of concern, identified the pathways and routes of intake that those contaminants gain access to exposed individuals, and quantitatively evaluated the potential excess life time cancer and non-cancer risk to these individuals. EPA National Oil and Hazardous Substances Pollution and Contingency Plan (NCP) 40 CFR § 300.430(e)(2)(i)(A)(2) states that for known or suspected carcinogens, acceptable exposure levels are generally concentration levels that represent an excess upper bound lifetime cancer risk to an individual of between $10^{-4}$ to $10^{-6}$ using information on the relationship between dose and response. The range is a one in ten thousand ($1 \text{ X } 10^{-4}$) to one in a million ($1 \text{ X } 10^{-6}$) probability for a hypothetical reasonable maximum exposed individual to develop cancer at any time during his/her lifetime due to exposure to site contaminants. A hazard index (HI) of less than or equal to 1 is used for non-carcinogen effects found at Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) sites.

A risk is a chance that something may occur, but not a guarantee that it will. For example, if you flip a coin, there is one chance in two, or a 50 percent chance, that the coin will land heads up. Cancer risk refers to the calculated numeric chance or probability of developing cancer during a specified time period- for example, within a year, within next five years, or during the course of a lifetime. A risk of five in ten thousand ($5 \text{ X } 10^{-4}$) would mean that out of ten thousand individuals, five individuals may develop cancer in their life-time. The national average for the general U.S. population to develop cancer in their lifetime is 1 in 2 for males and 1 in 3 for females. The national average for dying from cancer is 1 in 4 for males and 1 in 5 for females according to U.S. National Cancer Institute's Surveillance Epidemiology and End Results Database for the years 2008 through 2010.

The EPA, under Superfund program, does not wait to take action until an observed adverse effect is seen in a community. The EPA bases its actions on the potential or probability that an adverse effect might occur. Superfund uses a target risk range ($1 \text{ X } 10^{-4}$ to $1 \text{ X } 10^{-6}$) for site cleanup. The EPA follows CERCLA law, NCP, EPA's procedures, methods and guidance, which require a baseline human health risk assessment as a component of the Superfund process. The HHRA is not designed to find actual cases of cancer in a community but is designed to predict the probability of developing cancer for a hypothetical individual exposed to site

contaminants over a life-time, to inform risk management decisions as part of environmental response.

Table 1-1 below, provides summary of risks in a residential land-use scenario. The estimated excess lifetime cancer risk from exposure to Radionuclides of Potential Concern (ROPC) in soil at the Five Subdivisions was $2.4 \times 10^{-4}$ in a residential scenario setting. The residential scenario assumes exposure to soil through the incidental soil ingestion route, external exposure to gamma radiation, inhalation of radionuclides in airborne particulates, and ingestion of produce (vegetables and fruits) modeled through the uptake of radionuclides in soil into plants. The risk was primarily due to external exposure to radium -226+D (Ra-226 plus its daughters) which pose a potential risk of $1.9 \times 10^{-4}$ (see table 5-1).

The estimated excess lifetime cancer risk from exposure to ROPC in ambient air at the Five Subdivisions was $1.8 \times 10^{-3}$ in a residential scenario. The residential scenario assumes exposure to contaminants in air through the inhalation and submersion routes of intake. The risk was primarily due to inhalation of radon- 222 in ambient air which was calculated to be $1.7 \times 10^{-3}$ (see table 5-1).

The estimated excess lifetime cancer risk from exposure to radionuclides of concern in soil at the Background area was $1.8 \times 10^{-4}$ in a hypothetical residential setting. The soil background area was selected based on its location further south from the Five Subdivisions which is close enough to be of the same soil make up as that of the Five Subdivisions and far enough to be impacted by HMC site related contaminants. It is assumed that exposure to soil occurs through the incidental soil ingestion route, external exposure to gamma radiation, inhalation of radionuclides in airborne particulates, and ingestion of produce (vegetables and fruits) modeled through the uptake of radionuclides in soil into plants. The risk was primarily due to external exposure to radium -226+D (Ra-226 plus its daughters or progeny assuming secular equilibrium between the radionuclide and its progeny) which posed a risk by itself of $1.4 \times 10^{-4}$ (Table 5-2).

The estimated excess lifetime cancer risk from exposure to radionuclides of concern in ambient air at the background area was $1.3 \times 10^{-3}$ in a residential scenario. The radon in ambient air background area was carefully selected from a community (Bluewater Village) similar to the Five Subdivision communities. The residential scenario assumes exposure to contaminants in air through the inhalation and submersion routes of intake. The risk was primarily due to inhalation of radon- 222 in ambient air which was calculated at $1.3 \times 10^{-3}$ (see table 5-2).

The estimated excess lifetime cancer risk from exposure to radionuclides of concern in water at the Five Subdivisions was $2.2 \times 10^{-3}$ in a residential setting. This was based on 14 private well water samples tested for radionuclides of concern including radon gas. These private well waters were currently not in use for domestic purposes. Since at the time samples were collected, all residents at the Five Subdivisions had been connected to the Milan municipal water system with the exception of one Valle Verde resident that elected not to be connected to the Milan water supply system. However, for the purpose of this risk assessment which also evaluates potential future risk, an assumption was made that in the future a new resident might decide to install a well and use it for domestic purposes. Therefore, the risk from exposure to private well waters is an added hypothetical potential future risk if ground water is used in the future for domestic purposes. The residential scenario assumes exposure to water through the ingestion and inhalation of volatiles routes of intake. The risk was primarily due to inhalation of radon-222 +D emitted from water due to indoor domestic uses (showering, cooking, dishwashing, laundering etc.) which had a risk of $1.6 \times 10^{-3}$ and secondly from inhalation of radium-226+D and ingestion of radium-228+D which had a risk of $3.5 \times 10^{-4}$ and $2.2 \times 10^{-4}$ respectively (see table 5-1). Risk from exposure to groundwater through the ingestion and inhalation routes of intake include exposure to background contaminants. The alluvium groundwater has been determined to be impacted by site related contaminants and is undergoing remediation. A true groundwater background for the site was not determined. Background concentrations for alluvial ground water have been established; however, it has likely been impacted by historical mining activities in the San Mateo Creek basin, and possibly naturally occurring uranium deposits.

In a residential scenario, a hypothetical reasonable maximum exposed (RME) individual living at the Five Subdivisions area and exposed to different media namely soil, air and produce through different routes of intake and through external exposure, is expected to have a total excess cancer risk of $5.6 \times 10^{-4}$ after subtracting risk from background exposures to the same media through the same routes of intake. Subtracting background risk from total risk is not to determine if the estimated risk after subtracting background is less than $1 \times 10^{-4}$, but for risk managers to distinguish the contribution of background risk to site risk. In the HHRA, consistent with Superfund risk assessment guidance, background risk is included in the risk assessment. If a site-specific carcinogen is also present in background at the site, then background risk of that

carcinogen is included in the site risk (OSWER Directive 9285.6-07P). Most of the risk was due to inhalation of outdoor radon plus its progeny, assuming secular equilibrium between radon gas and its progeny, found in ambient air. Statistical comparison between outdoor radon at the Five Subdivisions versus outdoor radon levels at Bluewater (background) did show statistical significant increase in the average at the Five subdivisions area over that in the background area (p-value = 0.000001). Therefore, based on a hypothetical reasonable maximum exposure scenario (30 years of exposure), it is expected that 5 to 6 people out of 10,000 people exposed to site contaminants, may develop cancer in their lifetime which could be associated with the site if no long term action is taken.

Table 1-1: Summary of estimated excess lifetime cancer risk from radionuclides exposure by an RME individual living at the Five Subdivisions residential community located offsite and downgradient from HMC Superfund site assuming a current/future residential scenario.

| Medium | Exposure Pathway | Radionuclides Of Primary Concern | Cancer Risk- Five Subdivisions | Cancer Risk- Background | Life-time Cancer Risk with Background removed |
|---|---|---|---|---|---|
| Soil | Ingestion, external, inhalation and produce consumption | Ra-226+D (external exposure) | $2.4 \times 10^{-4}$ | $1.8 \times 10^{-4}$ | $6.0 \times 10^{-5}$ |
| Air | Inhalation of Ambient Air | Rn-222 +D (inhalation) | $1.8 \times 10^{-3}$ | $1.3 \times 10^{-3}$ | $5.0 \times 10^{-4}$ |
| Total | | | $2.0 \times 10^{-3}$ | $1.5 \times 10^{-3}$ | $5.6 \times 10^{-4}$ |
| Well Water Added Risk[1] | Ingestion and inhalation | Rn-222+D & Ra-226 +D (inhalation) | $2.2 \times 10^{-3}$ | See [2] | See [2] |

[1] This is the added cancer risk from exposure to radionuclides in well water in the event that a well is dug and used for domestic purposes sometime in the future. Currently all residents are on Milan municipal water system. The risk include background groundwater risk.

[2]A true background for groundwater was not determined.

The cancer risk from chemicals of potential concern (COPC) was found similar to the cancer risk from the background area and therefore not added to radionuclide cancer risk. The

non-cancer risk from COPC was 0.1 which is much lower than the benchmark of a HI =1. However, statistical test did show statistical significant increase of Molybdenum average concentration in the soil of the Five Subdivisions area than the Molybdenum in the soil of the background area. Indicating a potential pathway for contaminants on site carried down-gradient to the Five Subdivisions area. But the concentrations are not high enough to exceed the benchmark of a HI =1. Therefore, no adverse health effects are expected from non-carcinogens found at the five subdivisions area.

Table 1-2 below, provides summary of risks in an agriculture land-use scenario. The estimated excess lifetime cancer risk from exposure to ROPC in soil at the Five Subdivisions was $1.1 \times 10^{-3}$ in an agriculture land use scenario. The estimated excess lifetime cancer risk from exposure to same ROPC found in background soil was $8.8 \text{ X } 10^{-4}$ in an agriculture land-use scenario setting. The agriculture scenario assumes exposure to soil through the incidental soil ingestion route, external exposure to gamma radiation, inhalation of radionuclides in airborne particulates, ingestion of produce (vegetables and fruits) modeled through the uptake of radionuclides in soil into plants, ingestion of meat and consumption of milk from locally raised cows, ingestion of poultry and eggs. The risk was primarily due to external exposure to radium -226+D (Ra-226 plus its daughters) and Ra-226 plus U-234 and U-238 in milk.

In an agricultural scenario, a hypothetical RME individual living at the HMC Subdivision area and involved in subsistence living exposed to ROPC in different media namely soil, air, produce, beef, milk, poultry and eggs through different routes of intake and external exposure is expected to have a potential total excess cancer risk of $7.2 \times 10^{-4}$ after subtracting risk from background exposures to the same media through the same routes of intake. Most of the risk was due to inhalation of outdoor Radon 222 plus its progeny, assuming secular equilibrium between Radon 222 and its progeny, found in ambient air. The excess lifetime cancer risk from inhalation of outdoor radon 222 gas coming from a site related source is assumed to be similar to the residential scenario which was calculated to be $5.0 \text{ X } 10^{-4}$. The remaining excess lifetime cancer risk for a farmer following a subsistence life style is $2.2 \text{ X } 10^{-4}$ from a source other than background. The additional radon risk might be attributed to the HMC site as a source of contamination to the neighboring residential communities. Especially when statistical comparison between outdoor radon at the Five subdivisions versus outdoor radon levels at

Bluewater (background) did show statistical significant increase in the radon average at the Five Subdivisions area over that in the background area (p-value = 0.000001).

Table 1-2: Summary of estimated excess lifetime cancer risk from radionuclides exposure by an RME individual living at the Five Subdivision area, offsite and downgradient from HMC Superfund site, assuming a current/future agriculture/farmer scenario.

| Medium | Exposure Pathway | Radionuclides Of Primary Concern | Cancer Risk- Five Subdivisions | Cancer Risk- Background | Excess Life-time Cancer Risk |
|---|---|---|---|---|---|
| Soil | Ingestion, external, inhalation ,produce consumption, Beef, Milk, poultry and egg consumption | Ra-226+D (external exposure) and Ra-226+D, U-234 and U238 in milk | $1.1 \times 10^{-3}$ | $8.8 \times 10^{-4}$ | $2.2 \times 10^{-4}$ |
| Air | Inhalation of Ambient Air | Rn-222 +D (inhalation) | $1.8 \times 10^{-3}$ | $1.3 \times 10^{-3}$ | $5.0 \times 10^{-4}$ |
| Total | | | $2.9 \times 10^{-3}$ | $2.18 \times 10^{-3}$ | $7.2 \times 10^{-4}$ |
| Well Water Added Risk[1] | Ingestion and inhalation | Rn-222+D & Ra-226 +D (inhalation) Ra-228+D (ingestion) | $2.2 \times 10^{-3}$ | See [2] | See [2] |

[1] This is the added risk from exposure to radionuclides in well water in the event that a well is dug and used for domestic purposes sometime in the future. Currently all residents are on Milan municipal water system. Risk to groundwater include risk from background.

[2]A true background for groundwater was not determined.

Indoor Radon gas levels were found to exceed the EPA recommended guidance level of less than 4 pCi/L, in twelve houses at the five subdivision communities. For purposes of demonstrating compliance with the 0.02 Working Level (WL) Uranium Mill Tailings Radiation Control Act (UMTRCA) regulations as an applicable relevant and appropriate requirements (ARAR), it is assumed that the 4 pCi/L of Rn-222 corresponds to 0.02 WL assuming Rn-222 is in secular equilibrium(50%) with its progeny (USEPA, 1993). Eleven houses were mitigated and one declined the mitigation effort. Because the analysis of variance indicated a significant

difference among the data and a potential location effect exist, different “A Posteriori Tests" post-hoc comparison of group means (i.e., location means) were carried out to further define differences between locations and determine which location is causing this difference. The Scheffe test, Tukey unequal sample size test, and Dunnett test were performed on the indoor radon data. Based on all the Post-hoc statistical evaluation, of the indoor radon data collected from the Five Subdivisions and from Bluewater (background) areas, indicate that there is no significant difference between the indoor radon levels at the Five Subdivisions taken separately and the background area. Also Wilcoxon-Mann-Whitney test for two samples did not show a significant difference (p-value = 0.20) between the indoor radon data of the Five Subdivisions taken together and the indoor radon levels at the background area (Bluewater Village). Therefore it is concluded that there is no significant difference between the Five Subdivisions annual indoor air radon levels and the background annual indoor air radon levels.

The indoor radon annual average values corrected for thoron (thoron included) were compared to the annual radon data with thoron filter (thoron removed). The Two Sample Wilcoxon-Mann-Whitney test was run on the data and showed that both data were not significantly different from each other (p value = 0.943). This indicates that thoron values did not have a significant effect on indoor radon values.

For the outdoor radon levels the three post-hoc tests did show statistical increase of outdoor radon average levels in the Five Subdivisions over that of the background area (Bluewater Village) after the radon levels were corrected for thoron levels (thoron included). However, only the Scheffe post-hoc statistical comparison of the mean test did show statistical increase of outdoor radon levels at Murray Acres and Pleasant Valley over the background outdoor radon levels when data from radon air monitors with thoron filters (thoron removed) were used.

Outdoor radon levels monitored at the HMC facility, upgradient and downgradient from the facility and at the fence-line did show that the downgradient radon air monitors are impacted by thoron levels indicating a source of thoron at the HMC facility. The outdoor air radon monitors at the fence-line did show a statistical significant increase of average radon levels collected at the 6” high monitors over the radon average levels collected at the 5 feet high air monitors which

indicates an additional potential source of radon gas coming from the surface soil in the whole general area of the site and surrounding communities.

The large tailing pile (LTP) is a component of the groundwater restoration project and emission of radon gas from the large tailing pile will continue until the groundwater restoration project is completed and a permanent radon cover placed on top of the LTP. Once the permanent cover is installed and site closure and decommissioning completed, radon emission is expected to reduce significantly.

**Conclusion.**

Using Superfund Risk Assessment methods, the HHRA found that inhalation of radon gas in air is the predominant pathway leading to excess estimated cancer risk for a reasonable maximum exposed individual living in the Five Subdivisions. The radon in the area of the Five Subdivisions presents excess cancer risk greater than EPA's acceptable risk range. The HHRA calculates the source of the excess cancer risk as $13 \text{ X } 10^{-4}$ from background sources and $5 \text{ X } 10^{-4}$ from HMC facility sources. The level of risk presented by the HMC facility apart from background would generally indicate the need for long-term cleanup in the Superfund program. Long-term cleanup of the HMC facility is ongoing under state and federal authorities.

# 1. Section 1: Introduction

## 1.1 Overview

The Homestake Mining Company (HMC) uranium mill is located 5.5 miles north of the Village of Milan in northwest New Mexico. In 1958, milling operations began at Homestake's mill site. In 1961 the two milling facilities that existed at that time were combined under the Homestake-Sapin organization. In 1968, it became the United Nuclear-Homestake Partners after United Nuclear acquired interest in the partnership. In March 1981 Homestake purchased United Nuclear Corporation's interest and the operation became Homestake Mining Company-Grants. In 2001, Homestake merged with Barrick Gold Corporation as a wholly-owned subsidiary (HMC 2012a). For convenience every time we mention Homestake we are referring to the wholly-owned subsidiary of Barrick Gold Corporation.

The milling operations involved the use of an alkaline leach-caustic precipitation process to extract and concentrate uranium oxide from uranium ores. The byproducts (waste) were either disposed above ground in the two tailings impoundments or recycled back into the milling process. For approximately 30 years, Homestake milled uranium at the site. The site has two tailings piles, a groundwater treatment facility (using Reverse Osmosis), and three evaporation ponds. The large tailings pile is unlined, covers approximately 215 acres, is 85-90 feet tall, and contains approximately 20 million tons of tails. The small tailings pile is also unlined and covers approximately 40 acres, is 25 feet tall, and contains approximately 2 million tons of tails. The tailings piles overlie an alluvial groundwater aquifer, into which contaminants from the piles have migrated. Homestake began a state-approved groundwater restoration program in 1977. The program consists of a groundwater collection/injection system for the San Mateo alluvial aquifer and the Upper and Middle Chinle aquifers. The remedial objective for ground water is to reduce contaminant concentrations to meet the site-specific standards that have been established for the alluvial aquifer, and the upper, middle, and lower Chinle aquifers (HMC 2012a).

In September 1983, the USEPA placed the Homestake site on the National Priorities List (NPL), primarily due to groundwater contamination. Further investigations at the site identified groundwater contamination in on-site monitoring wells and some residential wells. Homestake and the USEPA signed an agreement in December 1983. The agreement required Homestake to provide an alternate water supply to nearby residences and to pay for water usage for 10 years. The alternate water supply connections to residences were completed in April 1985, with Homestake paying for water usage until 1995.

In 1990, the mill ceased operations and the mill operating facilities were decommissioned and demolished between 1993 and 1995. During 1993–1995, the NRC was the lead regulatory agency for site reclamation and closure activities. The soil cleanup and mill reclamation activities were completed in 1995 and approved by the Nuclear Regulatory Commission (NRC) in 1999. Although the mill ceased operation, the two tailings piles remain on site.

**Homestake Site Geology**

The Five Subdivisions are located primarily on alluvial deposits comprised mostly of silt and sand. The alluvium would mostly be derived from outcrop of the Todilto Limestone and related sedimentary rocks plus basalts of the La Jara Mesa to the north and east, from outcrops of the Chinle Formation to the west northwest, and from sediment carried downstream along San Mateo Creek from greater distances. Small open-pit uranium mines occur on the low mesas underlain by the Todilto limestone 4-6 miles to the east and north of the subdivision area. (See Thaden, R.E., Santos, E.S. and Ostling, E.J., 1967, Geologic map of the Dos Lomas quadrangle, Valencia and McKinley Counties, New Mexico: U.S. Geological Survey, Geologic Quadrangle Map GQ-680, scale 1:24000 AND Thaden, R.E. and Ostling, 1967, Geologic map of the Bluewater quadrangle, Valencia and McKinley Counties, New Mexico: U.S. Geological Survey, Geologic Quadrangle Map GQ-679, scale 1:24000). Section 3.1.4, Geology and Hydrogeology of this report provides more details on hydrology of the site area.

## 1.2 Scope of the Risk Assessment

There are four steps in the baseline risk assessment process: 1) data collection and analysis, 2) exposure assessment; 3) toxicity assessment; and 4) risk characterization (USEPA 1989c). Data collection and evaluation involves gathering and analyzing relevant site data. Exposure

assessment is conducted to analyze contaminant releases, identify exposed population, identify potential exposure pathways, estimates exposure concentrations for pathways and estimate contaminant intakes for pathways. Toxicity assessment considers the types of adverse health effect exerted on exposed individuals by collecting qualitative and quantitative toxicity information and determine appropriate toxicity values. Risk characterization integrates information of the previous three steps to characterize potential for adverse health effects to occur, estimate cancer risks, estimate non-cancer hazard quotients, evaluate uncertainty and summarize risk information.

### 1.2.1 Data Collection and Evaluation

The site history and records were collected and reviewed. Past site operations and types and quantities of radioactive material were reviewed. Existing radiological data and environmental monitoring data were also reviewed. Several site visits were made to understand the physical site characteristics and current and potential future land use. A conceptual site model was developed and a field sampling plan was prepared for the site. Figure 3-6 is the conceptual site model for the site. The site and its residential neighborhood were studied in the past. A lot of data from different medium exist and was used in this evaluation. The chemicals of potential concern (COPC) and radionuclides of potential concern (ROPC) are known for the site based on operational history and samples collected from the site (HMC 2012a, HMC 2012b). However, in this risk assessment, the list of inorganics and radionuclides was extended to include more chemicals and more radionuclides in different tested media to confirm the list of COPCs and ROPCs. A quality assurance project plan (QAPP) and Field Sampling Plan were prepared by U.S. Army Corps of Engineer (USACE) for EPA (U.S. EPA, 2010b and U.S. EPA, 2010c). A visual sampling plan (VSP) was developed to calculate number of samples needed for the site, and the quality management plan (QMP) of the laboratory that did the analysis addresses the accuracy of the lab results.

### 1.2.2 Exposure Assessment

In the exposure assessment, actual or potential contaminant fate and transport pathways are analyzed, actual or potentially exposed populations and exposure pathways are identified. Exposure point concentrations are determined and uptake of contaminants through different routes of intake is estimated.

Several visits to the site and its neighboring areas identified the site neighboring area to be essentially a residential community; some areas were identified as agricultural areas. Residents may be exposed to contaminants in and around their homes through: Incidental ingestion of soil and house dust; inhalation of airborne particulates; dermal exposure, external exposure to gamma radiation and ingestion of homegrown produce. For agriculture farm scenario, farmers are assumed to have same exposures as the residential scenario with additional exposure due to ingestion of beef and milk from home raised cows and ingestion of poultry and eggs.

The onsite area south of HMC facility is rented for commercial grazing of cattle. Also, hay or alfalfa which is grown in areas irrigated with contaminated water, are sold for grazing purposes. Consumption of beef and milk from cows raised on these areas is difficult to assess since cattle end up sold and sent to different areas around the United States markets.

### 1.2.3 Toxicity Assessment

Quantitative estimates and qualitative toxicity data for contaminants of concern are summarized in this section. They are obtained from the Integrated Risk Information System (IRIS) and Health Effects Assessment Summary Table (HEAST). For carcinogenic effects the estimates are oral or food cancer slope factors and inhalation unit risks; for noncarcinogenic effects, they are the oral reference dose (RfD) and the inhalation reference concentration (RfC).

### 1.2.4 Risk Characterization

Information gathered in the previous steps is integrated in the risk characterization. The likelihood and magnitude of adverse health risks are estimated in the risk characterization in the form of non-cancer hazard quotients (for COPCs) and/or excess lifetime cancer risks (for ROPCs and COPCs). Sources of uncertainty in the evaluation are then noted and discussed. This stepwise process is used in the following sections to evaluate potential health risks that may be associated with exposure to radiological and chemical contaminants.

## 2. Section 2: Identification of Radionuclides and Chemicals of Potential Concern

# 2 Description of Sampling Program and Design

## 2.1 Investigation Strategy

The field investigation at the Homestake Mining Co. (HMC) Superfund site consisted of three main elements: 1) Screening, scanning and survey evaluation, 2) Long term indoor and outdoor radon exposure evaluation and 3) Soil, produce and private well evaluation.

### 2.1.1 Screening, Scanning and Survey Evaluation

- Reviewed aerial gamma scanning for the site and surrounding areas. Reviewed site history operational activities. Reviewed old studies and evaluations of contaminants identified on site. Evaluated and studied existing data for possible use in any data gaps identified in our current study.
- Ran ground gamma scanning for the large area between the site treatment evaporation ponds and the fence line separating the site from residential communities.
- Radiation Structure Assessment in two phases: Phase 1, run gamma scanning around houses up to an area of 1 acre. Based on phase 1 results, carry on phase 2 inside houses by measuring indoor exposure radiation levels and collect wipe samples.
- Deployed short term radon ($\leq$ 7days) canisters to screen measure indoor air radon levels in order to address conditions that require immediate response action.

### 2.1.2 Indoor and Outdoor Radon Long Term Exposure Evaluation

- Placed radon etch track detectors indoors and in the yards for a year in houses with access agreement.
- Placed radon etch track detectors on the fence line that separates HMC from residential communities, at two different heights: at 5 feet and at 6 inches off the ground. This was done to study the impact of nearby soil on radon levels in air.
- Placed radon etch track detectors in triplicates up gradient and down gradient from HMC facilities. Down gradient radon air monitors were placed within HMC property.

This was done to measure the impact of radon emissions coming from the site on the down gradient air monitors.

### 2.1.3 Soil, Produce and Private Well Water

- Collected surface soil samples (upper 6" of soil) from yards around houses, soil samples were also taken on HMS property, from banks of evaporation ponds, irrigation field areas, central pivot areas and fence line.
- Collected produce samples from vegetable gardens from existing home gardens to evaluate risk to homeowners consuming vegetables grown in contaminated soil and irrigated with contaminated well water.
- Collected private well water samples to evaluate the additional risk to a hypothetical potential future resident that might dig a well and use it for domestic purposes.

## 2.2 Problem Definition

**The Problem to be addressed by the Project**

The purpose of this risk assessment was to address concerns raised by the public living in the Five Subdivisions (Murray Acres, Pleasant-Valley Estates, Broadview Acres, Valle Verde and Felice Acres) adjacent to the HMC site. Residents live downgradient from the HMC with some residences as close as 0.6 miles from the on-site ground water remediation project. The public was concerned that they had been exposed to unacceptable levels of radioactive contaminants through inhalation and ingestion. They alleged that the contaminants were transported into their homes through the spray mist from the evaporation pond associated with the ground water remediation activities and through their (the residents) use of contaminated ground water for domestic uses (such as cooking, showering, washing etc.). The residents were also concerned about contaminants transported from the site through the air or surface runoff to their backyard, and about consumption of produce in areas irrigated with contaminated ground water and consumption of livestock meat from cattle exposed to contaminated grazing areas.

## 2.3 The Environmental Question Asked

What is the increase in lifetime cancer risk to the current and potential future residents living near the HMC site that is attributable to ongoing remediation activities at the site and to residual hazardous materials remaining onsite from past milling activities?

## 2.4 Environmental Radiation Ground Scanning (ERGS)

The area between the evaporation ponds and fence line separating the HMC site from the residential subdivisions closest to the site was scanned. EPA Region 6 requested through the Office of Radiation and Indoor Air's (ORIA) Radiation Protection Division, that the Radiation and Indoor Environments (R&IE) national laboratory conduct a survey of the HMC site, in Grants New Mexico. R&IE conducted the scan using their Environmental Radiological Ground Scanning System (ERGS) from September 20 through October 28, 2010. The monitoring system consists of an array of 8 (4"x4"x16") Sodium Iodide (NaI) detectors, all summed to a single output.

The ERGS system was used to scan an estimated 250 acres of land composed mainly of soil and identify those areas with count rates that exceeded the background count rate (USEPA 2011). This scan identified those areas where further investigation might be warranted. Further investigation provided additional data and was used in the HHRA. The two main causes for concern was the practice of spraying uranium contaminated water high into the air and heavy rains in the recent years. It was felt that the spraying of contaminated water into the air could result in contaminants being deposited in the area down gradient from the evaporation ponds. It was further felt that the heavy rains could have resulted in contaminants being carried from the uranium mill tailing piles and evaporation ponds into adjacent residential neighborhoods located 1.0 kilometer (0.62 miles) south and down gradient from the ponds. If this occurred, it was expected that the scan would show higher count rates closer to the ponds, falling off steadily with increased distance from the ponds. In addition the scan would reveal if the areas between the HMC and subdivisions was impacted by residual contaminants left behind from milling activities in the past (this would be shown by count rates that were higher than those measured at the background area). Some channeling would be expected as the flooding water followed the path of least resistance. The purpose of this Project was to provide gamma count rates to help characterize the HMC site to help determine the extent of contamination and identify areas for further investigation. The ERGS survey consisted of driving the detector array back and forth over the ground surface at a nominal height of 12" inches. An overview of the ERGS scan is shown in Figure 2-1 which shows the results of ERGs scan. The two runs further south are the background areas selected to compare with the scans taken onsite.

Based only on the scan results, there was no definitive pattern leading away from the evaporation ponds. Count rates appeared to be greater at greater distances and lower directly adjacent to the ponds. Across the remediated flat and down gradient, there appeared to be a fairly consistent count rate.

Unpaved road areas and some water retention areas on the flat have been filled with volcanic crushed rock, which tends to show up on the graphic with a very low count rate. Many of the discrete higher count rate spots were surveyed with a hand-held meter and can likely be attributed to the burrowing activity of gophers in the area. These holes have dirt piled around them from below the surface soil causing discrete areas with an elevated count rate.

The study did not show a trend that would be consistent with the spraying of contaminated water into the air or mill tailings being carried down gradient or with an overtopping event of the retention/evaporation ponds. However, the increased count rates of the runs shown in *Figure 2-1* (as compared to the background count rates) indicated that the past milling activities of HMC have had a radiological impact in those areas.

## 2.5 Gamma Scanning around Homes and indoor alpha scanning

**Removal Assessment:**

Removal assessment work was done separately from the risk assessment project. The removal assessment was done throughout the mining district and its sampling effort and results were used to inform the risk assessment. Therefore a summary of the removal work is provided here. For more information on the removal assessment refer to the following documents: The Removal Assessment Report for Homestake Mining Company, Grants, Cibola County, New Mexico (EPA, 2012) and Protocol for Uranium Homes Site Assessment, Grants Mineral Belt Uranium Project, Cibola and McKinley Counties, New Mexico (EPA, 2009).

The removal assessment included identification and detection of radioactive contaminated objects around and inside houses. Most homes near the HMC site were built with modern construction methods and rocks were not used as a building material. However, lumber and metal from the mines may have been used to build the houses according to some residents. Radioactive materials may have been brought into the yards or deposited in the soils near these houses. Additionally, soil may have been contaminated as a result of the windblown material from tailings piles and impoundments on the HMC site. The removal assessment approach consisted of monitoring for gamma radiation using direct reading instruments and collecting samples of soil and other miscellaneous media for laboratory gamma spectroscopic analysis (USEPA, 2010a).

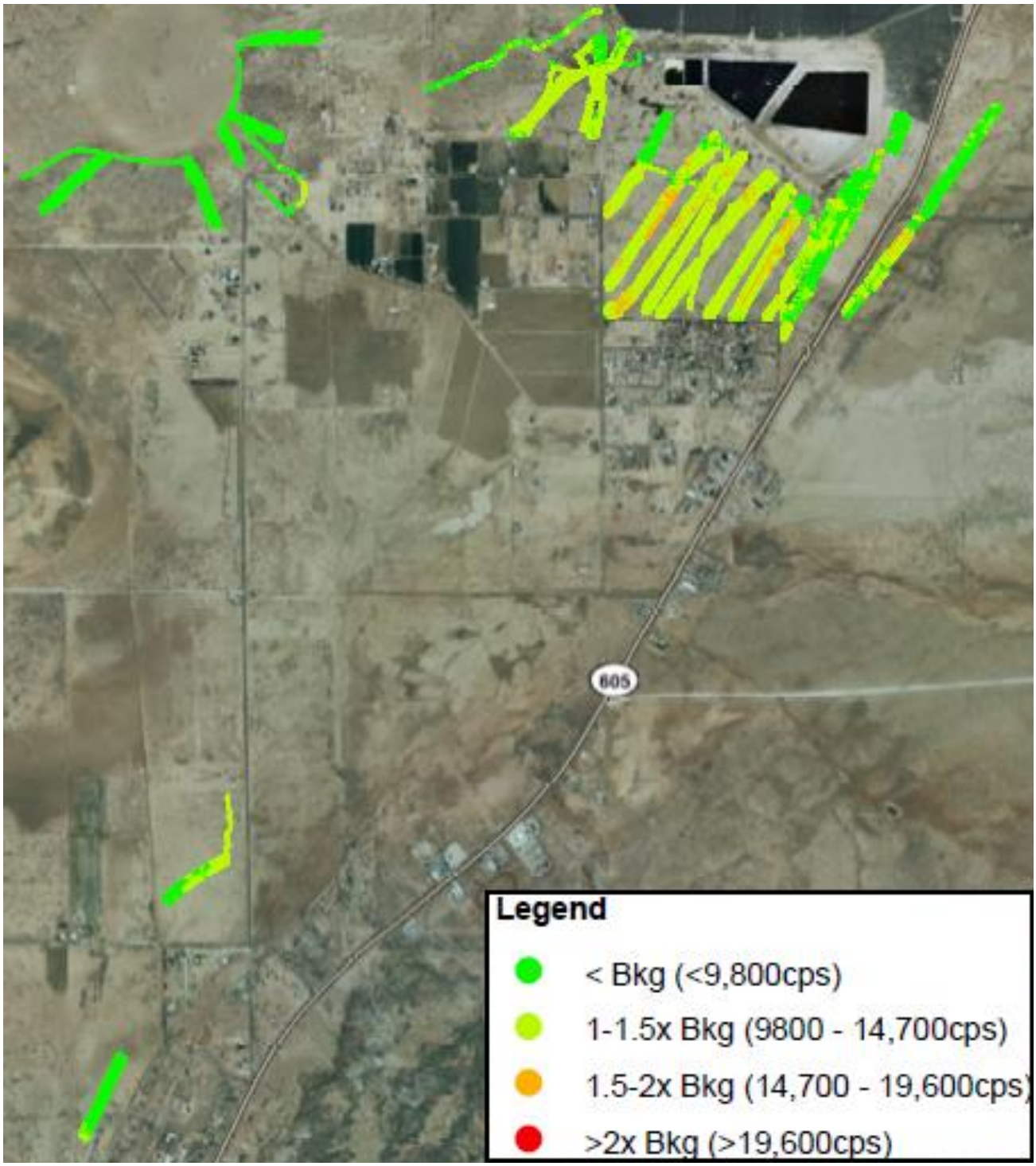



**Figure 2-1**. Displays an overview of the scan results. The two runs furthest south were the runs performed at the background areas identified by Region 6 personnel.

The removal assessment also analyzed soil samples for total uranium to address chemical (non-cancer) toxicity of uranium (US EPA 2010a). The removal Quality Assurance Sampling Plan (QASP) report provides details on sampling and analysis and can be found at:

**http://www.epa.gov/region6/6sf/newmexico/grants/nm_grants_index.html**

Scanning around a house is an evaluation technique performed while moving a radiation detector over a surface at a specified speed and distance above the surface (Figure 2-2). Count rate data is routinely collected at 2 second intervals, numerically converted to counts per minute (cpm), and often tagged with GPS coordinates using a global positioning system. Figure 2-3 is an example schematic of a gamma scan result done for all houses with access agreement, at the Five Subdivision area. Grab soil samples were then collected from subareas with clusters of high scan readings and analyzed for radionuclides of concern.

Each residence had two radiological action levels: Derived Concentration Guideline Level (DCGL) and gross alpha. The DCGL was calculated for each individual residence. See reference (USEPA 2012) for the details on calculating the DCGL. The DCGL was based on a dose of 15 millirem per year (mrem/yr), (US EPA, 1997). However, it should be noted that protectiveness for CERCLA sites should be determined based on the risk range of $1 \text{ X } 10^{-4}$ to $1 \text{ X } 10^{-6}$ excess cancer risk and not dose. Under certain circumstances for other radiation control programs developed by EPA, a level of 15 mrem/yr is generally considered protective. However, CERCLA dose assessments are generally conducted only where necessary to demonstrate ARAR compliance (see memorandum from Stephen D. Luftig titled "Distribution of OSWER Radiation Risk Assessment Q & A's Final Guidance" December 17, 1999, pp. 2-3) (USEPA, 1999)

The action level for gross alpha was 20 disintegrations per minute per 100 square centimeters (dpm/100 $cm^2$). The soil and miscellaneous material samples were delivered to the participating laboratory for gamma spectroscopy. The total concentration of uranium in soil was investigated using a non-cancer chemical screening level of 230 milligrams per kilogram (mg/kg). This screening level was taken from the EPA Regional Soil Screening Levels (http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/).

An HMC Removal Assessment was done by the EPA Region 6 Superfund Technical Assessment and Response Team (START-3) contractor. START-3 screened and sampled 86 residential properties in this removal assessment. Of the properties screened and sampled, 19 residential properties had outdoor levels above the Derived Concentration Guideline Level. Ten properties had discrete items that contained radioactive contamination, including pipe, rocks, and petrified wood. Indoor scanning indicated that one home had an indoor Total Effective Dose Equivalent (TEDE) greater than the 15 millirem per year (mrem/yr), and five other residences had total combined outdoor and indoor doses above 15 mrem/yr.

Analytical results from each of the 191 soil samples collected and analyzed for total uranium (chemical toxicity) were less than the EPA Regional Screening Levels (RSLs) action level of 230 milligrams per kilogram (mg/kg). Similarly, all 78 indoor-surface alpha-wipe sample results exhibited gross alpha concentrations that were less than the Nuclear Regulatory Commission (NRC) action level of 20 disintegrations per minute per 100 square centimeters (20 dpm/100 $cm^2$).

The Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) provides an approach to conducting radiation surveys and investigations at potentially contaminated sites (USEPA 2000c). The MARSSIM approach was followed and scanning surveys were incorporated into this removal assessment to maximize the use of field or in-situ data and to minimize the use of sampling requiring laboratory analysis. MARSSIM is not intended to replace or conflict with existing CERCLA guidelines, but is intended to provide supplemental guidance for specific situations involving radioactive contamination.

Figure 2-2 : Gamma scanning up to one acre around a house.

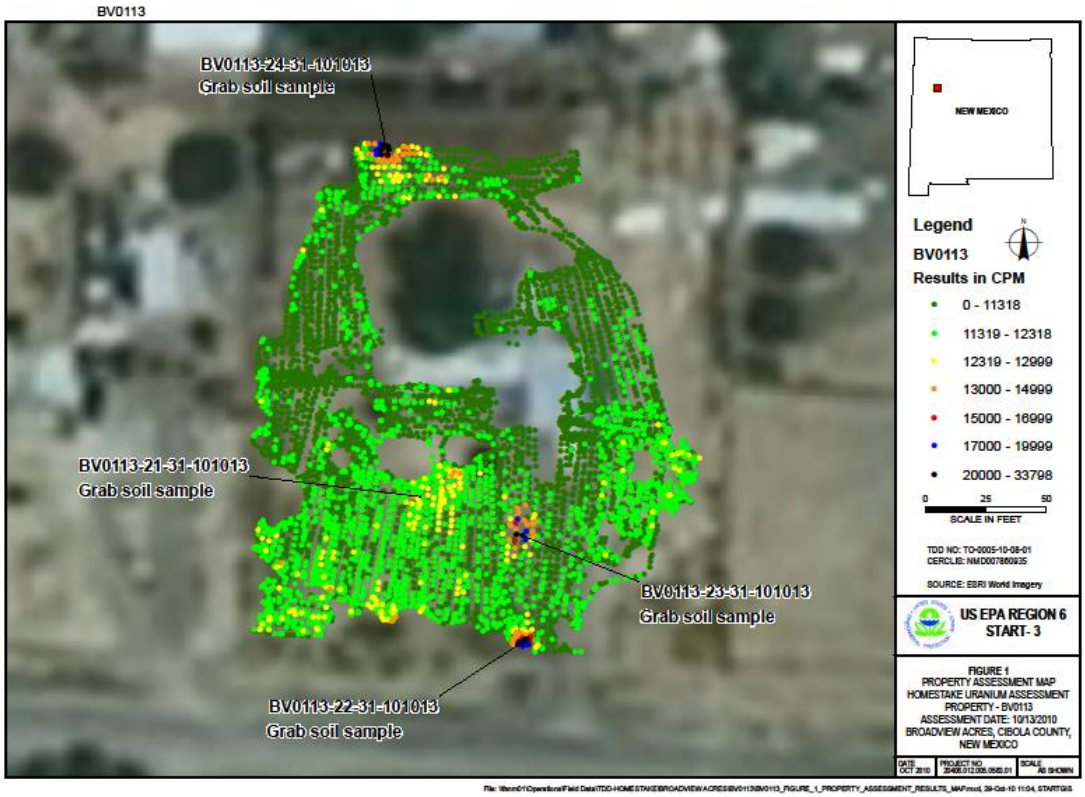



Figure 2-3: Example results of the buggy gamma scanning around house number BV0113.

## 2.6 Radon Data

### 2.6.1 General Information

Radon is a colorless and odorless gas, not detectable by human senses alone. At standard temperature and pressure, radon forms a monatomic gas with a density of 9.73 kg/m$^3$, about 8 times the density of the Earth's atmosphere at sea level, 1.217 kg/m$^3$. Radon is one of the densest gases at room temperature and is the densest of the noble gases. Because it is denser than air it tends to accumulate in low lying areas such as sumps and basements of houses. Radon-222 is a radioactive gas released during the natural decay of thorium and uranium, which are common, naturally occurring elements found in varying amounts in rock and soil (ICRP 2009). Because radon concentration inside a home is due to factors relating to its structure and geographic location, each individual home must be tested to determine its radon level. Two adjacent houses may have radically different radon levels. Any kind of home can have elevated levels, new or old, drafty or well-sealed, and basement or non-basement. Radon

gas can enter a home from the soil through cracks in concrete floors and walls, floor drains, sump pumps, construction joints, and tiny cracks or pores in hollow-block walls. Radon levels are generally highest in basements and ground floor rooms that are in contact with the soil. Factors such as the design, construction, and ventilation of the home affect the pathways and sources that can draw radon indoors. Another source of radon indoors may be air released by well water during showering and other household activities. Compared to radon entering the home through soil, radon entering the home through water will in most cases be a small source of risk. Outdoor radon is also a major source of radon to indoor radon levels. Outdoor radon concentration provides a baseline for indoor levels of radon. Outdoor radon could come from sources such as soil in house yards and soil at the HMC facility or from top of Homestake LTP or from air stripping of radon from evaporation pond water force sprayed high into the air. Due to air turbulent mixing the radon emitted from soil could be carried up and transported to indoor air of adjacent houses. Also due to atmospheric inversion radon from LTP could be trapped close to ground and transported to indoor air of houses adjacent to HMC. Sources of outdoor radon could also be coming from areas not related to the HMC facility. Sources related to the legacy uranium mines located north, north east and east of the HMC site. Radon-222 decays into radioactive elements, two of which, polonium-218 and polonium-214 emit alpha particles, which are highly effective in damaging lung tissues. These alpha-emitting radon decay products have been implicated in a causal relationship with lung cancer in humans.

### 2.6.2 Background Information

Radon occurs naturally as an indirect decay product of uranium or thorium found in soil. In addition to natural sources of radon gas in air, the other potential sources of radon gas in the ambient air and indoor air of residences adjacent to the HMC site are from the on-site tailing piles, spraying contaminated water from the evaporation ponds high into air to increase the rate of evaporation of pond water, reverse osmosis (RO) unit process. The process, which includes extracted groundwater that is pretreated with lime and processed in the clarifier before entering the RO unit, includes the RO brine waste in the collection pond. Radon gas could be emitted due to spreading of contaminated water onto the ground's surface through direct irrigation fields or through central pivot mechanical spraying. Outdoor radon could also be coming from areas to the north or northeast of HMC facility. Radon sampling was designed to capture potential contamination coming from all these sources.

Based on the radon emanation modeling that was done by Triad Inc., of Albuquerque, New Mexico in October 1976 for HMC (HMC 2012a Appendix B) for the tailings pile, it was concluded that it will require at least 15 feet of sand being placed on slimes in the tailing piles to reduce emissions of radon

from the slimes to negligible. Both slime and sand are products of the milling operation. The sand had an order of magnitude less radium than the slimes which significantly reduce the amount of soil cover material thickness. A one foot of cover material was recommended for radon release protection. It was not clear from the report if the recommendation was ever implemented but the important piece of information in the report referred to radium content of the slime to be about 900 pCi/g and radium content of the sand to be approximately 90 pCi/g. Although the plan was to reduce emission of radon to negligible levels, emission of radon from the top of the LTP continued to be measured. The top of the LTP is still being used as a major component in groundwater remediation.

In 1994, an interim cover was placed on the top of the LTP to control the dispersal of tailings by wind and water erosion. Radon barrier was applied to the north, west, east and south side slopes and completed in 1995. An evaporation pond was constructed on the Small Tailings Pile (STP) and interim cover placed on the remainder of the pile. Initial radon flux measurements were done in 1995, and were repeated annually. The average radon flux measurements done for the year 2011 on the LTP was 18.8 $pCi/m^2$- s, which is below the standard of 20 $pCi/m^2$-s as mentioned in 40 CFR part 61 subpart T (§61.222). But according to the report *Radon Flux Measurements for the HMC Tailings Piles* (HMC, 2011a) prepared by Environmental Restoration Group (ERG), Inc., for HMC, states "The July 2011 average measured flux of radon gas on the top of the pile was 53.95 $pCi/m^2$s. The September 2011 average flux on the top of the pile was 47.64 $pCi/m^2$ s. This compares to 42.1 $pCi/m^2$ s measured in 1995." This statement indicates that the top of the LTP is a continuing emission source of radon gas. When the average value is calculated for the whole pile which includes the radon flux measurement from the top of the pile and the sides of the pile, the average value drops down to 18.8 $pCi/m^2$-s.

### 2.6.3 Earlier Radon Studies for the HMC Surrounding Communities area

There were two radon studies done for the area surrounding HMC facility: the first in 1975 and the second in 1989. The first study was carried out by EPA's Las Vegas Laboratories which covered the whole Grant Mineral Belt area encompassing 4,400 $km^2$ area. Of interest are sample locations # 803 which fell in Broadview Acres neighborhood of the HMC site and # 801 which fell in Bluewater Village (USEPA 1976) . The Broadview Acre area was selected because it fell south-southwest of the United Nuclear- Homestake Partners Mill. The mill was still in operation at that time. The Bluewater village was selected since radon levels at this location were believed to be representative of local natural background conditions. Radon samples were collected during the month of November which represented winter time inversion conditions. Maximum levels of radon and its progeny were expected during this month. EPA was interested in earlier data and information where Bluewater Village was used

as a background location to the Five Subdivisions. The EPA study in 1975 used Bluewater Village as a background location to Broadview Acres. The data from these two locations was important for EPA as it is similar to the current EPA study which selected Bluewater Village as a background location for the Five Subdivisions, including Broadview Acres. EPA is providing more credible information for its decision of selecting Bluewater Village as an appropriate background location since it was previously selected by other researchers and scientists.

The monthly average ambient outdoor radon concentration at location # 801 in Bluewater Village was 0.79 ± 1.2 pCi/L with a range between 0.21 and 2.8 pCi/L and the average indoor radon progeny level was 0.0045 Working Level (WL). Compared to location # 803 in Broadview Acres which had a monthly average ambient outdoor air radon level of 2.1 pCi/L with a range between 0.24 and 3.6 pCi/L and an average indoor radon progeny level of 0.0271 WL. Both areas are geologically located on estimated thickness 50 to 90 feet of alluvium units which were considered as non-ore bearing because of the low uranium content. The author concluded that the active mill complex is the apparent source of elevated radon concentrations.

The second study was carried out by EPA as part of the Record of Decision (ROD) for the site. A preliminary radon screening program was initiated in October of 1987, after 66 of a possible 67 homeowners indicated their willingness to participate in the study. Results of the preliminary three-day screening indicated a range of indoor radon concentrations from 1.6 pCi/l to 12.1 pCi/1. In the absence of finding any acute concentrations (exceeding 20 pCi/1), the radon remedial investigation focused on long-term radon evaluations. Integrated radon concentrations were measured during a fifteen-month period in three-month Intervals. Concurrently, similar integrated radon measurements were made at 28 outdoor locations within the four subdivisions (USEPA 1989d).

A fifteen-month period was selected to cover the four seasons of the year and to provide measurement for two winter month periods when radon concentrations are usually the highest inside houses due to the homeowner attempts to keep homes tightly sealed against the weather. The overall annual average indoor radon concentration in the 59 houses was 2.7 pCi/1. The annual average outdoor radon concentration for the 28 monitoring stations was 1.9 pCi/1. Seasonal variation occurred in the indoor radon concentrations evidenced by higher levels in the quarters having the coldest weather. Only eight residences had annual average radon concentrations greater than 4 pCi/l. These eight values were 6.7 pCi/l, 6.2 pCi/l, 5.1 pCi/l, 4.6 pCi/l, 4.5 pCi/l, 4.2 pCi/l, 4.2 pCi/l and 4.1 pCi/l.

Based on the results of the remedial Investigation, EPA determined that the uranium mill and tailing embankments at the HMC site, though a potential source of radon near the site, were not contributing significantly to off-site subdivision radon concentrations. EPA concluded that the principle cause of elevated indoor radon in homes (homes having annual average radon concentrations exceeding 4 pCi/l) is related to local, native soil sources of radon in the subdivisions, and is a function of the type and quality of housing construction. As a result of this finding, EPA determined that it did not have authority under CERCLA Section 104 to address indoor radon concentrations identified as elevated in the Radon Operable Unit. The "no action decision formalized in the ROD, however, did not constitute a finding by EPA that adequate protection was achieved in the subdivisions. This was because 8 out of 66 residences investigated for radon had annual indoor radon concentrations above the 4 pCi/l action level guideline and ranged between 4.1 pCi/l and 6.7 pCi/l.

## 2.7 Evaluation of the Current Radon Study

### 2.7.1 Selection of Radon Background to the HMC Neighboring Communities

Selection of a true background area is a major task undertaken in developing human health risk assessment. It is an essential element or part of the risk assessment needed for proper evaluation of the impact of site related chemicals or radionuclides on communities surrounding a superfund site. After consultation with the U.S. Geological Survey (USGS), it was found very challenging to select an area that can be called a true background for the HMC subdivisions based solely on geological information. A true background is an area that is very similar to the studied area but is located away from the site. Therefore it has not been impacted by site releases or other site related sources of contamination and is not impacted by any site related contaminants from other sources more than the levels found onsite.

To properly evaluate indoor and outdoor air radon levels in the vicinity of the Five Subdivisions, it was essential to find a background community of residences that closely resembles the communities in the Five Subdivisions in ways that affect radon levels. This was important since radon gas is extremely variable and it can have many sources in addition to soil. Other factors that impact levels of radon include the type of area (i.e., an urban or rural area), type of house built (i.e. stucco, wood, brick, etc.), type of heating, ventilating and air conditioning (HVAC) system used inside the house, demographics and habits of individuals, movement of radon through the air from nearby sources, movement of radon gas released from contaminated groundwater plumes flowing under the residences, etc.

EPA Region 6 developed the following criteria to determine if a selected area could be considered a potential radon background candidate for the Five Subdivisions bordering the site:

1. ***Aerial Reconnaissance***
   Review EPA's Airborne Spectrophotometric Environmental Collection Technology (ASPECT) aerial photo scan to eliminate areas that show high gamma scan counts because of nearby mines or high uranium deposits.

2. ***Geological Features***
   Consult with USGS in evaluating the geology of the selected areas.

3. ***Soil Type***
   Evaluate the soil type of the area up to two meter below ground surface.

4. ***Site Reconnaissance***
   Tour the selected areas and evaluate the background community on the basis of rural vs. urban, type of the stock of housings, demographic makeup and distance from potential sources of radiation.

5. ***Historical Research***
   Review older studies and evaluate background areas used in those older documents.

6. ***Radiological Scanning***
   Conduct gamma scan screening of selected areas with hand-held sodium iodide detectors.

The following surrounding areas and communities were evaluated for the above mentioned criteria:

1) The Spanish Land Grant area including Seboyeta, Moquino, Bibo, and Paguate located approximately 29 miles east of the HMC subdivisions;
2) Prewitt community located 12.6 miles northwest of HMC subdivisions;
3) Bluewater community located about 6.4 miles west of HMC subdivisions;
4) San Rafael community located about 8.8 miles south of HMC subdivision;
5) Grants community between Lobo Canyon Road and Roosevelt avenue located at about 5.3 miles southeast of HMC subdivision; and
6) San Mateo community located about 13.4 miles northeast of HMC subdivision.

Based on the above mentioned criteria and as detailed in a draft memorandum evaluation report for selecting a radon gas background area for the site, Bluewater community was selected as the best available area to consider as a background area for the Five Subdivisions bordering the site (See Appendix F).

The EPA Region 6 collected indoor and outdoor air radon samples throughout the Five Subdivisions located south to southwest of the HMC. The purpose of the sampling was to determine if there are residents exposed to high levels of radon inside their homes and to determine if the radon levels are similar to natural levels found in that area of the county. For that reason radon samples were also collected from an area that was found to be the best location to represent a good background area to the Five Subdivisions area. This background area was Bluewater village about 6.4 miles away to the west of the HMC site.

### 2.7.2 Indoor Air Radon Evaluation

A total of 885 indoor radon samples were collected from 79 houses in the five subdivisions and 28 houses in the background community. Short term indoor air sampling was initially done as a screening approach to get an estimate of the levels of indoor radon present at the communities and later collected long term indoor and outdoor air radon levels for a year on a quarterly basis. Charcoal canisters air radon samplers were used for the short term sampling for a 2 to 6 day sampling period which were mostly collected between January 11, 2011 and March 29, 2011. At a minimum two charcoal canisters were placed next to each other in each sampled residence. Ten percent of the total samples were data quality assurance samples. The arithmetic mean of the short term data for each house was calculated to represent that house's short term indoor air radon level. The annual average radon level was used to evaluate both indoor and outdoor air radon level over longer period of time. Although short term radon levels give a good screening estimate of the level of radon in air, but the annual average air radon levels is a better estimate to represent long term exposure due to the inherent variability expected in the air radon measurements. The long term sampling was done using Radtrack passive Track-etch detectors (Landauer, Inc.). Both short term and the first quarter sample results were initially evaluated. The results for each house sampled for indoor air radon gas were reported in a personalized letter and disseminated to the residents of the subdivisions. EPA region 6 made two availability sessions at the site to discuss personalized reports with the residents on a one-on-one basis.

The long term air radon monitoring was done between Oct. 2010 and Dec. 03, 2011. The air monitoring samples were picked up every three months depending on the date they were installed. Some long term monitors were left for the entire year exposure. In the last two quarters, additional air monitoring was done using two types of monitors one with a thoron filter and another without thoron filter and placed next to each other. The sampling plan called for four quarters of radon sampling and not thoron sampling. The interest in measuring thoron was in determining the relationship between radon-222 gas and thoron gas, since thoron gas can largely interfere in radon-222 gas measurements. Thoron gas, which is an isotope of radon gas, is usually not tested for in an air radon investigation unless there is a specific reason to do so. By the second quarter of radon sampling, it was evident from incoming results that there was a thoron effect on the radon results. To study the effect of thoron gas on radon, an additional set of sampling was designed for that purpose. A set of radon air samplers, with thoron filters, were placed next to radon samplers without thoron filters. This was done for six months of continuous air monitoring.

The descriptive statistics for the indoor radon results using air monitors without thoron filter (i.e., the data measurements are for radon-222 plus thoron (radon-220)) are listed in table 2-1. The table represents the data for the Five Subdivisions put together and each subdivision and background area taken separately.

The number of houses sampled, the mean, geometric mean and median of the data were reported to select the appropriate mean value based on the tested distribution of the data. Minimum, maximum and range were reported to see the lowest and highest values of the data. The standard deviation and coefficient of variation were reported to see the spread of the data. The number of houses with indoor radon levels greater or equal ( ≥ ) to 4pCi/L which is the EPA recommended mitigation action guideline were also reported. It is assumed that the 4 pCi/L corresponds to the UMTRCA 0.02 WL ARAR (US EPA 1993). A test of the data distribution for both the subdivision data and the background data did show that the indoor radon data for the subdivision does not follow a specific distribution and the background data appear to be log-normally distributed. Based on this distribution the best averages of the two data sets i.e. the median for the indoor air radon data at the subdivisions of 1.34 pCi/l is compared with the geometric mean for indoor radon data in the background area of 1.25 pCi/l.

Table 2-1: Descriptive Statistics of the annual average indoor air radon data for houses at the Five Subdivisions and houses at background area (Bluewater Village)* in pCi/l. Radon measurements including thoron gas (Rn-222+Rn-220).

| Radon Adjusted for Thoron | Valid N | Mean | Geometric - Mean | Median | Min. | Max. | Range | Std. Dev. | Coef. Var. | Kurtosis | UCL 95% | UCL Basis | No. ≥ 4 pCi/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **All 5 subdivisions combined** | 79 | 1.86 | 1.42 | 1.34 | 0.36 | 7.20 | 6.84 | 1.40 | 75.33 | 1.59 | 2.54 | Non-Para | 11/79 |
| **Broadview Subdivision** | 26 | 1.20 | 0.92 | 0.77 | 0.36 | 4.36 | 4.00 | 1.06 | 88.63 | 3.76 | 2.103 | Non-Para | 2/26 |
| **Felice Acres Subdivision** | 7 | 1.80 | 1.57 | 1.71 | 0.66 | 3.08 | 2.42 | 0.95 | 52.69 | -1.94 | 2.5 | Student-t | 0/7 |
| **Murray Acres Subdivision** | 16 | 2.25 | 1.98 | 2.25 | 0.56 | 4.26 | 3.70 | 1.04 | 46.27 | -0.32 | 2.71 | Student-t | 2/16 |
| **Pleasant Valley Subdivision** | 18 | 1.70 | 1.38 | 1.16 | 0.60 | 4.68 | 4.08 | 1.25 | 73.60 | 0.99 | 2.34 | H-UCL lognormal | 2/18 |
| **Valle Verde Subdivision** | 12 | 3.04 | 2.30 | 3.03 | 0.48 | 7.20 | 6.72 | 2.03 | 66.93 | -0.09 | 4.09 | Student-t test | 5/12 |
| **Bluewater (Background Area)** | 28 | 1.57 | 1.25 | 1.39 | 0.41 | 5.37 | 4.96 | 1.16 | 74.04 | 3.59 | 1.97 | Gamma UCL | 3/28 |

*Descriptive statistics were done for all data excluding basement data. Basement data were included in the number of houses with indoor radon data ≥ 4 pCi/l.

Table 2-2, has the data for indoor radon collected from houses with basement. Indoor radon collected from the few houses with basement were treated separately as hot spot areas and its data excluded from the other indoor data to prevent false high average values. Most of the data from basements exceeded the EPA recommended action guidance of 4 pCi/l. In confined spaces such as basements, radon gas is heavier than air and is expected to accumulate in basement air.

Table 2-2: Annual average indoor air radon results for air monitors placed in basement of houses.

| Sample # | Analysis | Result | Uncertainty | Event | Location |
|---|---|---|---|---|---|
| BW0003-01-B | Radon | 1.8 | 0.06 | Indoor Radon | Basement |
| BW0003A | Radon | 2.9 | 0.18 | Indoor Radon | Basement |
| BW0003B | Radon | 3 | 0.19 | Indoor Radon | Basement |
| BW0031-01-A | Radon | 11.4 | 0.35 | Indoor Radon | North Wall in Basement |
| BW0031-02-A | Radon | 16.4 | 0.37 | Indoor Radon | N wall in basement |
| BW0031-03-A | Radon | 6.7 | 0.24 | Indoor Radon | N wall in basement |
| OT0035-01-A | Radon | 14.3 | 0.38 | Indoor Radon | Basement |
| OT0035-01-C | Radon | 16.5 | 0.41 | Indoor Radon | Basement |
| OT0035-01-FF | Radon | 14.7 | 0.35 | Indoor Radon | Basement near stairway |
| OT0035-02-F | Radon | 15.6 | 0.39 | Indoor Radon | Basement near stairway |
| OT0035-03-F | Radon | 11.1 | 0.31 | Indoor Radon | On beam in basement |
| OT0035-03-F-NTH | Radon | 12 | 0.32 | Indoor Radon | On beam in basement |
| OT0035-04-F | Radon | 14.6 | 0.37 | Indoor Radon | Basement beam |
| OT0035-04-F-NTH | Radon | 16 | 0.38 | Indoor Radon | Basement beam |
| OT0035A | Radon | 17.3 | 0.34 | Indoor Radon | basement table behind stair |
| OT0035B | Radon | 23.9 | 0.41 | Indoor Radon | basement table behind stair |
| OT0035C | Radon | 20.2 | 0.34 | Indoor Radon | basement table behind stair |
| VV0043-01-A | Radon | 2.9 | 0.14 | Indoor Radon | Basement office N wall |
| VV0043-02-A | Radon | 3.6 | 0.17 | Indoor Radon | Basement office N wall |

Table 2-3, is the descriptive statistics for indoor radon levels using air monitors with thoron filters for both the five subdivisions area and background area. The data measurements are for radon-222 only.

Table 2-3: Descriptive statistics for the annual average indoor air radon data for the Five Subdivisions and Bluewater using thoron filter detectors. That is measuring radon-222 gas only (pCi/l).

| Variable | Valid N | Mean | Geom. Mean | Median | Min. | Max. | Range | Std.Dev. | Coef. Var. | Kurtosis | 95% UCL | UCL Basis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **All 5 subdivisions** | 79 | 1.55 | 1.18 | 1.12 | 0.30 | 6.00 | 5.70 | 1.17 | 75.32 | 1.59 | 2.12 | Chebyshev |
| **Broadview Acres** | 26 | 0.99 | 0.77 | 0.64 | 0.30 | 3.63 | 3.33 | 0.88 | 88.61 | 3.76 | 1.75 | Chebyshev |
| **Felice Acres** | 7 | 1.50 | 1.31 | 1.43 | 0.55 | 2.57 | 2.02 | 0.79 | 52.65 | -1.93 | 2.08 | Student's -t |
| **Murray Acres** | 16 | 1.88 | 1.65 | 1.87 | 0.47 | 3.55 | 3.08 | 0.87 | 46.24 | -0.33 | 2.26 | Student's-t |
| **Pleasant Valley** | 18 | 1.41 | 1.15 | 0.97 | 0.50 | 3.90 | 3.40 | 1.04 | 73.59 | 0.99 | 1.95 | H-UCL |
| **Valle Verde Acres** | 12 | 2.52 | 1.92 | 2.53 | 0.40 | 6.00 | 5.60 | 1.69 | 66.93 | -0.09 | 3.41 | Student's-t |
| **Bluewater Village (Background Area)** | 28 | 1.16 | 0.92 | 1.02 | 0.30 | 3.95 | 3.65 | 0.86 | 74.00 | 3.59 | 1.45 | Gamma |

### 2.7.3 Outdoor Radon Data

A total of 751 outdoor long term annual (4 quarters) radon samples were collected from several areas around the HMC facility, the Five Subdivisions and Bluewater Village (background area). The outdoor radon data were separated into three categories (see figure 2-4). The first category data is for air monitors placed outside in the yard or at house fences. A total of 509 outdoor radon monitors were placed in the Five Subdivisions and Bluewater, with156 placed at the Bluewater (Background) area (see figure 2-5).

The second category data is for air monitors placed along HMC fence line between the HMC facility property and residential areas. At the HMC fence line two monitors were placed on each post. One was placed at a height of around 5 feet high from the ground surface and another was placed at around 6 inches off the ground. A total of 122 radon monitors were placed on twelve posts erected at the HMC fence line.

The third category data is for air monitors placed on HMC property downgradient from the HMC facility and radon air monitors placed upgradient from the HMC facility (see figure 2-5). Nine such posts were erected at different distances upgradient and downgradient of the HMC facility. Monitors

were placed in triplicate at 5 feet high on each post. This was done to address variability of radon data within each location. A total of 120 radon samples were placed within HMC property.

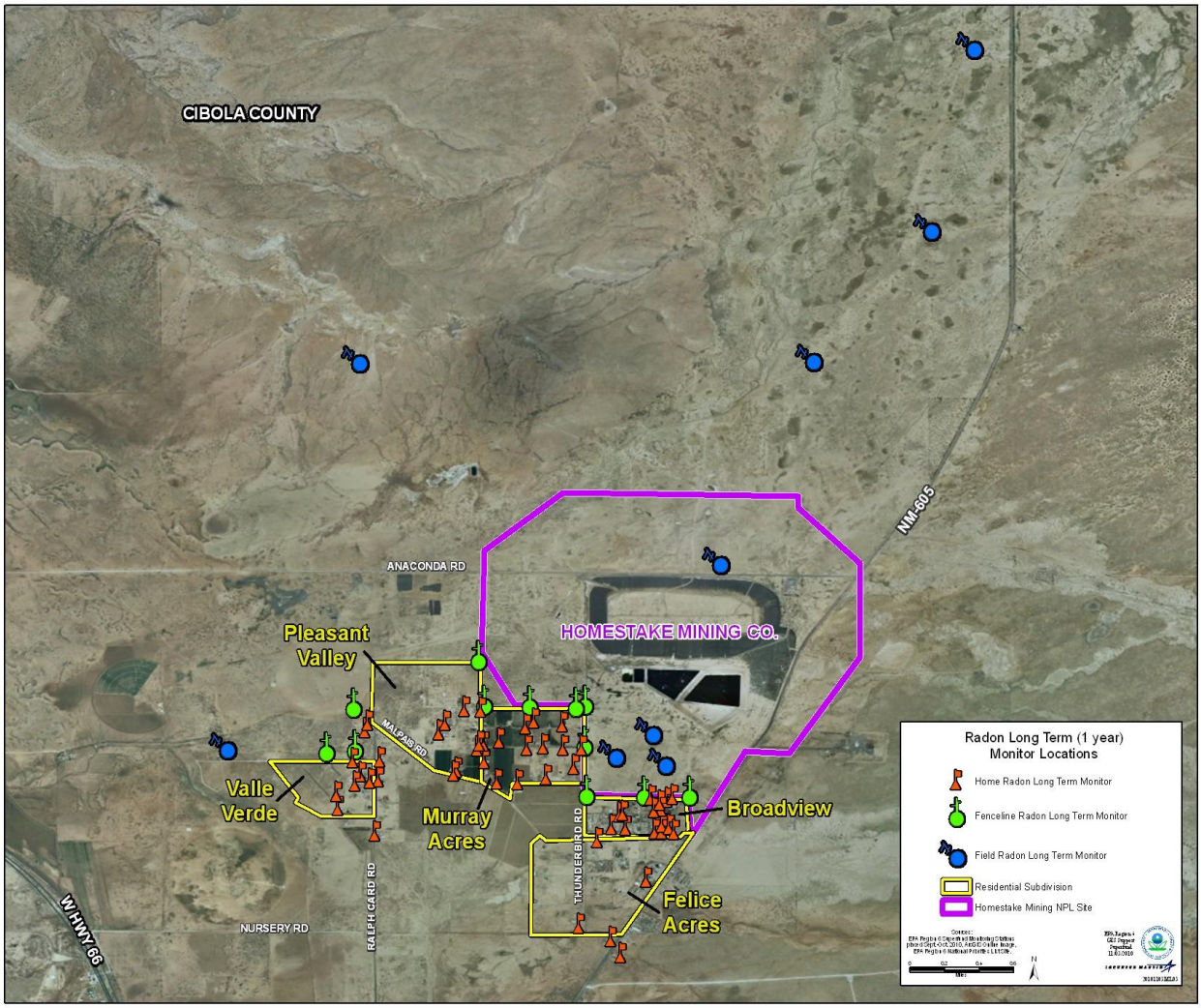



Figure 2-4: Placement of outdoor radon air monitors divided into three categories.

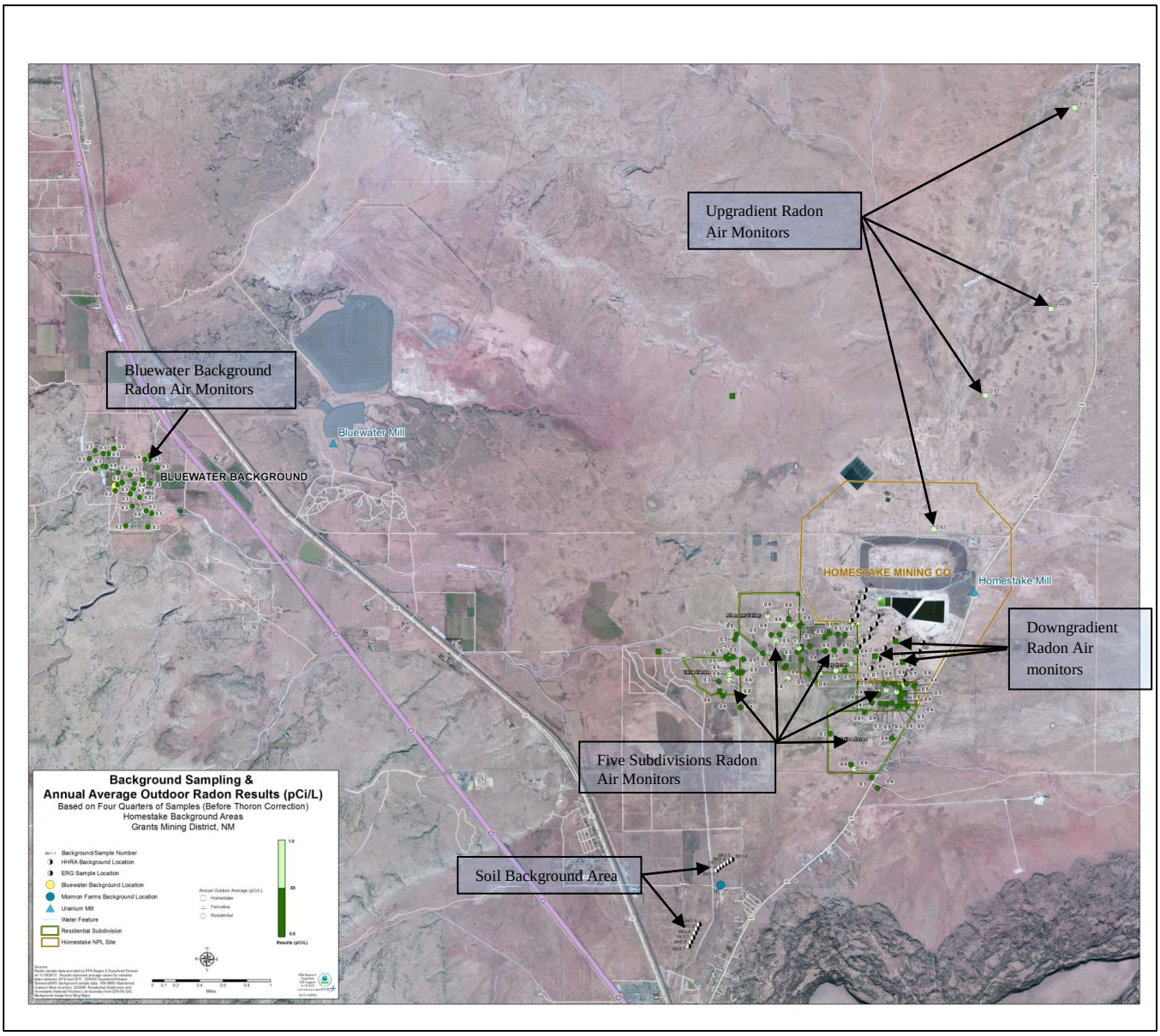



Figure 2-5: Placement of radon air monitors at Bluewater (Background area) relative to the site and radon air monitors placed at the Five Subdivisions. Also shown are upgradient radon air monitors relative to downgradient radon air monitors on HMC property.

Placement and collection of all outdoor track-etch detectors was based on leaving each detector in place for a 91-day (minimum) sample period. Detectors were in place for four consecutive quarters in order to provide data over a 1-year period. Ten percent of sample canisters had a second, co-located duplicate detector for data quality assurance.

Descriptive statistics and the 95% Upper Confidence Level (UCL) on arithmetic mean for category one outdoor radon data near residences are shown in table 2-4. STATIstica version 10 (Statistica, 2010) and ProUcl version 4.1(USEPA, 2010) were used for these calculations.

Table 2-4 : Descriptive statistics for one year outdoor air radon levels at the Five Subdivisions and Bluewater (Background Area) including thoron gas (Rn-222+Rn-220) in pCi/l.

| Location | Valid N | Mean | Geometric - Mean | Median | Min. | Max. | Range | Std. Dev. | Coef.Var. | Kurtosis | UCL 95% | Basis for UCL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **All 5 Subdivisions** | 79 | 1.29 | 1.25 | 1.24 | 0.68 | 2.75 | 2.06 | 0.36 | 27.95 | 3.73 | 1.356 | H-UCL |
| **Broadview Acres** | 26 | 1.22 | 1.20 | 1.17 | 0.76 | 1.93 | 1.17 | 0.26 | 21.54 | 0.56 | 1.31 | Student's-t UCL |
| **Felice Acres** | 7 | 1.10 | 1.10 | 1.05 | 0.83 | 1.58 | 0.76 | 0.25 | 23.17 | 1.54 | 1.285 | Student's-t UCL |
| **Murray Acres** | 16 | 1.38 | 1.33 | 1.26 | 0.83 | 2.41 | 1.58 | 0.42 | 30.85 | 1.35 | 1.573 | Gamma UCL |
| **Pleasant Valley Estates** | 17 | 1.38 | 1.32 | 1.24 | 0.69 | 2.75 | 2.06 | 0.45 | 32.34 | 5.25 | 1.572 | Gamma UCL |
| **Valley Verde Acres** | 13 | 1.30 | 1.26 | 1.28 | 0.69 | 2.20 | 1.51 | 0.35 | 27.13 | 3.36 | 1.475 | Student's-t UCL |
| **Bluewater Village (Background)** | 30 | 0.46 | 0.44 | 0.42 | 0.28 | 1.25 | 0.97 | 0.17 | 37.02 | 17.43 | 0.51 | Student's-t UCL |

Tables 2-5 and 2-6 below are the descriptive statistics for outdoor air radon levels for radon-222 (Rn-222) plus thoron gas (Rn-220) and outdoor air radon levels for radon-222 gas only respectively.

Table 2-5 : Descriptive statistics for outdoor air radon levels at the Five Subdivisions and Bluewater (Background Area) including thoron gas in pCi/l.

| Location | Valid N | Mean | Geometric - Mean | Median | Min. | Max. | Range | Std. Dev. | Coef. Var. | Kurtosis | UCL 95% | Basis for UCL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **All 5 Subdivisions** | 79 | 1.29 | 1.25 | 1.24 | 0.68 | 2.75 | 2.06 | 0.36 | 27.95 | 3.73 | 1.356 | H-UCL |
| **Boradview Acres** | 26 | 1.22 | 1.20 | 1.17 | 0.76 | 1.93 | 1.17 | 0.26 | 21.54 | 0.56 | 1.31 | Student's-t UCL |
| **Felice Acres** | 7 | 1.10 | 1.10 | 1.05 | 0.83 | 1.58 | 0.76 | 0.25 | 23.17 | 1.54 | 1.285 | Student's-t UCL |
| **Murray Acres** | 16 | 1.38 | 1.33 | 1.26 | 0.83 | 2.41 | 1.58 | 0.42 | 30.85 | 1.35 | 1.573 | Gamma UCL |
| **Pleasant Valley Estates** | 17 | 1.38 | 1.32 | 1.24 | 0.69 | 2.75 | 2.06 | 0.45 | 32.34 | 5.25 | 1.572 | Gamma UCL |
| **Valley Verde Acres** | 13 | 1.30 | 1.26 | 1.28 | 0.69 | 2.20 | 1.51 | 0.35 | 27.13 | 3.36 | 1.475 | Student's-t UCL |
| **Bluewater Village (Background)** | 30 | 0.46 | 0.44 | 0.42 | 0.28 | 1.25 | 0.97 | 0.17 | 37.02 | 17.43 | 0.51 | Student's-t UCL |

Table 2-6 : Descriptive statistics for outdoor air radon levels at the Five Subdivisions and Bluewater using radon with thoron filter detectors (i.e. radon-222 only) in pCi/l.

| Variable | Valid N | Mean | Geometric - Mean | Median | Min. | Max. | Range | Std. Dev. | Coef. Var. | Kurtosis | 95% UCL | UCL Basis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **All 5 Subdivisions** | 79 | 0.47 | 0.4 | 0.45 | 0.25 | 1.00 | 0.75 | 0.13 | 27.95 | 3.73 | 0.49 | Student's-t |
| **Broadview Acres** | 26 | 0.44 | 0.44 | 0.43 | 0.28 | 0.70 | 0.43 | 0.09 | 21.54 | 0.56 | 0.48 | Student's-t |
| **Felice Acres** | 7 | 0.40 | 0.39 | 0.38 | 0.30 | 0.58 | 0.28 | 0.09 | 23.17 | 1.54 | 0.47 | Student's-t |
| **Murrary Acres** | 16 | 0.50 | 0.48 | 0.46 | 0.30 | 0.88 | 0.58 | 0.15 | 30.84 | 1.35 | 0.57 | Gamma |
| **Pleasant Valley** | 17 | 0.50 | 0.48 | 0.45 | 0.25 | 1.00 | 0.75 | 0.16 | 32.34 | 5.25 | 0.57 | Gamma |
| **Valle Verde** | 13 | 0.47 | 0.46 | 0.47 | 0.25 | 0.80 | 0.55 | 0.13 | 27.13 | 3.36 | 0.54 | Student's-t |
| **Bluewater Village (Background)** | 30 | 0.33 | 0.32 | 0.30 | 0.20 | 0.90 | 0.70 | 0.12 | 37.02 | 17.43 | 0.37 | Student's-t |

For category two outdoor radon data, 122 Radtrack etch–track radon monitors were placed along the HMC Fence line separating the facility from residential areas, and data was collected on a quarterly basis for a one year period to provide annual data at the fence line. A total of twelve posts were erected along the fence line. Each post had two monitors, one placed at a height of around 5 feet high and the other was placed at a height of 6 inches off the ground. The purpose of two different heights was to check if there is a significant difference between the levels of radon at these two heights and determine whether soil is a significant contributor of radon gas to the ambient air radon level or not. Descriptive statistics for radon levels at both heights are provided in table 2-7. The radon levels detected at the 6 " height monitors showed slightly higher radon levels than the levels found at the 5 feet high radon air monitors. A Wilcoxon-Mann-Whitney two sample statistical test did show there is a significant difference (p-value = 0.0024) between the levels of radon at the two heights with the lower height (6"off the ground) measuring higher radon levels than the 5 feet high monitors. This indicates that soil is one of the contributing sources of radon gas to the radon gas level in the ambient air in the whole general area, in addition to other potential radon emission sources.

Table 2- 7: Descriptive statistics for outdoor air radon results including thoron gas (Rn-222+Rn-220) in pCi/l for monitors placed along the fence line between HMC property and residential areas. Monitors placed on top (5' high) and bottom (6" off the ground) at each post.

| Variable | Valid N | Mean | Geometric - Mean | Median | Min. | Max. | Range | Std.Dev. | Coef.Var. | Kurtosis | UCL 95% | Basis UCL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Top Fence (5' high)** | 56 | 1.12 | 1.07 | 0.996 | 0.75 | 1.99 | 1.25 | 0.37 | 32.69 | -0.83 | 1.21 | Student's-t test |
| **Bottom Fence (6'' high)** | 52 | 1.44 | 1.33 | 1.49 | 0.75 | 2.74 | 1.99 | 0.57 | 39.38 | -0.54 | 1.57 | Student's-t test |

For category three outdoor radon data, radon sample monitors were placed within HMC property area and around it, radon air monitors were placed upgradient of the HMC facility at four locations along a line at different distances and three downgradient at different locations and distances from the HMC facility within the HMC property. Monitors were placed along a line at various distances to study the impact of radon gas measured upgradient from the site on the downgradient air monitors within the HMC property and the impact on residential air radon levels. One monitor was placed to the west of the residential areas and another placed northwest of the HMC facility to study the impact of radon gas coming from the west and northwest areas. HMC had air monitors placed to the east of the HMC facility. In each location, radon air monitors were placed in triplicate to address variability of radon within its location. A total of 120 etch-track radon detectors were placed and collected on a quarterly basis for one year to study the air radon levels within and around the HMC facility and property. Table 2-8 is the annual outdoor air radon average levels for category three outdoor air radon monitors.

Table 2-8: Annual HMC radon results with thoron gas included (Rn-222+Rn-220) in pCi/L.

| Location | Results | Sub-Location |
|---|---|---|
| HMC01 | 0.91 | Upgradient North of Facility |
| HMC02 | 1.37 | Upgradient North of Facility |
| HMC03 | 1 | Upgradient North of Facility |
| HMC04 | 1.12 | Upgradient North of Facility |
| HMC05 | 2.1 | Downgradient South of Facility |
| HMC06 | 2.36 | Downgradient South of Facility |
| HMC07 | 2.36 | Downgradient South of Facility |
| HMC08 | 1.2 | West of the Facility |
| HMC09 | 0.54 | North West of the Facility. |

### 2.7.4 Radon in Ground water

Fourteen ground water samples from residents that use the ground water for irrigation were collected. Well waters were allowed to run for several seconds before collecting the sample to allow for any residual water in the hose to be removed. Residents are expected to use water as they open the water hose. The well waters were tested for radon gas. The protocol from *Standard Methods for the Examination of Water and Wastewater 20th Edition* under the 7500-Rn method was used. Radon gas was detected in some wells and others were not detected at a detection level of 49 pCi/l. Figure 2-6 record the radon results for the eleven residences with private well water. The results indicate that well water is also contaminated with radon gas and has the potential to contribute to indoor air radon level of houses which uses groundwater for domestic purposes.

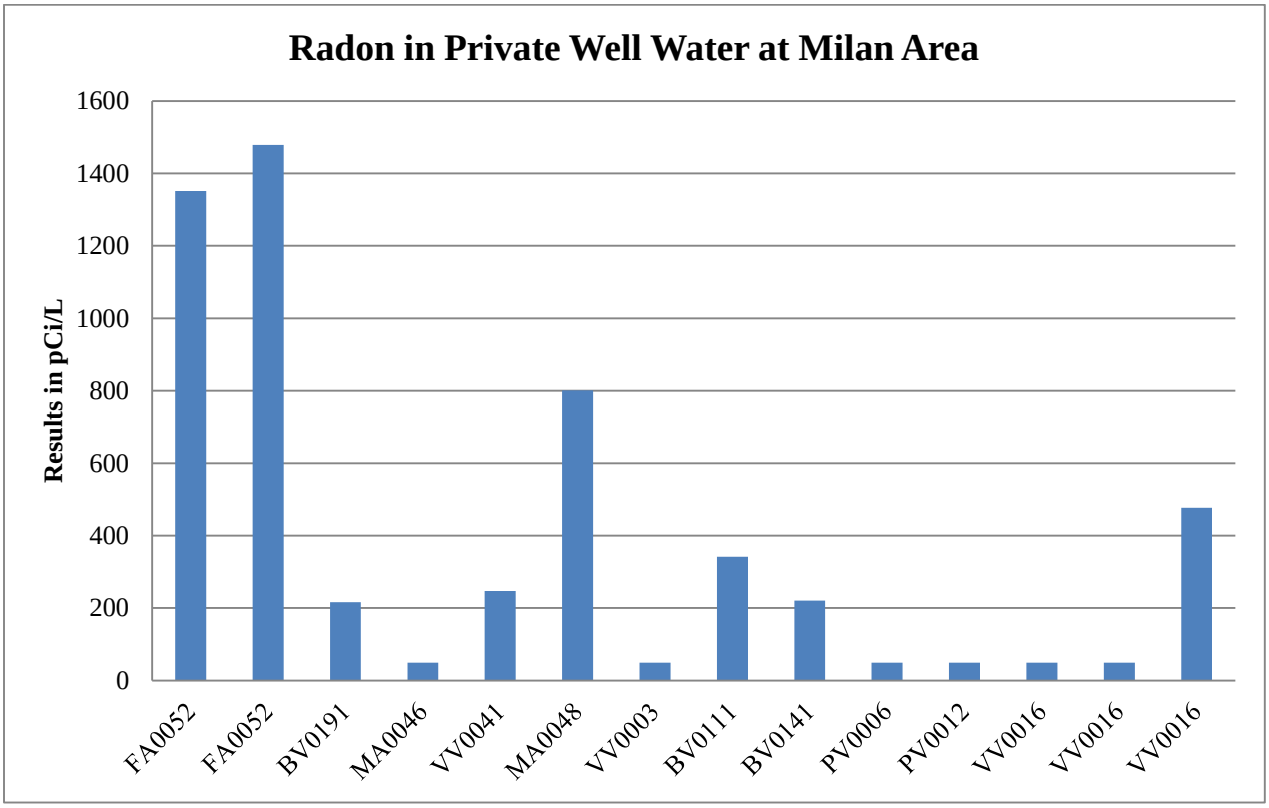



Figure 2-6: Bar chart for results of radon in private well water.

According to a 1999 report by the National Academy of Sciences (NAS) on radon in indoor air (Biological Effect of Ionizing Radiation (BEIR VI)), breathing radon in indoor air of homes is the primary public health risk from radon, contributing to about 20,000 lung cancer deaths each year in the United States, (NAS 1999). Radon is the second leading cause of lung cancer in the United States. Based on a second NAS report on radon in drinking water and compared to the estimate of 20,000 lung cancer deaths per year from inhalation of radon in indoor air, EPA estimates that radon in drinking water

causes about 168 cancer deaths per year. Eighty nine percent from lung cancer caused by breathing radon released from water, and 11 percent from stomach cancer caused by drinking radon-containing water. The NAS Committee recommends (NAS 1999a) that EPA continue to use 10,000 pCi/L in water to 1 pCi/L in air as the best estimate of the transfer of radon in drinking water to radon in indoor air (through showering, cooking, and other household water uses).

All radon levels in the private wells tested were below 1500 pCi/l. Thus radon in private well water is relatively contributing a small amount of radon to indoor air based on the transfer factor mentioned above. The risk associated with indoor air radon is generally high and is further increased depending on whether an individual smokes. The risk from inhalation of radon gas emitted during domestic uses of the contaminated well water will add to the overall risk of indoor radon.

In 1999, the U.S. EPA proposed regulations to reduce the public health risks from radon in water in the Federal Register (US EPA,1999b). The proposed regulation provides two options for the maximum level of radon that is allowable in community water supplies (CWS). The proposed maximum contaminant level (MCL) is 300 pico curies per liter (pCi/L) and the proposed alternative maximum contaminant level (AMCL) is 4,000 pCi/L. The drinking water standard that would apply for a system depends on whether or not the State or CWS develops a multimedia mitigation (MMM) program. The regulatory expectation of CWSs serving 10,000 persons or less is that they meet the 4,000 pCi/L AMCL and be associated with an approved MMM program plan - either developed by the State or by the CWS. Small systems may elect to comply with the MCL of 300 pCi/L, instead of developing a local MMM program. http://www.epa.gov/safewater/radon/proposal.html. The proposed 300/4000 pCi/l standard levels in water were used as screening levels in the HHRA.

### 2.7.5 Type of Housing and Indoor Radon Levels

In previous indoor radon studies of the HMC area (US EPA 1989d), the type of house structure was found to influence the indoor radon levels. In this current radon evaluation, we also considered the effect of house structure on the indoor radon levels. Table 2- 9 breaks down the houses at the Five Subdivisions into different types of structures with the number of houses in each type of structure and the mean of the indoor radon levels in houses of the same structure type. There are 30 trailers, 10 prefab, 16 stucco, 5 brick houses, from a total of 75 houses. The trailer houses had the lowest indoor radon average and the brick houses had the highest average. Figure 2-7 shows the houses at the Five Subdivisions area separated into two building construction types, trailer and non-trailer types with the indoor radon levels associated with these two types of houses.

Table 2-9: Breakdown table of descriptive statistics (house type and indoor radon results in pCi/l) at the Five Subdivisions area.

| | Exterior Type | Indoor Radon - Means | Indoor Radon - N | Indoor_Radon - Std.Dev. |
|---|---|---|---|---|
| | Prefab | 1.565600 | 10 | 1.287672 |
| | Unknown | 2.151714 | 7 | 1.043055 |
| | Trailer | 0.978400 | 30 | 0.634465 |
| | Stucco | 3.168250 | 16 | 1.536372 |
| | Wooden | 4.560000 | 1 | 0.000000 |
| | Lap Siding Home | 1.980000 | 3 | 0.799937 |
| | Warehouse | 2.730000 | 1 | 0.000000 |
| | Brick | 5.518400 | 5 | 6.796176 |
| | Cinderblock | 2.040000 | 1 | 0.000000 |
| | Stone | 3.456000 | 1 | 0.000000 |
| | All Grps | 2.094400 | 75 | 2.266664 |

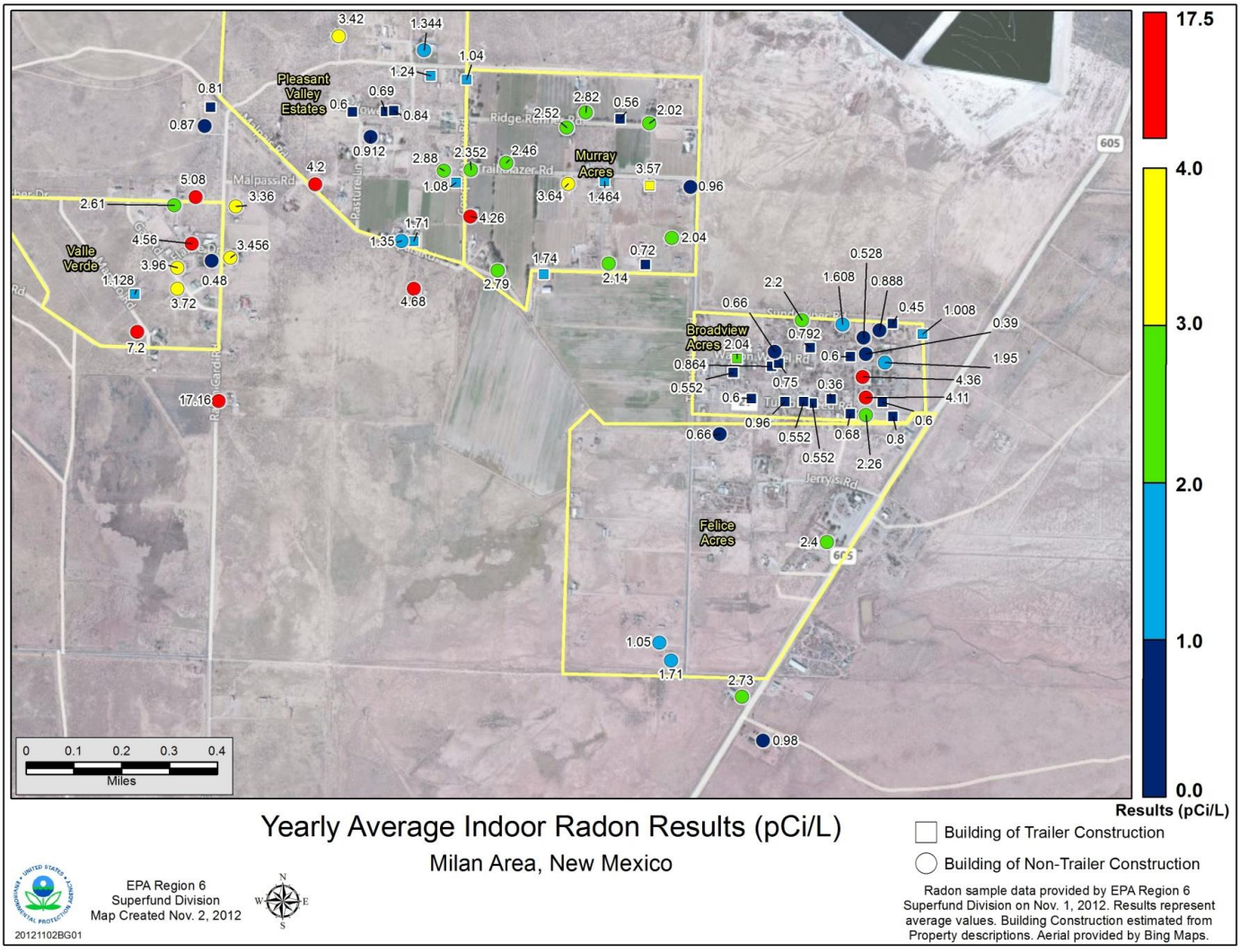



Figure 2-7: Yearly average indoor radon results for the five subdivisions area separated by building construction type whether they are trailer or non-trailer type.

### 2.7.6 HMC Historical Radon Levels at the Fence Line

The HMC has a fence line air monitoring system all around the tailing piles and evaporation ponds. It monitors for air particulates, radon gas and gamma direct radiation exposure. For air particulates HMC uses High Volume Air Samplers and test it for uranium, radium-226 and thorium 230. For radon gas, HMC uses Landauer Corporation track-etch passive radon monitors. Gamma direct radiation is monitored using optically stimulated luminescence (OSL) dosimeter badges. All samples are collocated at each station strategically identified to monitor air releases from the site (see figure 2-8). Location HMC # 4 and HMC# 5 are the closest monitors to the residential areas. Radon air monitor HMC # 16 is defined by HMC as the air monitor for background air radon level for the HMC site. Table 2-10 records the semi-annual results of radon gas since June of 2006. The etch-track monitors used by HMC were of the type that monitors for both radon-222 gas and thoron gas (Rn-220).

Table 2-10: Historical radon results for HMC air monitors placed by the fence around the facility (pCi/l) and managed by HMC staff.

| Monitoring period | HMC # 1 | HMC # 2 | HMC # 3 | HMC # 4 | HMC # 5 | HMC # 6 | HMC # 7 | HMC # 16 |
|---|---|---|---|---|---|---|---|---|
| 6/28/06 - 1/3/07 | 1.90E+00 | 1.70E+00 | 1.60E+00 | 2.40E+00 | 1.80E+00 | 1.70E+00 | 1.60E+00 | 1.50E+00 |
| 1/03/08- 6/26/08 | 1.40E+00 | 1.60E+00 | 1.40E+00 | 1.80E+00 | 2.20E+00 | 1.60E+00 | 1.30E+00 | 1.30E+00 |
| 6/30/10 - 9/30/10 | 1.40E+00 | 1.30E+00 | 8.00E-01 | 1.30E+00 | 1.40E+00 | 9.70E-01 | 8.30E-01 | 8.00E-01 |
| 9/30/10 - 1/4/11 | 3.60E+00 | 1.40E+00 | 1.10E+00 | 1.20E+00 | 1.60E+00 | 9.00E-01 | 1.20E+00 | 5.00E-01 |
| 6/30/2011- 1/9/12 | 1.10E+00 | 1.20E+00 | 6.60E-01 | 1.40E+00 | 1.20E+00 | 1.00E+00 | 1.20E+00 | 5.70E-01 |
| | | | | | | | | |
| Average | 1.88E+00 | 1.44E+00 | 1.11E+00 | 1.62E+00 | 1.64E+00 | 1.23E+00 | 1.23E+00 | 9.34E-01 |
| Std DEV | 1.003494 | 0.207364 | 0.394614 | 0.491935 | 0.384708 | 0.383119 | 0.275463 | 0.445286 |
| Max | 3.60E+00 | 1.70E+00 | 1.60E+00 | 2.40E+00 | 2.20E+00 | 1.70E+00 | 1.60E+00 | 1.50E+00 |

The HMC radon numbers compares well with the EPA radon numbers when radon results were adjusted for thoron gas (i.e. thoron gas included). A Wilcoxon Mann Whitney test did not show any significant difference between the two data sets at the 95% Confidence Level with an approximate p-value of 0.999. Table 2-11, is the descriptive statistics for ROPC in outdoor air particulates measured and reported by HMC in their annual air monitoring reports for the years 2007, 2008, 2010 and 2011 (HMC, 2011).

Table 2-11: Raw statistics and 95% UCL for particulates data in outdoor air collected at HMC #3,#4,#5,and #6 in pCi/$m^3$

| Variable | N | Minimum | Maximum | Mean | Median | SD | 95% UCL | UCL Basis Distribution |
|---|---|---|---|---|---|---|---|---|
| U nat (pCi/$m^3$) | 48 | 5.00E-05 | 8.30E-03 | 1.37E-03 | 8.32E-04 | 1.67E-03 | 2.42E-03 | Chebyshev |
| Th-230 (pCi/$m^3$) | 48 | 1.00E-05 | 7.42E-04 | 4.81E-05 | 3.00E-05 | 1.04E-04 | 1.14E-04 | Chebyshev |
| Ra226 (pCi/$m^3$) | 48 | 1.00E-05 | 7.40E-04 | 5.79E-05 | 5.00E-05 | 1.03E-04 | 1.23E-04 | Chebyshev |

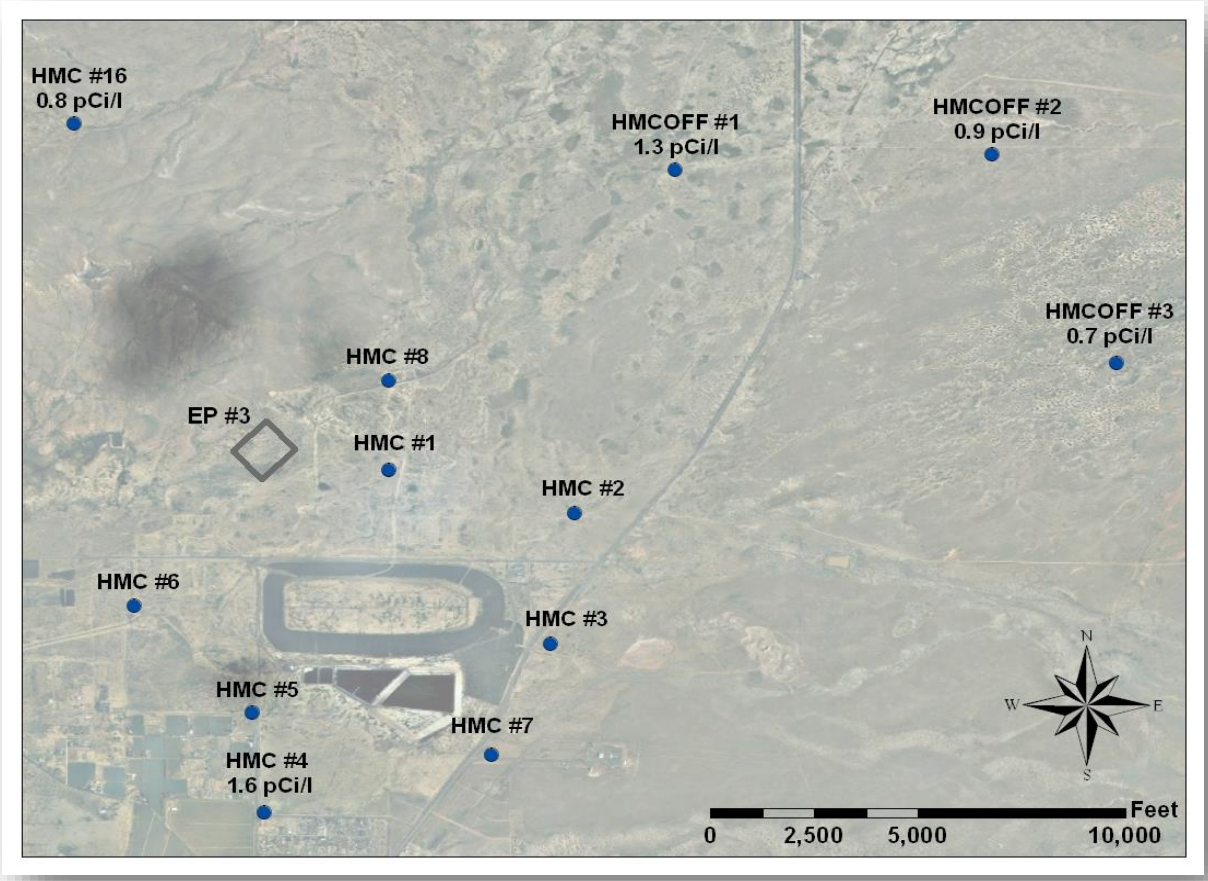



Figure 2-8: Location of air monitors placed and controlled by HMC personnel.

## 2.8 Environmental Data

### 2.8.1 Soil Data

Surface soil samples were collected from the yard of each house with an access agreement. One 20-point composite, surface soil sample (from the 20 stationary, 1-minute, gamma-measurement locations) was collected for laboratory analysis at the EPA National Air and Radiation Environmental Laboratory (NAREL) in Montgomery, Alabama. Another surface soil sample was collected of two 10-point, composite, surface soil samples (from the 20 stationary, 1-minute, gamma-measurement locations) for laboratory analysis of elemental uranium (non-radiological/ non-carcinogenic). This was used to evaluate the chemical toxicity due to uranium. Surface soil samples were also collected from 3 irrigation fields, the two central pivot fields, from evaporation pond banks and a background area. Surface soil samples were also collected from four runs that had the highest gamma radiation readings in the area between the evaporation ponds and the fence line. Table 2-12 and 2-13 are the descriptive statistics for chemicals and radionuclides tested in the soil for both the Five Subdivisions and the background area. The soil background area was selected based on its location. It is located further south from the residential Five Subdivisions area. It is close enough to have similar soil characteristics and make up as the Five

Subdivisions residential area but far enough not to be impacted by releases from the site. The ProUCL version 4.1 was used to calculate the 95% Upper Confidence Level (UCL) on the arithmetic mean. The data were first tested for its distribution and the 95% UCL was calculated on the best fit distribution for each data set. The number of samples, arithmetic mean, geometric mean, median, minimum and maximum for each data set was also calculated.

Table 2-12: Descriptive Statistics For metals (mg/Kg) and for Radionuclides (pCi/g) in Soil at the Background Area.

| | Valid N | Mean | Geometric - Mean | Median | Min. | Max. | Std. Dev. | CV | 95% UCL | UCL Basis |
|---|---|---|---|---|---|---|---|---|---|---|
| **Arsenic** | 12 | 4.80 | 4.79 | 4.68 | 4.25 | 5.52 | 0.40 | 8.33 | 5.01 | Student -t |
| **Lead** | 12 | 11.13 | 11.03 | 10.55 | 9.46 | 14.20 | 1.56 | 14.00 | 11.94 | Student -t |
| **Molybdenum** | 12 | 0.41 | 0.40 | 0.39 | 0.34 | 0.62 | 0.08 | 19.06 | 0.45 | Gamma |
| **Selenium** | 12 | 0.55 | 0.47 | 0.40 | 0.35 | 2.03 | 0.47 | 85.18 | 0.80 | Student -t |
| **Vanadium** | 12 | 27.55 | 27.22 | 28.05 | 20.40 | 36.50 | 4.47 | 16.23 | 29.87 | Student -t |
| **Alpha** | 12 | 4.91 | 4.54 | 5.70 | 2.00 | 6.70 | 1.79 | 36.38 | 5.83 | Student -t |
| **Ba140** | 12 | 0.07 | | 0.00 | 0.00 | 0.83 | 0.24 | 346.41 | 0.07 | Mean |
| **Beta** | 12 | 24.16 | 24.03 | 24.35 | 19.10 | 27.60 | 2.51 | 10.41 | 25.46 | Student -t |
| **Bi212** | 12 | 1.12 | 1.12 | 1.12 | 0.87 | 1.34 | 0.14 | 12.20 | 1.20 | Student -t |
| **Bi214** | 12 | 0.90 | 0.90 | 0.92 | 0.81 | 1.05 | 0.08 | 9.09 | 0.95 | Student -t |
| **Co60** | 12 | 0.00 | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | Student -t |
| **Cs137** | 12 | 0.07 | 0.07 | 0.06 | 0.05 | 0.09 | 0.01 | 15.82 | 0.07 | Student -t |
| **I131** | 12 | 0.00 | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | Student -t |
| **K40** | 12 | 17.82 | 17.79 | 17.65 | 16.60 | 19.90 | 0.96 | 5.40 | 18.32 | Student -t |
| **Pa234m** | 4 | 1.15 | 1.12 | 1.05 | 0.90 | 1.60 | 0.31 | 26.95 | | Student -t |
| **Pb212** | 12 | 1.04 | 1.04 | 1.04 | 0.89 | 1.22 | 0.11 | 10.68 | 1.10 | Student -t |
| **Pb214** | 12 | 0.97 | 0.97 | 0.99 | 0.84 | 1.10 | 0.09 | 9.27 | 1.02 | Student -t |
| **Ra223** | 9 | 0.27 | 0.27 | 0.26 | 0.22 | 0.34 | 0.04 | 14.08 | 0.30 | Student -t |
| **Ra226** | 12 | 1.70 | 1.69 | 1.74 | 1.29 | 2.00 | 0.21 | 12.28 | 1.81 | Student -t |
| **Ra228** | 12 | 1.08 | 1.07 | 1.11 | 0.91 | 1.26 | 0.11 | 10.17 | 1.14 | Student -t |
| **Th227** | 5 | 0.10 | 0.09 | 0.10 | 0.06 | 0.14 | 0.03 | 35.29 | 0.13 | Student -t |
| **Th228** | 5 | 1.23 | 1.22 | 1.21 | 0.98 | 1.44 | 0.19 | 15.10 | 1.41 | Student -t |
| **Th230** | 5 | 1.10 | 1.06 | 1.05 | 0.70 | 1.56 | 0.31 | 28.22 | 1.39 | Student -t |
| **Th232** | 5 | 1.04 | 1.03 | 1.09 | 0.87 | 1.12 | 0.10 | 10.00 | 1.14 | Student -t |
| **Th234** | 9 | 0.58 | 0.55 | 0.56 | 0.32 | 0.88 | 0.20 | 34.97 | 0.70 | Student -t |
| **Tl208** | 12 | 0.34 | 0.34 | 0.33 | 0.29 | 0.39 | 0.03 | 10.25 | 0.36 | Student -t |
| **U234** | 5 | 0.91 | 0.88 | 0.88 | 0.60 | 1.22 | 0.24 | 26.67 | 1.14 | Student -t |
| **U235** | 12 | 0.10 | 0.10 | 0.10 | 0.06 | 0.12 | 0.02 | 18.82 | 0.11 | Student -t |
| **U235** | 5 | 0.06 | | 0.06 | 0.00 | 0.12 | 0.05 | 81.62 | 0.11 | Student -t |
| **U238** | 5 | 0.95 | 0.93 | 0.89 | 0.73 | 1.21 | 0.21 | 21.76 | 1.15 | Student -t |

Table 2-13: Descriptive statistics for metals (mg/Kg) and radionuclides (pCi/g) in soil at the Five Subdivision.

| | Valid N | Mean | Geometric - Mean | Median | Min. | Max. | Range | Std. Dev | Coef. Var. | Kurtosis | 95% UCL | UCL Basis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Arsenic** | 84 | 4.5 | 4.08 | 4.33 | 0.02 | 10.60 | 10.58 | 1.45 | 32.16 | 3.90 | 4.76 | Student –t |
| **Lead** | 84 | 12.75 | 11.08 | 12.15 | 0.02 | 27.70 | 27.68 | 5.34 | 41.85 | 0.40 | 15.29 | Chebyshev |
| **Molybdenum** | 84 | 0.72 | 0.65 | 0.66 | 0.02 | 1.74 | 1.72 | 0.29 | 40.08 | 1.02 | 0.78 | Gamma |
| **Selenium** | 46 | 0.61 | 0.52 | 0.53 | 0.02 | 2.20 | 2.18 | 0.37 | 59.65 | 7.71 | 0.71 | Gamma |
| **Vanadium** | 46 | 23.95 | 20.31 | 23.40 | 0.02 | 38.90 | 38.88 | 7.38 | 30.82 | 1.49 | 25.78 | Student – t |
| **Alpha** | 86 | 8.04 | 7.24 | 7.85 | 0.80 | 26.60 | 25.80 | 3.75 | 46.65 | 6.76 | 8.75 | Gamma |
| **Ba140** | 86 | 0.00 | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | |
| **Beta** | 86 | 25.93 | 25.45 | 25.85 | 11.00 | 42.70 | 31.70 | 4.97 | 19.15 | 1.14 | 26.82 | Student – t |
| **Bi212** | 86 | 1.02 | 0.98 | 1.05 | 0.48 | 1.57 | 1.09 | 0.26 | 25.90 | -0.93 | 1.06 | Student- t |
| **Bi214** | 86 | 1.09 | 1.03 | 0.97 | 0.49 | 2.79 | 2.30 | 0.37 | 33.87 | 4.27 | 1.15 | Student- t |
| **Co60** | 86 | 0.00 | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | |
| **Cs137** | 86 | 0.06 | 0.06 | 0.06 | 0.01 | 0.12 | 0.11 | 0.02 | 35.42 | 0.01 | 0.07 | Student –t |
| **I131** | 86 | 0.00 | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 | 0.00 | | |
| **K40** | 86 | 16.48 | 16.39 | 16.75 | 12.70 | 20.70 | 8.00 | 1.70 | 10.33 | -0.44 | 16.79 | Student- t |
| **Pa234m** | 65 | 1.63 | | 1.40 | 0.00 | 4.80 | 4.80 | 0.90 | 55.46 | 1.60 | 2.12 | Chebyshev |
| **Pb210** | 4 | 0.94 | 0.92 | 0.94 | 0.70 | 1.18 | 0.48 | 0.20 | 21.49 | -0.16 | | |
| **Pb212** | 86 | 0.96 | 0.92 | 0.96 | 0.52 | 1.59 | 1.07 | 0.26 | 26.70 | -0.80 | 1.00 | Student- t |
| **Pb214** | 86 | 1.16 | 1.11 | 1.05 | 0.52 | 2.99 | 2.47 | 0.39 | 33.64 | 4.38 | 1.24 | Student- t |
| **Ra223** | 72 | 0.26 | 0.25 | 0.25 | 0.12 | 0.45 | 0.32 | 0.07 | 27.14 | -0.19 | 0.27 | Student –t |
| **Ra226** | 86 | 2.04 | | 1.83 | 0.00 | 6.04 | 6.04 | 0.88 | 43.22 | 4.34 | 2.45 | Chebyshev |
| **Ra228** | 86 | 0.98 | 0.95 | 0.97 | 0.50 | 1.58 | 1.08 | 0.25 | 25.35 | -0.87 | 1.03 | Student –t |
| **Th227** | 62 | 0.09 | | 0.08 | -0.01 | 0.32 | 0.32 | 0.07 | 74.32 | 0.82 | 0.13 | Chebyshev |
| **Th228** | 56 | 1.10 | 1.04 | 1.01 | 0.48 | 2.63 | 2.15 | 0.41 | 37.16 | 2.58 | 1.19 | Gamma |
| **Th230** | 56 | 1.42 | 1.31 | 1.26 | 0.56 | 3.71 | 3.15 | 0.65 | 45.43 | 3.28 | 1.56 | Gamma |
| **Th232** | 56 | 0.95 | 0.91 | 0.89 | 0.46 | 1.76 | 1.30 | 0.29 | 31.03 | 0.21 | 1.02 | Gamma |
| **Th234** | 72 | 0.93 | | 0.67 | 0.00 | 4.24 | 4.24 | 0.68 | 73.48 | 7.47 | 1.28 | Chebyshev |
| **Tl208** | 86 | 0.30 | 0.29 | 0.30 | 0.16 | 0.48 | 0.32 | 0.08 | 26.58 | -0.97 | 0.32 | Student-t |
| **U234** | 56 | 1.33 | 1.12 | 1.08 | 0.42 | 7.17 | 6.75 | 1.03 | 77.34 | 19.01 | 1.52 | Gamma |
| **U235** | 85 | 0.10 | 0.09 | 0.10 | 0.01 | 0.37 | 0.36 | 0.06 | 60.84 | 5.67 | 0.13 | Chebyshev |
| **U235** | 50 | 0.13 | 0.12 | 0.12 | 0.03 | 0.24 | 0.22 | 0.04 | 34.16 | 0.57 | 0.14 | Student –t |
| **U238** | 56 | 1.37 | 1.18 | 1.09 | 0.47 | 6.42 | 5.95 | 0.93 | 68.07 | 15.22 | 1.55 | Gamma |

Table 2-14 shows the descriptive statistics for soil samples collected from the area between the HMC evaporation ponds and the fence-line separating the HMC property from the residential areas. The ERGS scan runs that were carried out during the screening phase of the project were used to pick out four runs that recorded the highest gamma scan in counts per second. The top 6 inch surface soil samples were collected along a line to confirm the results of the ERGS scan. The results did not show a decreasing trend from the facility towards the residential areas confirming the ERGS scan results.

Table 2-14: Descriptive statistics for metals (mg/kg) and radionuclides (pCi/g) in soil at the HMC area between the Evaporation ponds and Fenceline.

| | Valid N | Mean | Geom. Mean | Median | Minimum | Maximum | Std.Dev. | Coef.Var. | 95% UCL | UCL Basis |
|---|---|---|---|---|---|---|---|---|---|---|
| Arsenic | 26 | 5.89 | 5.61 | 6.32 | 2.68 | 9.58 | 1.68 | 28.51 | 6.45 | Student's-t |
| Lead | 26 | 14.28 | 13.26 | 16.15 | 3.88 | 19.70 | 4.79 | 33.52 | 15.89 | Student's-t |
| Molybdenum | 26 | 6.93 | 2.19 | 1.81 | 0.62 | 126.00 | 24.33 | 351.09 | 27.73 | Chebyshev |
| Selenium | 26 | 1.37 | 0.93 | 0.75 | 0.37 | 11.10 | 2.09 | 152.32 | 3.16 | Chebyshev |
| Vanadium | 26 | 36.29 | 33.69 | 40.05 | 11.70 | 60.70 | 12.46 | 34.33 | 40.46 | Student's-t |
| Alpha | 25 | 12.35 | 11.06 | 10.30 | 4.60 | 28.50 | 6.18 | 50.07 | 14.62 | Gamma |
| Beta | 25 | 31.74 | 31.13 | 31.50 | 21.40 | 44.60 | 6.37 | 20.08 | 33.92 | Student's-t |
| Bi212 | 25 | 1.38 | 1.30 | 1.52 | 0.39 | 2.04 | 0.42 | 30.28 | 1.52 | Student's-t |
| Bi214 | 25 | 1.95 | 1.70 | 1.58 | 0.50 | 5.79 | 1.15 | 58.92 | 2.42 | H-UCL |
| Cs137 | 25 | 0.05 | | 0.04 | 0.00 | 0.15 | 0.05 | 93.25 | 0.10 | Chebyshev |
| K40 | 25 | 17.58 | 17.48 | 18.00 | 12.90 | 21.20 | 1.84 | 10.49 | 18.21 | Student's-t |
| Pa234m | 24 | 3.64 | 2.91 | 2.85 | 1.20 | 18.90 | 3.53 | 96.96 | 4.66 | Gamma |
| Pb212 | 25 | 1.24 | 1.18 | 1.39 | 0.43 | 1.67 | 0.36 | 28.96 | 1.37 | Student's-t |
| Pb214 | 25 | 2.06 | 1.79 | 1.72 | 0.54 | 6.13 | 1.23 | 59.70 | 2.56 | H-UCL |
| Ra223 | 19 | 0.37 | 0.34 | 0.37 | 0.10 | 0.67 | 0.14 | 38.42 | 0.43 | Student's-t |
| Ra226 | 26 | 3.50 | 3.12 | 3.06 | 1.48 | 8.90 | 1.78 | 50.82 | 4.14 | Gamma |
| Ra228 | 25 | 1.32 | 1.25 | 1.47 | 0.48 | 1.71 | 0.37 | 28.43 | 1.45 | Student's-t |
| Th227 | 24 | 0.18 | 0.14 | 0.13 | 0.03 | 0.57 | 0.13 | 72.93 | 0.23 | Gamma |
| Th228 | 24 | 1.46 | 1.34 | 1.49 | 0.56 | 2.34 | 0.54 | 36.86 | 1.64 | Student's-t |
| Th230 | 24 | 2.13 | 1.74 | 1.83 | 0.51 | 5.85 | 1.40 | 65.93 | 2.69 | Gamma |
| Th232 | 24 | 1.23 | 1.12 | 1.41 | 0.45 | 1.81 | 0.48 | 38.91 | 1.40 | Student's-t |
| Th234 | 20 | 2.34 | 1.77 | 1.80 | 0.28 | 11.20 | 2.28 | 97.48 | 3.18 | Gamma |
| Tl208 | 25 | 0.40 | 0.38 | 0.44 | 0.14 | 0.53 | 0.12 | 29.67 | 0.44 | Student's-t |
| U234 | 24 | 3.39 | 2.57 | 2.47 | 0.58 | 18.30 | 3.48 | 102.53 | 4.46 | Gamma |
| U235 | 26 | 0.25 | 0.22 | 0.22 | 0.07 | 0.70 | 0.14 | 55.22 | 0.30 | Gamma |
| U235 | 24 | 0.19 | 0.15 | 0.14 | 0.03 | 0.99 | 0.19 | 98.24 | 0.26 | H-UCL |
| U238 | 24 | 3.43 | 2.61 | 2.68 | 0.83 | 19.00 | 3.61 | 105.09 | 4.57 | H-UCL |

Table 2-15 is the descriptive statistics for ROPC and COPC data results for soil samples collected from the three flood irrigated areas. Table 2-16 is the descriptive statistics for ROPC and COPC data results for soil samples collected from the two central pivot irrigated areas.

| Table2- 15 : Descriptive statistics for metals (mg/kg) and radionuclides (pCi/g) in soil at the three irrigation fields. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Valid N | Mean | Geometric | Median | Minimum | Maximum | Std.Dev. | Coef.Var. | 95% UCL | UCL Basis |
| Arsenic | 6 | 6.13 | 6.11 | 6.03 | 5.48 | 6.79 | 0.55 | 8.94 | 6.58 | Student's t |
| Lead | 6 | 15.00 | 14.89 | 13.95 | 13.20 | 18.00 | 2.05 | 13.67 | 16.69 | Student's t |
| Molybdenum | 6 | 0.83 | 0.80 | 0.79 | 0.59 | 1.28 | 0.26 | 31.66 | 1.05 | Student's t |
| Selenium | 6 | 0.85 | 0.79 | 0.75 | 0.50 | 1.31 | 0.35 | 40.93 | 1.14 | Student's t |
| Vanadium | 6 | 33.32 | 33.05 | 30.95 | 29.50 | 39.60 | 4.72 | 14.17 | 37.71 | Gamma |
| Alpha | 6 | 4.87 | 4.61 | 5.00 | 2.30 | 7.30 | 1.62 | 33.23 | 6.20 | Student's t |
| Beta | 6 | 24.95 | 24.77 | 24.45 | 21.20 | 30.30 | 3.30 | 13.24 | 27.67 | Student's t |
| Bi212 | 6 | 1.46 | 1.45 | 1.42 | 1.34 | 1.71 | 0.13 | 9.08 | 1.56 | Student's t |
| Bi214 | 6 | 1.24 | 1.23 | 1.25 | 1.01 | 1.44 | 0.17 | 13.50 | 1.38 | Student's t |
| Cs137 | 6 | 0.06 | 0.06 | 0.06 | 0.05 | 0.09 | 0.01 | 23.55 | 0.07 | Student's t |
| K40 | 6 | 17.90 | 17.87 | 17.45 | 16.80 | 20.30 | 1.25 | 6.97 | 18.93 | Student's t |
| Pa234m | 6 | 1.78 | 1.67 | 1.40 | 1.25 | 3.30 | 0.78 | 43.92 | 2.42 | Student's t |
| Pb212 | 6 | 1.36 | 1.35 | 1.37 | 1.15 | 1.52 | 0.15 | 11.33 | 1.48 | Student's t |
| Pb214 | 6 | 1.34 | 1.32 | 1.38 | 1.03 | 1.55 | 0.19 | 14.33 | 1.49 | Student's t |
| Ra223 | 4 | 0.34 | 0.34 | 0.34 | 0.32 | 0.36 | 0.02 | 6.17 | | |
| Ra226 | 6 | 2.62 | 2.58 | 2.65 | 1.85 | 3.11 | 0.48 | 18.39 | 3.02 | Student's t |
| Ra228 | 6 | 1.43 | 1.42 | 1.43 | 1.21 | 1.66 | 0.15 | 10.87 | 1.55 | Student's t |
| Th227 | 6 | 0.11 | 0.09 | 0.09 | 0.06 | 0.27 | 0.08 | 73.86 | 0.20 | Gamma |
| Th228 | 6 | 1.48 | 1.44 | 1.56 | 1.02 | 1.84 | 0.35 | 23.60 | 1.76 | Student's t |
| Th230 | 6 | 1.48 | 1.46 | 1.45 | 1.15 | 1.88 | 0.28 | 18.95 | 1.71 | Student's t |
| Th232 | 6 | 1.48 | 1.45 | 1.48 | 1.04 | 1.92 | 0.32 | 21.69 | 1.74 | Student's t |
| Th234 | 4 | 1.14 | 1.03 | 0.86 | 0.74 | 2.09 | 0.64 | 56.21 | | |
| Tl208 | 6 | 0.43 | 0.43 | 0.42 | 0.38 | 0.50 | 0.05 | 10.48 | 0.47 | Student's t |
| U234 | 6 | 1.66 | 1.54 | 1.47 | 0.88 | 2.73 | 0.69 | 41.74 | 2.23 | Student's t |
| U235 | 6 | 0.16 | 0.16 | 0.17 | 0.12 | 0.19 | 0.03 | 18.08 | 0.19 | Student's t |
| U235 | 6 | 0.10 | 0.07 | 0.09 | 0.02 | 0.19 | 0.07 | 71.25 | 0.16 | Student's t |
| U238 | 6 | 1.76 | 1.68 | 1.67 | 1.06 | 2.49 | 0.55 | 31.36 | 2.21 | Student's t |

| Table 2-16: Descriptive statistics for metals (mg/kg) and radionuclides (pCi/g) in soil at the Central Pivot fields. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Valid N | Mean | Geom. Mean | Median | Minimum | Maximum | Std.Dev. | Coef.Var. | 95% UCL | UCL Basis |
| Arsenic | 13 | 2.58 | 2.53 | 2.29 | 2.04 | 3.56 | 0.55 | 21.19 | 2.85 | Student's-t |
| Lead | 13 | 4.45 | 4.40 | 4.42 | 3.47 | 5.76 | 0.70 | 15.65 | 4.8 | Student's-t |
| Molybdenu | 13 | 0.34 | 0.34 | 0.35 | 0.25 | 0.43 | 0.05 | 15.07 | 0.37 | Student's-t |
| Selenium | 13 | 0.48 | 0.46 | 0.46 | 0.29 | 0.71 | 0.11 | 23.24 | 0.53 | Student's-t |
| Vanadium | 13 | 12.37 | 12.11 | 11.70 | 9.16 | 16.90 | 2.68 | 21.70 | 13.69 | Student's-t |
| Alpha | 14 | 4.51 | 4.19 | 4.60 | 2.20 | 8.00 | 1.81 | 40.08 | 5.37 | Student's-t |
| Beta | 14 | 18.11 | 17.85 | 17.25 | 13.90 | 25.40 | 3.26 | 18.02 | 19.65 | Student's-t |
| Bi212 | 14 | 0.60 | 0.59 | 0.60 | 0.45 | 0.76 | 0.11 | 18.24 | 0.65 | Student's-t |
| Bi214 | 14 | 0.51 | 0.51 | 0.51 | 0.43 | 0.60 | 0.04 | 7.97 | 0.53 | Student's-t |
| Cs137 | 14 | 0.06 | 0.05 | 0.06 | 0.02 | 0.11 | 0.03 | 47.77 | 0.075 | Student's-t |
| K40 | 14 | 13.72 | 13.64 | 13.25 | 11.50 | 16.80 | 1.59 | 11.57 | 14.47 | Student's-t |
| Pa234m | 7 | 1.17 | 1.11 | 1.10 | 0.66 | 1.60 | 0.37 | 31.97 | 1.44 | Student's-t |
| Pb212 | 14 | 0.53 | 0.53 | 0.53 | 0.42 | 0.73 | 0.09 | 16.80 | 0.58 | Student's-t |
| Pb214 | 14 | 0.56 | 0.55 | 0.55 | 0.49 | 0.67 | 0.05 | 8.50 | 0.58 | Student's-t |
| Ra223 | 12 | 0.16 | 0.15 | 0.15 | 0.09 | 0.26 | 0.04 | 26.44 | 0.18 | Student's-t |
| Ra226 | 14 | 1.12 | 1.11 | 1.15 | 0.83 | 1.56 | 0.18 | 15.88 | 1.21 | Student's-t |
| Ra228 | 14 | 0.55 | 0.55 | 0.55 | 0.45 | 0.73 | 0.09 | 15.61 | 0.59 | Student's-t |
| Th227 | 12 | 0.04 | | 0.04 | 0.00 | 0.09 | 0.03 | 64.74 | 0.053 | Student's-t |
| Th228 | 12 | 0.54 | 0.53 | 0.55 | 0.35 | 0.83 | 0.11 | 20.57 | 0.6 | Gamma |
| Th230 | 12 | 0.48 | 0.47 | 0.47 | 0.29 | 0.70 | 0.12 | 24.25 | 0.55 | Student's-t |
| Th232 | 12 | 0.48 | 0.47 | 0.48 | 0.29 | 0.65 | 0.10 | 21.27 | 0.53 | Student's-t |
| Th234 | 10 | 0.45 | 0.44 | 0.46 | 0.27 | 0.62 | 0.11 | 25.34 | 0.52 | Student's-t |
| Tl208 | 14 | 0.16 | 0.16 | 0.16 | 0.13 | 0.23 | 0.03 | 17.14 | 0.18 | Student's-t |
| U234 | 12 | 0.70 | 0.69 | 0.73 | 0.56 | 0.84 | 0.09 | 13.43 | 0.75 | Student's-t |
| U235 | 9 | 0.07 | 0.07 | 0.07 | 0.06 | 0.10 | 0.01 | 14.49 | 0.08 | Student's-t |
| U235 | 12 | 0.05 | 0.04 | 0.06 | 0.02 | 0.08 | 0.03 | 51.64 | 0.06 | Student's-t |
| U238 | 12 | 0.63 | 0.62 | 0.61 | 0.48 | 0.89 | 0.12 | 19.33 | 0.69 | Student's-t |

Table 2-17 is descriptive statistics for samples collected from the evaporation pond bank and Table 2-18 is the descriptive statistics for soil at the fence line.

Table 2-17 : Descriptive statistics for metals (mg/kg) and radionuclides (pCi/g) in soil at the Evaporation pond ( white deposit).

| | Valid N | Mean | Geom. Mean | Median | Minimum | Maximum | Std.Dev. | Coef.Var. |
|---|---|---|---|---|---|---|---|---|
| Arsenic | 4 | 1.98 | 1.67 | 1.62 | 0.79 | 3.90 | 1.36 | 68.46 |
| Lead | 4 | 2.76 | 2.28 | 2.15 | 1.15 | 5.60 | 2.02 | 73.14 |
| Molybdenum | 4 | 59.85 | 47.15 | 55.40 | 20.60 | 108.00 | 43.17 | 72.14 |
| Selenium | 4 | 2.98 | 2.38 | 3.00 | 0.78 | 5.15 | 1.96 | 65.84 |
| Vanadium | 4 | 19.70 | 18.32 | 19.60 | 11.90 | 27.70 | 8.35 | 42.41 |
| Alpha | 2 | 48.65 | 44.19 | 48.65 | 28.30 | 69.00 | 28.78 | 59.16 |
| Beta | 2 | 67.40 | 66.01 | 67.40 | 53.80 | 81.00 | 19.23 | 28.54 |
| Bi212 | 2 | 0.44 | 0.42 | 0.44 | 0.34 | 0.53 | 0.13 | 30.89 |
| Bi214 | 2 | 2.40 | 2.07 | 2.40 | 1.18 | 3.62 | 1.73 | 71.89 |
| Cs137 | 2 | 0.01 | | 0.01 | 0.00 | 0.01 | 0.01 | 141.42 |
| K40 | 2 | 7.80 | 7.78 | 7.80 | 7.33 | 8.26 | 0.66 | 8.44 |
| Pa234m | 2 | 41.75 | 40.37 | 41.75 | 31.10 | 52.40 | 15.06 | 36.08 |
| Pb212 | 2 | 0.39 | 0.39 | 0.39 | 0.34 | 0.43 | 0.07 | 16.77 |
| Pb214 | 2 | 2.53 | 2.19 | 2.53 | 1.26 | 3.80 | 1.80 | 70.99 |
| Ra223 | 2 | 0.11 | 0.09 | 0.11 | 0.06 | 0.16 | 0.07 | 65.37 |
| Ra226 | 2 | 2.62 | | 2.62 | 0.00 | 5.24 | 3.71 | 141.42 |
| Ra228 | 2 | 0.44 | 0.43 | 0.44 | 0.39 | 0.48 | 0.07 | 15.57 |
| Th227 | 2 | 0.10 | 0.09 | 0.10 | 0.08 | 0.11 | 0.02 | 23.57 |
| Th228 | 2 | 0.53 | 0.52 | 0.53 | 0.49 | 0.56 | 0.05 | 9.43 |
| Th230 | 2 | 3.09 | 3.08 | 3.09 | 2.93 | 3.24 | 0.22 | 7.11 |
| Th232 | 2 | 0.41 | 0.40 | 0.41 | 0.32 | 0.50 | 0.13 | 31.04 |
| Th234 | 2 | 25.00 | 24.78 | 25.00 | 21.70 | 28.30 | 4.67 | 18.67 |
| Tl208 | 2 | 0.12 | 0.12 | 0.12 | 0.10 | 0.14 | 0.03 | 28.99 |
| U234 | 2 | 35.55 | 34.94 | 35.55 | 29.00 | 42.10 | 9.26 | 26.06 |
| U235 | 2 | 1.61 | 1.58 | 1.61 | 1.31 | 1.91 | 0.42 | 26.35 |
| U235 | 2 | 2.03 | 2.01 | 2.03 | 1.82 | 2.23 | 0.29 | 14.32 |
| U238 | 2 | 36.00 | 35.56 | 36.00 | 30.40 | 41.60 | 7.92 | 22.00 |

| Table 2-18:Descriptive statistics for meatals (mg/kg) and radionuclides (pCi/g) in soil at the Fenceline. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Valid N | Mean | Geom. Mean | Median | Minimum | Maximum | Std.Dev. | Coef.Var. |
| Arsenic | 4 | 3.72 | 3.63 | 3.76 | 2.67 | 4.71 | 0.95 | 25.39 |
| Lead | 4 | 9.31 | 8.87 | 8.74 | 6.45 | 13.30 | 3.33 | 35.80 |
| Molybdenum | 4 | 0.94 | 0.82 | 1.01 | 0.35 | 1.41 | 0.50 | 53.08 |
| Selenium | 4 | 0.48 | 0.44 | 0.50 | 0.23 | 0.68 | 0.22 | 45.42 |
| Vanadium | 4 | 20.58 | 19.83 | 19.85 | 15.10 | 27.50 | 6.38 | 31.02 |
| Alpha | 4 | 4.15 | 2.96 | 3.80 | 1.00 | 8.00 | 3.40 | 81.92 |
| Beta | 4 | 23.75 | 23.40 | 23.55 | 18.30 | 29.60 | 4.68 | 19.72 |
| Bi212 | 4 | 0.89 | 0.86 | 0.89 | 0.63 | 1.14 | 0.26 | 29.07 |
| Bi214 | 4 | 1.29 | 1.19 | 1.26 | 0.63 | 2.03 | 0.58 | 44.52 |
| Cs137 | 4 | 0.08 | 0.08 | 0.08 | 0.07 | 0.11 | 0.02 | 22.94 |
| K40 | 4 | 16.45 | 16.38 | 16.95 | 14.10 | 17.80 | 1.66 | 10.08 |
| Pa234m | 2 | 1.41 | 1.38 | 1.41 | 1.12 | 1.70 | 0.41 | 29.09 |
| Pb212 | 4 | 0.83 | 0.80 | 0.83 | 0.56 | 1.08 | 0.24 | 29.32 |
| Pb214 | 4 | 1.37 | 1.27 | 1.35 | 0.68 | 2.12 | 0.59 | 42.82 |
| Ra223 | 4 | 0.22 | 0.22 | 0.23 | 0.16 | 0.27 | 0.05 | 22.02 |
| Ra226 | 4 | 2.41 | 2.23 | 2.39 | 1.20 | 3.64 | 1.00 | 41.46 |
| Ra228 | 4 | 0.87 | 0.85 | 0.89 | 0.61 | 1.09 | 0.23 | 26.05 |
| Th227 | 4 | 0.12 | 0.11 | 0.10 | 0.06 | 0.23 | 0.08 | 61.50 |
| Th228 | 4 | 0.89 | 0.87 | 0.88 | 0.64 | 1.17 | 0.24 | 27.05 |
| Th230 | 4 | 1.56 | 1.39 | 1.50 | 0.66 | 2.58 | 0.80 | 51.27 |
| Th232 | 4 | 0.84 | 0.82 | 0.76 | 0.72 | 1.10 | 0.18 | 21.37 |
| Th234 | 4 | 0.84 | 0.64 | 0.58 | 0.26 | 1.95 | 0.76 | 90.23 |
| Tl208 | 4 | 0.26 | 0.25 | 0.26 | 0.17 | 0.35 | 0.08 | 32.50 |
| U234 | 4 | 1.17 | 1.04 | 1.13 | 0.49 | 1.95 | 0.62 | 53.01 |
| U235 | 4 | 0.15 | 0.14 | 0.15 | 0.08 | 0.22 | 0.06 | 40.42 |
| U235 | 4 | 0.12 | 0.11 | 0.12 | 0.08 | 0.17 | 0.05 | 40.22 |
| U238 | 4 | 1.14 | 1.03 | 1.07 | 0.52 | 1.90 | 0.57 | 50.08 |

### 2.8.2 Vegetable Data

Ten vegetable samples were collected from six gardens from houses that were observed growing vegetables in their yards. The vegetables collected were sage, artichoke, zucchini, corn, tomato, squash, pepper and miniature pumpkin. Table 2-19 below show the descriptive statistics for the radionuclides and chemicals found in the vegetable samples. Radium 226 and Radium 228 were not detected and half the average of the range of the sample-specific method detection concentration was used. Potassium 40 is the radionuclide of interest that did show up in the vegetable samples. Potassium 40 was found also in the soil samples and found in the background soil at the same concentrations. Potassium 40 is not site related and is naturally found in soil and in vegetation at the Five Subdivision area.

| Table 2-19 :Descriptive statistics for metals (mg/kg) and radionuclides (pCi/g) in vegetable[1] samples collected from existing home gardens. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Valid N | Mean | Geom. Mean | Median | Minimum | Maximum | Range | Std.Dev. | Coef.Var. | 95% UCL | Basis for UCL |
| Arsenic | 9 | 0.14 | 0.09 | 0.08 | 0.03 | 0.50 | 0.47 | 0.15 | 108.01 | 0.26 | Gamma |
| Lead | 9 | 0.17 | 0.11 | 0.11 | 0.03 | 0.70 | 0.67 | 0.21 | 119.87 | 0.35 | Gamma |
| Molybdenum | 9 | 1.82 | 1.28 | 1.06 | 0.45 | 6.29 | 5.84 | 1.84 | 100.63 | 3.37 | Gamma |
| K40 | 10 | 4.86 | 4.00 | 3.59 | 1.95 | 12.50 | 10.55 | 3.49 | 71.84 | 7.36 | Gamma |
| Pb212 | 3 | 0.03 | 0.02 | 0.03 | 0.01 | 0.05 | 0.04 | 0.02 | 63.63 | 0.03 | mean |
| Pb214 | 2 | 0.03 | 0.02 | 0.03 | 0.01 | 0.05 | 0.04 | 0.03 | 90.58 | 0.03 | mean |
| Ra226[2] | 10 | 0.00 | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.12 | 1/2 Avg MDC |
| Ra228[2] | 10 | 0.00 | | 0.00 | 0.00 | 0.04 | 0.04 | 0.01 | 316.23 | 0.05 | 1/2 Avg MDC |
| Th227 | 10 | 0.00 | | 0.02 | -0.11 | 0.10 | 0.21 | 0.06 | 1630.06 | 0.041 | Student's t |
| Th228 | 10 | 0.36 | 0.34 | 0.36 | 0.17 | 0.51 | 0.34 | 0.10 | 27.54 | 0.41 | Student's t |
| Th230 | 10 | 0.18 | 0.12 | 0.13 | 0.02 | 0.40 | 0.38 | 0.14 | 81.06 | 0.26 | Student's t |
| Th232 | 10 | 0.06 | | 0.03 | -0.03 | 0.18 | 0.21 | 0.07 | 112.81 | 0.1 | Student's t |
| Tl208 | 3 | 0.01 | 0.01 | 0.02 | 0.00 | 0.03 | 0.02 | 0.01 | 72.43 | 0.01 | mean |
| U234 | 10 | 0.48 | 0.31 | 0.37 | 0.09 | 1.81 | 1.72 | 0.52 | 108.34 | 0.91 | Gamma |
| U235 | 10 | 0.05 | | 0.05 | -0.02 | 0.10 | 0.12 | 0.03 | 73.65 | 0.064 | Student's t |
| U238 | 10 | 0.39 | 0.23 | 0.23 | 0.04 | 1.50 | 1.46 | 0.44 | 112.40 | 0.77 | Gamma |

[1] Vegetable samples collected were sage, zucchini, corn, tomato, squash, pepper, miniature pumpkin.

[2] Ra226 and Ra228 were not detected at the sample specific estimate of the minimum detecta ble concentration which ranged between MDC = 0.075 to 0.6 for Ra226 and between 0.035 and 0.21 pCi/g for Ra228.

### 2.8.3 Water Data

EPA collected 27 water samples from private wells in the residential area, evaporation pond, collection pond and animal water bins. Table 2-20 is the descriptive statistics for both chemical contaminants measured in µg/l and radionuclides measured in pCi/l from samples collected from private well waters located in the Five Subdivisions.

| Table 2-20: Descriptive statistics for metals (µg/l) and radionuclides (pCi/l) in water samples collected from private well waters at the Five Subdivisions. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Valid N | Mean | Geom. Mean | Median | Minimum | Maximum | Range | Std.Dev. | Coef.Var. | 95 % UCL | UCL Basis |
| Arsenic | 13 | 2.86 | 1.52 | 2.30 | 0.33 | 16.20 | 15.87 | 4.19 | 146.71 | 5.29 | Gamma |
| Lead | 13 | 4.70 | 1.34 | 0.64 | 0.19 | 24.20 | 24.01 | 6.92 | 147.37 | 13.80 | Chebyshev |
| Molybdenum | 13 | 2.43 | 1.67 | 1.49 | 0.56 | 8.85 | 8.29 | 2.39 | 98.38 | 3.92 | Gamma |
| Selenium[1] | 20 | 33.10 | | 32.00 | 7.00 | 66.00 | | 19.20 | 0.58 | 39.50 | Student's t |
| Alpha | 15 | 22.15 | 16.87 | 17.00 | 4.50 | 64.00 | 59.50 | 16.64 | 75.12 | 29.71 | Student's t |
| Ra-226 | 14 | 0.25 | 0.22 | 0.22 | 0.10 | 0.56 | 0.46 | 0.14 | 56.75 | 0.32 | Student's t |
| Ra-228 | 16 | 2.23 | | 0.43 | -0.42 | 30.90 | 31.32 | 7.66 | 342.81 | 10.58 | Chebyshev |
| Rn-222 | 14 | 388.00 | | 218.00 | 49.00 | 1479.00 | 1430.00 | 486.00 | 125.00 | 953.50 | Chebyshev |
| Th227 | 14 | 0.00 | | 0.00 | -0.05 | 0.03 | 0.08 | 0.02 | -1525.65 | 0.01 | Student's t |
| Th228 | 14 | 0.09 | | 0.10 | -0.03 | 0.22 | 0.25 | 0.06 | 61.43 | 0.12 | Student's t |
| Th230 | 14 | 0.04 | | 0.04 | -0.01 | 0.13 | 0.14 | 0.04 | 97.70 | 0.06 | Student's t |
| Th232 | 14 | 0.01 | | 0.00 | -0.04 | 0.05 | 0.09 | 0.02 | 351.13 | 0.02 | Student's t |
| U234 | 14 | 15.86 | 12.90 | 15.80 | 4.06 | 31.40 | 27.34 | 9.59 | 60.46 | 20.40 | Student's t |
| U235 | 14 | 0.57 | 0.43 | 0.55 | 0.11 | 1.34 | 1.23 | 0.40 | 69.66 | 0.76 | Student's t |
| U238 | 14 | 10.10 | 7.95 | 9.35 | 2.19 | 22.70 | 20.51 | 6.80 | 67.32 | 13.32 | Student's t |

[1] Selenium data obtained from HMC 2011 Annual Report Table B.4-4 Water Quality Analysis for the Subdivision Alluvial Wells.

Descriptive statistics for ROPC and COPC in the east and west evaporation ponds are shown in tables 2-21 and 2-22. Of interest is the high concentration of Molybdenum, U234 and U238 and the low concentration of Ra 226 and Ra 228.

Table 2-21: Descriptive statistics for Water Samples collected from the East Evaporation pond.

| Lab Matrix | Arsenic | Lead | Molybdenum | Ra_226 | Ra228 | Th227 | Th228 | Th230 | Th232 | U234 | U235 | U238 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Units | (µg/L) | (µg/L) | (µg/L) | ( pCi/L) | ( pCi/L) | ( pCi/L) | ( pCi/L) | ( pCi/L) | ( pCi/L) | ( pCi/L) | ( pCi/L) | ( pCi/L) |
| WATER | 1130 | 78.9 | 674000 | 96.70 | 0.8 | 59 | 87 | 900 | 3 | 119000 | 6300 | 116000 |
| WATER | 1070 | 4.85 | 658000 | 92.00 | 0.4 | 6 | 96 | 920 | 3 | 129000 | 6600 | 129000 |
| WATER | 1060 | 4.8 | 640000 | 100.20 | 0.0 | 19 | 135 | 1030 | 13 | 111000 | 5800 | 115000 |
| Average | 1086.67 | 30 | 657333 | 96 | 0.4 | 28 | 106 | 950 | 6 | 119667 | 6233 | 120000 |
| Std. Dev. | 37.86 | 43 | 17010 | 4 | 0.4 | 28 | 26 | 70 | 6 | 9018 | 404 | 7810 |
| N | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |

Table 2-22: Descriptive statistics for Water Samples collected from the West Evaporation pond.

| Lab Matrix | Arsenic | Lead | Molybdenum | Ra_226 ( pCi/L | Ra228 | Th227 | Th228 | Th230 | Th232 | U234 | U235 | U238 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Units | (µg/L) | (ug/L) | (ug/L) | ( pCi/L) | ( pCi/L) | ( pCi/L) | ( pCi/L) | ( pCi/L) | ( pCi/L) | ( pCi/L) | ( pCi/L) | ( pCi/L) |
| WATER | 259 | 4.71 | 94400 | 59.40 | 0.5 | -0.013 | 39 | 59 | 2.5 | 17200 | 780 | 16800 |
| WATER | | | | | | 0 | 4.1 | 60 | 1.4 | | | |
| WATER | 251 | 5 | 93000 | 52.50 | 0.6 | 5 | 103 | 101 | 34 | 16900 | 810 | 17200 |
| WATER | | | | | | 31 | 109 | 82 | 6 | 15900 | 840 | 16400 |
| Average | 255.00 | 5 | 93700 | 56 | 1 | 9 | 64 | 76 | 11 | 16667 | 810 | 16800 |
| Std. Dev. | 5.66 | 0 | 990 | 5 | 0 | 15 | 51 | 20 | 15 | 681 | 30 | 400 |
| Count | 2 | 2 | 2 | 2 | 2 | 4 | 4 | 4 | 4 | 3 | 3 | 3 |

Table 2-23 presents data from three houses with three media sampled namely soil, private well water and vegetables. Of interest is potassium-40 (K-40) in vegetables which seems to be transported from soil into edible parts of some species of vegetables at varying degrees. K-40 is not site related and naturally occurs in the Five Subdivisions' soil.

| Table 2-23: Results of ROPC in soil, private well water (WW) and vegetation collected from the same house. | | | | | | | |
|---|---|---|---|---|---|---|---|
| House ID | Sample Type | Ra-226 | Ra-228 | Th-230 | U-234 | U-238 | K-40 |
| BV0111 | WW (pCi/L) | 0.11 | 0.1 | 0.065 | 9.2 | 6.41 | ND |
| | Soil (pCi/g) | 2.26 | 1.05 | 1.64 | 1.31 | 1.31 | 17.4 |
| | Pepper (pCi/g) | ND | ND | 0.128 | 0.45 | 0.25 | 12.5 |
| | Squash(pCi/g) | ND | ND | 0.019 | 0.29 | 0.18 | 3.02 |
| BV0141 | WW (pCi/L) | 0.1 | 0.02 | 0.05 | 5.16 | 2.94 | ND |
| | Soil(pCi/g) | 1.72 | 0.59 | 2.29 | 0.63 | 0.83 | 12.9 |
| | Corn (pCi/g) | ND | 0.039 | 0.34 | 0.8 | 0.45 | 5.4 |
| VV0041 | WW (pCi/L) | 0.26 | 0.30 | 0.067 | 31.2 | 21.3 | ND |
| | Soil (pCi/g) | 1.13 | | | | | 21.5 |
| | Tomato(pCi/g) | ND | ND | 0.067 | 0.19 | 0.04 | 1.98 |

## 2.9 Selection of Chemicals or Radionuclides of Potential Concern

The HMC site was extensively studied and sampled in the past. The history of operations is well known and chemical of potential concern and radionuclides of potential concern were identified. Additional list of chemicals and radionuclides were added in this investigation to confirm the chemicals and radionuclides that are of potential concern in our study. Tables 2.1 to table 2.1.3 in Appendix A, list chemicals and radionuclides that were identified as potentially of concern and were included in this risk assessment evaluation.

The maximum detected value for each of the chemicals or radionuclides were compared with the cancer or noncancer screening value. The screening value is based on the media concentration associated with a one in a million cancer risk ($1 \text{ X } 10^{-6}$) or a hazard quotient of 1. If the maximum value was below the screening level, the risk associated with this chemical or radionuclide was considered negligible. However, if the maximum level was higher than the screening level, then each detected chemical or radionuclide was statistically compared to the same compound in the background or reference area. A combination of parametric (t-test for independent samples) and nonparametric statistical tests were used to identify statistically significant differences between the study area and reference or background area concentrations. A probability of 5% or less (p-value less than 0.05) that the concentrations in the study

group and reference area samples are the same indicates a significant difference. If the test statistics indicated significant difference then the chemical or radionuclide was included as a chemical or radionuclide of potential concern. If the same hazardous substance, pollutant, and contaminant associated with a release are also a background constituent, then these constituents were included in the risk assessment, particularly when their concentrations exceed risk-based concentrations. In cases where background levels are high or present health risks, this information may be important to the public. Some hazardous chemicals or radionuclides which are known to be associated with the history of operations at the site were not eliminated from the list of potential concern and were included in the risk assessment.

### 2.10 Data Usability Evaluation

EPA reviewed the validation of the data packages submitted by the NAREL laboratory. For all analyses except gamma spectroscopy, it is the policy of the lab to report results as generated together with the 2-sigma measurement uncertainty and a sample-specific estimate of the minimum detectable concentration (MDC). The activity, uncertainty and MDC are given in the same units. The activity and 2-sigma uncertainty for a radionuclide measured by gamma spectroscopy are reported only if the nuclide is detected; so the results of gamma analyses are never zero or negative. Nuclides that are not detected do not appear in the report, with the exception of Ba-140, Co-60, Cs-137, I-131, K-40, Ra-226, and Ra-228. If one of these seven nuclides is undetected, NAREL reported it as Not Detected and provided a sample-specific estimate of the MDC. Radionuclides or chemicals that were undetected the detection level was used and included in the risk assessment (USEPA 1992c). Quality control samples, such as method blanks, laboratory duplicates, matrix spikes and lab control samples were reviewed and those approved were used in the risk assessment (USEPA 1992d).

# 3 Section 3: Exposure Assessment

## 3.1 Exposure Setting

### 3.1.1 Site Location and Description

The HMC uranium mill opened in 1958 and is located 5.5 miles north of the Village of Milan in northwest New Mexico. In 1958, milling operations began at Homestake's mill site. The milling operations involved the use of an alkaline leach-caustic precipitation process to extract and concentrate uranium oxide from uranium ores. The byproducts (waste) were either disposed above ground in the two tailings impoundments or recycled back into the milling process. For approximately 30 years, HMC milled uranium at the site. The site has two tailings piles, a reverse osmosis groundwater treatment facility, and two existing evaporation ponds and a third recently constructed. The large tailings pile is unlined, covers approximately 215 acres, is 85-90 feet tall, and contains approximately 20 Million tons of tails. The small tailings pile is also unlined and covers approximately 40 acres, is 25 feet tall, and contains approximately 2 Million tons of tails. The tailings piles overlie an alluvial groundwater aquifer, into which contaminants from the piles have migrated. HMC began a state-approved groundwater restoration program in 1977. The program consists of a groundwater collection/injection system for the San Mateo alluvial aquifer and the Upper and Middle Chinle aquifers. The objective is to reduce contaminant concentrations to meet the site-specific standards that have been established for the alluvial aquifer, and the upper, middle and lower Chinle aquifers (HMC 2012a).

In September 1983, the EPA placed the HMC site on the NPL, primarily because of groundwater contamination (USEPA 1990b). Further investigations at the site identified groundwater contamination in on-site monitoring wells and some residential wells. HMC and the EPA signed a consent decree in December 1983 that required HMC to provide an alternate water supply to nearby residences and to pay for water usage for 10 years. The alternate water supply connections to residences were completed in April 1985, with Homestake paying for water usage until 1995. The soil cleanup and mill reclamation activities were completed in 1995 and approved by the NRC in 1999. In 1990, the mill ceased operations and the mill operating facilities were

decommissioned and demolished between 1993 and 1995. During that time, the NRC was the lead regulatory agency for site reclamation and closure activities. The soil cleanup and mill reclamation activities were completed in 1995 and approved by the NRC in 1999. Although the mill has ceased its operations, two tailings piles, a groundwater treatment facility using reverse osmosis, and two existing evaporation ponds and a third recently constructed pond remain on site.

### 3.1.2 Topography

The top surface soil at the HMC Subdivisions area (0-178 cm) is San Mateo clay loam and San Mateo sandy clay loam, 1 to 3 % slope alluvial fans**.** Figure 3-1 shows the surface land cover at and around HMC facility. It is mostly covered with grass and wild shrubs with some cultivated areas.

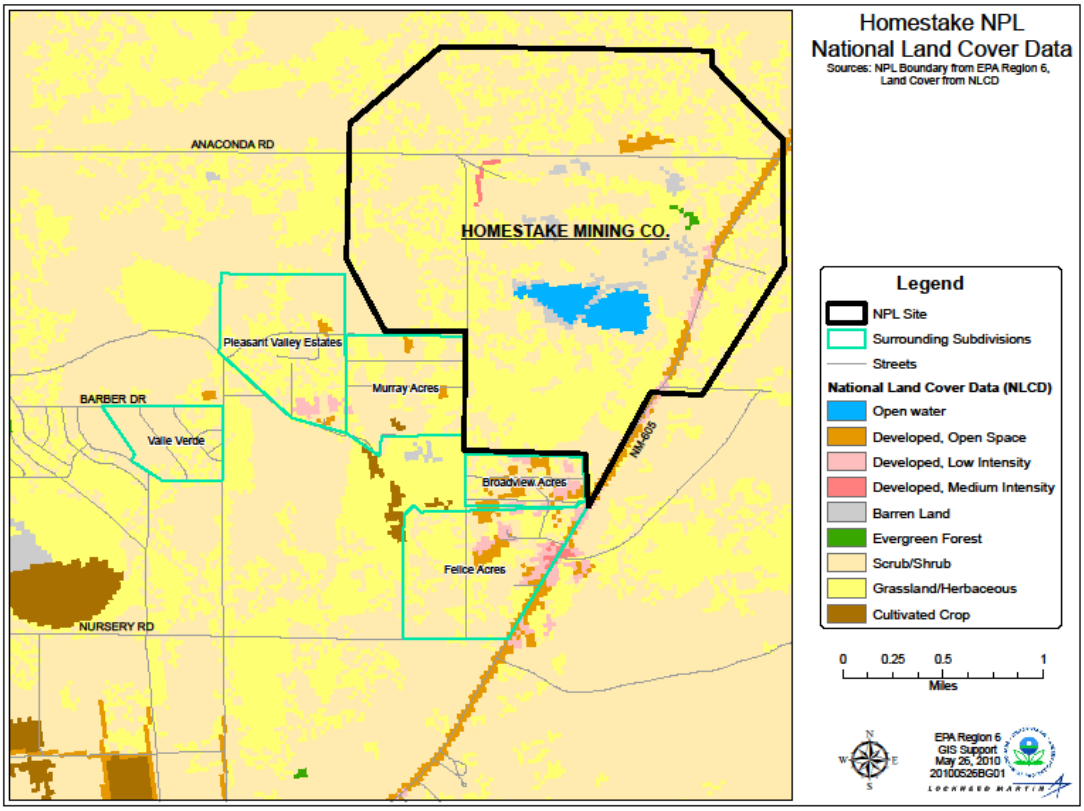



Figure 3-1: National Land cover at and around HMC facility.

### 3.1.3 Surface Water Bodies and Drainage

Surface drainage across the site is predominantly directed to the southwest. Ponding occurs after significant precipitation events, but this water either evaporates or infiltrates in the alluvium. The site lies partially within the broad floodplain of the San Mateo Creek, which is part of the Rio Grande drainage basin. The Arroyo Del Puerto is an ephemeral tributary stream to the San Mateo Creek drainage, which is also ephemeral at their confluence. This confluence is located approximately 10 miles north of the site. San Mateo creek has perennial flow at its headwaters on the north flank of Mount Taylor, intermittent over its middle reach, which is normally dry in the summer with the exception of high rainfall events and ephemeral in its lower reach where it meets Rio San Jose creek near Milan. During peak runoff from snow melt in the late spring or during heavy summer and fall rain storms, flood waters pass through the site and continue to the five residential subdivisions southwest of the site.

It is this kind of flooding that citizens living in the Five Subdivisions raised as one health concern. Flood water can carry contaminants from the site into their neighborhood as a potential fate and transport mechanism moving contaminants from the site onto their yard soils.

### 3.1.4 Geology and Hydrogeology

The San Mateo Creek from the north and the Lobo Canyon Creek from the east meet at the Homestake Site. The uranium-ore-bearing rocks are primarily to the north of the Site and exist as outcrops of Westwater Canyon Sandstone Member of the Morrison formation and the Todilto Limestone. These are found both in the San Mateo and Lobo Creek drainages.

Production of uranium started in the 1950s in the underground mines in the Ambrosia Lake area to the north. The majority of the production from this area was from the Ambrosia Lake mines. The alluvial systems in this area were produced from erosion of the bedrock materials in the drainage basin. Therefore, the alluvial material would be expected to contain above normal concentrations of uranium, selenium and molybdenum, constituents that are typically present in uranium deposits. The Chinle formation outcrops in a small portion of the drainage basin, but sub crops beneath a larger percentage of the San Mateo Creek drainage. The Chinle formation has been shown to contain significant natural levels of uranium and selenium.

The uppermost aquifer at Site is the San Mateo alluvial system. The alluvial aquifer system follows the San Mateo drainage. The alluvial aquifer south of the Site includes the saturated portion of the San Mateo downgradient of the site, and the Lobo Canyon and Rio San Jose alluviums. San Mateo Creek is a tributary to the Rio San Jose drainage while Lobo Canyon is a tributary to the San

Mateo. The alluvial aquifer is present from northeast of the Site, through the site and continuing to the south and to the west.

Beneath the Site, the Chinle Formation lies under the alluvium. The Chinle Formation is a massive shale, approximately 800 feet thick. The shale is a very effective aquitard and greatly restricts vertical groundwater flow from the overlying alluvial aquifer. Sandstone units are found within the Chinle shale and these sandstones form aquifers in this area. The sandstone unit closest to the ground surface has been named the Upper Chinle aquifer.

The second major continuous sandstone unit in the Chinle Formation is the Middle Chinle. The deepest permeable zone within the Chinle shale is the Lower Chinle aquifer.The Lower Chinle aquifer is located approximately 200 feet above the base of the Chinle Formation and consists mainly of fractured shale rather than continuous sandstone. Hence, the hydraulic properties are largely dependent on secondary permeability within the shale. The ability of the Lower Chinle aquifer to produce water is much lower and less consistent than in the overlying Middle and Upper Chinle sandstone aquifers.

The San Andres aquifer underlies the Chinle Formation at a depth of greater than 800 feet from the surface at the Site. This is the regional aquifer in the area.

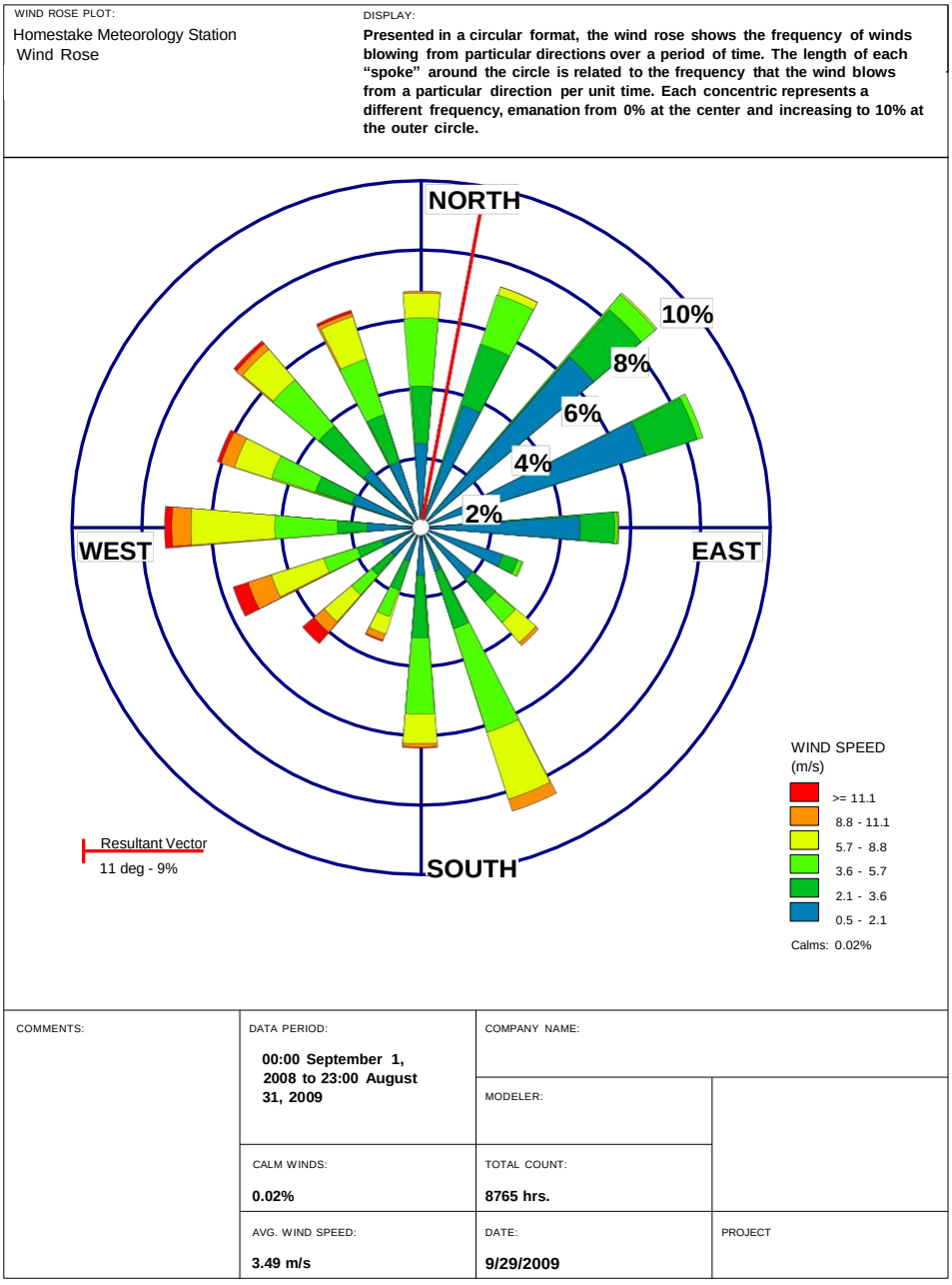
The five residential subdivisions are located primarily on alluvial deposits comprised mostly of silt and sand. The alluvium would mostly be derived from outcrop of the Todilto Limestone and related sedimentary rocks plus basalts of the La Jara Mesa to the north and east, from outcrops of the Chinle Formation to the west northwest, and from sediment carried downstream along San Mateo Creek from greater distances. Small open-pit uranium mines occur on the low mesas underlain by the Todilto limestone 4-6 miles to the east and north of the subdivision area. (Thaden, R.E. et. al, 1967).

### 3.1.5 Climate

The area has an arid to semi-arid temperate climate. The average precipitation is 10.4 inches per year, the US average is 37 inches. The average pan evaporation is 54.6 inches per year. Snowfall is 12 inches. The average US city gets 25 inches of snow per year. The number of days with any measurable precipitation is 59. On average, there are 273 sunny days per year. The July high is around 88$^{o}$F. The January low is 14$^{o}$ F(HMC 2012a).

The meteorology of the Homestake area is depicted by a wind rose in figure 3-2 below which was adopted from Homestake irrigation report 2009 (HMC, 2010)

**Figure 3-2:** Plot of the wind rose for the wind data measured at the meteorology station at Homestake from September 2008 through August 2009.



### 3.1.6 Land Use – Homestake Properties and Surrounding Areas

Homestake Mining Company owns a sizeable land area in and around the Grants Reclamation project. Much of the HMC lands held in the area that are not in immediate proximity to the tailings pile complex are utilized for livestock grazing on a lessor/lessee tenant arrangement. The land area within the immediate site boundary area containing the evaporation ponds, RO plant, both tailings pile areas and office / shop compound have been excluded from livestock grazing, and fenced to exclude grazing. Certain small areas in the southern and western portions of land within the Site Boundary are, however, seasonally utilized for livestock grazing. The major land use south and southwest of the Site consists of residential development located in the Pleasant Valley Estates, Murray Acres, Broadview Acres, Valle Verde and Felice Acres residential subdivisions (Figure 3-3). Over the years, permanent residential homes, modular homes and mobile homes have been established in the subdivision areas, and immediate adjacent areas, as would typify a rural residential neighborhood. A number of lots remain vacant, or are utilized for uses such as horse barns, corrals, equipment storage, etc. In some cases, dwellings are present on several lots throughout the subdivisions but are currently vacant or have been permanently abandoned and are in various states of disrepair. All or most of these houses were connected to the Milan municipal water system as private domestic wells that were completed into the underlying shallow alluvial aquifer were unsuitable for domestic uses. In 2012 one residence in Valle Verde was found to still using water from a domestic well supply (HMC 2012a). Future land use is expected to continue to be the same as is currently used. Although the New Mexico Office of the State Engineer issued a health advisory to prevent people from installing private wells, it is possible that a future resident may install the well and use it for domestic purpose (e.g. showering, laundering, dishwashing, cooling of indoor air, etc.).

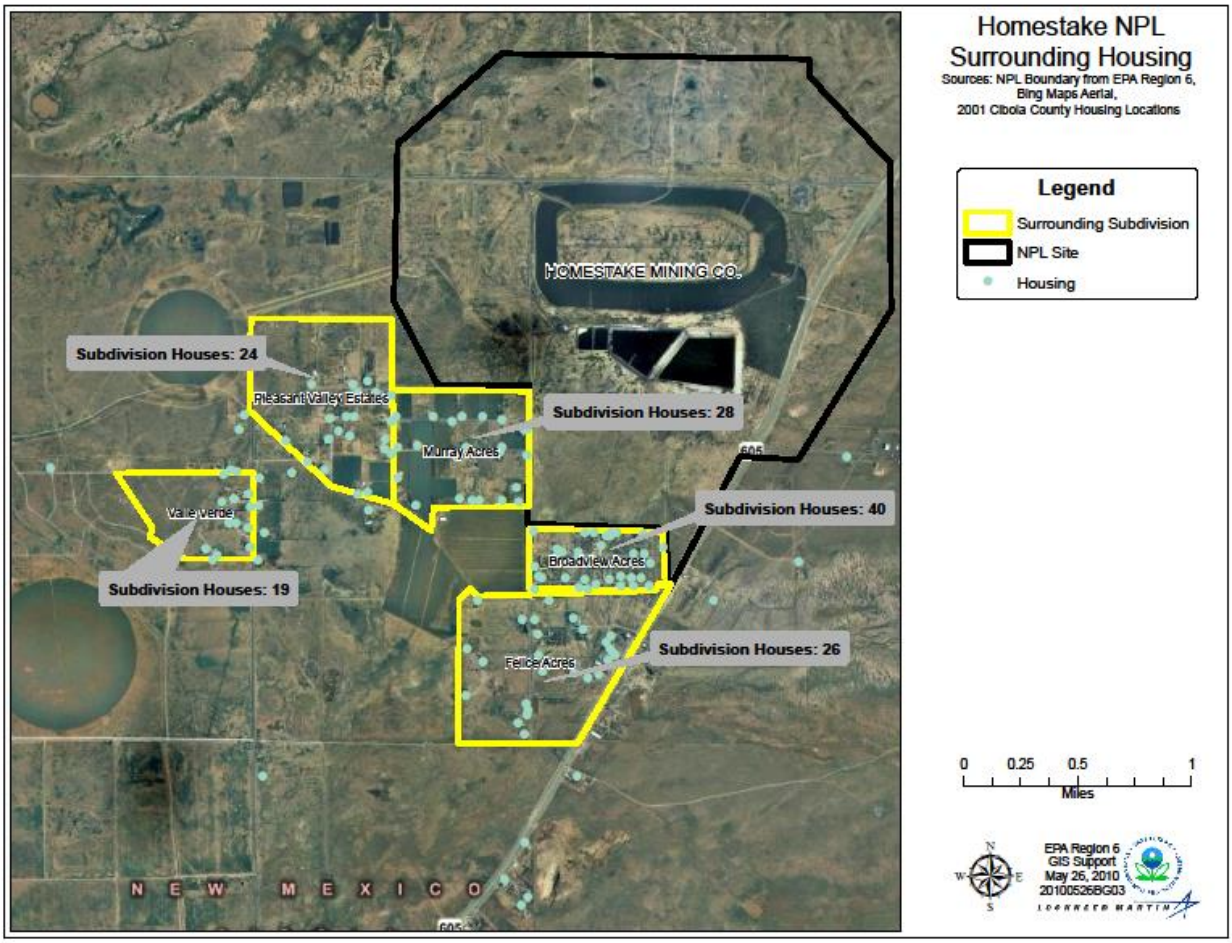



Figure 3-3: The HMC and Five Subdivisions with approximate estimate of the number of homes in each subdivision.

### 3.1.7 Potentially Exposed Populations

The potentially exposed populations can be divided into two groups; the onsite population and the offsite population. The onsite population is HMC workers who represent the small crew of men responsible for running the reclamation of ground water project. These workers operate under OSHA regulations following a health and safety plan that was specifically designed to protect them. As such this risk assessment did not evaluate the risk to the remediation crews.

The offsite population consists of people living adjacent to the site in Five Subdivisions (Broadview Acres, Felice Acres, Murray Acres, Pleasant Valley Estate and Valle Varde). Figures 3-3 and 3-4 show the number of houses in each subdivision and its race make up.

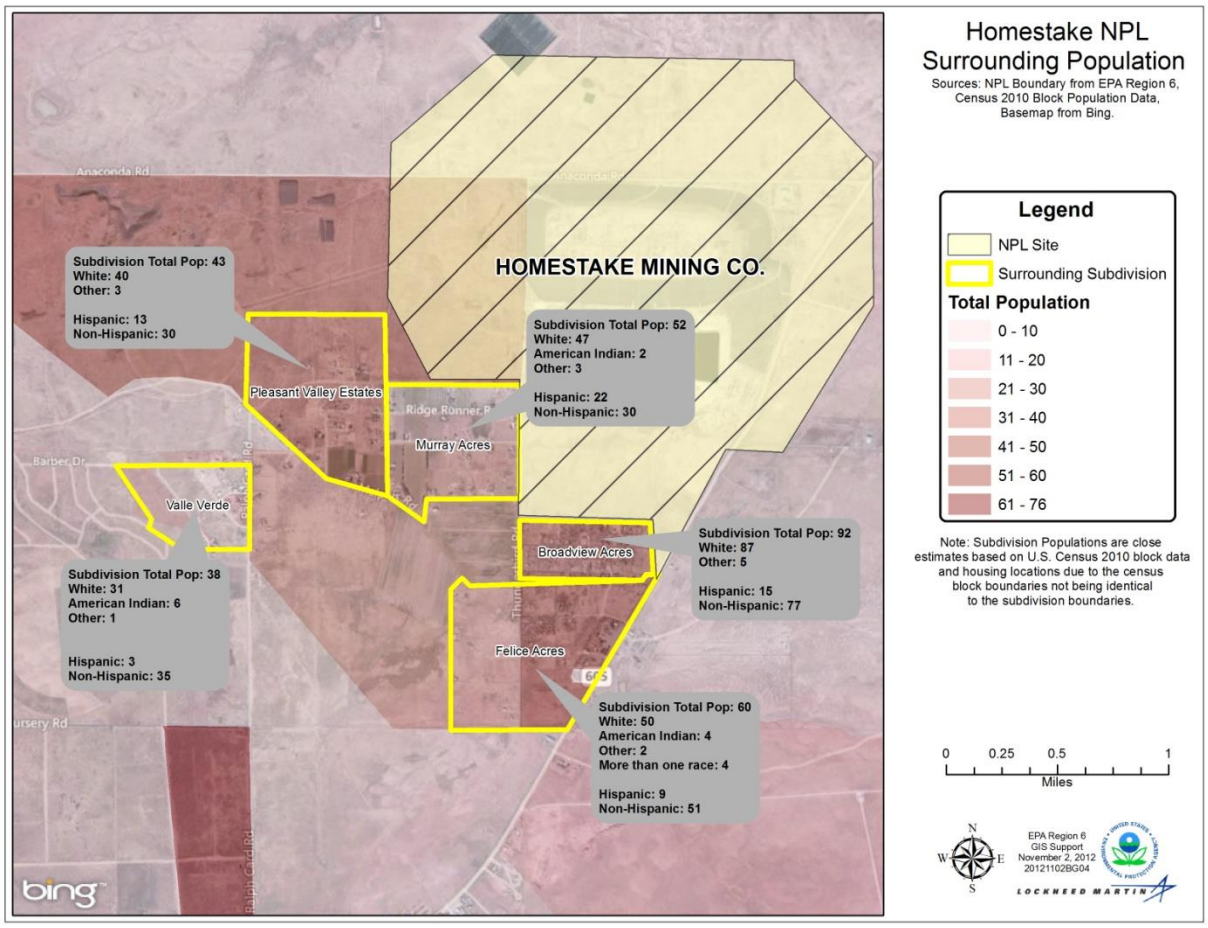



Figure 3-4: Total number and population make up divided by ethnicity in each subdivision.

Some of the residences are involved in subsistence or agricultural way of life. Therefore, the potentially exposed populations considered in this risk assessment are residents and farmers.

### 3.1.8 Selection of a Background Area

An area south of the five residential subdivisions was selected as a soil background area to the residential communities. The area was close enough to have same geological and surface soil make up as the Five Subdivisions but far enough to be impacted by the HMC site related contaminants. Although the background area was a vacant land and does not have houses or residents, comparison of the contaminants in the Five Subdivisions' soil and the background soil was the key to exposure since the soil was the main source of the contaminants that a resident is exposed to around his house. Soil concentration was also the input parameter required in transport models from soil into plants and domestic animals.

### 3.1.9 Sources, Releases, Migration, and Fate of Contaminants

The sources of contamination to the surrounding communities are the tailing piles, reverse osmosis unit process, evaporation pond, irrigation fields, and mechanical spraying of contaminated water at the central pivot area. The potential pathways of human exposure in and around the home are shown schematically in Figure 3-5. The conceptual site model (figure 3-6), provides a schematic depiction of the sources of contamination, the mechanism by which contaminants are released and transported in the environment and potential human receptors.

Contaminants such as radon gas can be released from the tailing piles, RO unit process and mist from force spraying of evaporation pond waters into the air and then dispersed by wind blowing in the direction of the Five Subdivisions. There is also the potential for fugitive emissions of contaminants on dust particles blowing from the site soil, tailings piles and banks of the evaporation ponds. Contaminants could also be carried away as run off during heavy rains from the site soils and tailings piles towards the Five Subdivisions and pools in the communities. The water pools evaporate into the air, and soluble contaminates percolate through the ground to leach into ground water, insoluble particulates will be left as residues on the surface soil. Most of the contaminants are not very soluble in water and are expected to stay behind on the surface of the soil. The contaminated surface soil becomes the secondary source of contamination to the air through fugitive emissions, to water bodies through run off, and to vegetation through the uptake of contaminants from the soil into plants. From plants to humans consuming these plants or to grazing animals consuming contaminated grass and animal feed. Contaminants in animal feed can end up in the meat or milk of the cattle. Grazing animals also pick up contaminated soil in their feed.

## 3.2 Summary of Residential and Agricultural Exposure Pathways

The potential sources of contamination at the HMC site, the mechanisms by which contaminants are released and transported to residential properties, and the potential pathways of human exposure in and around the home are shown schematically in figure 3-6, the conceptual site model. As shown in the tables above in section 2, levels of contaminants above the EPA soil screening levels were found in yard soil, indoor air, produce, private well waters and ambient air. Residents at the Five Subdivisions may have been exposed to these contaminants in and around their homes in several ways, including:

- Incidental ingestion of soil and home dust as a result of hand-to-mouth contact.
- Inhalation of radon gas in indoor air and outdoor ambient air

- Inhalation of fugitive emissions in ambient air
- Consumption of tap water and inhalation of radon in water if connected to a private well (potential future exposure).

  In addition, residents who garden and consume homegrown vegetables or fruits also can be exposed through:
- Consumption of homegrown produce that may have absorbed contaminants from the soil or absorbed contaminants via irrigation with contaminated ground water.

In an agriculture exposure scenario, a farmer will be exposed to contaminants through all the routes mentioned above in addition they can be exposed to contaminants through:

- Consumption of beef and /or milk from homegrown cows that graze on grass or hay grown on contaminated soil.
- Consumption of poultry and/or eggs from poultry raised on contaminated grains or feed grown on contaminated soil.

Other potential exposure pathways considered in a residential setting are absorption of contaminants through the skin from soil adhering to the skin or from bath water, and inhalation of contaminants volatilized from tap water. Although all of the COPC are metals and absorption through the skin is usually minimal, it was evaluated in this risk assessment. Although almost all of the houses are connected to the Milan municipal water, for this risk assessment we did an evaluation of the risk for a future resident who might install a private well for domestic purposes. Thus inhalation of volatiles and dermal contact with water is evaluated too. The rationale for including or omitting potential exposure pathways is summarized in Appendix A Table 1 to table 1.6.


Figure 3-5: Residential exposure schematic for an individual exposed to contaminants in his immediate surroundings.

### 3.2.1 Current and Potential Future Exposures

Current and potential future residential exposure conditions in the Five Subdivision areas are expected to be essentially the same. All of the potential exposures considered in this risk assessment may occur at existing residences and could continue to occur at residences in the future; therefore, no fundamental changes in the types of exposure that may occur are expected. The environmental conditions giving rise to the current exposure, the presence of the mill tailing piles, the evaporation ponds, RO unit process, direct and central pivot irrigation of surrounding fields is expected to continue in the near future but it might change in the long term since all these activities are associated with ground water reclamation project. The exposure scenario for a resident is assumed to be for 30 years and 40 years for an agricultural scenario without considering any remedial activities taking place at the Site.

### 3.2.2 Quantification of Exposure

#### 3.2.2.1 Exposure Point Concentration

Exposure and risk estimates were calculated for all COPC and ROPC. Because the exposure point concentrations calculated for some of the COPC and ROPCs for the Five Subdivisions area were close to or below the exposure point concentration for the reference background area, the exposures and risks were calculated for residents of both the Five Subdivisions and for a hypothetical reference area located further south of the Five Subdivisions for comparison. EPA guidance RAGS-HHEM (EPA 1989) recommends that the 95% upper confidence limit (UCL) on the arithmetic mean concentration be used as a conservative estimate of the average concentration in an exposure area for the purpose of estimating reasonable maximum exposures and risks. The ProUCL version 4.1 was used to determine distribution of the data and the UCL value that best fitted the data distribution ( Appendix G) . If the calculated 95% UCL concentration was higher than the maximum detected concentration, the maximum detected concentration was used as the exposure point concentration (EPA 1992). Exposure point concentrations were not calculated for chemicals not detected in a particular medium.

The exposure point concentrations used in the quantitative risk assessment are given in section 2. The 95% UCL on the arithmetic mean of the yard soil concentrations for the individual residences were used for calculating the exposure point concentrations for the Five Subdivisions.

The exposure point concentrations for water are the 95% UCL on the arithmetic mean or the maximum detected concentration for the private well water samples collected from the Five Subdivisions. Although residents are not using the well water for domestic uses since all residences except for one are connected to Milan municipal water, some residents are still using the private wells to water their yards

and vegetable gardens and their domesticated animals. Evaluation of risk was calculated for a future resident who moves into the community and decides to install a well and use it for domestic purposes.

The exposure point concentration for produce was the 95 % UCL on the arithmetic mean or maximum detected concentrations for all the vegetable samples collected from the Five Subdivisions. Also the 95% UCL on the arithmetic mean of the soil samples in the Five Subdivisions were used to model uptake of the contaminants from soil into plant. The modeled uptake of contaminants from soil into plant concentrations were then compared to the measured concentrations in the vegetable samples collected from garden vegetables. The modeled uptake of contaminants from soil into produce were used since there were no produce or vegetable gardens in the soil background area. The equations and models provided in the Preliminary Remediation Goal (PRG) electronic calculator (http://epa-prgs.ornl.gov/cgi-bin/radionuclides/rprg_search) were used to compare the results with contaminants uptake from soil into hypothetical vegetables grown in background soil.

The exposure point concentrations for radon gas in ambient air are the 95% UCL on the arithmetic mean or maximum detected concentrations measured in the Five Subdivisions areas and those measured in Bluewater (background) area. Also the 95% UCL of the data from the HMC High Volume air sampler stations # 4 and # 5 were used in the risk assessment. The air samplers were located within HMC boundary at the fence line closest to the residential areas.

The exposure point concentrations for soil are the 95% UCL on the arithmetic mean which were used into models to calculate produce concentrations, contaminant concentrations in beef and milk, poultry and egg.

#### 3.2.2.2 Exposure Estimation Calculations

The potential exposure of residents, of the Five Subdivisions area, to contaminants potentially released from the HMC site depends on their activity patterns and environmental factors such as the proximity of their homes to the tailings piles and whether rocks, scrap metals were brought from mines or mills into their homes. Therefore, as a group, residents of the Five Subdivisions could experience a range of potential exposures and risks. For this reason a “high end” estimate, termed the reasonable maximum exposure (RME) case is used and is intended to represent exposures at the high end of the plausible range, above the $90^{th}$ percentile but not higher than the highest exposure that could reasonably be expected for an individual in the group. Potential exposures were estimated using EPA’s standard default exposure assumptions (USEPA 1991a ) (USEPA 1989b).

Potential residential exposures to COPC were estimated for an age integrated receptor that includes both child and adult exposure; for risk assessment purposes, exposure was expressed as the amount of a substance inhaled or ingested per kilogram of body weight per day. Children and adults in the same exposure situation often experience different exposures because of differences in their activity patterns and their physiological characteristics such as breathing rate, food and water consumption rate, and body weight. The age-integrated receptor, which takes these differences into account by using time-weighted average intake rates that include both childhood and adult exposure, was used to assess general residential exposure. Young children constitute a sensitive subgroup because of their proportionality higher intake-to-body weight ratios (particularly for soil ingestion).

The reasonable maximum exposure duration for a resident was assumed to be 30 years which is the $90^{th}$ percentile length of time people live in the same residence and for agricultural scenario the RME exposure duration was assumed to be 40 years. For the age-integrated receptor, 6 of those years were assumed to be as a young child, 1 to 6 years of age, the remaining 24 years were assumed to be as an adult in a residential scenario or 34 years in an agricultural scenario.

In a residential scenario the following exposure pathways were considered and applied to all residents:

- R1- Incidental Ingestion of Yard Soil.
- R2- External Radiation Exposure.
- R3- Inhalation of Airborne Dust.
- R4- Ingestion of Homegrown Produce.
- R5-Ingestion and Inhalation of Radon in Tap Water.

The equations and exposure factors used to estimate potential exposures are given in table 3-1 through 3-26.

The contaminants concentration in soil are the upper 95% confidence limits on the arithmetic average concentration (95% UCL) or the maximum concentration (if maximum concentration is below the 95% UCL) detected in yard soil for the five subdivision and reference hypothetical residential area. The soil ingestion rate is the amount of soil that a child or adult might ingest through hand-to-mouth contact; the values used are EPA's standard default assumptions for child and adult residents. The values used for exposure duration (ED) and exposure frequency (EF) are the number of years and the number of days per year over which exposure could occur. The standard residential EF of 350 days/year was

used for adults and children. The body weights used for adults and children are standard default values. For noncarcinogens, the averaging time is equal to the exposure duration, while for carcinogens, it is taken as the standard life expectancy of 70 years, because the carcinogenic potency slope factors are based on lifetime exposure.

Intakes by inhalation, ingestion, and absorption are also potentially important exposure pathways for radionuclides, although radionuclide intake is typically expressed in units of activity (i.e., Becquerel (Bq) or Curie (Ci)) rather than in units of mass, for risk assessment purposes. Radionuclides that enter through these internal exposure pathways may become systemically incorporated and emit alpha, beta, or gamma radiation within tissues or organs. Unlike chemicals, radionuclides can have deleterious effects on humans without being taken into or brought in contact with the body. This is because high energy beta particles and photons from radionuclides in contaminated air, water, or soil can travel long distances with only minimum attenuation in these media before depositing their energy in human tissues. External radiation exposures can result from either exposure to radionuclides at the site area or to radionuclides that have been transported from the site to other locations in the environment. Gamma and x-rays are the most penetrating of the emitted radiations, and comprise the primary contribution to the radiation dose from external exposures. Alpha particles are not sufficiently energetic to penetrate the outer layer of skin and do not contribute significantly to the external dose. External exposure to beta particles primarily imparts a dose to the outer layer skin cells, although high-energy beta radiation can penetrate into the human body.

The quantification of the amount of energy deposited in living tissue due to internal and external exposures to radiation is termed radiation dosimetry. The amount of energy deposited in living tissue is of concern because the potential adverse effects of radiation are proportional to energy deposition. The energy deposited in tissues is proportional to the decay rate of a radionuclide, and not its mass. Therefore, radionuclide quantities and concentrations are expressed in units of activity (e.g., Bq or Ci), rather than in units of mass for the risk assessment.

Despite the fundamental difference between the way exposures are expressed for radionuclides and chemicals, the approach to exposure assessment for chemical contaminants largely applies to radionuclide contaminants. Specifically, the three steps of an exposure assessment for chemicals also apply to radionuclides: (1) characterization of the exposure setting; (2) identification of the exposure pathways; and (3) quantification of exposure. However, some of the methods by which these three steps are carried out are different for radionuclides. Initial characterization of the exposure setting for

radioactively contaminated sites is virtually identical to that described for chemicals. One additional consideration is that, at sites suspected of having radionuclide contamination, a survey should be conducted to determine external radiation fields using any one of a number of field survey instruments (Preferably Geiger-Muller (G-M) tubes and NaI(Tl) field detectors). The identification of exposure pathways for radioactively contaminated sites is very similar to that described for chemically contaminated sites, with the following additional guidance. In addition to the ingestion, inhalation, and direct contact pathways described for chemicals, external exposure to penetrating radiation should also be considered. Potential external exposure pathways to be considered include immersion in contaminated air, immersion in contaminated water, and radiation exposure from ground surfaces contaminated with beta and photon- emitting radionuclides. As with nonradioactive chemicals, environmentally dispersed radionuclides are subject to the same chemical processes that may accelerate or retard their transfer rates and may increase or decrease their bioaccumulation potentials. These transformation processes must be taken into consideration during the exposure assessment. Radionuclides undergo radioactive decay. Radioactive decay products can also contribute significantly to the radiation exposure and must be considered in the assessment.

### 3.2.3 Quantification of Exposure

One of the primary objectives of an exposure assessment is to make a reasonable estimate of the maximum exposure (RME) to individuals and critical population groups. A series of equations for quantification of chemical and radionuclides exposures are provided in Appendix B. These equations and default variable values are used in both chemical and radionuclides equations. However, equations for radionuclides are modified by deleting the body weight and averaging time from the denominator. Depending upon the characteristics of the radionuclides of concern, consideration of radioactive decay and in growth of radioactive decay products may be important additions, as well as the external exposure pathways. The sources for all the equations and default values used for COPC and ROPC are the EPA Regional Screening Table (http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/) and the PRG for Radionuclides calculator (http://epa-prgs.ornl.gov/radionuclides/) respectively. The equations in the PRG calculator were readjusted to calculate risk instead of PRGs.

#### 3.2.3.1 Internal Exposure

Tables 3-17, 3-18, 3-19, 3-20 and 3-23 present simplified models for the ingestion of water, food, and soil as pathways for the intake of environmental contaminants. The recommended assumptions for ingestion rates and exposure durations are applicable to radionuclide exposures and may

be used to estimate the intake rates of radionuclides by these pathways. As noted previously, however, these intake estimates for radionuclides should not be divided by the body weight or averaging time.

Table 3-18 presents the equation and assumptions used to estimate the contaminant intake from air. For radionuclides, the intake from inhalation of contaminated air is determined as the product of the radionuclide concentration in air ($pCi/m^3$), the breathing rate adjusted for age ($m^3$ per day) and exposure duration (year). Calculations without half-life decay were used since an assumption is made that the source of contamination is considered as unlimited source over the exposure period.

Tables 3-22 and 3-26 illustrate the dermal uptake of contaminants resulted from contact with soil. This route of uptake can be important for many organic chemicals; however, dermal uptake is generally not an important route of uptake for radionuclides or inorganic chemicals (metals), which have small dermal permeability constants. However, in this risk assessment dermal uptake of inorganic chemicals of potential concern were evaluated as a comparison to other routes of intake.

Table 3-6 illustrate the uptake of contaminants resulted from ingestion of produce grown in contaminated soil (vegetable garden). The intake from this pathway may be estimated as the product of the soil concentration (pCi/g) of the radionuclide of concern adjusted for decay over exposure period, soil to plant transfer factor (pCi/gram-plant per pCi/gram-soil), contaminated plant fraction, age-adjusted fruit and vegetable ingestion rate (kg/year), exposure duration (years) and exposure frequency (days/year). Table 3-6a is the foliage uptake of contaminants in well waters used for irrigating home grown vegetables. The equation and input parameters used were adopted from U.S. NRC Regulatory Guide 1.109 Office of Standards Development October 1977.

Table 3-13and Table 3-14 illustrate the uptake of contaminants resulted from ingestion of beef and milk from a home grown cattle in a farmer scenario. The intake from this pathway is estimated as the product of the soil concentration (pCi/g) of the radionuclide of potential concern adjusted for half-life decay over exposure period, soil to plant transfer factor, beef/milk transfer factor (day/kg), age-adjusted beef/milk ingestion rate (kg/year), fodder and soil cattle intake rate (kg/day), exposure duration (years) and exposure frequency (days/year).

Table 3-15 and Table 3-16 illustrate the uptake of contaminants resulted from ingestion of poultry and egg from home raised poultry in a farmer scenario. The intake from this pathway is estimated as the product of the soil concentration (pCi/g) of the radionuclide of potential concern adjusted for half-life decay over exposure period, soil to plant transfer factor (pCi/gram-plant per pCi/gram-soil), age-adjusted poultry/egg ingestion rate, poultry soil intake (kg/day), poultry/egg transfer factor (day/kg), exposure duration (years) and exposure frequency (days/year).

Tables 3-17 through Table 3-26 illustrate the uptake of inorganic chemicals (metals) of potential concern through the incidental ingestion of soil, inhalation of fugitive emissions of particulates in air, dermal contact with soil and water, and ingestion of water from private wells, considering both cancer and noncancer effects.

#### 3.2.3.2 External Exposure

Immersion in air containing certain beta-emitting and/or photon-emitting radioactive contaminants can also result in external exposures. Intake from external exposure are calculated as the product of the airborne radionuclide concentration ($pCi/m^3$), exposure time (hours/day), exposure frequency (days/year) and the duration of exposure (years).

The external exposure pathway of potential significance is irradiation from radionuclides deposited on the ground surface. The intake from this pathway may be estimated as the product of the soil surface concentration (pCi/g) of the photon-emitting radionuclides of concern, the slab size area correction factor ($m^3$), the indoor gamma shielding factor, exposure frequency (days/yr), exposure time indoor and outdoor, and exposure duration (years).

#### 3.2.3.3 Combining Intakes

The calculations described previously result in estimates of intakes from individual radionuclides and chemicals of potential concern via a large number of possible exposure pathways. Because a given population may be subject to multiple exposure pathways, the results of the exposure assessment is organized by grouping all applicable exposure pathways for each exposed population. Risks from various exposure pathways and contaminants then can be integrated during the risk characterization step.

## 3.3 Uncertainties in the Exposure Assessment

Several factors could cause the estimated exposure levels to differ from actual exposures. This section identifies these factors, discusses the potential effects of the factors on the exposure estimate whether over estimates or underestimates the calculated exposure estimates. Some uncertainty is inherent in the process of conducting predictive, quantitative human health evaluations. Environmental sampling and analysis, fate and transport modeling, and human exposure modeling are all prone to uncertainty, as are the available toxicity data used to characterize risks.

### 3.3.1 Environmental Sampling

Uncertainty associated with environmental sampling is generally related to the limitations of the sampling in terms of the number and distribution of samples. Uncertainty associated with the analysis of

samples is generally associated with systematic or random errors (e.g., false positive or negative results). Thus exposure may be overestimated or underestimated depending on how well the environmental medium is characterized.

### 3.3.2 Exposure Point Concentration

The exposure point concentrations used in the exposure assessment were estimated directly from measured concentrations in each exposure medium by calculating the 95% UCL on the arithmetic average without consideration of environmental migration, transformation, degradation, or loss. This should result in overestimates of long-term exposure. For radionuclides consideration for decay products and ingrowth might overestimate or underestimate the exposure levels. The 95% UCL might underestimate the exposure level to a maximally exposed individual.

### 3.3.3 Exposure Parameters

The main uncertainty regarding the exposure estimation calculations is associated with selection of appropriate parameter values. Individual parameter values were selected so that the overall pathway exposure estimates would approximate high-end exposures. While aspects of the exposure assessment methodology can result in overestimation or underestimation of long-term exposure, exposure is probably overestimated, overall, for the potentially exposed population evaluated.

Radionuclides and chemicals of potential concern adsorbed to respirable particulates made airborne from wind/mechanical erosion are based on conservative air dispersion modeling that over predicts air concentrations.

Assumptions and model input parameters that result in reasonable maximum exposure estimates are used in the exposure assessment; the actual frequencies and durations of exposure would probably be less than evaluated so that long-term exposure should be overestimated.

Transfer factors used in uptake models for plant, beef and milk tend to overestimate exposure. The assumption that the source of contamination does not decline overtime due to dispersion in the environment due to factors such as surface runoff or transport into the subsurface is usually overestimation. Factors such as runoff could lead to an increase of concentrations in some locations as the runoff material consolidated.

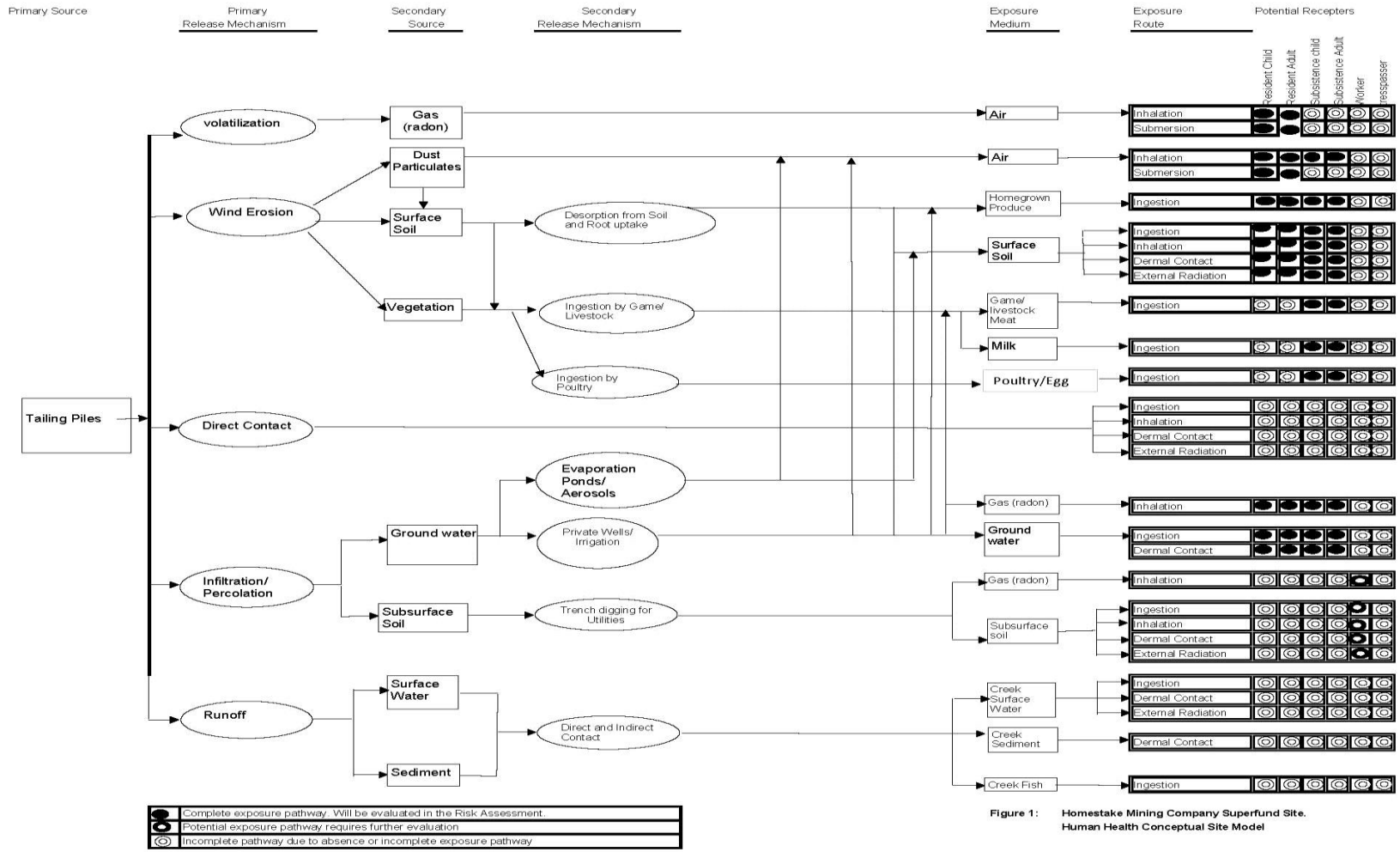



**Figure 3- 6 : Conceptual Site Model for Residential Exposure at the Residential Communities Downgradient from HMC site.**

**Table 3-1**

**Scenario 1- General Residential Exposure**

**Pathway R1- Incidental Ingestion of Radionuclides in Soil**

Equation for age -integrated (adult/child) receptors

$$Intake_{res-sol-Ing.}(pCi) = \frac{C_S\left(\frac{pCi}{g}\right) * \left(1 - e^{-\lambda t_r}\right) * IFS_{R-adj}\left(\frac{120mg}{day}\right) * EF_r\left(350\,\frac{day}{yr}\right) * ED_r\,(30\ yr) * \left(\frac{g}{1000mg}\right)}{t_r(yr) * \lambda\left(\frac{1}{yr}\right)}$$

$$IFS_{r-adj}\left(120\,\frac{mg}{day}\right) = \frac{(IRS_{r-c}\left(\frac{200mg}{day}\right) * ED_{r-c}(6\ yr) + IRS_{r-a}\left(100\,\frac{mg}{day}\right) * ED_{r-a}(24yr))}{ED_r(30\ yr)}$$

Where:

| Variable | Value |
|---|---|
| $C_s$ (UCL or maximum detected concentration in soil) pCi/g | Site-specific |
| $ED_{r\text{-}a}$ (exposure duration - resident adult) yr | 24 |
| $EF_r$ (exposure frequency - resident) day/yr | 350 |
| $IRS_{r\text{-}a}$ (soil intake rate - resident adult) mg/day | 100 |
| $IRS_{r\text{-}c}$ (soil intake rate - resident child) mg/day | 200 |
| $IFS_{r\text{-}adj}$ (age-adjusted soil ingestion factor - resident) mg/day | 120 |
| $ED_{r\text{-}c}$ (exposure duration - resident child) yr | 6 |
| $ED_r$ (exposure duration - resident) yr | 30 |
| $T_r$ (time-resident) yr | 30 |
| λ ( lambda decay constant) | Isotopic-specific |

**Table 3-2**

**Scenario 1- General Residential Exposure**

**Pathway R2- External Exposure to Ionizing Radiation from Contaminants in Soil**

$$External_{\,res-sol-ext} = \frac{C_s\left(\frac{pCi}{g}\right) * \left(1 - e^{-\lambda t_r}\right) * ACF * EF_r\left(\frac{350\ days}{yr}\right) * \left(\frac{1yr}{365days}\right) * ED_r(30\ yr) * [ET_{r-o}(0.073) + \left(ET_{r-i}(0.684) * GSF_i(0.4)\right)]}{t_r(yr) * \lambda(\frac{1}{yr})}$$

Where:

| Variable | Value |
|---|---|
| $C_s$ (UCL or maximum detected concentration in soil) pCi/g | Site-specific |
| Slab size for ACF (Area Correction factor) $m^3$ | Default (isotope-specific) |
| $EF_r$ (exposure frequency-resident) day/yr | 350 |
| $ED_r$ (exposure duration-resident) yr | 30 |
| $ET_{r-o}$ (exposure time-outdoor resident) hr/hr | 0.073 |
| $ET_{r-I}$ (exposure time-indoor resident) hr/hr | 0.684 |
| $GSF_i$ (gamma shielding factor-indoor)unitless | 0.4 |
| $T_r$ (time-resident) yr | 30 |
| λ ( lambda decay constant) | Isotopic-specific |

**Table 3-3**

**Scenario 1- General Residential Exposure**

**Pathway R3- Inhalation of Contaminants in Airborne Particulates**

$$Intake_{res-sol-inh.}(\boldsymbol{pCi}) = \frac{\boldsymbol{Cs_{res-sol-inh}}\left(\frac{\boldsymbol{pCi}}{\boldsymbol{g}}\right) * \left(1 - \boldsymbol{e^{-\lambda t_r}}\right) * \boldsymbol{IFA_{r-adj}}\left(18\frac{\boldsymbol{m^3}}{\boldsymbol{day}}\right) * \boldsymbol{EF_r}\left(350\frac{\boldsymbol{day}}{\boldsymbol{yr}}\right) * \boldsymbol{ED_r}(30\ \boldsymbol{yr}) * \frac{1}{\boldsymbol{PEF}\left(\frac{\boldsymbol{m^3}}{\boldsymbol{kg}}\right)} * \boldsymbol{ET_r}\left(24\frac{\boldsymbol{hr}}{\boldsymbol{day}}\right) * \left(\frac{\boldsymbol{1day}}{\boldsymbol{24hr}}\right) * \left(\frac{\boldsymbol{1000g}}{\boldsymbol{kg}}\right)}{\boldsymbol{t_r}(\boldsymbol{yr}) * \boldsymbol{\lambda}\left(\frac{\boldsymbol{1}}{\boldsymbol{yr}}\right)}$$

$$IFA_{r-adj}\left(18\frac{m^3}{day}\right) = \frac{IRA_{r-c}\left(10\frac{m^3}{day}\right) * ED_{r-c}(6\ yr) + IRA_{r-a}\left(20\frac{m^3}{day}\right) * ED_{r-a}\ (24\ yr)}{ED_r\ (30\ yr)}$$

Where:

| Variable | Value |
|---|---|
| $C_s$ (UCL or maximum detected concentration in soil) pCi/g | Site-specific |
| $IFA_{r\text{-}adj}$ (age-adjusted soil inhalation factor-resident) $m^3$/day | 18 |
| $EF_r$ (exposure frequency-resident) day/yr | 350 |
| $ED_r$ (exposure duration-resident) yr | 30 |
| PEF (particulate emission factor) $m^3$/kg | 1.36E+09 |
| $ET_r$ (exposure time-resident) hr/day | 24 |
| $IRA_{r\text{-}c}$ (inhalation rate-resident child) $m^3$/day | 10 |
| $IRA_{r\text{-}a}$ (inhalation rate-resident adult) $m^3$/day | 20 |
| $ED_{r\text{-}a}$ (exposure duration-resident adult) yr | 24 |
| $ED_{r\text{-}c}$ (exposure duration-resident child) yr | 6 |
| $T_r$ (time-resident) yr | 30 |
| λ ( lambda decay constant) | Isotopic-specific |

**Table 3-4**

**Scenario 1- General Residential Exposure**

**Pathway R4- Ingestion of Contaminants in Tap Water**

Equation for age -integrated (adult/child) receptors

$$Intake_{water-ing.}\ (pCi) = C_w \left(\frac{pCi}{L}\right) * EF_r \left(350\frac{day}{yr}\right) * ED_r(30\ yr) * IFW_{r-adj}\ (1.8\frac{L}{day})$$

$$IFW_{r-adj}\left(1.8\frac{L}{day}\right) = \frac{ED_{r-c}\ (6\ yr) * IRW_{r-c}\left(1\frac{L}{day}\right) + ED_{r-a}(24\ yr) * IRW_{r-a}(2\frac{L}{day})}{ED_r\ (30\ yr)}$$

Where:

| Variable | Value |
|---|---|
| $C_w$ (contaminant concentration in water) pCi/L | Site specific |
| $ED_{r\text{-}a}$ (exposure duration - resident adult) yr | 24 |
| $ED_{r\text{-}c}$ (exposure duration - resident child) yr | 6 |
| $EF_r$ (exposure frequency - resident) day/yr | 350 |
| $IRW_{r\text{-}a}$ (water intake rate - resident adult) L/day | 2 |
| $IRW_{r\text{-}c}$ (water intake rate - resident child) L/day | 1 |
| $IFW_{r\text{-}adj}$ (age-adjusted water ingestion factor - resident) L/day | 1.8 |
| $ED_r$ (exposure duration-resident) yr | 30 |

**Table 3-5**

**Scenario 1- General Residential Exposure**

**Pathway R5- Inhalation of Contaminants in Tap Water**

Equation for age -integrated (adult/child) receptors

$$Intake_{water-inh.}\ (pCi) = C_w \left(\frac{pCi}{L}\right) * EF_r \left(350\frac{day}{yr}\right) * ED_r(30\ yr) * IFA_{r-adj} \left(18\frac{m^3}{day}\right) * K\left(\frac{0.5L}{m^3}\right) * ET_r\left(\frac{24hr}{day}\right) * (\frac{1day}{24hr})$$

$$IFA_{r-adj}\left(18\frac{m^3}{day}\right) = \frac{ED_{r-c}\ (6\ yr) * IRA_{r-c}\left(10\frac{m^3}{day}\right) + ED_{r-a}(24\ yr) * IRA_{r-a}(20\frac{m^3}{day})}{ED_r\ (30\ yr)}$$

Where:

| Variable | Value |
|---|---|
| $C_w$ (contaminant concentration in water) pCi/L | Site specific |
| $ED_{r\text{-}a}$ (exposure duration - resident adult) yr | 24 |
| $ED_{r\text{-}c}$ (exposure duration - resident child) yr | 6 |
| $EF_r$ (exposure frequency - resident) day/yr | 350 |
| $IRA_{r\text{-}a}$ (water intake rate - resident adult) $m^3$/day | 20 |
| $IRA_{r\text{-}c}$ (water intake rate - resident child) $m^3$/day | 10 |
| $IFA_{r\text{-}adj}$ (age-adjusted water ingestion factor - resident) $m^3$/day | 18 |
| K (Andelman volatilization Factor) L/$m^3$ | 0.5 |
| $ED_r$ (exposure duration-resident) yr | 30 |
| $ET_r$ (exposure time-resident) hr | 24 |

**Table 3-6**

**Scenario 1- General Residential Exposure**

**Pathway R6- Ingestion of Produce (Fruits and Vegetables) Grown in Contaminated Soil**

Equation for age -integrated (adult/child) receptors

$$Intake_{res-produce-Ing.}(pCi) = \frac{C_S\left(\frac{pCi}{g}\right) * \left(1 - e^{-\lambda t_r}\right) * (IFF_{r-adj}\left(\frac{17.5kg}{year}\right) + IFV_{r-adj}\left(\frac{9.1kg}{year}\right)) * EF_r\left(350\,\frac{day}{yr}\right) * \left(\frac{1yr}{365day}\right) * ED_r\,(30\ yr) * \left(\frac{1000g}{kg}\right) * TF_p\left(\frac{day}{kg}\right) * CPF_r\,(0.25)}{t_r(yr) * \lambda\left(\frac{1}{yr}\right)}$$

Where:

$$IFF_{r-adj}\left(17.5\,\frac{kg}{year}\right) = \frac{(IRF_{r-c}\left(\frac{5.4kg}{year}\right) * ED_{r-c}(6\ yr) + IRF_{r-a}\left(20.5\,\frac{kg}{year}\right) * ED_{r-a}(24yr))}{ED_r(30\ yr)}$$

and

$$IFV_{r-adj}\left(9.1\,\frac{kg}{year}\right) = \frac{(IRV_{r-c}\left(\frac{3.8kg}{year}\right) * ED_{r-c}(6\ yr) + IRV_{r-a}\left(10.4\,\frac{kg}{year}\right) * ED_{r-a}(24yr))}{ED_r(30\ yr)}$$

**Table 3-6 (Contd.)**

**Scenario 1- General Residential Exposure**

**Pathway R6- Ingestion of Produce (Fruits and Vegetables) Grown in Contaminated Soil- Continued.**

| Parameters for age -integrated (adult/child) receptors | |
|---|---|
| Variable | Value |
| $C_s$ (UCL or maximum detected concentration in soil) pCi/g | Site-specific |
| $IFF_{r\text{-}adj}$ (age-adjusted fruit ingestion-resident) kg/yr | 17.5 |
| $IFV_{r\text{-}adj}$ ( age-adjusted vegetables ingestion-resident) kg/yr | 9.1 |
| $EF_r$ (exposure frequency-resident) day/yr | 350 |
| $ED_r$ (exposure duration-resident) yr | 30 |
| $TF_P$ (Soil to plant transfer factor) pCi/gram-plant per pCi/gram-soil | Isotope- specific |
| $CPF_r$ (Contaminated Plant Fraction-resident) unitless | 0.25 |
| $IRF_{r\text{-}c}$ (Ingestion of fruit rate-resident child) kg/year | 5.4 |
| $IRF_{r\text{-}a}$ (Ingestion of fruit rate-resident adult) kg/year | 20.5 |
| $IRV_{r\text{-}c}$ (Ingestion of vegetable rate-resident child) kg/year | 3.8 |
| $IRV_{r\text{-}a}$ (ingestion of vegetable rate-resident adult) kg/year | 10.4 |
| $ED_{r\text{-}a}$ (exposure duration-resident adult) yr | 24 |
| $ED_{r\text{-}c}$ (exposure duration-resident child) yr | 6 |
| $T_r$ (time-resident) yr | 30 |
| $\lambda$ ( lambda decay constant) | Isotopic-specific |

**Table 3-6a**

**Scenario 1- General Residential Exposure**

**Pathway R6- Ingestion of Produce Irrigated with Contaminated Water Well**

$$Intake_{vg} = \left\{ \frac{C_{iv} * \mathrm{IR} * \frac{1000\mathrm{g}}{\mathrm{Kg}} * \frac{\mathrm{EF}_r}{365} * \mathrm{ED}_r * [1 - \exp(-\lambda * \mathrm{t_r})]}{\lambda * \mathrm{t_r}} \right\}$$

$$C_{iv} = \mathrm{C_{iw}} * \mathrm{I} * \left\{ \frac{\mathrm{r} * [1 - \exp(-\lambda_{\mathrm{Ei}} * \mathrm{t_e})]}{\mathrm{Y_v} * \lambda_{\mathrm{Ei}}} \right\} * \exp(-\lambda_{\mathrm{i}} * \mathrm{t_h})$$

Where:

| Variable | Value |
|---|---|
| $C_{iv}$ = (Concentration of radionuclide i in vegetation) pCi/g | Site-specific |
| IR = (Ingestion rate) kg/year | 9.1 |
| $EF_r$ (exposure frequency-resident) day/yr | 350 |
| $ED_r$ (exposure duration-resident) yr | 30 |
| r = Fraction of deposited activity retained on crops, leafy vegetables, or pasture grass. | 0.25 |
| $t_h$ = (Holdup time that represents the time interval between harvest and consumption of the food) hours. | 24 |
| $t_r$ = (Residential exposure time) years. | 30 |
| $\lambda_i$ = (Radioactive decay constant of nuclide i) $yr^{-1}$. | Isotopic specific |
| $C_{iw}$ = (Concentration of radionuclide i in water used for irrigation) pCi/l. | Site-specific |
| I = (Average irrigation rates during the growing season) liters/$m^2$-hr | 0.072 |
| $\lambda_{Ei}$ = Effective removal rate constant for radionuclide i from crops, in $hr^{-1}$, where $\lambda_{Ei} = \lambda_i + \lambda_w$ , $\lambda_i$ = is the radioactive decay constant in $hr^{-1}$ , and $\lambda_w$ = is the removal rate constant for physical loss by weathering (corresponds to a 14-day half-life = 0.0021 $hr^{-1}$. | 0.0021 |
| $t_e$ = (Time period that crops are exposed to contamination during the growing season) hrs. | 1440 |
| Yv = (Agricultural productivity (yield) ) Kg (wet weight)/$m^2$. | 2 |

**Table 3-7**

**Scenario 1- General Residential Exposure**

**Pathway R7- Inhalation of Ambient Air (without half-life decay)**

Equation for age -integrated (adult/child) receptors

$$Intake_{res-air-Inh.-no\ decay}(pCi) = C_a\left(\frac{pCi}{m^3}\right) * ET_r\left(\frac{24hr}{day}\right) * \left(\frac{1day}{24hr}\right) * IFA_{r-adj}\left(\frac{18m^3}{day}\right) * EF_r\left(350\frac{day}{yr}\right) * ED_r\,(30\ yr)$$

$$IFA_{r-adj}\left(18\frac{m^3}{day}\right) = \frac{\left(IRA_{r-c}\left(\frac{10m^3}{day}\right) * ED_{r-c}(6\ yr) + IRA_{r-a}\left(\frac{20m^3}{day}\right) * ED_{r-a}(24yr)\right)}{ED_r(30\ yr)}$$

Where:

| Variable | Value |
|---|---|
| $C_a$ ( concentration in air) pCi/$m^3$ | Site-specific |
| $IFA_{r\text{-}adj}$ (age-adjusted air inhalation factor-resident) $m^3$/day | 18 |
| $EF_r$ (exposure frequency-resident) day/yr | 350 |
| $ED_r$ (exposure duration-resident) yr | 30 |
| $ET_r$ (exposure time-resident) hr/day | 24 |
| $IRA_{r\text{-}c}$ (inhalation rate-resident child) $m^3$/day | 10 |
| $IRA_{r\text{-}a}$ (inhalation rate-resident adult) $m^3$/day | 20 |
| $ED_{r\text{-}a}$ (exposure duration-resident adult) yr | 24 |
| $ED_{r\text{-}c}$ (exposure duration-resident child) yr | 6 |

**Table 3-8**

**Scenario 1- General Residential Exposure**

**Pathway R8- External Exposure to Ionizing Radiation in Ambient Air**

**(without half-life decay)**

Equation for adult receptors

$$Intake_{res-air-Inh.-no\ decay}(pCi-yr)/m^3) = C_a\left(\frac{pCi}{m^3}\right) * ET_r\left(\frac{24hr}{day}\right) * \left(\frac{1day}{24hr}\right) * EF_r\left(350\frac{day}{yr}\right) * ED_r\,(30\ yr) * \left(\frac{1yr}{365day}\right) * GSF_o(1.0)$$

Where:

| Variable | Value |
|---|---|
| $C_a$ (concentration in air - submersion) pCi/$m^3$ | Site-specific |
| $EF_r$ (exposure frequency-resident) day/yr | 350 |
| $ED_r$ (exposure duration-resident) yr | 30 |
| $ET_r$(exposure time-outdoor resident) hr/day | 24 |
| $GSF_o$(gamma shielding factor-outdoor) unitless | 1.0 |

**Table 3-9**

**Scenario 2- Farmer Exposure**

**Pathway R1- Incidental Ingestion of Contaminants in Soil**

Equation for age -integrated (adult/child) receptors

$$Intake_{f-sol-Ing.}(pCi) = \frac{C_S\left(\frac{pCi}{g}\right) * \left(1 - e^{-\lambda t_f}\right) * IFS_{f-adj}\left(\frac{115mg}{day}\right) * EF_f\left(350\,\frac{day}{yr}\right) * ED_f\,(40\ yr) * \left(\frac{g}{1000mg}\right)}{t_f(yr) * \lambda\left(\frac{1}{yr}\right)}$$

$$IFS_{f-adj}\left(115\,\frac{mg}{day}\right) = \frac{(IRS_{f-c}\left(\frac{200mg}{day}\right) * ED_{f-c}(6\ yr) + IRS_{f-a}\left(100\,\frac{mg}{day}\right) * ED_{f-a}(34yr))}{ED_f(40\ yr)}$$

Where:

| Variable | Value |
|---|---|
| $C_s$ (UCL or maximum detected concentration in soil) pCi/g | Site-specific |
| $ED_{f\text{-}a}$ (exposure duration - adult farmer) yr | 34 |
| $EF_f$ (exposure frequency - farmer) day/yr | 350 |
| $IRS_{f\text{-}a}$ (soil intake rate – adult farmer) mg/day | 100 |
| $IRS_{f\text{-}c}$ (soil intake rate – child farmer) mg/day | 200 |
| $IFS_{f\text{-}adj}$ (age-adjusted soil ingestion factor - farmer) mg/day | 115 |
| $ED_{f\text{-}c}$ (exposure duration – child farmer) yr | 6 |
| $ED_f$ (exposure duration - farmer) yr | 40 |
| $T_f$ ( time-farmer) yr | 40 |
| λ (lambda decay constant | Isotopic-specific |

**Table 3-10**

**Scenario 2- Agriculture Farmer Exposure**

**Pathway R2- External Exposure to Ionizing Radiation from Contaminants in Soil**

$$External_{f-sol-ext} = \frac{C_s\left(\frac{pCi}{g}\right) * \left(1 - e^{-\lambda t_f}\right) * ACF * EF_f\left(\frac{350\ days}{yr}\right) * \left(\frac{1yr}{365 days}\right) * ED_f(40\ yr) * [ET_{f-o}(0.507) + \left(ET_{f-i}(0.417) * GSF_i(0.4)\right)]}{t_f(yr) * \lambda(\frac{1}{yr})}$$

Where:

| Variable | Value |
|---|---|
| $C_s$ (UCL or maximum detected concentration in soil) pCi/g | Site-specific |
| Slab size for ACF (Area Correction factor) $m^3$ | Default (isotope-specific) |
| $EF_f$ (exposure frequency-farmer) day/yr | 350 |
| $ED_f$ (exposure duration-farmer) yr | 40 |
| $ET_{f-o}$ (exposure time-outdoor farmer) hr/hr | 0.507 |
| $ET_{f-I}$ (exposure time-indoor farmer) hr/hr | 0.417 |
| $GSF_i$ (gamma shielding factor-indoor)unitless | 0.4 |
| $T_f$ (time-farmer) yr | 40 |
| λ ( lambda decay constant) | Isotopic-specific |

**Table 3-11**

**Scenario 2- Agriculture Farmer Exposure**

**Pathway R3- Inhalation of Contaminants in Airborne Particulates**

$$Intake_{f-sol-inh.}(\boldsymbol{pCi}) = \frac{\boldsymbol{Cs_{f-sol-inh}}\left(\frac{\boldsymbol{pCi}}{\boldsymbol{g}}\right) * \left(\boldsymbol{1 - e^{-\lambda t_r}}\right) * \boldsymbol{IFA_{f-adj}}\left(\boldsymbol{18.5\frac{m^3}{day}}\right) * \boldsymbol{EF_f}\left(\boldsymbol{350\frac{day}{yr}}\right) * \boldsymbol{ED_f}(\boldsymbol{40\ yr}) * \frac{\boldsymbol{1}}{\boldsymbol{PEF}\left(\frac{\boldsymbol{m^3}}{\boldsymbol{kg}}\right)} * \boldsymbol{ET_f}\left(\boldsymbol{24\frac{hr}{day}}\right) * \left(\frac{\boldsymbol{1day}}{\boldsymbol{24hr}}\right) * \left(\frac{\boldsymbol{1000g}}{\boldsymbol{kg}}\right)}{\boldsymbol{t_f}(\boldsymbol{yr}) * \boldsymbol{\lambda}\left(\frac{\boldsymbol{1}}{\boldsymbol{yr}}\right)}$$

$$IFA_{f-adj}\left(18.5\frac{m^3}{day}\right) = \frac{IRA_{f-c}\left(10\frac{m^3}{day}\right) * ED_{f-c}(6\ yr) + IRA_{f-a}\left(20\frac{m^3}{day}\right) * ED_{f-a}\ (34\ yr)}{ED_f\ (40\ yr)}$$

Where:

| Variable | Value |
|---|---|
| $C_s$ (UCL or maximum detected concentration in soil) pCi/g | Site-specific |
| $IFA_{f\text{-}adj}$ (age-adjusted soil inhalation factor-farmer) $m^3$/day | 18.5 |
| $EF_f$ (exposure frequency- farmer) day/yr | 350 |
| $ED_f$ (exposure duration- farmer) yr | 40 |
| PEF (particulate emission factor) $m^3$/kg | 1.36E+09 |
| $ET_f$ (exposure time- farmer) hr/day | 24 |
| $IRA_{f\text{-}c}$ (inhalation rate-child farmer) $m^3$/day | 10 |
| $IRA_{f\text{-}a}$ (inhalation rate-adult farmer) $m^3$/day | 20 |
| $ED_{f\text{-}a}$ (exposure duration-adult farmer) yr | 34 |
| $ED_{f\text{-}c}$ (exposure duration- child farmer ) yr | 6 |
| $T_f$ (time- farmer) yr | 40 |
| λ ( lambda decay constant) | Isotopic-specific |

**Table 3-12**

**Scenario 2- Agriculture Farmer Exposure**

**Pathway R4- Ingestion of Produce (Fruits and Vegetables) Grown in Contaminated Soil**

Equation for age -integrated (adult/child) receptors

$$Intake_{f-produce-Ing.}(pCi) = \frac{C_S\left(\frac{pCi}{g}\right) * \left(1 - e^{-\lambda t_r}\right) * IFF_{f-adj}\left(\frac{18.235kg}{year}\right) + IFV_{f-adj}\left(\frac{9.41kg}{year}\right) * EF_f\left(350\frac{day}{yr}\right) * \left(\frac{1yr}{365day}\right) * ED_f\,(40\ yr) * \left(\frac{1000g}{kg}\right) * TF_p\left(\frac{day}{kg}\right) * CPF_f(1.0)}{t_f(yr) * \lambda\left(\frac{1}{yr}\right)}$$

Where:

$$IFF_{f-adj}\left(18.235\frac{kg}{year}\right) = \frac{(IRF_{f-c}\left(\frac{5.4kg}{year}\right) * ED_{f-c}(6\ yr) + IRF_{f-a}\left(20.5\frac{kg}{year}\right) * ED_{f-a}(34yr))}{ED_f(40\ yr)}$$

and

$$IFV_{f-adj}\left(9.41\frac{kg}{year}\right) = \frac{(IRV_{f-c}\left(\frac{3.8kg}{year}\right) * ED_{f-c}(6\ yr) + IRV_{f-a}\left(10.4\frac{kg}{year}\right) * ED_{f-a}(34yr))}{ED_f(40\ yr)}$$

**Table 3-12 (Contd.)**

**Scenario 2- Agriculture Farmer Exposure**

**Pathway R4- Ingestion of Produce (Fruits and Vegetables) Grown in Contaminated Soil- Continued.**

| Parameters for age -integrated (adult/child) receptors | |
|---|---|
| Variable | Value |
| $C_s$ (UCL or maximum detected concentration in soil) pCi/g | Site-specific |
| $IFF_{f\text{-}adj}$ (age-adjusted fruit ingestion-farmer) kg/yr | 18.235 |
| $IFV_{f\text{-}adj}$ ( age-adjusted vegetables ingestion-farmer) kg/yr | 9.41 |
| $EF_f$ (exposure frequency-farmer) day/yr | 350 |
| $ED_f$ (exposure duration-farmer) yr | 40 |
| $TF_P$ (Soil to plant transfer factor) pCi/gram-plant per pCi/gram-soil | Isotope- specific |
| $CPF_f$ (Contaminated Plant Fraction-farmer) unitless | 1.0 |
| $IRF_{f\text{-}c}$ (Ingestion of fruit rate- child farmer) kg/year | 5.4 |
| $IRF_{f\text{-}a}$ (Ingestion of fruit rate-adult farmer) kg/year | 20.5 |
| $IRV_{f\text{-}c}$ (Ingestion of vegetable rate-child farmer) kg/year | 3.8 |
| $IRV_{f\text{-}a}$ (ingestion of vegetable rate-adult farmer) kg/year | 10.4 |
| $ED_{f\text{-}a}$ (exposure duration-adult farmer) yr | 34 |
| $ED_{f\text{-}c}$ (exposure duration-child farmer) yr | 6 |
| $T_f$ (time-farmer) yr | 40 |
| $\lambda$ ( lambda decay constant) | Isotopic-specific |

**Table 3-13**

**Scenario 2- Agriculture Farmer Exposure**

**Pathway R5- Consumption of Beef**

Equation for age -integrated (adult/child) receptors

$$Intake_{soil-f-beef-Ing.}(pCi) = C_S\left(\frac{pCi}{g}\right) * \left(1 - e^{-\lambda t_f}\right) * IFB_{f-adj}\left(\frac{43.375kg}{year}\right) * EF_f\left(350\frac{day}{yr}\right) * \left(\frac{1yr}{365day}\right) * ED_f\,(40\ yr) * \left(\frac{1000g}{kg}\right) *$$

$$\frac{\left\{(TF_{beef} * FI_{beef} * TF_p) + \left(TF_{beef} * FI_{beef-s}\right) + (TF_{beef} * FI_{beef-w} * \ (1/(K_d + \sigma * \left(\frac{s}{\rho}\right) * \left(\frac{1}{DF_w}\right)\right\}}{t_f(yr) * \ \lambda\ \left(\frac{1}{yr}\right)}$$

Where:

$$IFF_{f-adj}\left(43.375\frac{kg}{year}\right) = \frac{(IRB_{f-c}\ \left(\frac{4.7kg}{year}\right) * ED_{f-c}(6\ yr) + IRB_{f-a}\left(50.2\frac{kg}{year}\right) * ED_{f-a}(34yr)}{ED_f(40\ yr)}$$

| Table 3-13 (Contd.)<br>Scenario 2- Agriculture Farmer Exposure<br>Pathway R5- Consumption of Beef | |
|---|---|
| Parameters for age -integrated (adult/child) receptors | |
| Variable | Value |
| $C_s$ (UCL or maximum detected concentration in soil) pCi/g | Site-specific |
| $IFB_{f\text{-}adj}$ (age-adjusted beef ingestion rate-farmer) kg/yr | 43.375 |
| $FI_{beef}$ (beef fodder intake rate) kg/day | 11.77 |
| $EF_f$ (exposure frequency-farmer) day/yr | 350 |
| $ED_f$ (exposure duration-farmer) yr | 40 |
| $TF_P$ (Soil to plant transfer factor) pCi/gram-plant per pCi/gram-soil | Isotope- specific |
| $FI_{beef\text{-}s}$ (beef soil intake rate) kg/day | 0.39 |
| $FI_{beef\text{-}W}$ (beef water intake rate) L/day | 53 |
| $K_d$ (soil to water partition coefficient) L/kg | Isotopic-specific |
| $\sigma$ (Total soil porosity) L water/L pore space | 0.5 |
| S (Fraction water content) L water/L pore space | 0.3 |
| P (Soil bulk density) kg/L soil | 1.5 |
| $IRB_{f\text{-}c}$ (beef Ingestion rate- child farmer) kg/year | 4.7 |
| $IRB_{f\text{-}a}$ (beef Ingestion rate-adult farmer) kg/year | 50.2 |
| $DF_w$ (Dilution factor for drinking water) unitless | 1 |
| $TF_{beef}$ (Beef transfer factor ) day/kg | Isotopic-specific |
| $ED_{f\text{-}a}$ (exposure duration-adult farmer) yr | 34 |
| $ED_{f\text{-}c}$ (exposure duration-child farmer) yr | 6 |
| $T_f$ (time-farmer) yr | 40 |
| $\lambda$ ( lambda decay constant) | Isotopic-specific |

**Table 3-14**

**Scenario 2- Agriculture Farmer Exposure**

**Pathway R6- Consumption of Milk From Locally Raised Cows**

Equation for age -integrated (adult/child) receptors

$$Intake_{soil-f-dairy-Ing.}(pCi) = C_S\left(\frac{pCi}{g}\right) * \left(1 - e^{-\lambda t_f}\right) * IFD_{f-adj}\left(\frac{43.375kg}{year}\right) * EF_f\left(350\,\frac{day}{yr}\right) * \left(\frac{1yr}{365day}\right) * ED_f\,(40\ yr) * \left(\frac{1000g}{kg}\right) * \frac{\{(TF_{dairy} * FI_{dairy} * TF_p) + (TF_{dairy} * FI_{dairy-s}) + (TF_{dairy} * FI_{dairy-w} * \ (1/(K_d + \sigma * \left(\frac{s}{\rho}\right) * \left(\frac{1}{DF_w}\right)\}}{t_f(yr) * \ \lambda\ \left(\frac{1}{yr}\right)}$$

Where:

$$IFF_{f-adj}\left(43.375\,\frac{kg}{year}\right) = \frac{(IRD_{f-c}\ \left(\frac{4.7kg}{year}\right) * ED_{f-c}(6\ yr) + IRD_{f-a}\left(50.2\,\frac{kg}{year}\right) * ED_{f-a}(34yr)}{ED_f(40\ yr)}$$

| Table 3-14 (Contd.)<br>Scenario 2- Agriculture Farmer Exposure<br>Pathway R6- Consumption of Milk | |
|---|---|
| Parameters for age -integrated (adult/child) receptors | |
| Variable | Value |
| $C_s$ (UCL or maximum detected concentration in soil) pCi/g | Site-specific |
| $IFD_{f\text{-}adj}$ (age-adjusted milk ingestion rate-farmer) kg/yr | 205.275 |
| $FI_{dairy}$ (dairy fodder intake rate) kg/day | 16.9 |
| $EF_f$ (exposure frequency-farmer) day/yr | 350 |
| $ED_f$ (exposure duration-farmer) yr | 40 |
| $TF_P$ (Soil to plant transfer factor) pCi/gram-plant per pCi/gram-soil | Isotope- specific |
| $FI_{dairy\text{-}s}$ (Dairy soil intake rate) kg/day | 0.41 |
| $FI_{dairy\text{-}W}$ (dairy water intake rate) L/day | 92 |
| $K_d$ (soil to water partition coefficient) L/kg | Isotopic-specific |
| σ (Total soil porosity) L water/L pore space | 0.5 |
| S (Fraction water content) L water/L pore space | 0.3 |
| P (Soil bulk density) kg/L soil | 1.5 |
| $IRD_{f\text{-}c}$ (milk Ingestion rate- child farmer) kg/year | 96.9 |
| $IRD_{f\text{-}a}$ (milk Ingestion rate-adult farmer) kg/year | 224.4 |
| $DF_w$ (Dilution factor for drinking water) unitless | 1 |
| $TF_{dairy}$ (dairy transfer factor ) day/kg | Isotopic-specific |
| $ED_{f\text{-}a}$ (exposure duration-adult farmer) yr | 34 |
| $ED_{f\text{-}c}$ (exposure duration-child farmer) yr | 6 |
| $T_f$ (time-farmer) yr | 40 |
| λ ( lambda decay constant) | Isotopic-specific |

**Table 3-15**

**Scenario 2- Agriculture Farmer Exposure**

**Pathway R7- Consumption of Home Raised Poultry**

Equation for age -integrated (adult/child) receptors

$$Intake_{soil-f-po-Ing.}(pCi) = C_S\left(\frac{pCi}{g}\right) * \left(1 - e^{-\lambda t_f}\right) * IFP_{f-adj}\left(\frac{31.18kg}{year}\right) * EF_f\left(350\frac{day}{yr}\right) * \left(\frac{1yr}{365day}\right) * ED_f\,(40\ yr) * \left(\frac{1000g}{kg}\right) *$$

$$\frac{\left\{(TF_{po}(\frac{day}{kg}) * FI_{po}(\frac{0.2kg}{day}) * TF_p(\frac{pCi}{g-plant}\ per\ \frac{pCi}{g-soil})) + \left(TF_{po}\left(\frac{day}{kg}\right) * FI_{po-s}(\frac{0.022kg}{day})\right)\right\}}{t_f(yr) * \lambda\left(\frac{1}{yr}\right)}$$

Where:

$$IFP_{f-adj}\left(31.18\frac{kg}{year}\right) = \frac{(IRP_{f-c}\left(\frac{5kg}{year}\right) * ED_{f-c}(6\ yr) + IRD_{f-a}\left(35.8\frac{kg}{year}\right) * ED_{f-a}(34yr)}{ED_f(40\ yr)}$$

| Table 3-15 (Contd.)<br>Scenario 2- Agriculture Farmer Exposure<br>Pathway R7- Consumption of Poultry | |
|---|---|
| Parameters for age -integrated (adult/child) receptors | |
| Variable | Value |
| $C_s$ (UCL or maximum detected concentration in soil) pCi/g | Site-specific |
| $IFP_{f\text{-}adj}$ (age-adjusted poultry ingestion rate-farmer) kg/yr | 31.18 |
| $FI_{po}$ (poultry intake rate) kg/day | 0.2 |
| $EF_f$ (exposure frequency-farmer) day/yr | 350 |
| $ED_f$ (exposure duration-farmer) yr | 40 |
| $TF_P$ (Soil to plant transfer factor) pCi/gram-plant per pCi/gram-soil | Isotope- specific |
| $FI_{po\text{-}s}$ (poultry soil intake rate) kg/day | 0.022 |
| $IRP_{f\text{-}c}$ (poultry Ingestion rate- child farmer) kg/year | 5 |
| $IRP_{f\text{-}a}$ (poultry Ingestion rate-adult farmer) kg/year | 35.8 |
| $TF_{po}$ (poultry transfer factor ) day/kg | Isotopic-specific |
| $ED_{f\text{-}a}$ (exposure duration-adult farmer) yr | 34 |
| $ED_{f\text{-}c}$ (exposure duration-child farmer) yr | 6 |
| $T_f$ (time-farmer) yr | 40 |
| $\lambda$ ( lambda decay constant) | Isotopic-specific |

**Table 3-16**

**Scenario 2- Agriculture Farmer Exposure**

**Pathway R8- Consumption of Eggs From Home Raised Poultry**

Equation for age -integrated (adult/child) receptors

$$Intake_{soil-f-egg-Ing.}(pCi) = C_S\left(\frac{pCi}{g}\right) * \left(1 - e^{-\lambda t_f}\right) * IFP_{f-adj}\left(\frac{13.01kg}{year}\right) * EF_f\left(350\frac{day}{yr}\right) * \left(\frac{1yr}{365day}\right) * ED_f\,(40\ yr) * \left(\frac{1000g}{kg}\right) *$$

$$\frac{\left\{(TF_e(\frac{day}{kg}) * FI_{po}(0.2\frac{kg}{day}) * TF_p(\frac{pCi}{g-plant}\,per\,\frac{pCi}{g-soil}\right) + \left(TF_e * FI_{po-s}\,(\frac{0.022kg}{day})\right)\}}{t_f(yr) * \lambda\left(\frac{1}{yr}\right)}$$

Where:

$$IFE_{f-adj}\left(31.01\frac{kg}{year}\right) = \frac{(IRE_{f-c}\left(\frac{2.3kg}{year}\right) * ED_{f-c}(6\ yr) + IRE_{f-a}\left(14.9\frac{kg}{year}\right) * ED_{f-a}(34yr)}{ED_f(40\ yr)}$$

| **Table 3-16 (Contd.)**<br><br>**Scenario 2- Agriculture Farmer Exposure**<br><br>**Pathway R8- Consumption of Eggs** | |
|---|---|
| Parameters for age -integrated (adult/child) receptors | |
| Variable | Value |
| $C_s$ (UCL or maximum detected concentration in soil) pCi/g | Site-specific |
| $IFE_{f\text{-}adj}$ (age-adjusted egg ingestion rate-farmer) kg/yr | 31.01 |
| $FI_{po}$ (poultry intake rate) kg/day | 0.2 |
| $EF_f$ (exposure frequency-farmer) day/yr | 350 |
| $ED_f$ (exposure duration-farmer) yr | 40 |
| $TF_P$ (Soil to plant transfer factor) pCi/gram-plant per pCi/gram-soil | Isotope- specific |
| $FI_{po\text{-}s}$ (poultry soil intake rate) kg/day | 0.022 |
| $IRE_{f\text{-}c}$ (egg Ingestion rate- child farmer) kg/year | 2.3 |
| $IRE_{f\text{-}a}$ (egg Ingestion rate-adult farmer) kg/year | 14.9 |
| $TF_e$ (egg transfer factor ) day/kg | Isotopic-specific |
| $ED_{f\text{-}a}$ (exposure duration-adult farmer) yr | 34 |
| $ED_{f\text{-}c}$ (exposure duration-child farmer) yr | 6 |
| $T_f$ (time-farmer) yr | 40 |
| $\lambda$ ( lambda decay constant) | Isotopic-specific |

**Table 3-17**

**Scenario 3- General Residential Exposure**

**Pathway R1- Incidental Ingestion of Chemicals in Soil**

Equation for age -integrated (adult/child) receptors – **Non-Cancer**

$$Intake_{res-sol-Ing.}\left(\frac{mg}{Kg-day}\right) = \frac{C_S\left(\frac{mg}{Kg}\right) * IFS_{r-adj}\left(\frac{114mg-yr}{Kg-day}\right) * EF_r\left(350\,\frac{day}{yr}\right) * (10^{-6}\,\frac{Kg}{mg})}{ATr\ (30\ years) * \left(\frac{365days}{year}\right)}$$

$$IFS_{r-adj}\left(114\,\frac{mg-yr}{Kg-day}\right) = \frac{(IRS_{r-c}\left(\frac{200mg}{day}\right) * ED_{r-c}(6\ yr)}{BW_c\ (15\ Kg)} + \frac{+IRS_{r-a}\left(100\,\frac{mg}{day}\right) * ED_{r-a}(24yr)}{BW_a\ (70\ Kg)}$$

Where:

| Variable | Value |
|---|---|
| $C_s$ (UCL or maximum detected concentration in soil) mg/Kg | Site-specific |
| $ED_{r\text{-}a}$ (exposure duration - resident adult) yr | 24 |
| $EF_r$ (exposure frequency - resident) day/yr | 350 |
| $IRS_{r\text{-}a}$ (soil intake rate - resident adult) mg/day | 100 |
| $IRS_{r\text{-}c}$ (soil intake rate - resident child) mg/day | 200 |
| $IFS_{r\text{-}adj}$ (age-adjusted soil ingestion factor - resident) mg-yr/Kg-day | 114 |
| $ED_{r\text{-}c}$ (exposure duration - resident child) yr | 6 |
| $ED_r$ (exposure duration - resident) yr | 30 |
| $AT_r$ (time-resident) yr | 30 |

**Table 3-18**

**Scenario 3- General Residential Exposure**

**Pathway R2- Inhalation of Chemicals in Airborne Particulates**

Non-Cancer

$$Intake_{res-sol-inh.}\left(\frac{mg}{m^3}\right) = \frac{Cs_{res-sol-inh}\left(\frac{mg}{Kg}\right) * EF_r\left(350\frac{day}{yr}\right) * \frac{1}{PEF\left(\frac{m^3}{kg}\right)} * ET_r\left(24\frac{hr}{day}\right) * \left(\frac{1day}{24hr}\right) * ED_r(30\ yr)}{AT_r(30yr) * \frac{365days}{year}}$$

Where:

| Variable | Value |
|---|---|
| $C_s$ (UCL or maximum detected concentration in soil) mg/Kg | Site-specific |
| $EF_r$ (exposure frequency-resident) day/yr | 350 |
| $ED_r$ (exposure duration-resident) yr | 30 |
| PEF (particulate emission factor) $m^3/kg$ | 1.36E+09 |
| $ET_r$ (exposure time-resident) hr/day | 24 |
| $AT_r$ (time-resident) yr | 30 |

**Table 3-19**

**Scenario 3- General Residential Exposure**

**Pathway R3- Dermal Contact of Chemicals in Soil**

Equation for age -integrated (adult/child) receptors – **Non-Cancer**

$$Intake_{res-sol-Ing.}\left(\frac{mg}{Kg-day}\right)=\frac{C_S\left(\frac{mg}{Kg}\right)*DFS_{r-adj}\left(\frac{361mg-yr}{Kg-day}\right)*EF_r\left(350\frac{day}{yr}\right)*\left(10^{-6}\frac{Kg}{mg}\right)*ABS_d/ABS_o}{ATr\ (30\ years)*\ \left(\frac{365days}{year}\right)}$$

$$DFS_{r-adj}\left(361\frac{mg-yr}{Kg-day}\right)=\frac{SA_{r-c}\left(\frac{2800cm^2}{day}\right)*ED_{r-c}(6\ yr)*AF_c\ \left(\frac{0.2mg}{cm^2}\right)}{BW_c\ (15\ Kg)}+\frac{SA_{r-a}\left(5700\frac{cm^2}{day}\right)*ED_{r-a}(24yr)*AF_a\ \left(\frac{0.07mg}{cm^2}\right)}{BW_a\ (70\ Kg)}$$

**Table 3-19 (Contd.)**

**Scenario 3- General Residential Exposure**

**Pathway R3- Dermal Contact with Chemicals in Soil- Continued**

Equation for age -integrated (adult/child) receptors – **Non-Cancer**

| Variable | Value |
|---|---|
| $C_s$ (UCL or maximum detected concentration in soil) mg/Kg | Site-specific |
| $DFS_{r\text{-}adj}$ (age-adjusted soil inhalation factor-resident) mg-yr/Kg-day | 361 |
| $EF_r$ (exposure frequency-resident) day/yr | 350 |
| $ED_r$ (exposure duration-resident) yr | 30 |
| $SA_{r\text{-}c}$ (Skin surface area- resident child) $cm^2$ | 2800 |
| $SA_{r\text{-}a}$ (skin surface area-resident adult) $cm^2$ | 5700 |
| $AF_{r\text{-}c}$ (Adherence factor-resident child) $mg/cm^2$ | 0.2 |
| $AF_{r\text{-}a}$ (inhalation rate-resident adult) $mg/cm^2$ | 0.07 |
| $ED_{r\text{-}a}$ (exposure duration-resident adult) yr | 24 |
| $ED_{r\text{-}c}$ (exposure duration-resident child) yr | 6 |
| $AT_r$ (time-resident) yr | 30 |
| $BW_c$ (body weight-child) Kg | 15 |
| $BW_a$ (body weight- adult)Kg | 70 |
| $ABS_d$ (dermal absorption) unitless | Chemical specific |
| $ABS_o$ (oral or GI absorption) unitless | Chemical specific |

**Table 3-20**

**Scenario 3- General Residential Exposure**

**Pathway R4- Incidental Ingestion of Chemicals in Soil**

Equation for age -integrated (adult/child) receptors – **Carcinogens**

$$Intake_{res-sol-Ing.}\left(\frac{mg}{Kg-day}\right) = \frac{C_S\left(\frac{mg}{Kg}\right) * IFS_{r-adj}\left(\frac{114mg-yr}{Kg-day}\right) * EF_r\left(350\,\frac{day}{yr}\right) * (10^{-6}\,\frac{Kg}{mg})}{LT_r\ (70\ years) * \ (\frac{365days}{year})}$$

$$IFS_{r-adj}\left(114\,\frac{mg-yr}{Kg-day}\right) = \frac{(IRS_{r-c}\left(\frac{200mg}{day}\right) * ED_{r-c}(6\ yr) + IRS_{r-a}\left(100\,\frac{mg}{day}\right) * ED_{r-a}(24yr))}{BW_c\ (15\ Kg) + \ BW_a\ (70\ Kg)}$$

Where:

| Variable | Value |
|---|---|
| $C_s$ (UCL or maximum detected concentration in soil) mg/Kg | Site-specific |
| $ED_{r\text{-}a}$ (exposure duration - resident adult) yr | 24 |
| $EF_r$ (exposure frequency - resident) day/yr | 350 |
| $IRS_{r\text{-}a}$ (soil intake rate - resident adult) mg/day | 100 |
| $IRS_{r\text{-}c}$ (soil intake rate - resident child) mg/day | 200 |
| $IFS_{r\text{-}adj}$ (age-adjusted soil ingestion factor - resident) mg-yr/Kg-day | 114 |
| $ED_{r\text{-}c}$ (exposure duration - resident child) yr | 6 |
| $ED_r$ (exposure duration - resident) yr | 30 |
| $LT_r$ (Life time-resident) yr | 70 |

**Table 3-21**

**Scenario 3- General Residential Exposure**

**Pathway R5- Inhalation of Chemicals in Airborne Particulates Emitted from Soil**

Carcinogens

$$Intake_{res-sol-inh.}\left(\frac{\mu g}{m^3}\right) = \frac{Cs_{res-sol-inh}\left(\frac{mg}{Kg}\right) * 1000\ \left(\frac{\mu g}{mg}\right) * EF_r\left(350\frac{day}{yr}\right) * \frac{1}{PEF\left(\frac{m^3}{kg}\right)} * ET_r\left(24\frac{hr}{day}\right) * \left(\frac{1day}{24hr}\right) * ED_r\ (30\ yr)}{LT_r(70yr) * \frac{365days}{year}}$$

Where:

| Variable | Value |
|---|---|
| $C_s$ (UCL or maximum detected concentration in soil) mg/Kg | Site-specific |
| $EF_r$ (exposure frequency-resident) day/yr | 350 |
| $ED_r$ (exposure duration-resident) yr | 30 |
| PEF (particulate emission factor) $m^3$/kg | 1.36E+09 |
| $ET_r$ (exposure time-resident) hr/day | 24 |
| $LT_r$ (Life time-resident) yr | 70 |

**Table 3-22**

**Scenario 3- General Residential Exposure**

**Pathway R6- Dermal Contact of Chemicals in Soil**

Equation for age -integrated (adult/child) receptors – **Carcinogenic**

$$Intake_{res-sol-Ing.}\left(\frac{mg}{Kg-day}\right)=\frac{C_S\left(\frac{mg}{Kg}\right)*DFS_{r-adj}\left(\frac{361mg-yr}{Kg-day}\right)*EF_r\left(350\,\frac{day}{yr}\right)*\left(10^{-6}\,\frac{Kg}{mg}\right)*ABS_d/ABS_o}{LTr\ (70\ years)*\ \left(\frac{365days}{year}\right)}$$

$$DFS_{r-adj}\left(361\,\frac{mg-yr}{Kg-day}\right)=\frac{SA_{r-c}\ \left(\frac{2800cm^2}{day}\right)*ED_{r-c}(6\ yr)*AF_c\ \left(\frac{0.2mg}{cm^2}\right)}{BW_c\ (15\ Kg)}+\frac{SA_{r-a}\left(5700\,\frac{cm^2}{day}\right)*ED_{r-a}(24yr)*AF_a\ \left(\frac{0.07mg}{cm^2}\right)}{BW_a\ (70\ Kg)}$$

**Table 3-22 (contd.)**

**Scenario 3- General Residential Exposure**

**Pathway R6- Dermal Contact with Chemicals in Soil- Continued**

Equation for age -integrated (adult/child) receptors – **Carcinogens**

| Variable | Value |
|---|---|
| $C_s$ (UCL or maximum detected concentration in soil) mg/Kg | Site-specific |
| $DFS_{r\text{-}adj}$ (age-adjusted soil inhalation factor-resident) mg-yr/Kg-day | 361 |
| $EF_r$ (exposure frequency-resident) day/yr | 350 |
| $ED_r$ (exposure duration-resident) yr | 30 |
| $SA_{r\text{-}c}$ (Skin surface area- resident child) $cm^2$ | 2800 |
| $SA_{r\text{-}a}$ (skin surface area-resident adult) $cm^2$ | 5700 |
| $AF_{r\text{-}c}$ (Adherence factor-resident child) $mg/cm^2$ | 0.2 |
| $AF_{r\text{-}a}$ (Adherence factor-resident adult) $mg/cm^2$ | 0.07 |
| $ED_{r\text{-}a}$ (exposure duration-resident adult) yr | 24 |
| $ED_{r\text{-}c}$ (exposure duration-resident child) yr | 6 |
| $LT_r$ (Life time-resident) yr | 70 |
| $BW_c$ (body weight-child) Kg | 15 |
| $BW_a$ (body weight- adult)Kg | 70 |
| $ABS_d$ (dermal absorption) unitless | Chemical specific |
| $ABS_o$ (oral or GI absorption) unitless | Chemical specific |

**Table 3-23**

**Scenario 3- General Residential Exposure**

**Pathway R7- Ingestion of Chemical Contaminants in Tap Water-Metal-Cancer**

Equation for age -integrated (adult/child) receptors

$$Intake_{water-Ca-ing.}\left(\frac{mg}{Kg-day}\right)=\frac{C_w\left(\frac{\mu g}{L}\right)*EF_r\left(350\frac{day}{yr}\right)*IFW_{r-adj}\,(1.086\frac{L-yr}{Kg-day})}{AT_r\left(365\frac{day}{yr}\right)*LT_r(70years)*(1000\,\frac{\mu g}{mg})}$$

$$IFW_{r-adj}\left(1.086\frac{L-yr}{Kg-day}\right)=\frac{ED_{r-c}\,(6\,yr)*IRW_{r-c}\left(1\frac{L}{day}\right)}{BW_c(15\,Kg)}+\frac{ED_{r-a}(24\,yr)*IRW_{r-a}(2\frac{L}{day})}{BW_a(70\,Kg)}$$

Where:

| Variable | Value |
|---|---|
| $C_w$ (contaminant concentration in water) µg/L | Site specific |
| $ED_{r\text{-}a}$ (exposure duration - resident adult) yr | 24 |
| $ED_{r\text{-}c}$ (exposure duration - resident child) yr | 6 |
| $EF_r$ (exposure frequency - resident) day/yr | 350 |
| $IRW_{r\text{-}a}$ (water intake rate - resident adult) L/day | 2 |
| $IRW_{r\text{-}c}$ (water intake rate - resident child) L/day | 1 |
| $IFW_{r\text{-}adj}$ (age-adjusted water ingestion factor - resident) L-yr/Kg-day | 1.086 |
| BWa (Body weight-resident adult) Kg | 70 |
| BWc (Body weight-resident child) Kg | 15 |
| $LT_r$ (Life time-resident) yr | 70 |

**Table 3-24**

**Scenario 3- General Residential Exposure**

**Pathway R8- Dermal Contact of Chemical Contaminants in Tap Water-Inorganics-Cancer**

Equation for age -integrated (adult/child) receptors

$$Intake_{water-Ca-der.}\left(\frac{mg}{Kg-day}\right)=\frac{C_w\left(\frac{\mu g}{L}\right)*K_p\left(\frac{cm}{hr}\right)*EF_r\left(350\frac{day}{yr}\right)*\ DFW_{r-adj}\left(8811.4\frac{cm^2-event-yr}{Kg-day}\right)*ET_{rw-adj}(0.664\frac{hr}{event})}{AT_r\left(365\frac{day}{yr}\right)*LT_r(70years)*\left(1000\ \frac{\mu g}{mg}\right)*\left(1000\frac{cm^3}{L}\right)*GIABS}$$

$$DFW_{r-adj}\left(8811.4\frac{cm^2-event-yr}{Kg-day}\right)$$
$$=\frac{ED_{r-c}\ (6\ yr)*EV_{r-c}\left(1\frac{event}{day}\right)*\ SA_c(6{,}600\ cm^2)}{BW_c(15\ Kg)}+\frac{ED_{r-a}(24\ yr)*EV_{r-a}\left(1\frac{event}{day}\right)*\ SA_c(18{,}000\ cm^2)}{BW_a(70\ Kg)}$$

$$ET_{rw-adj}\left(0.664\frac{hr}{event}\right)=\frac{ET_{rwc}\ \left(1\frac{hr}{event}\right)*ED_c\ (6\ years)+ET_{rwa}\ \left(0.58\frac{hr}{event}\right)*ED_a\ (24\ years)}{ED_r(30\ years)}$$

**Table 3-24 (Contd.)**

**Scenario 3- General Residential Exposure**

**Pathway R8- Dermal Contact with Chemicals in Tap Water-Metals-Cancer- Continued**

Equation for age -integrated (adult/child) receptors – **Carcinogens**

| Variable | Value |
|---|---|
| $C_w$ (contaminant concentration in water) µg/L | Site-specific |
| $DFW_{\mathbf{r\text{-}adj}}$ (age-adjusted water dermal factor - resident) $cm^2$-event-yr/Kg-day | 8811.4 |
| $EF_r$ (exposure frequency-resident) day/yr | 350 |
| $ED_r$ (exposure duration-resident) yr | 30 |
| $SA_{r\text{-}c}$ (Skin surface area- resident child) $cm^2$ | 6,600 |
| $SA_{r\text{-}a}$ (skin surface area-resident adult) $cm^2$ | 18,000 |
| $K_p$ ( dermal permeability coefficient)cm/hr | Chemical specific |
| $ET_{rw\text{-}adj}$ (exposure time-age adjusted-resident water)hr/event | 0.664 |
| $ET_{rwc}$ (exposure time-water resident child) hr | 1 |
| $ET_{rwa}$ (exposure time-water resident adult) hr | 0.58 |
| $ED_{r\text{-}a}$ (exposure duration-resident adult) yr | 24 |
| $ED_{r\text{-}c}$ (exposure duration-resident child) yr | 6 |
| $LT_r$ (Life time-resident) yr | 70 |
| $BW_c$ (body weight-child) Kg | 15 |
| $BW_a$ (body weight- adult)Kg | 70 |
| $GIABS_o$ (oral or GI absorption) unitless | Chemical specific |

**Table 3-25**

**Scenario 3- General Residential Exposure**

**Pathway R9- Ingestion of Chemical Contaminants in Tap Water-Metal-NonCancer**

Equation for age -integrated (adult/child) receptors

$$Intake_{water-nc-ing.}\left(\frac{mg}{Kg-day}\right)=\frac{C_w\left(\frac{\mu g}{L}\right)*EF_r\left(350\frac{day}{yr}\right)*IFW_{r-adj}\left(1.086\frac{L-yr}{Kg-day}\right)}{AT_r\left(365\frac{day}{yr}\right)*ED_r(30years)*\left(1000\frac{\mu g}{mg}\right)}$$

$$IFW_{r-adj}\left(1.086\frac{L-yr}{Kg-day}\right)=\frac{ED_{r-c}\,(6\,yr)*IRW_{r-c}\left(1\frac{L}{day}\right)}{BW_c(15\,Kg)}+\frac{ED_{r-a}(24\,yr)*IRW_{r-a}(2\frac{L}{day})}{BW_a(70\,Kg)}$$

Where:

| Variable | Value |
|---|---|
| $C_w$ (contaminant concentration in water) µg/L | Site specific |
| $ED_r$ (exposure duration - resident) yr | 30 |
| $ED_{r-a}$ (exposure duration - resident adult) yr | 24 |
| $ED_{r-c}$ (exposure duration - resident child) yr | 6 |
| $EF_r$ (exposure frequency - resident) day/yr | 350 |
| $IRW_{r-a}$ (water intake rate - resident adult) L/day | 2 |
| $IRW_{r-c}$ (water intake rate - resident child) L/day | 1 |
| $IFW_{r-adj}$ (age-adjusted water ingestion factor - resident) L-yr/Kg-day | 1.086 |
| BWa (Body weight-resident adult) Kg | 70 |
| BWc (Body weight-resident child) Kg | 15 |

**Table 3-26**

**Scenario 3- General Residential Exposure**

**Pathway 10- Dermal Contact of Chemical Contaminants in Tap Water-Inorganics-NonCancer**

Equation for age -integrated (adult/child) receptors

$$Intake_{water-nc-der.}\left(\frac{mg}{Kg-day}\right) = \frac{C_w\left(\frac{\mu g}{L}\right) * K_p\left(\frac{cm}{hr}\right) * EF_r\left(350\frac{day}{yr}\right) * DFW_{r-adj}\left(8811.4\frac{cm^2-event-yr}{Kg-day}\right) * ET_{rw-adj}(0.664\frac{hr}{event})}{AT_r\left(365\frac{day}{yr}\right) * ED_r(30years) * \left(1000\ \frac{\mu g}{mg}\right) * \left(1000\frac{cm^3}{L}\right) * GIABS}$$

$$DFW_{r-adj}\left(8811.4\frac{cm^2-event-yr}{Kg-day}\right) = \frac{ED_{r-c}\ (6\ yr) * EV_{r-c}\left(1\frac{event}{day}\right) * SA_c(6{,}600\ cm^2)}{BW_c(15\ Kg)} + \frac{ED_{r-a}(24\ yr) * EV_{r-a}\left(1\frac{event}{day}\right) * SA_c(18{,}000\ cm^2)}{BW_a(70\ Kg)}$$

$$ET_{rw-adj}\left(0.664\frac{hr}{event}\right) = \frac{ET_{rwc}\left(1\frac{hr}{event}\right) * ED_c\ (6\ years) + ET_{rwa}\left(0.58\frac{hr}{event}\right) * ED_a\ (24\ years)}{ED_r(30\ years)}$$

**Table 3-26 (Contd.)**

**Scenario 3- General Residential Exposure**

**Pathway R10- Dermal Contact with Chemicals in Tap Water-Metals-NonCancer- Continued**

Equation for age -integrated (adult/child) receptors – **Carcinogens**

| Variable | Value |
|---|---|
| $C_w$ (contaminant concentration in water) µg/L | Site-specific |
| $DFW_{\textbf{r-adj}}$ (age-adjusted water dermal factor - resident) $cm^2$-event-yr/Kg-day | 8811.4 |
| $EF_r$ (exposure frequency-resident) day/yr | 350 |
| $ED_r$ (exposure duration-resident) yr | 30 |
| $SA_{r-c}$ (Skin surface area- resident child) $cm^2$ | 6,600 |
| $SA_{r-a}$ (skin surface area-resident adult) $cm^2$ | 18,000 |
| $K_p$ ( dermal permeability coefficient)cm/hr | Chemical specific |
| $ET_{rw-adj}$ (exposure time-age adjusted-resident water)hr/event | 0.664 |
| $ET_{rwc}$ (exposure time-water resident child) hr | 1 |
| $ET_{rwa}$ (exposure time-water resident adult) hr | 0.58 |
| $ED_{r-a}$ (exposure duration-resident adult) yr | 24 |
| $ED_{r-c}$ (exposure duration-resident child) yr | 6 |
| $BW_c$ (body weight-child) Kg | 15 |
| $BW_a$ (body weight- adult)Kg | 70 |
| $GIABS_o$ (oral or GI absorption) unitless | Chemical specific |

## 3.4 Radiation Exposure and Dose Assessment

Potentially important pathways for radionuclides are through the inhalation, ingestion and absorption routes of intake. By these internal exposure pathways radionuclides become incorporated systematically and emit alpha, beta, or gamma radiation within tissues or organs. Emitted radiation can transfer enough energy to atoms to remove electrons from their electric field and thus destroy cellular constituents and produce free radicals. Extensive biological damage can lead to adverse health effects. External exposure to radionuclides refers to the irradiation of human tissues by radiations emitted by radionuclides located outside the body either dispersed in the air, water, on skin surfaces, or deposited on ground surfaces. All types of radiation may contribute to internal exposure, whereas only gamma, beta and neutron radiations contribute significantly to external exposure.

Deleterious effects on biological tissues caused by ionizing radiation occur only when the energy released during radioactive decay is absorbed in tissue. The absorbed dose by any radiation divided by the absorbed dose of a reference radiation that produces the same biological endpoint is called the Relative Biological Effectiveness (RBE). For regulatory purposes, consensus RBE estimate called the Quality Factor or Q is often used. The dose equivalent was developed to normalize the unequal biological effects produced from equal absorbed doses of different types of radiation. The dose equivalent is the product of the absorbed dose, quality factor and Modifying factor. The conventional unit is the rem (radiation equivalent man). Quality factors assigned by the Commission on Radiological Protection (ICRP) include values of Q=20 for alpha particles, Q=10 for neutrons and protons, and Q=1 for beta particles, positrons, x-rays, and gamma rays. That is if an equal amount of energy is absorbed, an alpha particle will inflict approximately 20 times more damage to biological tissue than a beta particle or gamma ray, and twice as much damage as a neutron. The modifying factor is currently assigned a value of 1. When subjected to equal doses of radiation, organs and tissues in the human body will exhibit different caner induction rates. To account for these differences and to normalize radiation doses and effects on a whole body basis for regulation of occupational exposure, the ICRP developed the concept of the effective dose equivalent which is defined as weighted sums of the organ-specific dose equivalents.

The total activity inventory and individual concentrations of radionuclides at a Superfund site will change with time as some radionuclides decay away and others grow in as a result of radioactive decay processes.

Estimates of dose equivalent may be used for comparison with radiation protection standards and criteria. Dose conversion factors (DCFs) for a given radionuclide represent the dose equivalent per unit intake or external exposure of that radionuclide. The DCFs are used to convert a radionuclide concentration in soil, air, water, or food stuffs to a radiation dose. The primary use of DCFs in Superfund risk assessment is to compute doses resulting from site-related exposures for comparison with radiation protection standards that are determined to be ARARs.

Unlike excess cancer risk, which represents cumulative lifetime exposure, dose estimates are typically expressed in terms of annual exposure such as mrem/year. The Radionuclide ARAR Dose Compliance Concentrations (DCCs) for Superfund calculator may be found at the following website: http://epa-dccs.ornl.gov/ . The electronic calculator is intended to help site decision makers demonstrate compliance with dose-based ARARs at radioactively contaminated CERCLA sites.

This DCC calculator focuses on the application of a generic and simple site-specific approaches that are part of a larger framework for calculating concentration levels for complying with dose based ARARs. Generic DCCs for a 1 mrem standard are provided by viewing either the tables in the Download Area section of this calculator or by running the DCC Search section of this calculator with the "Get Default ARAR Concentrations" option. Part 3 of the Soil Screening Guidance for Radionuclides: Technical Background Document provides more information about more detailed approaches that are part of the same framework.

Generic DCCs are calculated from the same equations presented in the site-specific portion of the calculator, but are based on a number of default assumptions chosen to be protective of human health for most site conditions. Generic DCCs, which should be scaled to the same dose level as the standard being complied (e.g., multiplied by a factor of ten for a 10 mrem/yr standard) can be used in place of site-specific DCC levels; however, in general, they are expected to be more conservative than site-specific levels.

Another method for calculating dose is the RESidual RADioactive (RESRAD) computer model which is designed to estimate radiation doses and risks from residual radioactive materials. This computer model was also used to estimate radiation dose from the site. However, results from RESRAD model use was not incorporated in any EPA Superfund remedial decisions (see section 5 for more details).

### 3.4.1 Equations for Dose Calculations without Half-Life Decay - EPA DCC calculator

#### 3.4.1.1 Inhalation (without half-life decay)

$$DCC_{res\text{-}air\text{-}inh\text{-}nodecay}\left(pCi/m^3\right)=\frac{DL(mrem)}{ET_r\left(\frac{24\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hr}\right)\times EF_r\left(\frac{350\ day}{yr}\right)\times ED_r(1\ yr)\times DCF_i\left(\frac{mrem}{pCi}\right)\times IFA_{r\text{-}adj}\left(\frac{18\ m^3}{day}\right)}$$

where:

$$IFA_{r\text{-}adj}\left(\frac{18\ m^3}{day}\right)=\frac{IRA_{r\text{-}c}\left(\frac{10\ m^3}{day}\right)\times ED_{r\text{-}c}(1\ yr)\times AAF_{r\text{-}c}(0.2)+IRA_{r\text{-}a}\left(\frac{20\ m^3}{day}\right)\times ED_{r\text{-}a}(1\ yr)\times AAF_{r\text{-}a}(0.8)}{ED_r(1\ yr)}$$

#### External exposure to ionizing radiation (without half-life decay)

$$DCC_{res\text{-}air\text{-}sub\text{-}nodecay}\left(pCi/m^3\right)=\frac{DL(mrem)}{ET_r\left(\frac{24\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hr}\right)\times EF_r\left(\frac{350\ day}{yr}\right)\times ED_r(1\ yr)\times DCF_{sub}\left(\frac{mrem/yr}{pCi/m^3}\right)\times\left(\frac{1\ yr}{365\ day}\right)\times GSF_o(1.0)}$$

#### Total (without half-life decay)

$$DCC_{res\text{-}air\text{-}tot\text{-}nodecay}\left(pCi/m^3\right)=\frac{1}{\frac{1}{DCC_{res\text{-}air\text{-}inh\text{-}nodecay}}+\frac{1}{DCC_{res\text{-}air\text{-}sub\text{-}nodecay}}}$$

**Where:**

| **Variable** | Default Value |
|---|---|
| DL (dose limit) mrem | 1 |
| $t_r$ (time - resident) yr | 1 |
| $ET_r$ (exposure time - resident) hr | 24 |
| $EF_r$ (exposure frequency) day/yr | 350 |
| $ED_r$ (exposure duration - resident) yr | 1 |
| $ED_{r\text{-}c}$ (exposure duration - child) yr | 1 |
| $IRA_{r\text{-}a}$ (inhalation rate - adult) $m^3$/day | 20 |
| $IRA_{r\text{-}c}$ (inhalation rate - child) $m^3$/day | 10 |
| $GSF_o$ (gamma shielding factor - outdoor) | 1 |
| $IFA_{r\text{-}adj}$ (age-adjusted inhalation factor) $m^3$/day | 18 |
| $AAF_{r\text{-}c}$ (annual age fraction - child resident) | 0.2 |
| $AAF_{r\text{-}a}$ (annual age fraction - adult resident) | 0.8 |

### 3.4.2 Soil Equations

**Incidental ingestion of soil,**

$$DCC_{res\text{-}sol\text{-}ing}(pCi/g) = \frac{DL(mrem) \times t_r(yr) \times \lambda\left(\frac{1}{yr}\right)}{\left(1-e^{-\lambda t_r}\right) \times DCF_o\left(\frac{mrem}{pCi}\right) \times IFS_{r\text{-}adj}\left(\frac{120\ mg}{day}\right) \times EF_r\left(\frac{350\ day}{yr}\right) \times ED_r(1\ yr) \times \left(\frac{g}{1000\ mg}\right)}$$

where

$$IFS_{r\text{-}adj}\left(\frac{120\ mg}{day}\right) = \frac{\left(IRS_{r\text{-}c}\left(\frac{200\ mg}{day}\right) \times ED_{r\text{-}c}(1\ yr) \times AAF_{r\text{-}c}(0.2) + IRS_{r\text{-}a}\left(\frac{100\ mg}{day}\right) \times ED_{r\text{-}a}(1\ yr) \times AAF_{r\text{-}a}(0.8)\right)}{ED_r(1\ yr)}$$

**Inhalation of particulates emitted from soil,**

$$DCC_{res\text{-}sol\text{-}inh}(pCi/g) = \frac{DL(mrem) \times t_r(yr) \times \lambda\left(\frac{1}{yr}\right)}{\left(1-e^{-\lambda t_r}\right) \times DCF_i\left(\frac{mrem}{pCi}\right) \times IFA_{r\text{-}adj}\left(\frac{18\ m^3}{day}\right) \times EF_r\left(\frac{350\ day}{yr}\right) \times ED_r(1\ yr) \times \frac{1}{PEF\left(\frac{m^3}{kg}\right)} \times ET_r\left(\frac{24\ hr}{day}\right) \times \left(\frac{1\ day}{24\ hr}\right) \times \left(\frac{1000\ g}{kg}\right)}$$

where

$$IFA_{r\text{-}adj}\left(\frac{18\ m^3}{day}\right) = \frac{IRA_{r\text{-}c}\left(\frac{10\ m^3}{day}\right) \times ED_{r\text{-}c}(1\ yr) \times AAF_{r\text{-}c}(0.2) + IRA_{r\text{-}a}\left(\frac{20\ m^3}{day}\right) \times ED_{r\text{-}a}(1\ yr) \times AAF_{r\text{-}a}(0.8)}{ED_r(1\ yr)}$$

**External exposure to ionizing radiation, and**

$$DCC_{res\text{-}sol\text{-}ext}(pCi/g) = \frac{DL(mrem) \times t_r(yr) \times \lambda\left(\frac{1}{yr}\right)}{\left(1-e^{-\lambda t_r}\right) \times DCF_{ext\text{-}sv}\left(\frac{mrem/yr}{pCi/g}\right) \times ACF \times EF_r\left(\frac{350\ day}{yr}\right) \times \left(\frac{1\ yr}{365\ day}\right) \times ED_r(1\ yr) \times \left[ET_{r\text{-}o}(0.073) + \left(ET_{r\text{-}i}(0.684) \times GSF_i(0.4)\right)\right]}$$

**Consumption of produce - direct. The exposed and root vegetable consumption rates were combined to represent total vegetable consumption.**

$$DCC_{res\text{-}prod\text{-}ing}(pCi/g)=\frac{DL(mrem)}{ED_r(1\ yr)\times EF_r\left(\frac{350\ day}{yr}\right)\times\left(\frac{1\ yr}{365\ day}\right)\times DCF_o\left(\frac{mrem}{pCi}\right)\times\left(IFF_{r\text{-}adj}\left(\frac{17.48\ kg}{yr}\right)+IFV_{r\text{-}adj}\left(\frac{9.08\ kg}{yr}\right)\right)\times\left(\frac{1000\ g}{kg}\right)\times CPF_r(0.25)}$$

where:

$$IFF_{r\text{-}adj}\left(\frac{17.48\ kg}{yr}\right)=\frac{ED_{r\text{-}c}(1\ yr)\times AAF_{r\text{-}c}(0.2)\times IRF_{r\text{-}c}\left(\frac{5.4\ kg}{yr}\right)+ED_{r\text{-}a}(1\ yr)\times AAF_{r\text{-}a}(0.8)\times IRF_{r\text{-}a}\left(\frac{20.5\ kg}{yr}\right)}{ED_r(1\ yr)}$$

and

$$IFV_{r\text{-}adj}\left(\frac{9.08\ kg}{yr}\right)=\frac{ED_{r\text{-}c}(1\ yr)\times AAF_{r\text{-}c}(0.2)\times IRV_{r\text{-}c}\left(\frac{3.8\ kg}{yr}\right)+ED_{r\text{-}a}(1\ yr)\times AAF_{r\text{-}a}(0.8)\times IRV_{r\text{-}a}\left(\frac{10.4\ kg}{yr}\right)}{ED_r(1\ yr)}$$

**Consumption of produce - back-calculated from soil.**

$$DCC_{soil\text{-}res\text{-}prod\text{-}ing}(pCi/g)=\frac{DCC_{res\text{-}prod\text{-}ing}(pCi/g)}{\left(R_{upv}+R_{es}\right)}$$

where

$R_{upv}=Bv_{\blacksquare}$ ; $R_{es}=MLF(0.26)$

**Total**

$$DCC_{soil\text{-}res\text{-}prod\text{-}tot}(pCi/g)=\frac{1}{\frac{1}{DCC_{res\text{-}sol\text{-}ing}}+\frac{1}{DCC_{res\text{-}sol\text{-}inh}}+\frac{1}{DCC_{res\text{-}sol\text{-}ext}}+\frac{1}{DCC_{res\text{-}prod\text{-}ing}}}$$

**Default**
**Resident Equation Inputs for Soil**

| Variable | Value |
|---|---|
| Slab size for ACF (area correction factor) $m^2$ | Default |
| DL (dose limit) mrem | 1 |
| $t_r$ (time - resident) yr | 1 |
| $ED_r$ (exposure duration - resident) yr | 1 |
| $ET_{r-o}$ (outdoor exposure time fraction - resident) hr/hr | 0.073 |
| $ET_{r-i}$ (indoor exposure time fraction - resident) hr/hr | 0.684 |
| $ED_{r-c}$ (exposure duration - child) yr | 1 |
| $EF_r$ (exposure frequency) day/yr | 350 |
| $IRS_{r-a}$ (soil intake rate - adult) mg/day | 100 |
| $IRS_{r-c}$ (soil intake rate - child) mg/day | 200 |
| $IRF_{r-a}$ (fruit consumption rate - adult) mg/day | 20.5 |
| $IRF_{r-c}$ (fruit consumption rate - child) mg/day | 5.4 |
| $IRV_{r-a}$ (vegetable consumption rate - adult) mg/day | 10.4 |
| $IRV_{r-c}$ (vegetable consumption rate - child) mg/day | 3.8 |
| $IRA_{r-a}$ (inhalation rate - adult) $m^3$/day | 20 |
| $IRA_{r-c}$ (inhalation rate - child) $m^3$/day | 10 |
| $IFF_{r-adj}$ (age-adjusted fruit ingestion factor) mg-yr/kg-day | 17.48 |
| $IFV_{r-adj}$ (age-adjusted vegetable ingestion factor) mg-yr/kg-day | 9.08 |
| $IFS_{r-adj}$ (age-adjusted soil ingestion factor) mg/day | 120 |
| $IFA_{r-adj}$ (age-adjusted soil inhalation factor) $m^3$/day | 18 |
| $GSF_i$ (gamma shielding factor - indoor) | 0.4 |
| $CPF_r$ (contaminated plant fraction) | 0.25 |

### 3.4.3 Equations for Tap Water

**Ingestion of tap water**,

$$DCC_{water\text{-}ing}\,(pCi/L) = \frac{DL\,(mrem)}{EF_r\left(\frac{350\ day}{yr}\right)\times ED_r\,(1\ yr)\times DCF_o\left(\frac{mrem}{pCi}\right)\times\left(IFW_{r\text{-}adj}\left(\frac{1.8\ L}{day}\right)\right)}$$

where:

$$IFW_{r\text{-}adj}\left(\frac{1.8\ L}{day}\right) = \frac{ED_{r\text{-}c}\,(1\ yr)\times AAF_{r\text{-}c}\,(0.2)\times IRW_{r\text{-}c}\left(\frac{1\ L}{day}\right) + ED_{r\text{-}a}\,(1\ yr)\times AAF_{r\text{-}a}\,(0.8)\times IRW_{r\text{-}a}\left(\frac{2\ L}{day}\right)}{ED_r\,(1\ yr)}$$

**Inhalation (The inhalation exposure route is only calculated for C-14, H-3, Ra-224, Ra-226, and Ra-226+D). Also, volatilization in the equation comes from household uses of water (e.g., showering, laundering, and dish washing),**

$$DCC_{water\text{-}inh}\,(pCi/L)=\frac{DL(mrem)}{EF_r\left(\frac{350\ day}{yr}\right)\times ED_r(1\ yr)\times DCF_i\left(\frac{mrem}{pCi}\right)\times IFA_{r\text{-}adj}\left(\frac{18\ m^3}{day}\right)\times K\left(\frac{0.5\ L}{m^3}\right)\times ET_r\left(\frac{24\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hr}\right)}$$

where

$$IFA_{r\text{-}adj}\left(\frac{18\ m^3}{day}\right)=\frac{IRA_{r\text{-}c}\left(\frac{10\ m^3}{day}\right)\times ED_{r\text{-}c}(1\ yr)\times AAF_{r\text{-}c}(0.2)+IRA_{r\text{-}a}\left(\frac{20\ m^3}{day}\right)\times ED_{r\text{-}a}(1\ yr)\times AAF_{r\text{-}a}(0.8)}{ED_r(1\ yr)}$$

Note: the inhalation exposure route is only calculated for C-14, H-3, Ra-224, Ra-226, and Ra-226+D and volatilization in the equation comes from household uses of water (e.g., showering, laundering, dish washing)

**and immersion**,

$$DCC_{water\text{-}imm}\,(pCi/L)=\frac{DL(mrem)}{EF_r\left(\frac{350\ day}{yr}\right)\times ED_r(1\ yr)\times DCF_i\left(\frac{mrem/yr}{pCi/L}\right)\times\left(\frac{1\ yr}{8760\ hr}\right)\times DFA_{r\text{-}adj}\left(\frac{0.664\ hr}{day}\right)\times ET_r\left(\frac{24\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hr}\right)}$$

where

$$DFA_{r\text{-}adj}\left(\frac{0.664\ hr}{day}\right)=\frac{t_{c\text{-}event}\left(\frac{1\ hr}{event}\right)\times EV\left(\frac{1\ event}{day}\right)\times ED_{r\text{-}c}(1\ yr)\times AAF_{r\text{-}c}(0.2)+t_{a\text{-}event}\left(\frac{0.58\ hr}{event}\right)\times EV\left(\frac{1\ event}{day}\right)\times ED_{r\text{-}a}(1\ yr)\times AAF_{r\text{-}a}(0.8)}{ED_r(1\ yr)}$$

**Default**
**Resident Equation Inputs for Tap Water**

| Variable | Value |
|---|---|
| DL (dose limit) mrem | 1 |
| $ED_r$ (exposure duration - resident) yr | 1 |
| $ED_{r\text{-}c}$ (exposure duration - child) yr | 1 |
| $EF_r$ (exposure frequency) day/yr | 350 |
| $ET_r$ (exposure time - resident) hr/day | 24 |
| $IRW_{r\text{-}a}$ (water intake rate - adult) L/day | 2 |
| $IRW_{r\text{-}c}$ (water intake rate - child) L/day | 1 |
| $IFW_{r\text{-}adj}$ (adjusted intake factor) L-yr/kg-day | 1.8 |
| $IRA_{r\text{-}a}$ (inhalation rate - adult) $m^3$/day | 20 |
| $IRA_{r\text{-}c}$ (inhalation rate - child) $m^3$/day | 10 |
| $IFA_{r\text{-}adj}$ (age-adjusted inhalation factor) $m^3$/day | 18 |
| $AAF_{r\text{-}c}$ (annual age fraction - child resident) | 0.2 |
| $AAF_{r\text{-}a}$ (annual age fraction - adult resident) | 0.8 |
| K (volatilization factor of Andelman) L/$m^3$ | 0.5 |

# 4 Section 4.Toxicity Assessment

The purpose of the toxicity assessment is to compile toxicity information regarding the ROPCs and COPCs and to provide an estimate of the relationship between extent of exposure to a contaminant and likelihood or severity of adverse health effects. The toxicity assessments accomplished in two steps: hazard identification and dose-response assessment.

Hazard identification is a qualitative description of the potential toxic properties of a ROPC or COPC.

The dose-response evaluation is a process that results in quantitative estimates of indices of toxicity for COPCs or ROPCs.

## 4.1 Assessment of Carcinogens

For carcinogenic effects, the index of toxicity is the slope factor (SF), and for noncarcinogenic effects, the index of toxicity is the chronic reference dose (RfD). Uncertainties in the toxicity assessment process are discussed. The toxicity assessment, also termed the dose-response assessment, characterizes the relationship between the magnitude of exposure and the potential that an adverse effect will occur. It involves determining whether exposure to a radionuclide can cause an increase in the incidence of a particular adverse health effect, and characterizing the nature and strength of the evidence of causation. The toxicity information is then quantitatively evaluated and the relationship between the dose of the contaminant received and the incidence of adverse effects in the exposed population is evaluated. Long-term radiation exposure has been found to increase the risk of developing cancer in humans. The risk assessment methodology is consistent with the “no-threshold” hypothesis, i.e., any radiation dose conveys some measurable carcinogenic risk. At Superfund sites the exposures which can occur at the site are mostly chronic exposures at low doses. Acute effects from high level, short-term radiation exposures are not found at this site and are therefore not evaluated as part of this radiological risk assessment.

The USEPA and other regulatory agencies have performed cancer potency assessments for numerous radionuclides and the guidance they provide are used in this human health evaluation. Carcinogenic slope factors for the evaluation of cancer risk from lifetime exposure to radionuclides are obtained from the USEPA HEAST, which are tabular presentations of provisional toxicity data (USEPA, 1995).

Both carcinogenic and noncarcinogenic health effects are evaluated quantitatively in this risk assessment for chemicals of potential concern. Endpoints of these two different types of effect are assessed differently because the mechanism by which chemicals cause cancer is fundamentally different from the processes by which noncarcinogenic effects are caused. The principal difference in assessment reflects the assumption that noncancer effects exhibit a threshold dose below which no adverse effects occur, whereas no such threshold has been proven to exist for carcinogenic effects. Because exposure to some chemicals may result in carcinogenic and noncarcinogenic effects, both endpoints associated with a COPC were evaluated quantitatively in this risk assessment.

The likelihood that an agent is a human carcinogen is specified by EPA's weight-of-evidence classification. EPA's guidelines recognize three broad categories of data: (1) human data (primarily epidemiological); (2) results of long-term experimental animal bioassays; and (3) supporting data, including a variety of short-term tests for genotoxicity and other relevant properties, pharmacokinetic and metabolic studies, and structure-activity relationships. In hazard identification of carcinogens under the guidelines, human data, animal data, and supporting evidence are combined to characterize the weight-of-evidence (WOE) regarding the agent's potential as a human carcinogen. The 2005 carcinogen risk assessment guideline (USEPA 2005), recommend expressing WOE by narrative statements rather than only hierarchical categories, and expressing them separately for the oral and inhalation routes. The general categories recognized by the 2005 guidelines are:

- Carcinogenic to Humans
- Likely to be Carcinogenic to Humans
- Suggestive Evidence of Carcinogenic Potential
- Inadequate Information to Assess Carcinogenic Potential
- Not Likely to be Carcinogenic to Humans

Under the 1986 carcinogen risk assessment guidelines (USEPA 1986), this WOE was summarized as fitting one of several hierarchic categories:

Group A -- Carcinogenic to Humans: Agents with adequate human data to demonstrate the causal association of the agent with human cancer (typically epidemiologic data).

Group B -- Probably Carcinogenic to Humans: Agents with sufficient evidence (i.e., indicative of a causal relationship) from animal bioassay data, but either limited human evidence (i.e., indicative of a possible causal relationship, but not exclusive of alternative explanations; Group B1), or with little or no human data (Group B2).

Group C -- Possibly Carcinogenic to Humans: Agents with limited animal evidence and little or no human data.

Group D -- Not Classifiable as to Human Carcinogenicity: Agents without adequate data either to support or refute human carcinogenicity.

Group E -- Evidence of Non-carcinogenicity for Humans: Agents that show no evidence for carcinogenicity in at least two adequate animal tests in different species or in both adequate epidemiologic and animal studies.

These WOE categories express the relative level of certainty that these agents may cause cancer in humans. EPA's WOE classifications are focused on the amount and quality of evidence regarding whether or not a substance is carcinogenic to humans, not on the level of risk a substance might present. Since the publication of EPA's original cancer guidelines in 1986, considerable new knowledge has been developed regarding the processes of chemical carcinogenesis and the evaluation of human cancer risk. The 2005 guidelines recognize both linear and nonlinear modes of action for carcinogens. When assessing the dose-response relationship under the guidelines, cancer data in the observable range are analyzed using a dose-response model similar to the models used for noncancer effects. The method of extrapolation to lower doses from the point of departure may vary depending on whether the available data indicate a linear or nonlinear mode of action.

Under the guidelines, linear extrapolation is appropriate when the evidence supports the mode of action of gene mutation due to direct DNA reactivity or another mode of action that is thought to be linear in the low dose region. A linear mode of action will also be the approach when available evidence is not sufficient to support a nonlinear extrapolation procedure, even in the absence of evidence of DNA reactivity. Nonlinear methods are to be used if there is sufficient evidence to support a nonlinear mode of action.

### 4.2 Assessment of Noncarcinogens

The potential for adverse health effects associated with noncarcinogens (i.e., organ damage, immunological effects, birth defects, skin irritation, neurological effects etc…) usually is assessed by comparing the estimated average exposure dose to the reference dose (RfD). EPA develops the RfD by identifying the no-observed-adverse-effect level (NOAEL) or lowest-observed-adverse-effect level (LOAEL) in scientific literature, then adjusting that value using uncertainty factors (UFs) so that the resulting RfD is protective of human population. NOAELs and LOAELs may be obtained from either human epidemiological studies or animal studies; however, because human data often are lacking, they usually are obtained from laboratory animal studies in which relatively high doses are administered. UFs

are applied to the NOAELs and LOAELs to compensate for the data limitations of the critical study and for the uncertainties associated with differences between the study conditions and human exposure situations. The usual bases for application of UFs are as follows (EPA 1989c ):

- A UF of 10 is used to account for variation in the general population. This factor is intended to protect sensitive subpopulations (i.e., the elderly and children);
- A UF of 10 is used when extrapolating data from animals to humans. This factor is intended to account for the interspecies variability between humans and other mammals;
- A UF of 10 is used when a NOAEL is derived from a subchronic, rather than a chronic, study: and
- A UF of 10 is used when a LOAEL is used instead of a NOAEL. This factor is intended to account for the uncertainty associated with extrapolating data from LOAELs to NOAELs.

In addition to the UFs listed above, a modifying factor (MF) is applied:

- A MF ranging from 1 to 10 is included to reflect a qualitative professional assessment of additional uncertainties in the critical study and in the entire database. The default value for the MF is 1.

EPA assigns a qualitative level of confidence (i.e., low, medium, or high) to the RfD based on its confidence in the critical study and the database of supporting studies. The relative degree of uncertainty associated with the RfD and the level of confidence that EPA assigns to the data and toxicity value are considered when evaluating the quantitative results of the baseline human health risk assessment.

RfDs are expressed in units of mg/kg-day. EPA frequently provides noncancer toxicity criteria for inhalation exposure as reference concentrations (RfCs). The RfC value is reported as a concentration in air ($mg/m^3$) for continuous, 24 hour per day exposure. The RfC is derived in essentially the same way as the RfD.

The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of the daily intake in humans, including sensitive subgroups, that should not result in an appreciable risk of deleterious effects (EPA 1989c). The RfD is used as a reference point for gauging the potential effects of other exposures. Usually, exposures that are less than the RfD are not associated with health risks. The likelihood of adverse health effects in a human population increases if the predicted exposures exceed the RfD.

Noncarcinogenic risks are usually addressed by calculating a hazard quotient (HQ), as follows:

HQ = ADI/RfD

Where:

HQ = Hazard quotient

ADI = Average daily intake

RfD = Reference dose

HQs that are associated with the same type of critical effect should be summed across pathways and chemicals to obtain a hazard index (HI) for that effect. A HI greater than 1.0 indicates that adverse effects might be possible, whereas a HI less than 1.0 indicates that adverse effects would not be expected. Oral and inhalation RfDs for the selected COPC are presented in Table. The table also lists for each RfD the target organ.

## 4.3 Toxicity Assessment Uncertainties

A degree of uncertainty is inherent in the numerical toxicity values used in any risk assessment; this uncertainty reflects the large number of assumptions and calculations associated with SFs and RfDs.

### 4.3.1 Carcinogenic Toxicity Assessment Assumptions

Rodent bioassays and human epidemiological studies would require tens of thousands of animals or human beings to determine whether a chemical is carcinogenic at low doses. The estimated cancer SF depends on several critical factors, including the relationship between tumor location, time to appearance, and the proportion of animals exhibiting tumors. Carcinogenic extrapolation models are used to estimate low-dose SFs from effects seen at high doses because animal bioassay or human epidemiological data are usually insufficient to directly estimate SFs at low doses. These models are based on the assumption that there is no threshold dose below which carcinogenic risks will not occur. EPA also assumes that the dose-response relationship is linear at low doses, in contrast to other toxic effects for which thresholds are assumed to exist. Based on human epidemiological and animal data, EPA considers that cancer follows a series of discrete stages (i.e., initiation, promotion, and progression) that ultimately can result in uncontrolled cell proliferation (i.e. cancer). Consistent with this conclusion, the use of the linear multistage model permits an upper-bound estimate of the SF. However, compelling

scientific arguments can be made for several other extrapolative models that would result in significantly lower SFs. Thus, most SFs represent upper-bound values based on animal data, which should not necessarily be interpreted as equivalent to actual human cancer potencies.

### 4.3.2 Noncarcinogenic Toxicity Assessment Assumptions

Key assumptions used in assessing the likelihood of noncarcinogenic effects are that threshold doses exist below which various noncarcinogenic effects do not occur, and that occurrence or absence of noncarcinogenic effects can be extrapolated between species and occasionally between routes of exposure and over varying exposure durations. The threshold assumption appears to be sound for most noncarcinogens, based on reasonably good fits of experimental data to usual dose-response curves.

Other assumptions generally appear to be true to varying degrees. For example, the effects observed in one species or by one route of exposure may not occur in another species or by another route. The effects may occur at higher or lower doses because of differences in the bio-kinetics of a compound in different species or when exposure occurs by different routes. The uncertainty in these assumptions is taken into account by using UFs in the derivation of RfDs. The UFs reflect the uncertainty associated with species- to species extrapolation and include safety factors to protect sensitive individuals. In addition, a MF is applied to reflect a qualitative professional assessment of additional scientific uncertainties in the critical study and in the entire database. The UFs and MFs used by EPA are conservative (health-protective); consequently, the resulting RfDs are likely to be conservative.

EPA has applied a consistent priority scheme to the sources of chronic dose-response information described above. Draft RfCs, RfDs, and unit risk estimates (UREs) under development for the EPA IRIS process were given first priority on a case-by-case basis, where such assessments have already undergone external peer review and subsequent revision. Where externally peer reviewed IRIS draft assessments were not selected to supersede existing EPA IRIS values. For substances lacking current IRIS assessments, ATSDR chronic minimum risk level (MRLs) (available only for noncancer effects) received next preference, followed by CalEPA chronic (reference exposure levels (RELs) and UREs. Where ATSDR or CalEPA assessments did not exist, Health Effect Assessment Summary Table (HEAST) assessments are used. http://www.epa.gov/oswer/riskassessment/pdf/hhmemo.pdf

### 4.3.3 Dose Estimates

There are no EPA dose conversion factor for inhalation of radon gas in ambient air. Calculated dose (mrem/year) for radon exposure through the ambient air is underestimated. Comparison of the calculated dose for radon gas to the 10 mrem/year NESHAP (40 CFR 61.22 subpart B) radon 222 inhalation standards without considering the inhalation of radon exposure route is not adequate. Using NRC dose conversion factor for radon 222, would give dose estimate greater than the NESHAP (40 CFR 61.22 subpart B) standards of 10 mrem/yr (see section 5.1.6).

## 4.4 Health Effects of Radiation

Some atoms are not stable. The excess energy contained in an unstable atom is released in one of a few basic particles and energetic waves. Radioactive materials that decay spontaneously produce ionizing radiation. Ionization is a process by which sufficient localized energy is transferred to atoms of living tissues to remove electrons from the electric field of their nucleus. Any living tissue in the human body can be damaged by ionizing radiation in a unique manner. It can produce chemically reactive ions or free radicals, destroy cellular constituents, and damage DNA. The body attempts to repair the damage, but sometimes the damage is of a nature that cannot be repaired or it is too severe or widespread to be repaired. Irreparable DNA damage is thought to be a major factor in carcinogenesis. Also, mistakes made in the natural repair process can lead to cancerous cells. The most common forms of ionizing radiation are alpha and beta particles, gamma and x-rays. Only when energy from ionizing radiation is absorbed by a living tissue, does damage and deleterious effects to the tissue occur.

The alpha particles are high-energy particles that are expelled from unstable nuclei of heavy elements. The alpha particle is a helium atom and contains two neutrons and two protons. They are not very penetrating and are easily absorbed. A sheet of paper or a 3 –cm layer of air is sufficient to stop them. Its energy is transferred within a short distance to the surrounding media. The alpha particle emitter will not penetrate the outer layer of our skin, but is dangerous if inhaled or swallowed. The delicate internal workings of the living cell forming the lining of the lungs or internal organs, can be changed or mutated or destroyed by the energetic alpha particle. Radon, the gas produced by the decay of radium-226 emits alpha particles, which poses a hazard to the lungs and airways when inhaled.

Beta particles are much lighter energy particles. They are energetic electron given off by the nucleus of unstable isotopes to restore an energy balance. They can be stopped, for instance, by an aluminum sheet a few millimeters thick or by 3 meters of air. Beta particle is capable of penetrating much deeper into

living matter. Each encounter with a living cell, and there may be many before the beta energy is dissipated, is likely to damage some of the chemical links between the living molecules of the cell or cause some permanent genetic change in the cell nucleus. If the damage occurs within the generative cells of the ovaries or testes, the damage may be passed to new generations.

Gamma rays or X-ray, is an energetic photon or light wave in the same electromagnetic family as light and x-rays, but is much more energetic and harmful. It is capable of damaging living cells as it slows down by transferring its energy to surrounding cell components. They travel much further and have more penetrating power than either alpha or beta particles.

### 4.4.1 Hazard Identification

There are two broad health effects: chronic and acute health effects also known as stochastic and non-stochastic respectively. Chronic effects are associated with long–term low level exposure to radiation. Cancer is the primary health effect from chronic radiation exposure. Exposure at Superfund sites are mostly of this type chronic health effects. Acute effects are associated with short-term, high level exposure. Such as happens in accident at nuclear facilities. Health effects appear quickly and are severe and could lead to death within weeks or few months depending on dose. Medical patients receiving radiation treatments often experience acute effects. This is referred to as radiation sickness. The symptoms of radiation sickness include: nausea, hair loss, weakness, skin burns and diminished organ functions.

Other adverse biological effects caused by ionizing radiation in addition to carcinogenicity, is mutagenicity and teratogenicity. Mutagenicity is the property of a radionuclide to induce genetic mutation, which may be in the nucleus of either somatic or germ cells. Mutations in germ cells lead to genetic or inherited defects. Teratogenicity is the ability of an agent to induce or increase the incidence of congenital malformations produced during the growth and development of an embryo. The age of the fetus at the time of exposure is the most important factor in determining the extent and type of damage from radiation. Embryos are most sensitive in the first two to eight weeks after conception. Effects were noted on the nervous system, skeletal system, eyes, genitalia, and skin. The brain is most sensitive at 8 to 15 weeks which is the time the nervous system is undergoing the most rapid differentiation and proliferation of cells. It could lead to brain damage.

The risk of cancer is generally assumed to be limiting for risk assessments at Superfund sites, because teratogenic effects can be induced only during the nine months of pregnancy and genetic effects are induced during the 30-year reproductive generation. But cancer can be induced at any point during a lifetime. If a radiation source is not controlled, therefore, the cumulative risk of cancer may be many

times greater than the risk of genetic or teratogenic effects due to the potentially longer period of exposure. Therefore the risk of cancer may be used as the sole basis for assessing the radiation-related human health risks of a site contaminated with radionuclides.

In most cases , the radiation hazard is much greater than the chemical hazard, except in some cases both radiation and chemical hazard are of concern. For example Uranium-238 tends to pose both a radiation and chemical hazard. In such situations, EPA regulates uranium-238 as both a chemical and a radiation hazard.

### 4.4.2 Specific Chemical or Radionuclide of Concern Health Effect Summaries

Appendix D , is a compilation of the health effects summary for each chemical or radionuclide of concern adopted from the Agency of Toxic Substance and Disease Registry (ATSDR1990,2008, 2003) tox profiles and Center for Disease Control (CDC).

### 4.4.3 Epidemiology Studies for Grants New Mexico

Two epidemiological studies (Boice, 2008 and Boice, 2010) were carried out for Grants, New Mexico. In the first published paper a cohort study of workers engaged in uranium milling and mining activities near Grants, Cibola County, New Mexico, found lung cancer mortality between 1979 and 2005 to be significantly increased among underground miners exposed to radon gas and its decay products but not to uranium workers working above ground. The second study evaluated cancer mortality during 1950-2004 and cancer incidence during 1982-2004 among county residents. The total numbers of cancer deaths and incident cancers were close to that expected based on New Mexico cancer rates. Lung cancer mortality and incidence were significantly increased among men but not women. Similarly, among the population of the three census tracts near the Grants Uranium Mill, lung cancer mortality was significantly elevated among men but not women. The lung cancer among men seem likely to be due to previously reported risks among underground miners from exposure to radon gas and its decay products. With the exception of male lung cancer, this study provides no clear or consistent evidence that the operation of uranium mills and mines adversely affected cancer incidence or mortality of county residents.

# 5 Section 5: Risk Characterization

Risk Characterization is the final step in the risk assessment. It integrates information from exposure assessment and toxicity assessment (section 3 and 4). The information is then used to obtain quantitative estimates of potential risks to human health from individual radionuclides and chemicals found at the offsite residential communities at the Homestake Superfund site.

## 5.1 Risk Characterization for Chemicals and Radionuclides

The following subsections review the processes for quantitatively estimating carcinogenic and noncarcinogenic risks and present quantitative estimates of the risks associated with the COPCs and ROPC at the HMC offsite residential communities.

### 5.1.1 Risk Estimation Procedures

Potential cancer risks are assessed by multiplying the estimated absorbed dose of a carcinogen or lifetime average daily intake (LADI), by its slope factor (SF). This calculated risk is expressed as the probability of an individual developing cancer over a lifetime and is an estimated upper-bound incremental probability. Cancer risks initially are estimated separately for exposure to each chemical or radionuclide for each exposure pathway and receptor category. Separate cancer risk estimates then are summed across chemicals, radionuclides, receptors, and all exposure pathways applicable to the same population to obtain the total excess lifetime cancer risk for that population. Cancer risk estimates are provided in scientific notation; $1 \times 10^{-6}$ is equal to 1E-06, which equals 0.000001 or 1 in 1,000,000 or one in a million.

The potential for adverse effects resulting from exposure to a noncarcinogen is assessed by comparing the estimated chronic daily intake (CDI) of a substance to its chronic RfD. This comparison is made by calculating the ratio of the estimated CDI to the corresponding RfD to yield a hazard quotient (HQ). HQs that are associated with similar critical effects (e.g., liver damage) should be summed together to obtain a hazard index (HI) for that effect, whereas HQs for different critical effects should be kept separate.

For radionuclides, the slope factors for the inhalation pathway should be multiplied by the estimated inhaled activity, using same equations as for chemicals but without division of the body weight and averaging time, for each radionuclide of concern to estimate risks from the inhalation pathway. Similarly, risks from the ingestion pathway should be estimated by multiplying the ingestion slope factors by the activity ingested for each radionuclide of concern, using equations as for chemical but without division by the body weight and averaging time. Estimates of the risk from the air immersion pathway should be computed by multiplying the appropriate slope factors by the airborne radionuclide concentration and the duration of exposure. Risk from the ground surface pathway should be computed as the product of the slope factor, the soil concentration and the duration of exposure for each ROPC.

The sum of the risks from all radionuclides and pathways yields the lifetime risk for the overall exposure.

**Resident Ambient Air.** This receptor spends most, if not all, of the day at home except for the hours spent at work. The activities for this receptor involve typical home making chores (cooking, cleaning and laundering) as well as gardening. The resident is assumed to be exposed to contaminants via the following pathways: inhalation of ambient air and external radiation from contaminants in ambient air. To take into account the different inhalation rates for children and adults, age adjusted intake equations were developed to account for changes in intake as the receptor ages. In Superfund an assumption is made of a continuous infinite source of contamination is made until the source of contamination is remediated. Therefore equations which consider this assumption of infinite source is used by removing half-life decay from consideration. Secular equilibrium is also assumed for infinite sources.

Equations for Risk from exposure to Residential Ambient Air:

1) Residential Inhalation Risk from Ambient Air (without half-life decay).

$$Risk = C_{res-air-inh}\left(\frac{pCi}{m^3}\right) * ET_r\left(24\frac{hr}{day}\right) * \left(\frac{1day}{24hr}\right) * EF_r\left(350\frac{day}{yr}\right) * ED_r(30\ yr) * SF_i\left(\frac{risk}{pCi}\right) * IFA_{r-adj}(18\frac{m^3}{day})$$

$$IFA_{r-adj}\left(\frac{18m^3}{day}\right) = \frac{IRA_{r-c}\left(\frac{10m^3}{day}\right) * ED_{r-c}(6\ yr) + IRA_{r-a}\left(\frac{20m^3}{day}\right) * ED_{r-a}(24\ yr)}{ED_{r\ (30\ yr)}}$$

2) Residential external exposure to ionizing radiation in ambient Air (without half-life decay)

$$Risk = C_{res-air-sub}\left(\frac{pCi}{m^3}\right) * ET_r\left(\frac{24hr}{day}\right) * \left(\frac{1day}{24hr}\right) * EF_r\left(\frac{350day}{yr}\right) * ED_r(30\ yr) * SF_{sub}\left(\frac{\frac{risk}{yr}}{pCi/m3}\right) * \left(\frac{1yr}{365day}\right) * GSF_0(1.0)$$

### 5.1.2 Risk Estimates

Federal environmental laws and regulations recognize that estimates of very small levels of risk are insignificant. The concept of de minimis risk refers to a level below which risks are so small that they are not of concern.

EPA typically regard cancer risks less than $1 \times 10^{-6}$ as de minimis and consider risks between $1 \times 10^{-6}$ and $1 \times 10^{-4}$ to be within a generally acceptable range. These regulatory risk levels have been adopted by the EPA Superfund program. Under current EPA Superfund policy, as stated in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (EPA 1992d), acceptable exposures to known or suspected carcinogens are generally those that represent an excess upper-bound lifetime cancer risk to an individual of between $1 \times 10^{-6}$ and $1 \times 10^{-4}$. In addition, the EPA uses the $1 \times 10^{-6}$ risk level as the point of departure for determining remediation goals for NPL sites (EPA 1992d).

For evaluating noncarcinogenic effects, EPA defines acceptable exposure levels as those to which the human population, including sensitive subgroups, may be exposed without adverse effects during a lifetime or part of a lifetime, incorporating an adequate margin of safety (EPA 1989a). This acceptable exposure level is approximated by an HI equal to 1. If the HI is less than 1, adverse effects usually would not be expected. However, adverse effects may occur when the HI is greater than 1. Depending on nature of exposure and type of COPC, EPA has accepted HI levels that are slightly above 1 and excess cancer risk that are slightly above $1 \times 10^{-4}$.
Detailed tables containing estimates of potential exposures and associated risks for the residential scenarios that were described in section 3 can be found in Appendix C. Tables 5-4 and 5-5 summarize the carcinogenic risks and noncarcinogenic risks, respectively, from the detailed tables.

### 5.1.3 Risks for multiple Substances and Across Different Pathways

At Superfund sites, a mixture of chemicals and radionuclides may be present at the same time as is the case at Homestake Superfund site. In such a case cancer risk from both chemicals and radionuclides are added to assess potential health effects from simultaneous exposure to

multiple chemicals and radionuclides. Also combining risks across exposure pathways may be necessary after properly examining whether it is likely that the same individuals would consistently face the RME from more than one pathway. Such as adding risk for an individual who is exposed to COPC and ROPCs associated with drinking well water and at the same time exposed to contaminants in soil through the incidental oral ingestion route of intake.

### 5.1.4 Cancer Risks

#### 5.1.4.1 Residential Scenario - Radionuclides

The estimated excess lifetime cancer risk from exposure to radionuclides of concern in soil at the Five Subdivisions was $2.4 \times 10^{-4}$ in a residential setting (Table 5-1). The residential scenario assumes exposure to soil through the incidental soil ingestion route, external exposure to gamma radiation, inhalation of radionuclides in airborne particulates, and ingestion of produce (vegetables and fruits) modeled through the uptake of radionuclides in soil into plants. The risk was primarily due to external exposure to radium -226+D (Ra-226 plus its daughters) which posed a risk by itself of $1.9 \times 10^{-4}$ (Table 5-1).

The estimated excess lifetime cancer risk from exposure to radionuclides of concern in ambient air at the Five Subdivisions was $1.8 \times 10^{-3}$ in a residential scenario. The residential scenario assumes exposure to contaminants in air through the inhalation and submersion routes of intake. The risk was primarily due to inhalation of radon- 222 in ambient air which was calculated to be $1.7 \times 10^{-3}$ (Table 5-1).

The estimated excess lifetime cancer risk from exposure to radionuclides of concern in soil at the Background area was $1.8 \times 10^{-4}$ in a hypothetical residential setting. The soil background area was selected based on its location further south from the Five Subdivisions which is close enough to be of the same soil make up as that of the Five Subdivisions and far enough to be impacted by HMC site related contaminants. It is assumed that exposure to soil occurs through the incidental soil ingestion route, external exposure to gamma radiation, inhalation of radionuclides in airborne particulates, and ingestion of produce (vegetables and fruits) modeled through the uptake of radionuclides in soil into plants. The risk was primarily due to external exposure to radium -226+D (Ra-226 plus its daughters or progeny assuming secular equilibrium between the radionuclide and its progeny) which had a calculated risk by itself of $1.4 \times 10^{-4}$ (Table 5-2).

Table 5-1: Risk Summary for an RME resident living at the Five subdivision area adjacent to HMC facility

| Exposure Point | Exposure Medium | Radionuclide of Concern | Carcinogenic Risk | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Ingestion | Inhalation of Particulates | Inhalation of Air (Outdoor/Indoor) | Submersion Air | Ingestion of Produce | External (Radiation) | Exposure Routes Total |
| Five Subdivisions | Soil | Radium-226 +D | 2.28E-06 | 1.39E-09 | | | 1.02E-05 | 1.89E-04 | 2.01E-04 |
| | | Radium-228 +D | 7.77E-07 | 6.77E-11 | | | 3.07E-06 | 2.97E-05 | 3.35E-05 |
| | | Thorium 230 | 4.07E-07 | 2.19E-09 | | | 3.64E-08 | 1.17E-08 | 4.57E-07 |
| | | Uranium-234 | 2.99E-07 | 8.23E-10 | | | 7.13E-08 | 3.76E-09 | 3.75E-07 |
| | | Uranium-238 +D | 4.23E-07 | 7.20E-10 | | | 9.25E-08 | 1.63E-06 | 2.15E-06 |
| | | Radionuclide Total | 4.2E-06 | 5.2E-09 | | | 1.3E-05 | 2.2E-04 | 2.4E-04 |
| | Exposure Medium Total | | | | | | | | 2.4E-04 |
| | Outdoor Air | Radon-222 (Rn-222) | | | 1.7E-03 | 1.1E-04 | | | 1.8E-03 |
| | | Thoron (Rn-220)[1] | | | 0.0E+00 | 4.0E-08 | | | 4.0E-08 |
| | | Uranium- nat | | | 4.3E-06 | 8.5E-12 | | | 4.3E-06 |
| | | Thorium-230 | | | 6.1E-07 | 4.3E-15 | | | 6.1E-07 |
| | | Radium-226 | | | 2.7E-07 | 2.8E-11 | | | 2.7E-07 |
| | | Radionuclide Total | | | 1.7E-03 | 1.1E-04 | | | 1.8E-03 |
| | Exposure Medium Total | | | | | | | | 1.8E-03 |
| Receptor Total | | | | | | | | | 2.0E-03 |
| | Private Well[1] Water | Radium-226+D | 2.33E-06 | | 3.5E-04 | | | | 3.5E-04 |
| | | Radium-228+D | 2.2E-04 | | | | | | 2.2E-04 |
| | | Thorium-230 | 1.0E-07 | | | | | | 1.0E-07 |
| | | Uranium-234 | 2.7E-05 | | | | | | 2.7E-05 |
| | | Uranium-235 | 1.0E-06 | | | | | | 1.0E-06 |
| | | Uranium-238+D | 2.1E-05 | | | | | | 2.1E-05 |
| | | Radon 222+D | | | 1.6E-03 | | | | 1.6E-03 |
| | | Radionuclide Total | 3E-04 | | 2.0E-03 | | | | 2.2E-03 |
| | Exposure Medium Total | | | | | | | | 2.2E-03 |
| Receptor Total | | | | | | | Receptor Risk Total | | 4.3E-03 |

[1] Residents are connected to Milan municipal water. This is the additional risk if a resident in the future decides to dig a well and use it for domestic purposes.

Table 5-2 : Risk summary to an RME hypothetical resident living at the soil background area.

| Exposure Point | Exposure Medium | Radionuclide of Concern | Carcinogenic Risk | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Ingestion | Inhalation of Particulates | Inhalation of Air | Submersion Air | Ingestion of Produce | External Radiation | Exposure Routes Total |
| Background Area | Soil | Radium-226 +D | 1.64E-06 | 9.98E-10 | | | 7.34E-06 | 1.36E-04 | 1.45E-04 |
| | | Radium-228 +D | 8.54E-07 | 7.45E-11 | | | 3.37E-06 | 3.26E-05 | 3.68E-05 |
| | | Thorium 230 | 3.56E-07 | 1.92E-09 | | | 3.18E-08 | 1.03E-08 | 4.00E-07 |
| | | Uranium-234 | 2.19E-07 | 6.03E-10 | | | 5.23E-08 | 2.76E-09 | 2.75E-07 |
| | | Uranium-238 +D | 3.18E-07 | 5.40E-10 | | | 6.93E-08 | 1.23E-06 | 1.62E-06 |
| | | Radionuclide Total | 3.4E-06 | 4.1E-09 | | | 1.1E-05 | 1.7E-04 | 1.8E-04 |
| | Exposure Medium Total | | | | | | | | 1.8E-04 |
| | Outdoor Air | Radon-222 (Rn-222) | | | 1.3E-03 | 8.4E-05 | | | 1.3E-03 |
| | | Thoron (Rn-220)[1] | | | 0.0E+00 | 6.5E-09 | | | 6.5E-09 |
| | | Radionuclide Total | | | 1.3E-03 | | | | 1.3E-03 |
| | Exposure Medium Total | | | | | | | | 1.3E-03 |
| Receptor Total | | | | | | | | | 1.5E-03 |

[1]Thoron gas does not have an inhalation slope factor. Risk is due to submersion only.

The estimated excess lifetime cancer risk from exposure to radionuclides of concern in ambient air at the background area was $1.3 \times 10^{-3}$ in a residential scenario. The background area was carefully selected from a community (Bluewater Village) that is similar to the Five Subdivision communities as discussed above in section 2.7.1. The residential scenario assumes exposure to contaminants in air through the inhalation and submersion routes of intake. The risk was primarily due to inhalation of radon- 222 gas in ambient air which was calculated at $1.3 \times 10^{-3}$ (see table 5-2).

The estimated excess lifetime cancer risk from exposure to radionuclides of concern in well water at the Five Subdivisions was $2.2 \times 10^{-3}$ in a residential setting. This was based on 14 private well water samples tested for radionuclides of concern including radon gas. These private well waters were currently not in use for domestic purposes. Since as of early 2013, all domestic water supply connections to Milan municipal water system were completed at the Five Subdivisions with the exception of one Valle Verde resident that elected not to be connected to Milan water supply system. However, for the purpose of this risk assessment which also

evaluates potential future risk, an assumption was made that in the future a new resident might decide to install a well water and use it for domestic purposes. Although New Mexico Office of State Engineer issued a health advisory to prevent people from installing a private well, it is still possible that a future resident may install the well and use it for domestic purpose. Therefore, the risk from exposure to private well waters is an added hypothetical potential future risk if ground water is used in the future for domestic purposes. The residential scenario assumes exposure to water through the ingestion and inhalation of volatiles routes of intake. The risk was primarily due to inhalation of radon-222 +D emitted from water due to indoor domestic uses (showering, cooking, dishwashing, laundering etc.) which had a risk of $1.6 \times 10^{-3}$ and secondly from inhalation of radium-226+D and ingestion of radium-228+D which had a risk of $3.5 \times 10^{-4}$ and $2.2 \times 10^{-4}$ respectively (see table 5-1). Risk from exposure to groundwater through the ingestion and inhalation routes of intake include exposure to background contaminants. EPA evaluates risk with background levels included. The alluvium groundwater has been determined to be impacted by site related contaminants and is undergoing remediation. A true groundwater background for the site was not determined. Instead a site specific background concentrations for alluvial ground water have been established; however, it has likely been impacted by historical mining activities in the San Mateo Creek basin, and possibly naturally occurring uranium deposits. The maximum contaminant level (MCL) primary drinking water standards for radium 226 and radium 228 combined is 5 pCi/L and for Uranium is 30 µg/L. Proposed MCL for radon gas in water is 300/4000 pCi/L (see section 2.7.4).

The estimated excess lifetime cancer risk from exposure to radionuclides of potential concern is shown in table 5.1. In a residential scenario, a hypothetical RME individual living at the Five Subdivisions area and exposed to different media namely soil, air and produce through different routes of intake or through external exposure is expected to have a total excess cancer of $2.0 \text{ X } 10^{-3}$ and a risk of $5.6 \times 10^{-4}$ after subtracting risk from background exposures to the same media through the same routes of intake. EPA evaluates risk with background levels included. Subtraction of the background levels is not to determine if the estimated risk after subtracting background is less than $1 \times 10^{-4}$, but for risk managers to distinguish the contribution of background risk to site risk. Most of the risk was due to inhalation of outdoor radon plus its progeny, assuming secular equilibrium between radon gas and its progeny, found in ambient air and due to Ra-226 + D through the external exposure pathway. Statistical comparison between

outdoor radon at the Five Subdivisions versus outdoor radon levels at Bluewater Village (background) did show statistical significant increase in the average radon levels at the Five Subdivisions area over that in the background area (p-value = 0.000001).

A closer look at the soil concentrations of the ROPC show that the median of Ra-226, Thorium 230, Uranium 234 and Uranium 238 were 1.8 pCi/g, 1.26 pCi/g, 1.08 pCi/g and 1.1 pCi/g respectively were slightly higher than the Ra-226, Thorium 230, Uranium 234 and Uranium 238 in the background soil concentration of 1.7 pCi/g, 1.05 pCi/g, 0.88 pCi/g and 0.9 pCi/g respectively. The median soil levels in the soil of the area between the evaporation pond and the fence line were 3.06 pCi/g, 1.83pCi/g, 2.47 pCi/g and 2.68 pCi/g for Ra-226, Thorium 230, Uranium 234 and Uranium 238 respectively. The 95% UCL on the arithmetic mean for Ra-226, Thorium 230, Uranium 234 and U 238 were 2.45 pCi/g,1.56 pCi/g, 1.52 pCi/g and 1.55 pCi/g respectively. Compared to the 95% UCL on the arithmetic mean for Ra-226, Th-230, U-234 and U-238 in background soil of 1.81 pCi/g, 1.39 pCi/g, 1.14 pCi/g and 1.15 pCi/g respectively. The 95% UCL for the soil level of Ra-226, Th-230, U-234 and U-238 in the soil of the area between the evaporation pond and fence line were 4.14 pCi/g, 2.69 pCi/g, 4.46 pCi/g and 4.57 pCi/g respectively. Based on the median and 95% UCL on the arithmetic means of ROPC in soil, there seems to be a trend of ROPC concentrations in the soil leading from the area between the evaporation pond to the Five Subdivisions and least at the soil background area. Although the soil levels of the ROPC in the Five Subdivisions had higher soil levels than the soil background, the increase was not high enough to be detected by statistical tests at a confidence level of 95%. Therefore there seem to be an impact from HMC activities on the adjacent neighborhood communities but the impact is very slight to be detected statistically.

Table 5-3 is a summary of the risk to a reasonable maximum exposed individual living in the Five Subdivisions and exposed to contaminants of concern in soil through the incidental ingestion of soil, inhalation of particulates in air, external exposure and consumption of produce. The same individual is exposed to radon gas in ambient air. Exposure to contaminants of concern in private well water was added for a hypothetical future residential scenario.

Table 5-3: Estimated excess lifetime cancer risk from radionuclides exposure by an RME individual living at the Five Subdivisions residential community located offsite and downgradient from HMC Superfund site assuming a current/future residential scenario.

| Medium | Exposure Pathway | Radionuclides Of Primary Concern | Cancer Risk- Five Subdivisions | Cancer Risk- Background | Site Related Excess Life-time Cancer Risk |
|---|---|---|---|---|---|
| Soil | Ingestion, external, inhalation and produce consumption | Ra-226+D (external exposure) | $2.4 \times 10^{-4}$ | $1.8 \times 10^{-4}$ | $6.0 \times 10^{-5}$ |
| Air | Inhalation of Ambient Air | Rn-222 +D (inhalation) | $1.8 \times 10^{-3}$ | $1.3 \times 10^{-3}$ | $5.0 \times 10^{-4}$ |
| Total | | | $2.0 \times 10^{-3}$ | $1.5 \times 10^{-3}$ | $5.6 \times 10^{-4}$ |
| Well Water Added Risk[1] | Ingestion and inhalation | Rn-222+D & Ra-226 +D (inhalation) Ra-228+D (ingestion) | $2.2 \times 10^{-3}$ | See [2] | See [2] |

[1] This is the added cancer risk from exposure to radionuclides in well water in the event that a well is dug and used for domestic purposes sometime in the future. Currently all residents except for one Valle Verde resident are on Milan municipal water system. The risk include background ground water risk.

[2] A true background was not determined for the site.

### 5.1.4.2 Residential Scenario- Chemicals of Potential Concern

The estimated excess lifetime cancer risk from exposure to chemicals of potential concern in soil at the Five Subdivisions is $1.2 \times 10^{-5}$ in a residential setting. The residential scenario assumes exposure to soil through the incidental soil ingestion route, inhalation of COPC in airborne particulates, and dermal contact with soil. The risk is primarily due to arsenic through the incidental ingestion of soil which posed a potential risk of $1.1 \times 10^{-5}$ (see table 5-4). The estimated excess lifetime cancer risk from exposure to chemicals of potential concern in soil at the background area is $1.3 \times 10^{-5}$. The risk is primarily due to arsenic through the incidental ingestion of soil. Therefore cancer risk from COPC at the site is similar to background cancer risk.

The estimated noncancer risk from exposure to chemicals of potential concern in soil at the Five Subdivisions calculated a hazard index of $9.0 \times 10^{-2}$ through the incidental ingestion of soil, inhalation of particulates and dermal contact with soil.

The estimated noncancer risk from exposure to chemicals of potential concern in soil at the background area calculated a hazard index of $9.3 \times 10^{-2}$ through the same pathways and routes of intake as those for the five subdivisions. Therefore the noncancer risk at the five subdivisions is similar to background and the hazard index is less than the generally acceptable level of a HI of 1.

However, it should be noted that molybdenum soil concentrations at the five subdivisions did show a statistical significant increase over that in the background soil molybdenum levels (p-value < 0.5) indicating a potential additional source at the Five Subdivisions which is not present at the background area. Molybdenum is a chemical of potential concern and found at very high levels in the HMC east evaporation pond. The average molybdenum concentration in the east evaporation pond is 657,333 µg/L. The water in the evaporation pond is force sprayed high in the air to speed the evaporation rate. This practice could result in carrying contaminants in the evaporation pond through the air towards the Five Subdivisions yards. Molybdenum was also found at higher levels in the soil in the area between the evaporation pond and the fence line than it is in the soil in the Five Subdivisions. But this increase in molybdenum concentration in the soil of the five subdivisions did not raise the risk from exposure to molybdenum to go above the bench mark of a HI of 1.

The estimated excess lifetime cancer risk from chemicals in ground water was calculated to be $1.2 \times 10^{-4}$ primarily due to arsenic through the ingestion of water route of intake. The concentration of arsenic associated with the cancer risk is 5.3 µg/l which is less than the maximum contaminant level (MCL) primary drinking water standard of 10 µg/l. The estimated noncancer risk is a HI of 1.1 primarily due to the noncaner effect of arsenic and secondly due to selenium and uranium. However due to different primary target organ that is impacted by these metals, the organ specific HI is below the bench mark of 1 when considered separately. As mentioned above the added risk from well water domestic usage is based on the assumption that a resident might use the ground water for domestic purposes sometime in the future, since currently all houses are now hooked up to the Milan Municipal water system except for one Valle Verde resident who refused to connect his house to the Milan Municipal water system.

Table 5-4 Estimated excess lifetime cancer and non-cancer risk from COPC exposure by an RME individual. The individual is assumed to be living at the Five Subdivisions communities in a current/future residential land use scenario.

| Medium | Exposure Pathway | COPC | Cancer Risk Five Subdivisions | Cancer Risk Background | Site Related Cancer Risk[2] | HI[3] - Five Subdivisions | HI- Background | Site Related Non-cancer Risk |
|---|---|---|---|---|---|---|---|---|
| Soil | Ingestion, inhalation and dermal | As, Mo, V, U,total | As $1.2 \times 10^{-5}$ | As $1.3 \times 10^{-5}$ | -0- | $1.24 \times 10^{-1}$ | $9.1 \times 10^{-2}$ | $3.3 \times 10^{-2}$ |
| Total | | | $1.2 \times 10^{-5}$ | $1.2 \times 10^{-5}$ | | $1.24 \times 10^{-1}$ | $9.1 \times 10^{-2}$ | $3.3 \times 10^{-2}$ |
| Well Water Added Risk[1] | Ingestion and dermal | As, Mo, V, U,total | As $1.2 \times 10^{-4}$ | | | $1.1 \times 10^{0}$ | | |

[1] This is the added risk from exposure to COPC in well water in the event that a well is installed and used for domestic purposes in the future. Currently all residents except for one Valle Verde resident are on Milan municipal water system.

[2] A difference of zero means there is no additional risk over background risk.

[3] HI= Hazard Index for evaluating non-cancer risk. HI less than 1means non-cancer health effects are not expected.

#### 5.1.4.3 Agricultural (Farmer) Scenario – Radionuclides

The estimated excess lifetime cancer risk from exposure to radionuclides of concern in soil at the Five Subdivisions is $1.1 \times 10^{-3}$ in an agricultural setting. The farmer scenario assumes exposure to soil through the incidental soil ingestion route, external exposure to gamma radiation, inhalation of radionuclides in airborne particulates, and ingestion of produce (vegetables and fruits) modeled through the uptake of radionuclides in soil into plants. The farmer scenario has additional exposure over that of a residential scenario. It was observed in the Five Subdivisions that some residents are involved in raising cows, goats, ducks, rabbits and poultry for subsistence use. In this risk assessment a farmer scenario is assumed to be indirectly exposed to contaminants in soil through the consumption of beef, milk, poultry and eggs. The risk was primarily due to external exposure to radium -226+D (Ra-226 plus its daughters) which posed a potential risk of $2.5 \times 10^{-4}$ (Appendix A table 7.2.2) and from ingestion of milk

contaminated with Ra-226+D, U-234 and U-238 which had an excess cancer risk of 3.2 X $10^{-4}$, 1.3 X $10^{-4}$, and 1.8 X $10^{-4}$ respectively.

The estimated excess lifetime cancer risk from exposure to radionuclides of concern in ambient air at the Five Subdivisions would be the same as that for a residential scenario which was calculated to be 1.8 x $10^{-3}$ in a residential scenario. The residential scenario assumes exposure to contaminants in air through the inhalation and submersion routes of intake. The risk was primarily due to inhalation of radon- 222 in ambient air which was calculated to be 1.7 x $10^{-3}$ (Appendix A table 7.1.2).

The estimated excess lifetime cancer risk from exposure to radionuclides of concern in soil at the background area was 8.8 x $10^{-4}$ in an agricultural setting. The farmer scenario assumes exposure to soil through the incidental soil ingestion route, external exposure to gamma radiation, inhalation of radionuclides in airborne particulates, and ingestion of produce (vegetables and fruits) modeled through the uptake of radionuclides in soil into plants. The farmer scenario has additional exposure over that of a residential scenario. It was observed in the Five Subdivisions that some residents are involved in raising cows, goats, ducks, rabbits and poultry for subsistence use. In this risk assessment a farmer scenario is assumed to be indirectly exposed to contaminants in soil through the consumption of beef, milk, poultry and eggs. The same exposures were assumed for a hypothetical farmer living in the background area. The risk is primarily due to external exposure to radium -226+D (Ra-226 plus its daughters) in soil which had a calculated potential risk by itself of 1.8 x $10^{-4}$ (see Appendix A table 7.2.3) and from ingestion of milk contaminated with Ra-226+D, U-234 and U-238 which had an excess cancer risk of 2.3 X $10^{-4}$, 9.6 X $10^{-5}$, and 1.3 X $10^{-4}$ respectively.

The soil background area was selected based on its location further south from the Five Subdivisions which is close enough to be of the same soil make up as that of the Five Subdivisions but far enough to be impacted by HMC site related contaminants. The background farmer scenario was based on a hypothetical farmer living in the selected background area and is involved in subsistence living.

The estimated excess lifetime cancer risk from exposure to radionuclides of potential concern is shown in table 5-5 below. In an agricultural scenario, a hypothetical RME individual living at the Five Subdivision area and involved in subsistence living exposed to radionuclides of potential concern in different media namely soil, air, produce, beef, milk, poultry and egg

through different routes of intake and external exposure is expected to have a total excess cancer of 2.9 X $10^{-3}$ and a risk of 7.2 x $10^{-4}$ after subtracting risk from background exposures to the same media through the same routes of intake. EPA evaluates risk with background levels included. Subtraction of the background levels is not to determine if the estimated risk after subtracting background is less than 1 x $10^{-4}$, but for risk managers to distinguish the contribution of background risk to site risk. Most of the risk was due to inhalation of outdoor Radon 222 plus its progeny, assuming secular equilibrium between Radon 222 and its progeny, found in ambient air. The excess lifetime cancer risk from radon 222 gas from site-related contamination was calculated to be 5.0 X $10^{-4}$. The excess lifetime cancer risk for a farmer following a subsistence life style from direct and indirect exposure to ROPC in soil from site-related contamination is 2.2 X $10^{-4}$. Statistical comparison between outdoor radon at the Five Subdivisions versus outdoor radon levels at Bluewater Village (background) show statistical significant increase in the average of radon gas at the Five Subdivisions area over that in the background area (p-value = 0.000001).

Table 5-5 Estimated excess lifetime cancer risk from radionuclides exposure by an RME individual living at the Five Subdivisions residential communities located offsite and downgradient from HMC Superfund site assuming a current/future agriculture/farmer land use scenario.

| Medium | Exposure Pathway | Radionuclides Of Primary Concern | Cancer Risk Five Subdivisions | Cancer Risk- Background | Site Related Excess Life-time Cancer Risk |
|---|---|---|---|---|---|
| Soil | Ingestion, external, inhalation ,produce consumption, Beef, Milk, poultry and egg consumption | Ra-226+D (external exposure) and Ra-226+D, U-234 and U238 in milk | 1.1 x $10^{-3}$ | 8.8 x $10^{-4}$ | 2.2 x $10^{-4}$ |
| Air | Inhalation of Ambient Air | Rn-222 +D (inhalation) | 1.8 x $10^{-3}$ | 1.3 x $10^{-3}$ | 5.0 x $10^{-4}$ |
| Total | | | 2.9 x $10^{-3}$ | 2.18 x $10^{-3}$ | 7.2 x $10^{-4}$ |
| Well Water Added Risk[1] | Ingestion and inhalation | Rn-222+D & Ra-226 +D (inhalation) Ra-228+D (ingestion) | 2.2 x $10^{-3}$ | See [2] | See [2] |

[1] This is the added risk from exposure to radionuclides in well water in the event that a well is dug and used for domestic purposes sometime in the future. Currently all residents except for one Valle Verde resident are on Milan municipal water system. Risk to groundwater include risk from background.

[2] A true background was not determined for the site.

#### 5.1.4.4 Combined Risks from Radionuclides and Chemicals of Potential Concern

Risk assessment guidance (RAGS Vol. 1part A) recommend to add estimate of excess cancer risk to exposed individuals resulting from exposure to radionuclides and chemicals in different media as long as it is reasonable to assume that the same exposed individual will be exposed to both contaminants at the same time. This assumption is reasonable for an individual exposed to a mixture of radionuclide and chemical contaminants in the same media as expected at a Superfund site. In this risk assessment, cancer risk from exposure to COPC was similar to the cancer risk from background. Therefore the excess lifetime cancer risk from COPC were not added to the excess cancer risk from radionuclides associated with the site.

### 5.1.5 Risk from Consumption of Home grown Produce

Levels of ROPC in homegrown produce were both measured and modeled. The modeled levels were based on uptake of ROPC from soil into edible part of plant. Radionuclide specific transfer factors which are incorporated in the EPA Radionuclide Preliminary Remediation Goal (PRG) calculator were used in the model equations through the uptake of the ROPC from soil into plant. The modeled estimated total risk from ingestion of home grown produce in the Five Subdivisions was calculated at $1.3 \times 10^{-5}$ (table 5-1) most of the risk was from modeled uptake of Ra-226 and Ra-228 from soil into plant. However, measured Radium 226 and Radium 228 were not detected in almost all the vegetable samples. The modeled estimated total cancer risk from ingestion of home grown produce in a hypothetical vegetable garden in the background area was calculated at $1.1 \times 10^{-5}$. Of interest was the risk associated with modeled uptake of potassium 40 in soil into plant. Potassium 40 is not a site related radionuclide and occurs naturally in soil. The risk from ingestion of produce contaminated with modeled potassium 40 uptake from soil into plant at the Five Subdivisions was $3.4 \times 10^{-5}$. Compared to the risk of $3.8 \times 10^{-5}$ from ingestion of modeled uptake of potassium 40 in background soil into plant, indicates that the risk is due to background levels of potassium 40. The measured ROPC in the vegetation was found to vary among the different kinds of vegetation. Potassium 40 was found to accumulate the highest in pepper. Tomato had the least accumulation of potassium 40.
Risk from exposure to modeled uranium uptake from soil into plant was less than the EPA generally accepted lower end of the risk range of $1 \times 10^{-6}$ excess cancer risk (see table 5-1).

However, the risk from measured uranium 234 and uranium 238 in vegetables were 6.6 X $10^{-5}$ and 1.8 X $10^{-5}$ respectively (see table 5-5b). The HMC in its irrigation report (HMC 2010) did find accumulation of uranium in the top 3 feet of soil in the flood and central pivot irrigated fields. A factor of 2.59 over background was found in the irrigated section area No. 34 for an irrigation period from 2001 to 2009. Therefore, with continuous irrigation of vegetable gardens with contaminated well water will cause the contaminants to accumulate in the top 3 feet of soil and could lead to increase in the risk in the future.

The risk was evaluated based on modeling uptake of contaminants from soil into the roots and up into plants. The modeling was carried out since there were no vegetable gardens in the background soil area, which is a vacant open land, to compare it with the risk from consumption of home grown vegetables at the Five Subdivisions residential communities. The soil component is likely well-established enough to evaluate risk for many of the contaminants. Such evaluation include below ground vegetables such as carrots and potatoes. It also include above ground vegetables as the contaminants move from the roots up the stem into edible vegetables and fruits above ground. The foliar route, i.e. uptake of contaminants from irrigation water directly into leaves, remains an unknown, although there are certain constraints that limit risk. The typical irrigation cycle can be from one to many hours. Once plant surfaces are initially wetted, subsequent water flows to soil as run-off. This would likely be true for chemical forms having low to intermediate absorption rates and for elements with low adsorption rates, or with high absorption rates with limited leaf-surface binding sites. It may not be true for elements with exceptionally high bioavailability, as would possibly be the case for technetium and nickel. The question is how much of a particular element can be entrained, adsorbed, and/or absorbed during an irrigation event. Contribution of contaminants from irrigation water is usually much less than the uptake through the soil. But foliar interception, foliar absorption, transport, and leaching studies, while limited, tend to indicate that foliar contamination for at least some elements can be a significant added risk factor. Elements such as plutonium, americium, and cesium can be absorbed and transported to other plant structures. Data for many key radionuclides are not available and need to be determined. However, there are models that can roughly estimate the amount of nuclides that might be taken up through the foliage route from irrigation water into the edible part of vegetables. EPA attempt to model the sub-pathway through the foliage uptake of contaminants in irrigation water up into plant (see equation in table 3-6a) (U.S. NRC, 1977). The

risk from uptake of ROPC through the irrigation with contaminated well water is provided in table 5-5a.

Table 5-5a: Risk from consumption of produce irrigated with contaminated water wells at the Five Subdivisions

| Radionuclide | Conc. In Water Well (pCi/L) | Modeled Conc. in Plant (pCi/g) | Excess Cancer Risk |
|---|---|---|---|
| U-238+D | 13.32 | 5.43E-02 | 1.30E-06 |
| U-234 | 20.4 | 8.32E-02 | 6.07E-06 |
| Th-230 | 0.06 | 2.45E-04 | 5.60E-09 |
| Ra-228+D | 10.58 | 4.31E-02 | 1.08E-06 |
| Ra-226+D | 0.32 | 1.30E-03 | 1.27E-07 |
| Total | | | 8.50E-06 |

To reduce the uncertainty in modeling the uptake of contaminants from irrigation water or soil into the edible part of plant, EPA collected different types of vegetable samples after washing them with distilled water from private residential vegetable gardens observed in the Five Subdivisions and measured the level of radionuclides in them. The measured values for uranium was higher than the modeled value which is contrary to what one would expect since modeling tend to be conservative in its assumptions. The difference could be due to the use of fertilizers which are known to contain naturally occurring radionuclides material (NORM) especially uranium and its decay daughters. http://www.epa.gov/radiation/tenorm/fertilizer.html

EPA collected vegetable samples from different gardens from within the Five Subdivisions residential communities adjacent to Homestake Superfund site. Vegetable samples collected were sage, zucchini, corn, tomato, squash, pepper and miniature pumpkin. EPA measured for several radionuclides in these vegetable samples. Table 5-5b below provide the ROPC tested in vegetable samples, their corresponding concentration as the 95 % upper confidence level (UCL) on the arithmetic mean of all vegetable sample results and excess cancer risk from each radionuclide. The total cancer risk from consumption of vegetables grown in the Five

Subdivisions was calculated to be 1.0E-04. This risk includes radionuclides found in the background which are naturally occurring radioactive materials found in soil or water. The risk is at the upper end of the EPA generally accepted risk range of between 1 X $10^{-4}$ to 1 X $10^{-6}$. If the risk from potassium 40, which occurs naturally in the environment, is added to the risk, it pushes the risk to 1.5 X $10^{-4}$ which is slightly higher than the upper end of the acceptable EPA risk range of 1 X $10^{-4}$.

Table 5-5b provides the 95% UCL on the arithmetic mean of measured ROPC in different vegetable samples collected from the Five Subdivisions. Measured ROPC in vegetable samples include background levels. The risk from ingestion of vegetables contaminated with ROPC plus potassium 40 is 1.5 X $10^{-4}$. Which is slightly higher than the upper end of the EPA's generally accepted risk range target.

Table 5-5b. Excess cancer risk from consumption of vegetables contaminated with radionuclides measured in vegetable samples collected from gardens at the Five Subdivisions residential communities.

| Radionuclide | Plant Concentration (pCi/g)[1] | Excess Cancer Risk |
|---|---|---|
| Uranium-238 | 0.77 | 1.8E-05 |
| Uranium-234 | 0.91 | 6.6E-05 |
| Thorium-230 | 0.26 | 5.9E-06 |
| Radium-228 | 0.05 | 3.7E-06 |
| Radium-226 | 0.12 | 1.2E-05 |
| | Total | 1.0E-04 |
| Potassium-40* | 7.36 | 4.8E-05 |

*Potassium-40 occurs naturally in soil and in plant. Risk from potassium 40 is provided for general public information.

### 5.1.6 DCC calculator Results

The Radiation Risk Q&A guidance (U.S. EPA, 2012a) recommends that dose assessments only be conducted under CERCLA where necessary to demonstrate compliance with ARARs. The electronic calculator is intended to help site decision makers demonstrate compliance with dose-based ARARs (USEPA 1997a) at radioactively contaminated CERCLA sites. Dose estimates are typically expressed in terms of annual exposure such as mrem/year. The Radionuclide ARAR Dose Compliance Concentrations (DCCs) for Superfund electronic

calculator (USEPA 2004a) may be found at the following website: http://epa dccs.ornl.gov/ radionuclides /

This DCC calculator focuses on the application of a generic and simple site-specific approaches that are part of a larger framework for calculating concentration levels for complying with dose based ARARs. Generic DCCs for a 1 mrem standard are provided by viewing either the tables in the Download Area section of this calculator or by running the DCC Search section of this calculator with the "Get Default ARAR Concentrations" option. Part 3 of the Soil Screening Guidance for Radionuclides: Technical Background Document provides more information about more detailed approaches that are part of the same framework.

Generic DCCs are calculated from the same equations presented in the site-specific portion of the calculator, but are based on a number of default assumptions chosen to be protective of human health for most site conditions. Generic DCCs, which should be scaled to the same dose level as the standard being complied (e.g., multiplied by a factor of ten for a 10 mrem/year standard) can be used in place of site-specific DCC levels; however, in general, they are expected to be more conservative than site-specific levels.

Tables 5-6 to table 5-8 summarize the results of the DCC calculator for radionuclides in soil, ambient air and water at the Five Subdivisions area. Table 5-6 shows that the total dose from exposure to ROPC in soil through the incidental ingestion of soil, inhalation of particulates, external exposure and consumption of produce excluding background is 2.48 mrem/year. The dominant radionuclide contributing the majority of this dose is radium 226.

Table 5-6: ARARs Dose Compliance calculator results for radionuclides of concern in **soil** and the dose estimated for the Five Subdivisions area.

| ROPC | Soil (pCi/g) | Background Soil (pCi/g) | Difference (pCi/g) | Total DCC (pCi/g)[1] | Dose (mrem/yr) |
|---|---|---|---|---|---|
| Ra-226 | 2.5 | 1.81 | 0.69 | 0.28 | 2.46 |
| Ra-228 | 1 | 1.14 | 0 | 0.4 | 0.00 |
| Th-230 | 1.6 | 1.39 | 0.21 | 26.2 | 0.01 |
| U-234 | 1.5 | 1.14 | 0.36 | 93.7 | 0.00 |
| U-238 | 1.6 | 1.15 | 0.45 | 100 | 0.00 |
| | | | | | |
| | | | | Total | 2.48 |

[1] Total DCC includes exposure through the ingestion of soil, inhalation of particulates, external exposure and consumption of produce. Numbers produced from EPA DCC calculator.
Soil concentration in pCi/g associated with 1 mrem/yr

In table 5-7, the dose from exposure to ROPC in air through the inhalation and submersion routes of exposure excluding background is 8.14 mrem/year. The dominant radionuclide contributing to the majority of the dose is radon 222 +D. The dose for radon was from external exposure only since there is no EPA dose conversion factor for inhalation route of intake.

Table 5-7: ARARs Dose Compliance calculator results for radionuclides of concern in ambient **air** and the dose estimated for the Five Subdivisions area.

| ROPC | Air Conc.(pCi/$m^3$) | Background Air Conc. (pCi/m3) | Difference (pCi/m3) | Total DCC (pCi/m3)[1] | Dose (mrem/yr) |
|---|---|---|---|---|---|
| Radon+D[2] | 1360 | 510 | 850 | 107 | 7.94 |
| Uranium | 0.00242 | | 0.00242 | 0.0148 | 0.16 |
| Th-230 | 0.000114 | | 0.000114 | 0.00306 | 0.04 |
| Ra-226 | 0.000123 | | 0.000123 | 0.0123 | 0.01 |
| | | | | Total | 8.14 |

[1] Total DCC includes exposure through the inhalation and submersion (external exposure) routes of intake.
Air conc. Associated with 1 mrem/yr.
[2] Radon dose is through external exposure route only there are no EPA Dose Conversion Factor for inhalation.

Therefore the total dose for a hypothetical RME individual living in the Five Subdivisions community and exposed to ambient air and soil will have a total dose excluding background of 10.62 mrem/year (2.48 mrem/yr +8.14 mrem/yr). The Air emissions criteria set by the National Emission Standards for Hazardous Air Pollutants (40 CFR 61.H&I ) for emissions of radionuclides other than radon is 10 mrem/year to the nearest off-site receptor. Also National Emission Standards for Radon Emissions From Underground Uranium Mines (40 CFR 61.22 subpart B) says the "Emissions of radon-222 to the ambient air from an underground uranium mine shall not exceed those amounts that would cause any member of the public to receive in any year an effective dose equivalent of 10 mrem/y.

Although the EPA-promulgated standards in the UMTRCA do not apply to the site, they are considered relevant and appropriate since the material is mill tailings. The NESHAP (40 CFR 61.22 subpart B) standard for radon-222 of 10 mrem/year is an ARAR for the site. The dose level of 8.14 mrem/year calculated for air exposure is less than the ARAR. However, dose from inhalation of radon was not included in the dose calculations. If we use the inhalation DCF used by HMC and NRC then the calculation will yield higher levels. The NRC 10 CFR Part 20 Appendix B provides an inhalation dose conversion factor of 0.1 pCi/l associated with

committed effective dose equivalent (CEDE) of 50 mrem/year (or 500 mrem per 1 pCi/l). If we assume a 50% equilibrium factor as recommended by NRC when exposure is for both indoor and outdoor radon gas and a 75% occupancy factor, then a dose conversion factor of 188 mrem/year would be associated with 1 pCi/l (500 x 50% X 75%). The radon concentration at the five subdivisions is 1360 pCi/$m^3$ or (1.36 pCi/l). Subtracting a background level of 510 pCi/$m^3$ or (0.51 pCi/l) from 1.36 pCi/l will yield 0.85 pCi/l, which is similar to what Homestake reported for its air monitors (HMC # 4 and HMC # 5) at the Homestake fence line. The 0.85 pCi/l radon gas will be associated with an effective dose equivalent (EDE) of 160 mrem/year (188 mrem/year X 0.85) which is much higher than the NESHAP (40 CFR 61.22 subpart B) standards of 10 mrem/yr.

In table 5-8, an additional exposure was calculated using the ingestion of tap water pathway. This pathway is considered in the rare event that a new resident move into the community and does not get connected to Milan municipal water and dig a private well for domestic uses (ingestion, cooking, showering, dishwashing etc.). The total dose including background is 38.23 mrem/year. The groundwater in the alluvium aquifer was found contaminated by site related contaminants. Currently homes at the Five Subdivision are all connected to the Milan municipal water except for one Valle Verde resident who refused to connect his water supply to the municipal water. There is no EPA dose conversion factor for radon gas and thus was not included in the calculations. The dose is expected to be higher than the 38.23 mrem/year if radon gas is included.

Table 5-8 :ARARs Dose Compliance calculator results for radionuclides of concern in Private well water and the dose estimate for the Five Subdivisions residential communities..

| ROPC | Well Water 95% UCL (pCi/l) | Background Water 95% U | Difference | Total DCC (pCi/l)[1] | Dose (mrem/yr) |
|---|---|---|---|---|---|
| Ra-226 [2] | 0.32 | N/A[3] | 0.32 | 0.0241 | 13.28 |
| Ra-228+D | 11 | N/A | 11 | 0.517 | 21.28 |
| Th-230 | 0.06 | N/A | 0.06 | 2.04 | 0.03 |
| U-234 | 20 | N/A | 20 | 8.76 | 2.28 |
| U-238 | 13 | N/A | 13 | 9.53 | 1.36 |
| Rn-222 | 950 | N/A | 950 | N/C[4] | N/C |
| | | | | Total | 38.23 |

[1] Total DCC includes exposure through the inhalation and ingestion routes of intake. Water concentration associated with 1 mrem/yr.

[2] Ra-226 was evaluated through the ingestion plus inhalation routes of intake. All other radionuclides through the ingestion route only.

[3] N/A = Not Available.

[4] N/C = Not calculated since there are no EPA dose conversion factor for radon gas.

#### 5.1.6.1 RESRAD Calculations

Another method for calculating dosages and risks is the RESRAD computer model. RESRAD is a computer model designed to estimate radiation doses and risks from RESidual RADioactive materials. The computer code was first released in 1989 and has been updated since then to improve the models within the codes and to use new state of science radiation dose and risk factors (Yu, L 1993). Argonne National Lab provides documentation and training on its use. Their web address is http://www.evs.anl.gov/resrad . EPA Superfund risk assessment does not recommend this model approach in its evaluation of risk at Superfund sites and instead recommends the use of its risk assessment procedures to be consistent in its risk evaluation with chemical contaminants and with its CERCLA rules (USEPA 1999). However, EPA Region 6 Superfund program decided to use the RESRAD computer model in addition to its standard way of developing risk assessment for Superfund sites since the United States Nuclear Regulatory Commission (NRC) and the Department of Energy (DOE) are stakeholders in this site and RESRAD is their reference model for such evaluations. Appendix C provides the results of RESRAD calculations for the Five Subdivisions residential communities adjacent to the HMC site and for the background area selected for the Five Subdivisions residential communities. Both dose and cancer risk calculations were made using the model.

The maximum total dose with radon calculations suppressed for the Five subdivisions is 40.26 mrem/year at time = 72.5±0.1 years. The maximum total dose with radon calculations suppressed for the background area is 31.9 mrem/year at time = 2.05±0.004 years. Therefore the extra maximum total dose with radon calculations suppressed at the Five subdivisions is:

40.26 mrem/yr - 31.9 mrem/yr = 8.36 mrem/year excluding background.

The maximum total dose with radon calculations activated for the Five subdivision is 178.4 mrem/year at time = 2.05 ±0.004 years and the maximum total dose from background is 132.1 mrem/year at time = 1.776±0.004 years. Therefore the extra maximum total dose with radon calculations activated excluding background is 46.1 mrem/year at the Five Subdivisions.
The total dose was based on the sum of doses from Radium 226, Radium 228, Thorium230, Uranium 234 and Uranium 238 through the Ground (external), Inhalation, Radon, Plant, Meat, Milk and Soil exposure pathways.

Figures 5-1 to figure 5-4 depicts the radionuclides evaluated through different pathways of exposures. It is clear from the figures that radium 226 is the dominant nuclides of concern and its decay product radon gas contributes most of the dosage exposure.

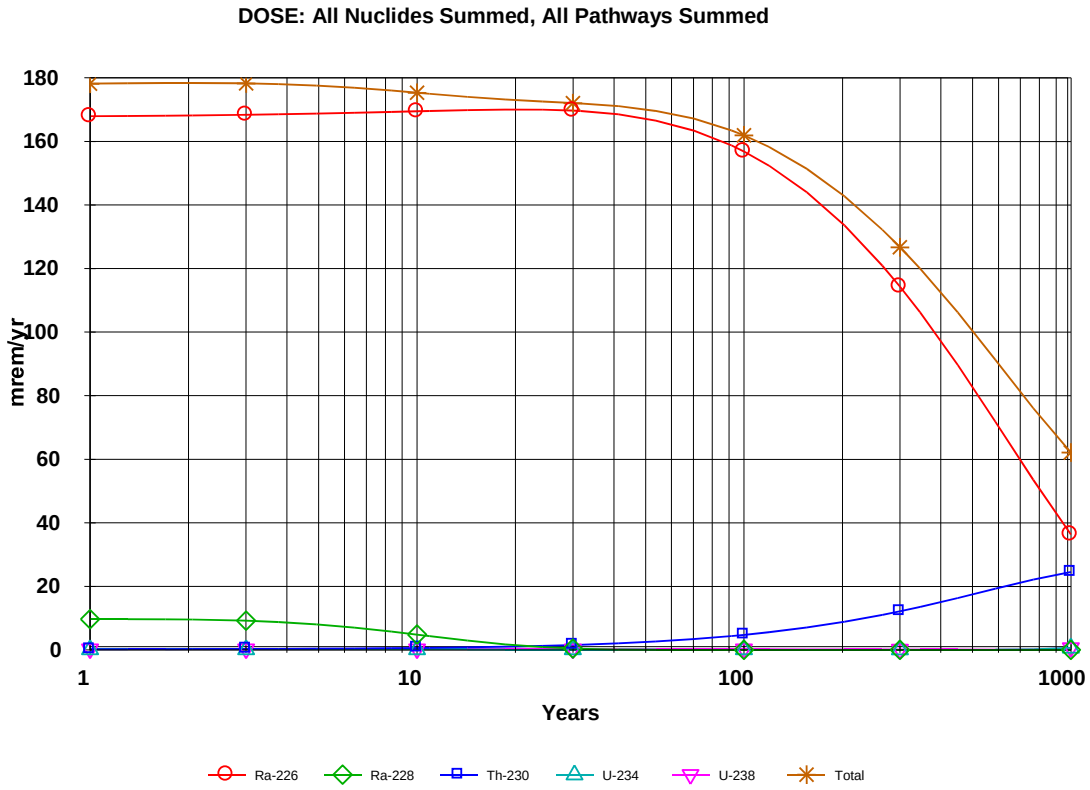



Figure 5-1: Dose estimates including background calculated for all nuclides of potential concern with radon calculations activated and summed for a predicted time of 1000 years in the future.

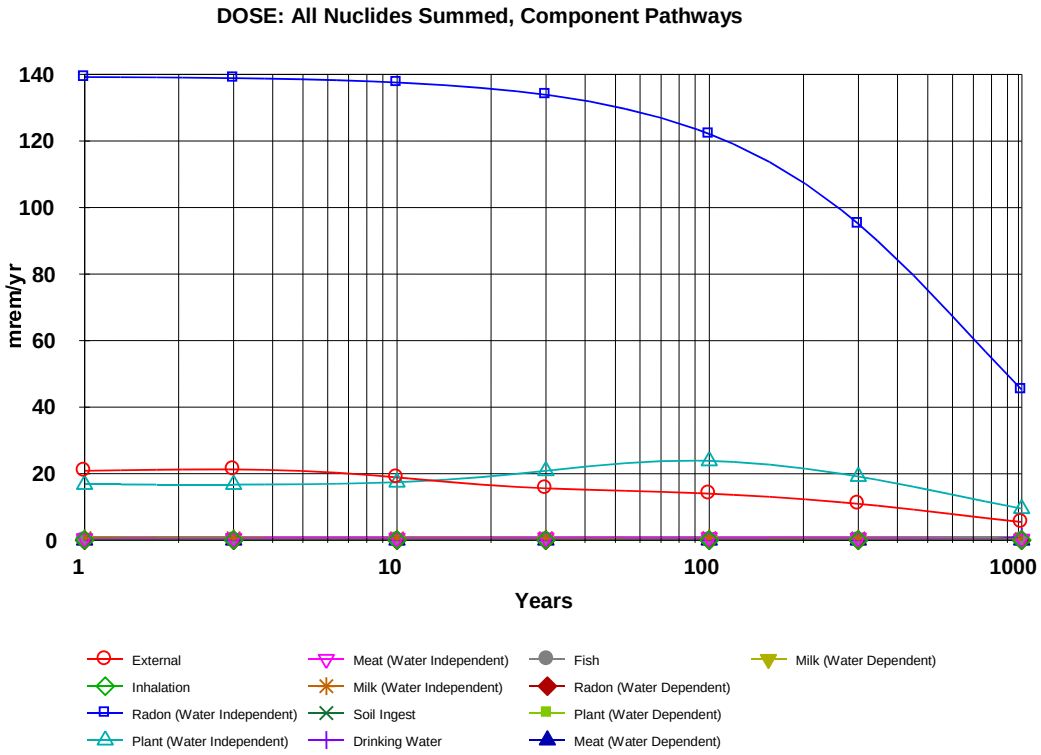



Figure 5-2: Estimated dose calculated for ROPC and through different pathways of exposure predicted for a 1000 years in the future.

EPA also ran the RESRAD analysis by first subtracting the background radionuclides concentrations from the radionuclide concentrations measured in the five subdivisions and using the difference as the RESRAD input value. Figures 5-3 and 5-4 depicts the estimated dose excluding background through different pathways of exposure predicted for a 1000 years in the future. The maximum Tdose (t) was 47.9 mrem/year at t = 23.10 years. Most of the dose (79%) was contributed by radon gas. Plant consumption contributed 11% and external ground exposures contributed 9% of the dose.

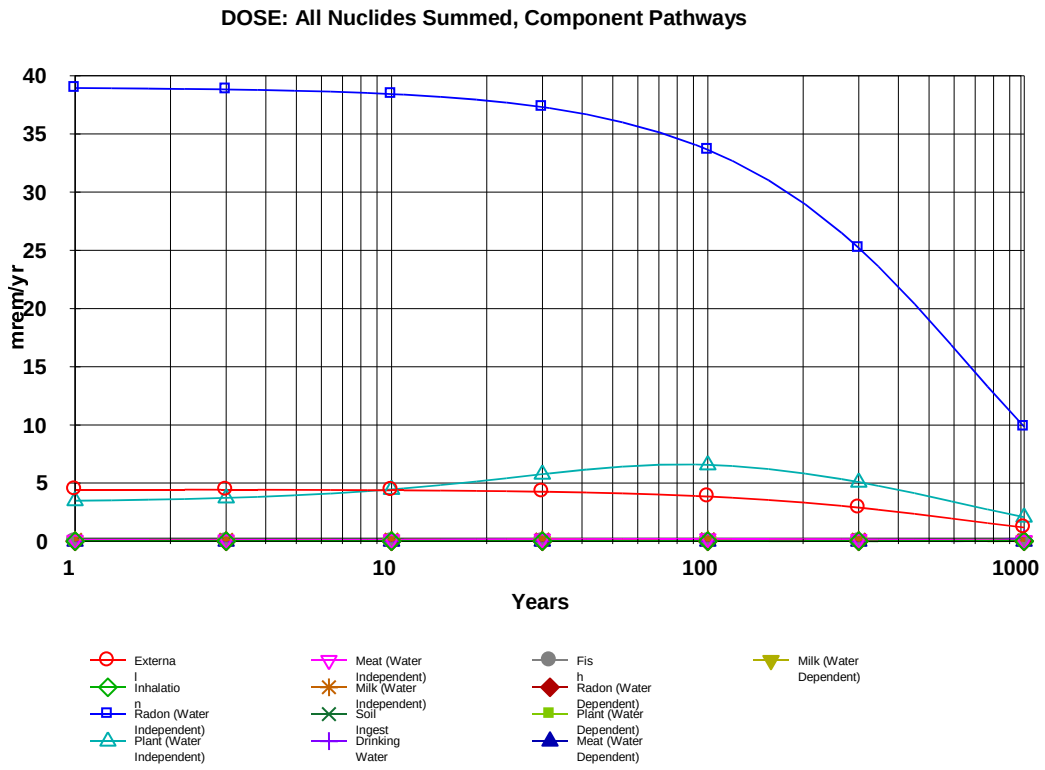



Figure 5-3: Dose calculated excluding background, from exposure to all ROPC through all the pathways with radon calculations activated and predicted for a 1000years in the future.

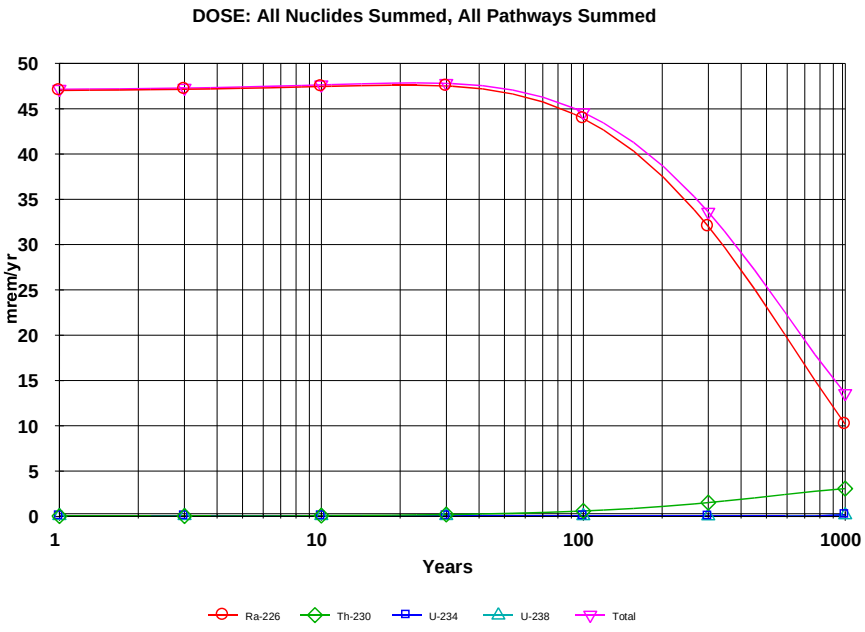



Figure 5-4: Dose excluding background from ROPC summed up for all pathways.

In addition to dose calculations, the RESRAD model can be used to calculate excess cancer risk. Figure 5-5 below depicts the excess cancer risk over 1000 years in the future. Of interest is the risk at 30 years in the future which had a total risk from combined exposure to ROPC through the inhalation (excluding radon), ingestion of soil, ground or external exposure, inhalation of radon gas, consumption of plant, meat and milk, routes of intake had a total excess cancer risk of 8.3E-04. Exposure to radon in air is the predominant radionuclides responsible for 6.48E-04 of the total excess cancer risk, followed by external exposure and plant ingestion which had an excess cancer risk of 9.5E-05 and 8.0E-05 respectively.

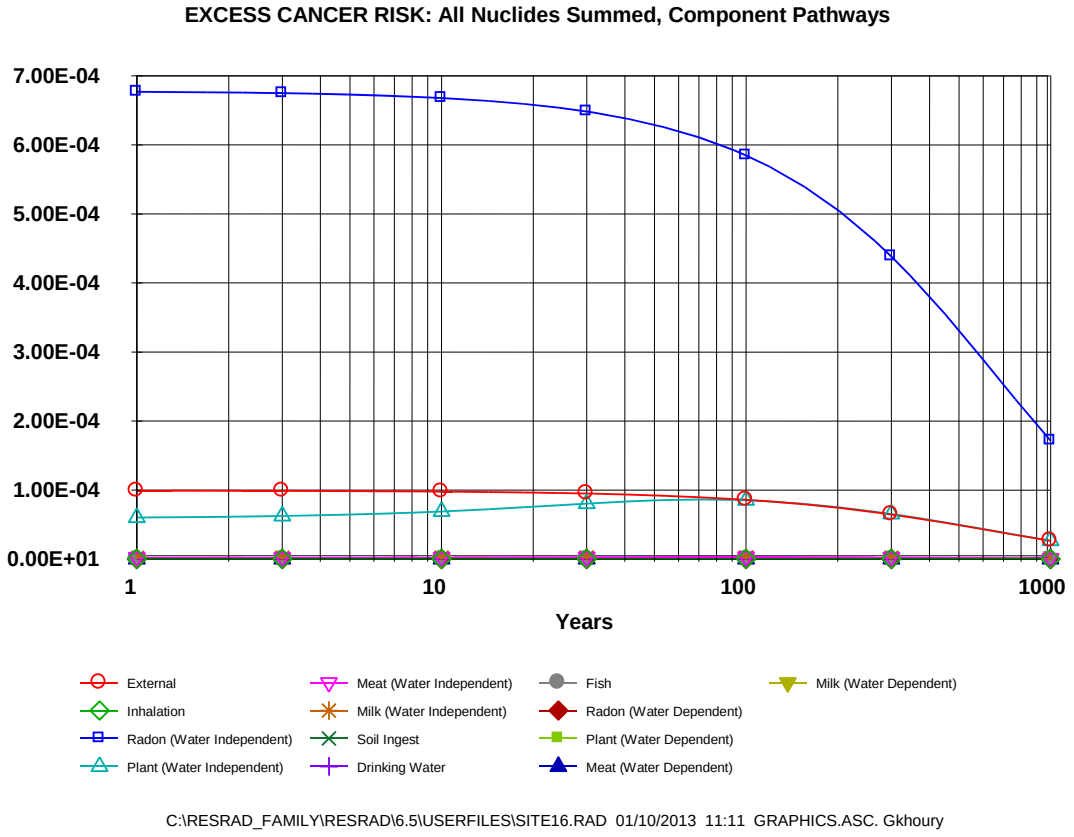



Figure 5-5: Excess cancer risk excluding background through different pathways as calculated by the ResRad model for an individual living in the Five Subdivision area.

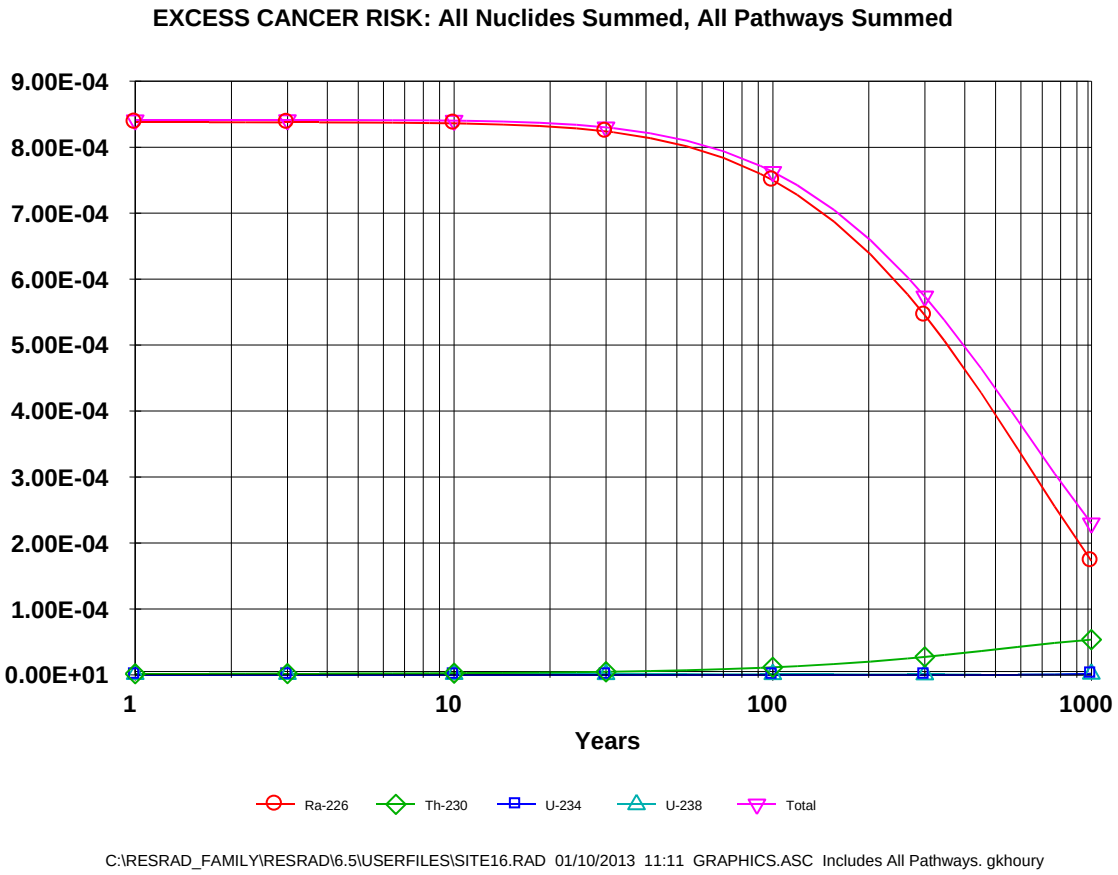



Figure 5-6: Risk calculations for the Five Subdivision excluding background using RESRAD All pathways summed. It shows the ROPC with the highest risk.

## 5.2 Radon Evaluation

Radon sampling was divided into three categories. First category was sampling residential areas indoor air and outdoor ambient air in the immediate vicinity of the residences. Second category was sampling of radon at different locations along the fence line between the residential areas and HMC properties. Third category was sampling along a line starting from an area upgradient from HMC facility to downgradient within site boundary of HMC facility towards the fence line separating the HMC site from the residential area. Each category had a specific objective and each objective was tested statistically to answer a specific question regarding radon contamination and its source as described below.

Descriptive statistics for each category were reported and discussed in section 2. However, statistical evaluation beyond the descriptive statistics was necessary to better understand the radon data. Analysis of variance (ANOVA) tests were first performed using STATISTICA version 10 program to determine the significance of location interactions on the indoor or outdoor air radon measurements. If significance was determined by ANOVA tests, then different “A Posteriori Tests" post-hoc comparison of group means (i.e., location means) were carried out to further define differences between locations and determine which location is causing the difference. That is check if there is a significant difference in the indoor or outdoor air radon levels among the Five Subdivisions (Broadview Acre, Pleasant Valley Estate, Murray Acre, Felice Acre and Valle Verde) and the background area taken each separately. Also Wilcoxon-Mann-Whitney for two samples statistical test was carried out, using ProUCL version 4.1, for all indoor or outdoor radon data from all the subdivisions taken together and compared to all background indoor or outdoor radon data.

For category one indoor radon, the statistical tests did <u>not</u> show significant difference between the subdivisions and the background area (p-value = 0.20). However, the tests did show significant difference between the outdoor radon levels in the Five Subdivisions as compared to the background outdoor radon levels at p-value < 0.05 for each subdivision when compared to the background. This is discussed further below.

For category 2 radon data, the Wilcoxon-Mann-Whitney two sample statistical test did show a significant difference between levels of radon collected at the 6 inches high monitors and the 5 feet high air monitors both placed at the same posts at the fence line. This indicates that soil in the investigation area is one of the contributing sources to radon gas in ambient air in addition to other natural and man-made sources of radon at the site.

For category 3 radon data, analysis of variance and post-hoc tests performed on the outdoor radon data collected from each of the Five Subdivisions, fence line, and upgradient from HMC showed significant difference of each of the locations with the air monitors placed on HMC property within site boundary downgradient from the evaporation pond but not among each other.

EPA monitored the air radon levels at the area north to north east (upgradient) of the Homestake site to assess the impact of radon gas coming towards the Homestake facility from natural and anthropogenic background sources (especially legacy mines spread to the north and east of the Site). EPA placed its air monitoring stations along a line in the drainage low-lying areas since radon gas is much heavier than air and is expected to accumulate in these areas more than it would in other locations.

The upgradient air monitors did not show a trend in the level of radon-222 flowing from the north towards the HMC Facility. Upwind air monitor closest to the LTP from the north had radon-222 levels higher than the radon-222 levels in the air further north of the LTP. Total radon (radon-222 + thoron gas) measured at the downgradient air monitors within the HMC site boundary showed higher levels than the upgradient air total radon levels. A comparison between the upgradient air monitors and the downgradient air monitors within the Homestake facility boundary showed a statistically significant increase in the mean level of total radon (radon-222 + radon-220) at the air monitors downgradient from the HMC facility over that of upgradient radon levels. Indicating a nearby source of radon gas which EPA believes is mainly coming from the LTP.

The impact of radon/thoron gas that was seen at the HMC downgradient monitors and within site boundary was not seen at the fence line air monitors or at the community at large. Although, the average of radon at the fence line and at the Five Subdivisions residential communities' air

monitors were higher than the upgradient air monitors, the statistical tests were unable to pick up the difference at the 95% confidence interval between upgradient monitors and monitors at the fence line or in the residential communities. This shows that the impact of the outdoor radon gas coming from the site towards the residential communities is small relative to indoor radon gas. But still presented a risk of $5 \times 10^{-4}$ which is higher than the EPA acceptable upper end of the risk range of $1 \times 10^{-4}$.

**Effect of Thoron on Radon Data.**

Thoron gas (Rn-220) which is an isotope of Radon gas (Rn-222) has been recently found to impact measurements of radon-222 gas (Shang et al 2008). Radon gas is ubiquitous and relatively stable. It has two naturally occurring isotopes – radon (Rn222) and thoron (Rn220). Both have 86 protons but they have different numbers of neutrons which gives them different atomic mass numbers (ANL 2007). The parent radium isotope for Rn-222 is Ra-226 and the parent radium isotope for Rn-220 or thoron is Ra-224. Although thoron is produced from the radioactive decay of Ra-224, it is often referred to as a decay product of Ra-228, which is a longer-lived precursor typically measured in environmental samples. Thoron itself has only a 55.6 second half life compared to radon's 3.825 days. Thoron like Rn-222 is also a noble gas, which means it is a free agent in the soil and can easily move out of the soil into homes. The difference however is while Rn-222 has plenty of time to meander up through the soil once it is produced by radium's decay in the soil; thoron has literally a few minutes to make it. In the Homestake study the thoron gas was not found at significant levels along with radon -222 inside the homes as was seen in the outdoor ambient air. This could mean that the source of thoron may be coming through the air from a continuous source such as the HMC facility and not from soil. However, because of its short half-life, thoron seems to decay in the air before it arrives to the community. Rn-222 decay product is solid and behaves as an airborne particle. When thoron decays it becomes a solid reactive particle that will easily cling to dirt in the soil or dust in the air. The decay product of thoron, lead-212, has a fairly long half-life of 10.6 hours so it is likely to be breathed into the lungs if it is air borne. But because of its long half-life compared to radon decay product half-life the lungs may be able to push it back out before it decays. These two factors of not having enough time to get out of the soil and into a home and the long decay life of

its decay product has generally placed thoron in the low risk category for inducing lung cancer. However, thoron and its progenies can still contribute to lung dose (Tschiersch, W.B. Li, 2007)

Thoron gas is usually not investigated for at NPL sites unless there is a reason to do so. Initially EPA did not have a reason to suspect a thoron effect, but towards the middle of the investigation, sampling results started coming back indicating potential thoron effects on the results. Therefore, for a period of six months, i.e. during the third and fourth quarter period of collecting indoor and outdoor radon samples, EPA investigated the thoron effect on radon results by placing side by side air radon monitors with and without thoron filters and developed radon correction factors. Thoron gas is then calculated based on equations and procedures provided by Department of Energy (Pearson, et al. 1991). A total of 156 air samples for both types of air monitors were collected from the whole investigation area including the background area. From the investigation area, fifty co-located samples (with and without thoron filters) were collected from the Five Subdivisions area, thirty eight co-located samples were collected from the fence line and twenty four co-located samples were collected from the Homestake area. Forty four co-located samples were collected from the background area. For indoor radon results, the average correction factors for thoron for both the Five Subdivisions and Bluewater areas were 1.2 and 1.36 respectively. For outdoor radon results, the average thoron correction factors for the Five Subdivisions, Bluewater (background), fence line, upgradient and downgradient from HMC were, 2.75, 1.39, 2.74, 1.79 and 5.15 respectively. It is of interest to note that the thoron impact on radon levels was much higher on radon levels at Homestake property within site boundary just downgradient from the HMC facility compared to background radon levels and radon levels upgradient from the HMC facility (Table 5-9). Implying a potential thoron source in the nearby vicinity of the downgradient area of HMC facility, most likely the LTP.

The thoron investigation indicated that the LTP, a common source for radon-222 and thoron gas at the HMC site is a source of total radon gas (Radon-222 plus Thoron gas (Radon-220)) to the downgradient communities. As discussed in Section 5.2 (Radon Evaluation) of the HHRA, the downgradient air radon monitors within HMC boundary reported higher average levels of radon (1.8 pCi/L, thoron gas included) than the average HMC upgradient radon levels (1.0 pCi/L, thoron gas included). Given that thoron gas has a half-life of 55.6 seconds, the difference in upgradient and downgradient readings indicates that radon gas is coming from nearby sources such as the LTP or the evaporation ponds. Again as mentioned above, the amount

of radon gas coming from the site is small, but the excess cancer risk was 5 X $10^{-4}$ which is slightly above the EPA's acceptable upper end of the risk range of 1 X $10^{-4}$. The majority of the risk is due to radon-222 while thoron gas has negligible risk (See table 5-1 for the risk contributed by thoron gas).

Table 5-9: Comparison of radon results using air monitors with and without thoron filters collocated at HMC property during the 3rd and 4th quarter radon sampling periods (pCi/L).

| Location | Monitors with Thoron Filters | Monitors without Thoron Filters | Correction Factors for Thoron gas | Correction Factors Average of 2 Qs |
|---|---|---|---|---|
| HMC01-03-A | 0.4 | 0.8 | 2.00 | 1.75 |
| HMC01-04-A | 0.6 | 0.9 | 1.50 | |
| HMC02-03-A | 0.6 | 1 | 1.67 | 2.13 |
| HMC02-04-A | 0.5 | 1.3 | 2.60 | |
| HMC04-03-A | 0.9 | 1.2 | 1.33 | 1.50 |
| HMC04-04-A | 0.6 | 1 | 1.67 | |
| HMC05-03-A | 0.3 | 1.7 | 5.67 | 5.33 |
| HMC05-04-A | 0.4 | 2 | 5.00 | |
| HMC07-03-A | 0.3 | 1.7 | 5.67 | 4.96 |
| HMC07-04-A | 0.4 | 1.7 | 4.25 | |
| HMC08-03-A | 0.3 | 1 | 3.33 | 2.57 |
| HMC08-04-A | 0.5 | 0.9 | 1.80 | |

In order to better understand what the radon data is telling us, further analysis beyond descriptive statistics of the data were performed. Analysis of variance and hypothesis testing comparing different means of the Five Subdivisions with the background area were performed.

An analysis of variance (ANOVA) test statistics was carried out for all the indoor radon data put together including the background (Bluewater) data to determine the significance of location interactions on the indoor air radon measurements. The analysis did show a significant difference between the data (See table 5-10) at the 95% confidence interval (CI) indicating a significant location interaction at a p-value of 0.001740. Because the analysis of variance indicated a significant difference among the data and a potential location effect exist, different "A Posteriori Tests" post-hoc comparison of group means (i.e., location means) were carried out to further define differences between locations and determine which location is causing this difference. The Scheffe test, Tukey unequal sample size test, and Dunnett test were performed on the indoor data. Significance in any one of the three test would indicate a significance in the compared data.

The Dunnett test was considered in this evaluation since the test can be used to compare all group means taken separately to be compared with a control group regardless of the outcome of the overall F value. In HMC case the control group was considered to be the background (Bluewater Village) area. The Scheffe test (table 5-11) show that there is a statistical significant increase of radon level at Valle Varde compared to Broadview Acres (p-value of 0.005422) but not with the background area (Bluewater Village).

Table 5-10. Analysis of Variance (ANOVA) test statistics for indoor radon data at the Five Subdivisions and Bluewater.

| Variable | Analysis of Variance (All data put together including background data) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | SS Effect | df Effect | MS Effect | SS Error | df Error | MS Error | F | Analysis of Variance. Marked effects are significant at p < 0.05 |
| Radon without Thoron Filter | 32.70 | 5 | 6.54 | 158.37 | 101 | 1.57 | 4.17 | 0.001740 |

The "Cell No." in Table 5-11 denotes the Location. So Cell No. 5 is associated with Valle Verde location. The Cell No. placed at the top of each column refer to the location associated with the number. So the data from Broadview were tested against Valle Verde (Column head 5) data and the results show a significant difference with p-value denoted here in bold red color of 0.005422. A p-value less than 0.05 indicates significance.

Table 5-11:Scheffe post hoc statistic test to check if indoor radon levels are impacted by location.

| Cell No. | Scheffe test; variable Radon without Thoron Filter (Indoor Radon Data for Five Subdivisions and Bluewater). Probabilities for Post Hoc Tests Error: Between MS = 1.5680, df = 101.00 | | | | | | |
|---|---|---|---|---|---|---|---|
| | Location | 1 1.1967 | 2 1.8014 | 3 2.2535 | 4 1.6987 | 5 3.0358 | 6 1.5715 |
| 1 | Broadview | | 0.935238 | 0.226699 | 0.886377 | **0.005422** | 0.943087 |
| 2 | Felice Acres | 0.935238 | | 0.985998 | 0.999988 | 0.511328 | 0.999204 |
| 3 | Murray Acres | 0.226699 | 0.985998 | | 0.892188 | 0.749079 | 0.696962 |
| 4 | Pleasant Valley | 0.886377 | 0.999988 | 0.892188 | | 0.155721 | 0.999773 |
| 5 | Valle Verde | **0.005422** | 0.511328 | 0.749079 | 0.155721 | | **0.050625** |
| 6 | Bluewater | 0.943087 | 0.999204 | 0.696962 | 0.999773 | **0.050625** | |

In table 5-12, the Tukey Unequal number Honestly Significant Difference (HSD) test confirmed the above test and in table 5-13, no significant difference between the Five Subdivisions locations and the background was observed using the Dunnett test.

Table 5-12 Tukey Unequal number HSD test performed on indoor radon data for the Five Subdivisions and Bluewater.

| Cell No. | Unequal N HSD; variable Radon without Thoron Filter (Radon Data for Five Subdivisions and Bluewater)<br>Approximate Probabilities for Post Hoc Tests<br>Error: Between MS = 1.5680, df = 101.00 | | | | | | |
|---|---|---|---|---|---|---|---|
| | Location | 1<br>1.1967 | 2<br>1.8014 | 3<br>2.2535 | 4<br>1.6987 | 5<br>3.0358 | 6<br>1.5715 |
| 1 | Broadview | | 0.944836 | 0.170769 | 0.834695 | **0.006569** | 0.888594 |
| 2 | Felice Acres | 0.944836 | | 0.984332 | 0.999989 | 0.442593 | 0.999407 |
| 3 | Murray Acres | 0.170769 | 0.984332 | | 0.809352 | 0.645713 | 0.639231 |
| 4 | Pleasant Valley | 0.834695 | 0.999989 | 0.809352 | | 0.102960 | 0.999678 |
| 5 | Valle Verde | **0.006569** | 0.442593 | 0.645713 | 0.102960 | | **0.055731** |
| 6 | Bluewater | 0.888594 | 0.999407 | 0.639231 | 0.999678 | **0.055731** | |

Table 5-13. Dunnett test compares the mean of a control group or background area (Bluewater) to the mean of each subdivision at the Five Subdivisions area.

| Cell No. | Dunnett test; variable Radon without Thoron Filter (Radon Data for Five Subdivisions and Bluewater)<br>Probabilities for Post Hoc Tests (M<Control)<br>Error: Between MS = 1.5680, df = 101.00 | |
|---|---|---|
| | Location | 6<br>1.5715 |
| 1 | Broadview | 0.412926 |
| 2 | Felice Acres | 0.958394 |
| 3 | Murray Acres | 0.999673 |
| 4 | Pleasant Valley | 0.945724 |
| 5 | Valle Verde | 0.999956 |
| 6 | Bluewater | |

Based on all the Post-hoc statistical evaluation, of the indoor radon data collected from the Five Subdivisions and from Bluewater (background) areas, indicate that there is no significant

difference between the indoor radon levels at the Five Subdivisions taken separately and the background area. Also Wilcoxon-Mann-Whitney test for two samples did not show a significant difference (p-value = 0.20) between the indoor radon data of the Five Subdivisions taken together and the indoor radon levels at the background area (Bluewater Village). Therefore it is concluded that there is no significant difference between the Five Subdivisions annual indoor air radon levels and the background annual indoor air radon levels.

The indoor radon annual quarterly average values corrected for thoron (thoron gas included) were compared to the annual radon data with thoron filter (thoron gas removed). The Two Sample Wilcoxon-Mann-Whitney test was run on the data and showed that both data were not significantly different from each other (p value = 0.943). This indicates that thoron values did not have a significant effect on indoor radon values as is expected since homes shield the thoron from entering into the residence.

Table 5-14 and table 5-15 show the descriptive statistics for indoor radon data at the Five Subdivisions using radon air detectors with and without thoron filter.

Table 5-14: Descriptive statistics for indoor radon data for the Five Subdivisions and Bluewater using thoron filter detectors (Rn-222 only) in pCi/l.

| Variable | Valid # | Mean | Geometric - Mean | Median | Min. | Max. | Range | Std. Dev. | Coef. Var. | Kurtosis | 95% UCL | UCL Basis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **All 5 subdivisions** | 79 | 1.55 | 1.18 | 1.12 | 0.30 | 6.00 | 5.70 | 1.17 | 75.32 | 1.59 | 2.12 | Chebyshev |
| **Broadview Acres** | 26 | 0.99 | 0.77 | 0.64 | 0.30 | 3.63 | 3.33 | 0.88 | 88.61 | 3.76 | 1.75 | Chebyshev |
| **Felice Acres** | 7 | 1.50 | 1.31 | 1.43 | 0.55 | 2.57 | 2.02 | 0.79 | 52.65 | -1.93 | 2.08 | Student’s -t |
| **Murray Acres** | 16 | 1.88 | 1.65 | 1.87 | 0.47 | 3.55 | 3.08 | 0.87 | 46.24 | -0.33 | 2.26 | Student’s-t |
| **Pleasant Valley** | 18 | 1.41 | 1.15 | 0.97 | 0.50 | 3.90 | 3.40 | 1.04 | 73.59 | 0.99 | 1.95 | H-UCL |
| **Valle Verde Acres** | 12 | 2.52 | 1.92 | 2.53 | 0.40 | 6.00 | 5.60 | 1.69 | 66.93 | -0.09 | 3.41 | Student’s-t |
| **Bluewater Village** | 28 | 1.16 | 0.92 | 1.02 | 0.30 | 3.95 | 3.65 | 0.86 | 74.00 | 3.59 | 1.45 | Gamma |

Table 5-15: Descriptive Statistics (Indoor Radon Data for houses at the Five Subdivisions) and houses at Background Area (Bluewater Village)* in pCi/l. Radon measurements include thoron gas (Rn-222+Rn-220).

| Radon Adjusted for Thoron | Valid N | Mean | Geometric - Mean | Median | Min. | Max. | Range | Std. Dev. | Coef. Var. | Kurtosis | UCL 95% | UCL Basis | No. ≥ 4 pCi/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **All 5 subdivisions combined** | 79 | 1.86 | 1.42 | 1.34 | 0.36 | 7.20 | 6.84 | 1.40 | 75.33 | 1.59 | 2.54 | Non-Para | 11/79 |
| **Broadview Subdivision** | 26 | 1.20 | 0.92 | 0.77 | 0.36 | 4.36 | 4.00 | 1.06 | 88.63 | 3.76 | 2.103 | Non-Para | 2/26 |
| **Felice Acres Subdivision** | 7 | 1.80 | 1.57 | 1.71 | 0.66 | 3.08 | 2.42 | 0.95 | 52.69 | -1.94 | 2.5 | Student-t | 0/7 |
| **Murray Acres Subdivision** | 16 | 2.25 | 1.98 | 2.25 | 0.56 | 4.26 | 3.70 | 1.04 | 46.27 | -0.32 | 2.71 | Student-t | 2/16 |
| **Pleasant Valley Subdivision** | 18 | 1.70 | 1.38 | 1.16 | 0.60 | 4.68 | 4.08 | 1.25 | 73.60 | 0.99 | 2.34 | H-UCL log norm | 2/18 |
| **Valle Verde Subdivision** | 12 | 3.04 | 2.30 | 3.03 | 0.48 | 7.20 | 6.72 | 2.03 | 66.93 | -0.09 | 4.09 | Student-t test | 5/12 |
| **Bluewater (Background Area)** | 28 | 1.57 | 1.25 | 1.39 | 0.41 | 5.37 | 4.96 | 1.16 | 74.04 | 3.59 | 1.97 | Gamma UCL | 3/28 |

*Descriptive statistics were done for all data excluding basement data. Basement data were included in the number of houses with indoor radon data **≥ 4 pCi/l**

The Scheffe test run (table 5-16) on indoor radon data using detectors with thoron filters show a significant difference between Valle Verde and Broadview Acres and Bluewater (background area). This indicates that when we remove the effect of thoron on radon, we see a statistical significant increase of Rn-222 at only one (Valle Verde) subdivision over that at the background area. Valle Verde community tend to be located the farthest west from the other communities. This shows that there is a source of radon 222 at Valle Verde which is not found in the other communities and is not coming from the HMC site.

| Table 5-16: Scheffe test for radon with thoron filter (Rn-222 Only) for indoor radon data. | | | | | | | |
|---|---|---|---|---|---|---|---|
| Cell No. | Scheffe test; variable Radon with Thoron Filter for indoor Radon Data at the Five Subdivisions and Bluewater using Thoron Filter detectors.<br>Probabilities for Post Hoc Tests<br>Error: Between MS = 1.0331, df = 101.00 | | | | | | |
| | Location | 1<br>.99724 | 2<br>1.5024 | 3<br>1.8781 | 4<br>1.4156 | 5<br>2.5299 | 6<br>1.1561 |
| 1 | Broadview | | 0.927243 | 0.200404 | 0.874500 | **0.003835** | 0.996960 |
| 2 | Felice Acres | 0.927243 | | 0.984414 | 0.999986 | 0.481941 | 0.985228 |
| 3 | Murray Acres | 0.200404 | 0.984414 | | 0.880620 | 0.727467 | 0.405634 |
| 4 | Pleasant Valley | 0.874500 | 0.999986 | 0.880620 | | 0.134345 | 0.981755 |
| 5 | Valle Verde | **0.00383** | 0.481941 | 0.727467 | 0.134345 | | **0.012765** |
| 6 | Bluewater | 0.996960 | 0.985228 | 0.405634 | 0.981755 | **0.012765** | |

Tables 5-17 and 5-18 below are the descriptive statistics for outdoor air radon levels using detectors with thoron filters and those that were corrected for the presence of thoron in air.

Table 5-17: Descriptive Statistics for Outdoor Radon at the Five Subdivisions and Bluewater (Background Area) including thoron gas (Rn-220).

| Location | Valid # | Mean | Geometric - Mean | Median | Min. | Max. | Range | Std. Dev. | Coef. Var. | Kurtosis | UCL 95% | Basis for UCL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **All 5 Subdivisions** | 79 | 1.29 | 1.25 | 1.24 | 0.68 | 2.75 | 2.06 | 0.36 | 27.95 | 3.73 | 1.356 | H-UCL |
| **Broadview Acres** | 26 | 1.22 | 1.20 | 1.17 | 0.76 | 1.93 | 1.17 | 0.26 | 21.54 | 0.56 | 1.31 | Student's-t UCL |
| **Felice Acres** | 7 | 1.10 | 1.10 | 1.05 | 0.83 | 1.58 | 0.76 | 0.25 | 23.17 | 1.54 | 1.285 | Student's-t UCL |
| **Murray Acres** | 16 | 1.38 | 1.33 | 1.26 | 0.83 | 2.41 | 1.58 | 0.42 | 30.85 | 1.35 | 1.573 | Gamma UCL |
| **Pleasant Valley Estates** | 17 | 1.38 | 1.32 | 1.24 | 0.69 | 2.75 | 2.06 | 0.45 | 32.34 | 5.25 | 1.572 | Gamma UCL |
| **Valley Verde Acres** | 13 | 1.30 | 1.26 | 1.28 | 0.69 | 2.20 | 1.51 | 0.35 | 27.13 | 3.36 | 1.475 | Student's-t UCL |
| **Bluewater Village (Background)** | 30 | 0.46 | 0.44 | 0.42 | 0.28 | 1.25 | 0.97 | 0.17 | 37.02 | 17.43 | 0.51 | Student's-t UCL |

Table 5-18: Descriptive Statistics for Outdoor Radon at the Five Subdivision and Bluewater using radon with Thoron Filter detectors.

| Variable | Valid N | Mean | Geometric - Mean | Median | Min. | Max. | Range | Std. Dev. | Coef. Var. | Kurtosis | 95% UCL | UCL Basis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **All 5 Subdivisions** | 79 | 0.47 | 0.4 | 0.45 | 0.25 | 1.00 | 0.75 | 0.13 | 27.95 | 3.73 | 0.49 | Student's-t |
| **Broadview Acres** | 26 | 0.44 | 0.44 | 0.43 | 0.28 | 0.70 | 0.43 | 0.09 | 21.54 | 0.56 | 0.48 | Student's-t |
| **Felice Acres** | 7 | 0.40 | 0.39 | 0.38 | 0.30 | 0.58 | 0.28 | 0.09 | 23.17 | 1.54 | 0.47 | Student's-t |
| **Murray Acres** | 16 | 0.50 | 0.48 | 0.46 | 0.30 | 0.88 | 0.58 | 0.15 | 30.84 | 1.35 | 0.57 | Gamma |
| **Pleasant Valley** | 17 | 0.50 | 0.48 | 0.45 | 0.25 | 1.00 | 0.75 | 0.16 | 32.34 | 5.25 | 0.57 | Gamma |
| **Valle Verde** | 13 | 0.47 | 0.46 | 0.47 | 0.25 | 0.80 | 0.55 | 0.13 | 27.13 | 3.36 | 0.54 | Student's-t |
| **Bluewater Village (Background)** | 30 | 0.33 | 0.32 | 0.30 | 0.20 | 0.90 | 0.70 | 0.12 | 37.02 | 17.43 | 0.37 | Student's-t |

A two sample Wilcoxon-Mann-Whitney test was used to compare the outdoor radon levels at the Five Subdivisions with the background (Bluewater) area air radon levels including thoron gas. The ProUCL version 4.1 statistical program was used for this test. The test showed a significant difference between the outdoor air radon levels at the Five Subdivisions as compared to the background (Bluewater) outdoor air radon levels (p-value = 0.00000)

An analysis of variance (ANOVA) test statistics was carried out for category one outdoor radon data, i.e. radon monitors placed near residences including the background (Bluewater) data, to determine the significance of location interactions on the outdoor air radon measurements. The analysis did show a significant difference among the data (See table 5-19) at the 95% confidence interval (CI) indicating a significant location interaction (p-value of 0.00000) for the outdoor radon data.

Table 5-19. Analysis of Variance (ANOVA) test statistics for outdoor radon data near residences for all Five Subdivisions and Bluewater data

| Variable | Analysis of Variance (Outdoor Radon Category one data at Five Subdivisions and Bluewater. Marked effects are significant at p < .05000 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | SS Effect | df Effect | MS Effect | SS Error | df Error | MS Error | F | p |
| Radon without Thoron Filter | 15.70764 | 5 | 3.141528 | 10.34613 | 103 | 0.100448 | 31.27522 | **0.00000** |

Because the analysis of variance indicated a location effect on the data, different "A Posteriori Tests" post-hoc comparison of group means (i.e., location means) were carried out to further define differences between locations. The Scheffe test, Tukey unequal sample number Honestly Significant Difference test and Dunnett test were performed on the outdoor radon data. Significance in any one of the three test would indicate a significance in the compared data. The Dunnett test was considered in this evaluation since the test can be used to compare group means taken separately with a control group regardless of the outcome of the overall F value. In HMC case the control group was considered to be the background (Bluewater Village) area.

The Scheffe post hoc test showed a significant difference between background outdoor air radon levels and all of the Five Subdivisions outdoor air radon levels taken separately (see table 5-20 for p-values). The Five Subdivisions did not show significant difference among each other.

Table 5-20: Scheffe statistical test for detecting location effects on radon levels at the Five Subdivisions and Background (Bluewater) areas.

| Location | Scheffe Test; Variable: Radon without Thoron Filter (Outdoor Radon at Five Subdivisions and Bluewater) Marked differences are significant at p < .05000 | | | | | |
|---|---|---|---|---|---|---|
| | 1<br>M=1.2245 | 2<br>M=.45746 | 3<br>M=1.0980 | 4<br>M=1.3793 | 5<br>M=1.3780 | 6<br>M=1.3006 |
| 1 Broadview | | **0.000000** | 0.971197 | 0.795750 | 0.788586 | 0.991887 |
| 2 Bluewater | **0.000000** | | **0.000740** | **0.000000** | **0.000000** | **0.000000** |
| 3 Felice Acres | 0.971197 | **0.000740** | | 0.575652 | 0.570759 | 0.866975 |
| 4 Murray Acres | 0.795750 | **0.000000** | 0.575652 | | 1.000000 | 0.993918 |
| 5 Pleasant Valley | 0.788586 | **0.000000** | 0.570759 | 1.000000 | | 0.994008 |
| 6 Valle Verde | 0.991887 | **0.000000** | 0.866975 | 0.993918 | 0.994008 | |

The Tukey unequal number Honestly Significant Difference test also found a significant difference between background (Bluewater) outdoor air radon levels and all Five Subdivisions locations (see table 5-21 for p-values).

The Dunnett test confirmed the findings above and showed a significant difference between background outdoor air radon level (Control Group) and outdoor radon levels at all Five Subdivisions taken separately (see table 5-22 for p-values).

| Table 5-21: Tukey's Honestly Significant Difference (HSD) for unequal number of samples test to detect location effect at the Five Subdivisions and Bluewater areas. | | | | | | |
|---|---|---|---|---|---|---|
| Location | Unequal N HSD; Variable: Radon without Thoron Filter (Outdoor Radon at Five Subdivisions and Bluewater)<br>Marked differences are significant at p < .05000 | | | | | |
| | 1<br>M=1.2245 | 2<br>M=.45746 | 3<br>M=1.0980 | 4<br>M=1.3793 | 5<br>M=1.3780 | 6<br>M=1.3006 |
| 1 Broadview | | **0.000121** | 0.975587 | 0.737800 | 0.719471 | 0.989972 |
| 2 Bluewater | **0.000121** | | **0.003573** | **0.000121** | **0.000121** | **0.000121** |
| 3 Felice Acres | 0.975587 | **0.003573** | | 0.561049 | 0.566050 | 0.838009 |
| 4 Murray Acres | 0.737800 | **0.000121** | 0.561049 | | 1.000000 | 0.988340 |
| 5 Pleasant Valley | 0.719471 | **0.000121** | 0.566050 | 1.000000 | | 0.989196 |
| 6 Valle Verde | 0.989972 | **0.000121** | 0.838009 | 0.988340 | 0.989196 | |

| Table 5-22: Dunnett statistical test to compare the mean of each group taken separately with a control group (Bluewater). | | |
|---|---|---|
| Cell No. | Dunnett test; variable Radon without Thoron Filter (Outdoor Radon at Five Subdivisions and Bluewater)<br>Probabilities for Post Hoc Tests (M>Control)<br>Error: Between MS = .10045, df = 103.00 | |
| | Location | 2<br>.45746 |
| 1 | Broadview | **0.000021** |
| 2 | Bluewater | |
| 3 | Felice Acres | **0.000033** |
| 4 | Murray Acres | **0.000021** |
| 5 | Pleasant Valley | **0.000021** |
| 6 | Valle Verde | **0.000021** |

This also is another indication that there is a source of radon that is present at the subdivision areas which is not present in the background area.

The Scheffe and Dunnett statistical tests were run on outdoor radon data with thoron filter detectors (Rn-222 only). The Scheffe test (table 5-23) showed that there is significant difference between Murray Acre and Pleasant Valley estate and Bluewater Village (background area). However, the Dunnett test, table 5-24, did not show this difference.

| Table5-23: Scheffe test for radon with thoron filter (Rn-222 Only) for Outdoor radon at Five Subdivisions and Bluewater. | | | | | | | |
|---|---|---|---|---|---|---|---|
| Cell No. | Scheffe test; variable Radon with thoron Filter (Outdoor Radon Five Subdivisions and Bluewater)<br>Probabilities for Post Hoc Tests<br>Error: Between MS = .01639, df = 103.00 | | | | | | |
| | Location | 1<br>.44526 | 2<br>.32911 | 3<br>.39929 | 4<br>.50156 | 5<br>.50109 | 6<br>.47295 |
| 1 | Broadview | | 0.050918 | 0.981922 | 0.859374 | 0.854031 | 0.995036 |
| 2 | Bluewater | 0.050918 | | 0.886950 | **0.003454** | **0.002730** | 0.051187 |
| 3 | Felice Acres | 0.981922 | 0.886950 | | 0.683723 | 0.679534 | 0.911126 |
| 4 | Murray Acres | 0.859374 | **0.003454** | 0.683723 | | 1.000000 | 0.996293 |
| 5 | Pleasant Valley | 0.854031 | **0.002730** | 0.679534 | 1.000000 | | 0.996349 |
| 6 | Valle Verde | 0.995036 | 0.051187 | 0.911126 | 0.996293 | 0.996349 | |

| Table 5-24: Dunnett statistical test for radon with thoron filter (Rn-222 only) for outdoor radon data at Five Subdivisions and Bluewater Village. | | |
|---|---|---|
| Cell No. | Dunnett test; variable Radon with thoron Filter (Outdoor Radon Five Subdivisions and Bluewater)<br>Probabilities for Post Hoc Tests (M<Control)<br>Error: Between MS = .01639, df = 103.00 | |
| | Location | 2<br>.32911 |
| 1 | Broadview | 0.999956 |
| 2 | Bluewater | |
| 3 | Felice Acres | 0.997817 |
| 4 | Murray Acres | 0.999956 |
| 5 | Pleasant Valley | 0.999956 |
| 6 | Valle Verde | 0.999956 |

This analysis clearly shows that when we compare outdoor ambient air radon levels with thoron gas removed (i.e. only Rn-222) then we don't see much difference between the Five Subdivisions and the background area in two of the statistical tests used. But using the Scheffe statistical test we see significant difference between outdoor radon with thoron removed in Murray Acres and Pleasant Valley and the background area. This means that areas closest to the large tailing pile could also be impacted by radon 222 only. When we compare outdoor ambient air radon levels with thoron included (i.e. Rn-222 + Rn-220) then we see a statistical significant increase of radon levels at the Five Subdivisions as

compared to the background radon levels. Therefore we conclude that there is also a source of thoron gas (Rn-220) that is impacting the five subdivisions and not the background area.

For category two outdoor radon data, i.e. data placed along the HMC fence line separating the facility from residential areas, 122 Radtrack etch–track passive air radon monitors were placed and collected on a quarterly basis for a one year period to provide annual data of radon at the fence line. A total of twelve posts were erected along the fence line. Each post had two monitors, one placed at a height of around 5 feet and the other was placed at a height of around 6 inches off the ground. The purpose of two different heights was to check if there is a significant difference between the levels of radon at these two heights and thus determine if soil is a source of radon gas to the ambient air. Descriptive statistics for radon levels at both heights are provided in table 5-25. The radon levels detected at the 6" height monitors showed slightly higher radon levels than the levels found at the 5 feet high radon monitors. A Wilcoxon-Mann-Whitney two sample statistical test showed a significant difference (p-value = 0.0024) between the levels of radon at the two heights with the lower height (6"off the ground) measuring higher radon levels than the 5 feet high monitors. This indicates that soil at the investigation area could be a contributing source to the radon in ambient air in addition to other natural or man-made radon sources.

Table 5-25: Descriptive Statistics for outdoor radon results in pCi/L for monitors placed along the fence line between HMC property and residential areas. Monitors placed on top (5' high) and bottom (6" off the ground) at each post.

| Variable | Valid N | Mean | Geometric - Mean | Median | Min. | Max. | Range | Std. Dev. | Coef. Var. | Kurtosis | UCL 95% | Basis UCL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Adjusted for Thoron Top Fence** | 56 | 1.12 | 1.07 | 0.996 | 0.75 | 1.99 | 1.25 | 0.37 | 32.69 | -0.83 | 1.21 | Student'-t test |
| **Adjusted for Thoron Bottom Fence** | 52 | 1.44 | 1.33 | 1.49 | 0.75 | 2.74 | 1.99 | 0.57 | 39.38 | -0.54 | 1.57 | Student'-t test |

For category three outdoor radon data, i.e. data for radon sample monitors placed on and off HMC property, monitors were placed upgradient of HMC facility at four locations along a line at different distances and three downgradient at different locations and distances from the HMC facility within HMC boundary. One monitor was placed to the west of residential areas and another placed northwest of the HMC facility. In each location monitors were placed in triplicate to address variability of radon within its location. A total of 120 etch-track radon detectors were placed and collected on a quarterly basis for a period of one year. The radon data were adjusted for thoron using a correction factor of 1.79 for upgradient monitors and a correction factor of 5.15 for downgradient monitors within

HMC boundary (see table 5-26). The downgradient thoron level was found at much higher level than upgradient thoron level.

Table 5-26: Calculation of correction factor to adjust radon results to the presence of thoron (Rn-220).

| Location | Result | NTH* Results | % Thoron | Ratio | Avg. of 2 Quarters | Correction Factor Upgradient | Correction Factor Downgradient | Correction Factor HMC08 West |
|---|---|---|---|---|---|---|---|---|
| HMC01-03-A | 0.4 | 0.8 | 50.00 | 2.00 | 1.75 | 1.79 | 5.15 | 2.57 |
| HMC01-04-A | 0.6 | 0.9 | 33.33 | 1.50 | | | | |
| HMC02-03-A | 0.6 | 1 | 40.00 | 1.67 | 2.13 | | | |
| HMC02-04-A | 0.5 | 1.3 | 61.54 | 2.60 | | | | |
| HMC04-03-A | 0.9 | 1.2 | 25.00 | 1.33 | 1.50 | | | |
| HMC04-04-A | 0.6 | 1 | 40.00 | 1.67 | | | | |
| HMC05-03-A | 0.3 | 1.7 | 82.35 | 5.67 | 5.33 | | | |
| HMC05-04-A | 0.4 | 2 | 80.00 | 5.00 | | | | |
| HMC07-03-A | 0.3 | 1.7 | 82.35 | 5.67 | 4.96 | | | |
| HMC07-04-A | 0.4 | 1.7 | 76.47 | 4.25 | | | | |
| HMC08-03-A | 0.3 | 1 | 70.00 | 3.33 | 2.57 | | | |
| HMC08-04-A | 0.5 | 0.9 | 44.44 | 1.80 | | | | |

*NTH = No thoron filter (measures both Rn-222+Rn-220)

The annual average radon level at each location corrected for thoron are reported in table 5-27 below.

Table 5-27: Annual HMC Radon results corrected for thoron gas in pCi/l.

| Location | Annual HMC radon results corrected for thoron gas | Sub-Location |
|---|---|---|
| HMC01 | 0.91 | Upgradient North of Facility |
| HMC02 | 1.37 | Upgradient North of Facility |
| HMC03 | 1 | Upgradient North of Facility |
| HMC04 | 1.12 | Upgradient North of Facility |
| HMC05 | 2.1 | Downgradient South of Facility |
| HMC06 | 2.36 | Downgradient South of Facility |
| HMC07 | 2.36 | Downgradient South of Facility |
| HMC08 | 1.2 | West of the Facility |
| HMC09 | 0.54 | North West of the Facility. |

An analysis of variance statistical test was run on outdoor radon data, corrected for thoron levels, collected from the Five Subdivisions, fence line, upgradient and downgradient from HMC facility. This

was done to see if there is any significant difference among the data. The ANOVA test (see table 5-28) did show that there is a significant difference among the data (p-value of 0.000058).

Table 5-28: Analysis of Variance (ANOVA) test for outdoor radon data at HMC property.

| Variable | Analysis of Variance<br>Marked effects are significant at p < .05000 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | SS Effect | df Effect | MS Effect | SS Error | df Error | MS Error | F | p |
| Radon without Thoron Filter | 4.011879 | 7 | 0.573126 | 10.00004 | 90 | 0.11111 | 5.158112 | **0.000058** |

To understand if and which location has impact on this significant difference, a post-hoc Scheffe test (see table 5-29) and Dunnett statistical test (see table 5-30) were run on the data and both test did show that the downgradient HMC data was significantly different from all other locations ( the Five Subdivisions taken separately and upgradient HMC).

Table 5-29: Scheffe Test on outdoor radon adjusted for thoron. Marked differences are significant at p < .05000

| Variable | {1} - M=1.2245 | {2} - M=1.0980 | {3} - M=1.3793 | {4} - M=1.3780 | {5} - M=1.3006 | {6} - M=1.1225 | {7} - M=2.2733 | {8} - M=1.1000 |
|---|---|---|---|---|---|---|---|---|
| Broadview {1} | | 0.997324 | 0.949811 | 0.947026 | 0.999569 | 0.997585 | **0.001159** | 0.999464 |
| Felice Acres {2} | 0.997324 | | 0.835723 | 0.832487 | 0.974107 | 1.000000 | **0.001371** | 1.000000 |
| Murray Acres {3} | 0.949811 | 0.835723 | | 1.000000 | 0.999714 | 0.769396 | **0.017380** | 0.942732 |
| Pleasant Valley {4} | 0.947026 | 0.832487 | 1.000000 | | 0.999720 | 0.762129 | **0.016192** | 0.942347 |
| Valle Verde {5} | 0.999569 | 0.974107 | 0.999714 | 0.999720 | | 0.969478 | **0.007632** | 0.992421 |
| Fence line {6} | 0.997585 | 1.000000 | 0.769396 | 0.762129 | 0.969478 | | **0.000616** | 1.000000 |
| Downgradient HMC {7} | **0.001159** | **0.001371** | **0.017380** | **0.016192** | **0.007632** | **0.000616** | | **0.006537** |
| Upgradient HMC {8} | 0.999464 | 1.000000 | 0.942732 | 0.942347 | 0.992421 | 1.000000 | **0.006537** | |

| Table 5-30: Dunnett test for outdoor radon adjusted for thoron | | |
|---|---|---|
| Cell No. | Dunnett test; variable Radon without Thoron Filter. Probabilities for Post Hoc Tests (2-sided). Error: Between MS = .11111, df = 90.000 | |
| | Location | 7<br>2.2733 |
| 1 | Broadview | **0.000019** |
| 2 | Felice Acres | **0.000022** |
| 3 | Murray Acres | **0.000354** |
| 4 | Pleasant Valley | **0.000322** |
| 5 | Valle Verde | **0.000123** |
| 6 | Fence line | **0.000014** |
| 7 | Downgradient HMC | |
| 8 | Upgradient HMC | **0.000102** |

Outdoor radon data from samples collected using thoron filter detectors were statistically tested for significant difference among different locations. The Scheffe post-hoc test was applied on the data (see table 5-31). As shown by the table, there was no significant difference among the data when location of the samples were considered separately.

| Table 5-31: Scheffe test for outdoor radon with thoron filter (Rn-222 only) for category three data. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cell No. | Scheffe test; variable Radon with thoron Filter (Scribe FMS Radon 6 25 12)<br>Probabilities for Post Hoc Tests<br>Error: Between MS = .01496, df = 90.000 | | | | | | | | |
| | Location | 1<br>.44526 | 2<br>.39929 | 3<br>.50156 | 4<br>.50109 | 5<br>.47295 | 6<br>.45250 | 7<br>.44333 | 8<br>.62025 |
| 1 | Broadview | | 0.997475 | 0.952192 | 0.949525 | 0.999594 | 1.000000 | 1.000000 | 0.427181 |
| 2 | Felice Acres | 0.997475 | | 0.842224 | 0.839086 | 0.975410 | 0.996832 | 0.999921 | 0.318485 |
| 3 | Murray Acres | 0.952192 | 0.842224 | | 1.000000 | 0.999731 | 0.992519 | 0.999065 | 0.880821 |
| 4 | Pleasant Valley | 0.949525 | 0.839086 | 1.000000 | | 0.999737 | 0.992374 | 0.999085 | 0.875165 |
| 5 | Valle Verde | 0.999594 | 0.975410 | 0.999731 | 0.999737 | | 0.999983 | 0.999991 | 0.726876 |
| 6 | Fence line | 1.000000 | 0.996832 | 0.992519 | 0.992374 | 0.999983 | | 1.000000 | 0.584457 |
| 7 | Downgradient HMC | 1.000000 | 0.999921 | 0.999065 | 0.999085 | 0.999991 | 1.000000 | | 0.823105 |
| 8 | Upgradient HMC | 0.427181 | 0.318485 | 0.880821 | 0.875165 | 0.726876 | 0.584457 | 0.823105 | |

The type of house structure was found in earlier studies (U.S. EPA 1989d) to show significant difference between trailer houses and non-trailer houses. In this study we found that the type of houses that is causing the statistical significant difference among the non-trailer is the brick houses and somewhat the stucco houses is showing higher indoor radon levels than the others see table 5-32 below. Therefore the type of housing structure is adding to the total increase in indoor radon levels. Radon-222 from the large tailings pile seems to impact mainly Murray Acre and Pleasant Valley indoor radon levels. Thoron from the large tailings pile also impact slightly the total radon levels in the five subdivisions. Radon gas from the soil also is adding to the levels, radon gas in private well water could be adding radon gas and lastly the type of house structure is contributing to the level of indoor radon gas. Outdoor air radon in the vicinity of the house is also contributing to indoor air radon levels. The source of indoor radon seems to come from several sources complicating the general view of the main source of radon to indoor air in the five subdivisions.

Table 5-32: Unequal N HSD; Variable: Indoor Radon (House Type and Radon Results) Marked differences are significant at p < .05000

| | {1} - M=1.56 | {2} - M=2.15 | {3} - M=.978 | {4} - M=3.16 | {5} - M=4.56 | {6} - M=1.98 | {7} - M=2.73 | {8} - M=5.51 | {9} - M=2.04 | {11} - M=3.45 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Prefab {1}** | | 0.9999 | 0.9996 | 0.7260 | 0.9860 | 1.0000 | 0.9999 | 0.0679 | 1.0000 | 0.99959 |
| **Unknown {2}** | 0.999 | | 0.9820 | 0.9935 | 0.9971 | 1.0000 | 1.0000 | 0.1997 | 1.0000 | 0.99998 |
| **Trailer {3}** | 0.9996 | 0.9820 | | 0.0730 | 0.9547 | 0.9998 | 0.9997 | **0.0187** | 0.9999 | 0.99648 |
| **Stucco {4}** | 0.7260 | 0.9935 | 0.0730 | | 0.9999 | 0.9992 | 1.0000 | 0.6835 | 0.9999 | 1.00000 |
| **Wooden {5}** | 0.9860 | 0.9971 | 0.9547 | 0.9999 | | 0.9952 | 0.9996 | 0.9999 | 0.9959 | 0.99999 |
| **Lap Siding Home {6}** | 1.0000 | 1.0000 | 0.9998 | 0.9992 | 0.9952 | | 1.0000 | 0.4740 | 1.0000 | 0.99994 |
| **Warehouse {7}** | 0.9999 | 1.0000 | 0.9997 | 1.0000 | 0.9996 | 1.0000 | | 0.9915 | 1.0000 | 1.00000 |
| **Brick {8}** | 0.0679 | 0.1997 | **0.0187** | 0.6835 | 0.9999 | 0.4740 | 0.9915 | | 0.9622 | 0.99916 |
| **Cinderblock {9}** | 1.0000 | 1.0000 | 0.9999 | 0.9999 | 0.9959 | 1.0000 | 1.0000 | 0.9622 | | 0.99996 |
| **Stone {11}** | 0.9995 | 0.9999 | 0.9964 | 1.0000 | 0.9999 | 0.9999 | 1.0000 | 0.9991 | 0.9999 | |
| | | | | | | | | | | |

### 5.2.1 Current Radon Study

In this radon study EPA region 6 evaluated the risk from exposure to radon gas indoors and outdoors at the Five Subdivisions area. Eleven out of 79 homes tested for indoor radon were found to have radon levels greater than the EPA recommended mitigation level of 4 pCi/l. Ten homes were mitigated through

the Superfund removal program, one refused EPA mitigation efforts. The EPA recommended mitigation level of 4 pCi/l for the Five Subdivisions was based on measurement of total radon gas (Radon-222 plus thoron (Rn-220)). The 4 pCi/L is assumed to correspond to the ARAR level of 0.02 WL which does not differentiate between the two radon isotopes. Although there was no significant difference between the indoor radon levels with or without thoron filter, only indoor radon levels as measured by air monitors without thoron filter (total radon) were used to compare with the 4 pCi/l level. Statistical evaluation of the indoor radon levels did not show significant difference at the 95% confidence interval between the Five Subdivisions and a background community (Bluewater Village). However, the average of indoor radon level at the Five Subdivisions was slightly higher than the background average indoor radon levels.

Studies have shown that when residences are built in uranium rich geological areas, the soil around residences is a source of radon to indoor air as was shown in the current study. The current study also showed that there are additional sources of radon coming through the air from nearby sources (Homestake Superfund site or from other natural and anthropogenic background sources). Radon gas could also be coming from uranium contaminated ground water if used for domestic purposes. Contribution of measured dissolved radon levels in private well waters to indoor air radon levels at the Five Subdivisions is expected to be small if private well water is ever used for domestic purposes.

As to the outdoor radon levels, there was a clear statistically significant increase between the average of the outdoor total radon (radon-222 + thoron (Rn-220)) levels at the Five Subdivisions as compared to the average of the outdoor total radon levels at the background area. Two communities in the Five Subdivisions, Murray Acre and Pleasant Valley, had statistically significant increase of radon-222 gas only over that in the background community. But the increase of radon coming through the air, especially Radon-222, was in our study very slight compared to indoor radon levels.

To properly evaluate indoor radon and outdoor air radon levels in the vicinity of the Five Subdivisions, it was essential to find a background community of residences that closely resembles the communities in the Five Subdivisions in ways that affect radon levels. This was important since radon gas is extremely variable and it can have many sources in addition to soil. The other factors that impact levels of radon include the type of area (i.e., an urban or rural area), type of house built (i.e. stucco, wood, brick, etc.), type of HVAC system used inside the house, demographics and habits of individuals, movement of radon through the air from nearby sources, movement of radon gas released from contaminated groundwater plumes flowing under the residences, etc.

EPA selected a community similar to the Five Subdivisions as a background location for indoor air and outdoor air radon. Bluewater Village was selected based on the following: 1) use of available aerial reconnaissance of the whole region, 2) consultation with the U.S. Geological Survey (USGS) on local geological features, 3) a tour of selected communities to observe the type and age of housing, rural or urban areas, distance from local sources of radon, etc., 4) literature search for historical radon studies which selected background areas in the Homestake area, 5) soil type, 6) radiological screening of selected areas. These six criteria meet requirements set forth in EPA guidance for background selection (USEPA 2002).

In addition to the residential areas evaluated as potential radon gas background locations for the Five Subdivisions, EPA also evaluated a radon gas background area upgradient to the north and north east of the Site (See figure 5-7). EPA used this location to study the impact of radon gas flowing towards the Homestake site from the north. The impact from the north includes natural and anthropogenic sources, especially legacy mines spread over the area north of the Site. The average upgradient radon-222 gas levels (0.62 pCi/L) was higher than the downgradient air radon-222 levels (0.44 pCi/L) within the HMC site boundaries. Because the upgradient radon-222 levels were higher than the site radon-222 levels, it was not possible to determine the impact of the site radon-222 levels on the Five Subdivisions. Also there are no studies to show the level of radon gas, if any, is coming from the legacy mine sources and whether it is impacting the air at the Five Subdivisions area. There was no trend in radon levels for radon monitors placed upgradient from the site to indicate radon gas is coming towards the HMC site. In contrast, total radon (radon-222 + thoron gas) measured at the downgradient air monitors within the HMC site boundaries showed higher levels than the upgradient air total radon levels, indicating a potential nearby source of total radon which EPA believes it to be the LTP.

One goal of the HHRA was to determine if radiation originating from the HMC facility (RO Process units, LTP, Evaporation Ponds etc.) results in an increased risk, above the risk from natural and manmade background sources. The results of this risk assessment indicate that majority of the risk is coming from background sources, but it also shows that additional incremental risk originates from HMC site. Since radon-222 gas is known to be extremely variable and could change from year to year, statistical analysis alone would not be sufficient to address the investigation question at hand. So EPA in addition to statistical evaluation looked at several lines of evidence in this investigation.

The HHRA found that the excess lifetime cancer risk from exposure to radon-222 coming from the site was $5 \times 10^{-4}$ (i.e. five individuals from a population of ten thousand might develop cancer in their lifetime). EPA relied on the following lines of evidence to show that this risk originates from HMC:

1) Annual radon emissions from the LTP, according to the report *Radon Flux Measurements for the HMC Tailings Piles* (Environmental Restoration Group (ERG), Inc., October 2011) prepared for HMC, states "The July 2011 average measured flux of radon gas on the top of the pile was 53.95 pCi/$m^2$s. The September 2011 average flux on the top of the pile was 47.64 pCi/$m^2$ s. This compares to 42.1 pCi/$m^2$ s measured in 1995." This statement clearly indicates that the top of the LTP is a continuing emission source of radon gas.
2) The two closest subdivisions to the LTP, namely Murray Acres and Pleasant Valley, showed a statistically significant increase in the mean of air radon-222 levels over the mean in the background air radon-222 level.
3) The thoron investigation indicated that the LTP, a common source for radon-222 and thoron gas at the HMC site (HMC site here means HMC facility as defined above and all vacant land within the fence line borders and all irrigation fields), is a source of total radon gas (radon-222 plus thoron gas (radon-220)) to the downgradient communities. As discussed in Section 5.2 (Radon Evaluation) of the HHRA, the downgradient air radon monitors within HMC boundary reported higher average levels of radon (1.8 pCi/L, thoron gas included) than the average HMC upgradient radon levels (1.0 pCi/L, thoron gas included). Given that thoron gas has a half-life of 55.6 seconds, the difference in upgradient and downgradient readings indicates that thoron gas is coming from nearby sources such as the LTP or the evaporation ponds.
4) Historical radon results from HMC's air monitors consistently measured higher average radon levels (HMC air monitor #4 =1.63 pCi/L) than the background average radon level (HMC # 16 =0.93 pCi/L).

Based on these lines of evidence, EPA concluded that there is incremental risk from radon gas originating from the HMC site. The Site poses a long-term chronic risk, (i.e. not an immediate risk) that EPA expects will be reduced to background levels when a permanent radon cover is placed on top of the large tailings pile and evaporation ponds are remediated and other response measures completed.

**Radon Study Conclusion**

Using Superfund Risk Assessment methods, the HHRA found that inhalation of radon gas in air is the predominant pathway leading to excess estimated cancer risk for a reasonable maximum exposed individual (RME) living in the Five Subdivisions. The radon in the area of the Five Subdivisions presents excess cancer risk greater than EPA's acceptable risk range. The HHRA calculates the source of the excess cancer risk as 13 X $10^{-4}$ from background sources and 5 X $10^{-4}$ from HMC facility sources. The level of risk presented by the HMC facility apart from background would generally indicate the

need for long-term cleanup in the Superfund program. Long-term cleanup of the HMC facility is ongoing under state and federal authorities.

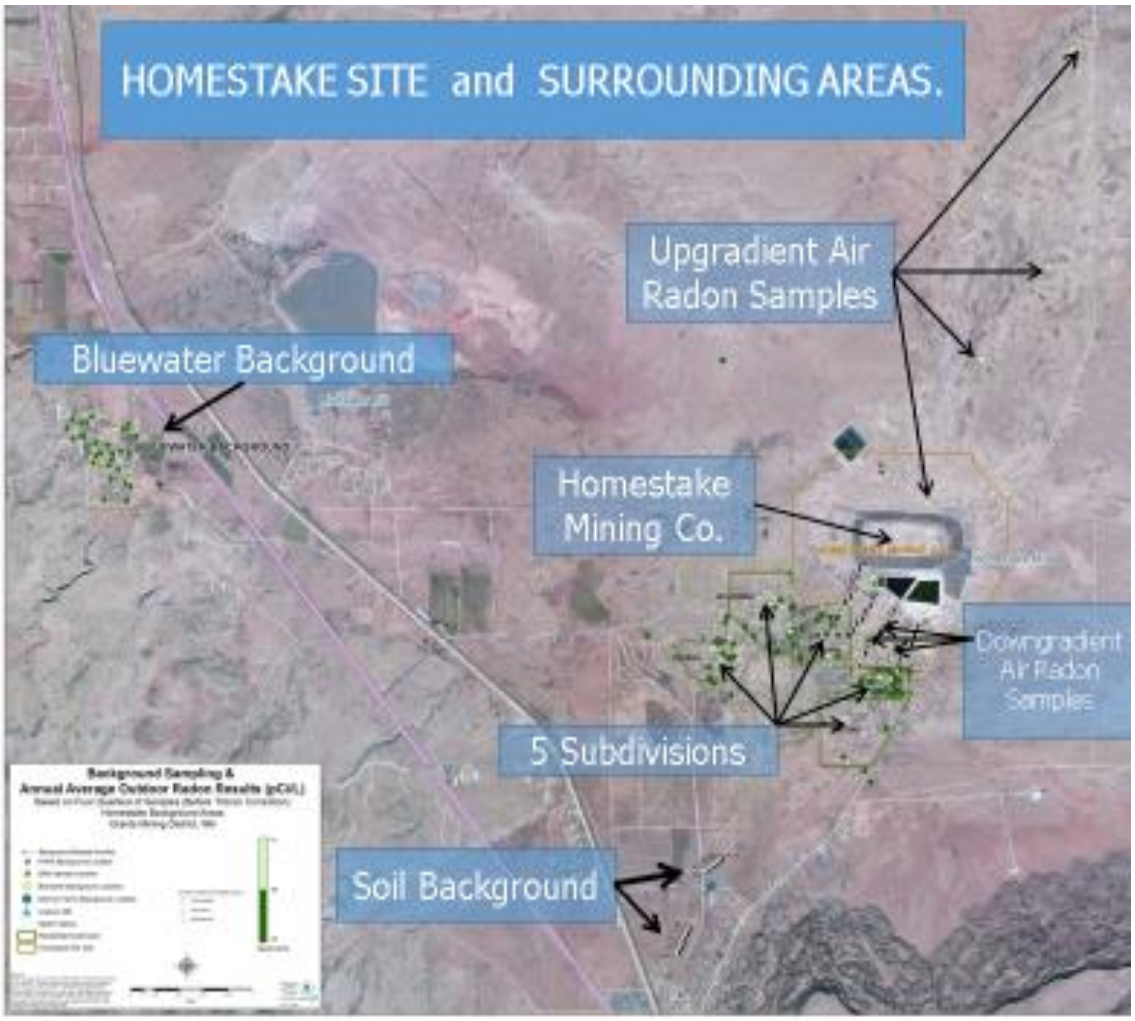



Figure 5-7: Location of radon air monitors at HMC on-site and off-site and at the Bluewater background area. Soil background location is also shown.

### 5.3 Uncertainties in Risk Characterization

The derivation of health effects criteria that form the basis of the risk characterization can result in overestimates or underestimates of potential health risks. In most cases, the criteria are derived from extrapolation from laboratory animal data to humans. RfDs and cancer slope factors for oral exposure are used as criteria to assess exposure from dermal absorption. While the criteria for oral exposure are

adjusted for such use following USEPA guidance, oral absorption for the organic chemicals is assumed to be 100% which may overestimate risks through oral ingestion and may underestimate dermal contact risks for some chemicals. For those chemicals with specific oral absorption factors, consideration was not given to the absorption efficiency of the exposure vehicle used in the studies on which the toxicity factors are based; this may overestimate or underestimate dermal contact risks for some chemicals. Furthermore, for some chemicals, health criteria are insufficient to determine reference doses or slope factors for oral and/or inhalation exposure. As a result, the overall risks may be underestimated. Extrapolation from animal data to humans for chemical carcinogens is a major source of uncertainty. Also extrapolation from high dose to low-level exposures for both chemical carcinogens and radionuclides typically constitutes the greatest source of uncertainty.

Uncertainties could be associated with instrumentation and measurements used to characterize the nature and extent of radionuclides of concern. Parameters used to characterize potential exposures of current and future receptors add also to the uncertainty in the numbers calculated for risk characterization.

Unlike chemical assessments, an exposure assessment for radioactive contaminants can include an explicit estimation of the radiation dose equivalent. The dose equivalent is an expression that takes into consideration both the amount of energy deposited in a unit mass of a specific organ or tissue as a result of the radioactive decay of a specific radionuclide, as well as the relative biological effectiveness of the radiations emitted by that nuclide. (Note that the term dose has a different meaning for radionuclides [dose = energy imparted to a unit mass of tissue] than that used in for chemicals [dose, or absorbed dose = mass penetrating into an organism].

The cumulative effect of using conservative assumptions throughout the risk estimation process could overestimate the true risks. However, some exposure factors used in this risk assessment were based on site-specific information, whenever it was available. Thus, the risk estimated obtained are believed to be sufficiently conservative to adequately protect human health while generally remaining within the range of risks that individuals in the area may actually experience.

The likelihood of the postulated exposures actually occurring at the HMC offsite residential communities is another uncertainty factor. The exposure pathways evaluated are all plausible and exposure is either presently occurring by these pathways or such exposure could reasonably be expected. Although the postulated frequencies of occurrence may overestimate average occurrence, they could reflect the actual exposures of some individuals.

Thoron gas has no inhalation toxicity value and was evaluated through the submersion route of intake only. Dissolved radon gas in water has no ingestion slope factor and was not evaluated through the ingestion of contaminated well waters. Risk will be underestimated since not including the risk evaluation from ingestion of radon gas in water or considering exposure to thoron gas through the inhalation route of intake.

# 6 References


ANL 2007. Radiological and Chemical Fact Sheets to Support Health Risk Analyses for Contaminated Areas. Argonne National Laboratory. Environmental Science Division.

Agency for Toxic Substances and Disease Registry (ATSDR), 1990. Public Health Statement for Radium . Atlanta, GA: U.S. Public Health Service.

ATSDR, 2008. Public Health Statement for Radon. Atlanta, GA: U.S. Public Health Service.

ATSDR, 2003. Public Health Statement for Selenium. Atlanta, GA: U.S. Public Health Service.

ATSDR, 1990. Public Health Statement for Thorium. Atlanta, GA: U.S. Public Health Service.

ATSDR, 1999. Public Health Statement for Uranium. Atlanta, GA: U.S. Public Health Service.

ATSDR, 2003. Public Health Statement for Vanadium. Atlanta, GA: U.S. Public Health Service.

Boice, J.D. Jr et al 2008. Boice, J.D. Jr et al 2008. A cohort study of uranium millers and miners of Grants, New Mexico, 1979-2005. J. Radiation Protection 28, 303-325.

Boice, J.D. Jr et al 2010. Cancer Incidence and Mortality in Populations Living Near Uranium Milling and Mining Operations in Grants, New Mexico 1950-2004. Radiation Research 174, 624-636.

CDC 2012. Health Effects of Molybdenum. Centers for Disease Control and Prevention. Atlanta, GA: U.S. Public Health Service.

ERG, 2011. Radon Flux Measurements for the HMC Tailings Piles Environmental Restoration Group. October, 2011.

Gilbert, R.O. 1987. Statistical Methods for Environmental Pollution Monitoring. New York, NY: Van Nostrand Reinhold.

HMC 1989. Final Report Remedial Investigation Grants, New Mexico Subdivision. Radon Study. Grants, New Mexico

HMC 2009. Annual Monitoring Report/Performance Review for Homestake's Grants Project 2008. Homestake Mining Company of California. Grants, New Mexico

HMC 2010. Grants Reclamation Project Evaluation of Years 2000 Through 2009 Irrigation with Alluvial Groundwater . Homestake Mining Company of California. Grants, New Mexico.

HMC 2011. Semi-Annual Environmental Monitoring Report July-December. Homestake Mining Company of California. Grants, New Mexico.

HMC 2012a. Grants Reclamation Project Updated Corrective Action program (CAP). Homestake Mining Company of California Grants, New Mexico.

HMC 2012b. Grants Reclamation Project. 2011 Annual Monitoring Report/Performance Review for Homestake's Grant Project. Grants, New Mexico.

ICRP 2009. International Commission on Radiological Protection. Statement on Radon. ICRP Ref 00/902/09.

King, A.D. 2006. Comparison of Standard Radiological Risk Models and Using RESRAD to Derive Generic Risk-Based Area Factors for Final Status Surveys. Risk Analysis, Vol. 26, No.1,2006.

Lapham, S.C. and Millard, J.B. 1989. Health Implications of Radionuclide Levels in Cattle Raised Near U Mining and Milling Facilities in Ambroisa Lakes, New Mexico. Health Physics, 56 (3): 327-340.

Millard, J.B. and Baggett, D.T. 1984. Radiological Assessment of the Populated Areas Southwestof the Homestake Company Uranium Mill. Radiation Protection Bureau.

National Academy of Sciences (NAS) 1999. Health Effects of Exposure to Radon. National Research Council. Committee on the Health Effects of Exposure to Radon (BEIR VI). National Academy Press, Washington, DC.

National Academy of Sciences (NAS) 1999a. Risk Assessment of Radon in Drinking Water. National Academy Press. Washington, DC.

NCSS 2008. San Mateo Established Series. Rev. TLP/RJA/LWH/. National Cooperative Soil Survey. Soil Resources. California, Davis.

Neves, O and Abreu, M.M. 2009. Are Uranium-contaminated Soil and irrigation water a risk for human vegetables consumers? A Study Case with Solanum tuberosum. L., Phaseobes Vulgaris, L. and Lactuca Sativa, L. Ecotoxicology 18: 1130-1136.

Pearson, M.D. and Apangler, R.R. 1991. Calibration of alpha Track monitors for measurement of Thoron ($^{220}$Rn). Health Physics Vol. 60, No.5 (May), pp: 697-701.

Shang, B. et al 2008. Radon Survey in Dwellings of Gansu, China : The Influence of Thoron and an Attempt for Correction. Radiation Environ Biophys (2008) 47: 357-373.

Statistica 2010. Statistical Soft ware package Version 10. StatSoft , Inc. Tulsa, Oklahoma.

Thaden, R.E., Santos, E.S. and Ostling, E.J., 1967, Geologic map of the Dos Lomas quadrangle, Valencia and McKinley Counties, New Mexico: U.S. Geological Survey, Geologic Quadrangle Map GQ-680, scale 1:24000 AND Thaden, R.E. and Ostling, 1967, Geologic map of the Bluewater quadrangle, Valencia and McKinley Counties, New Mexico: U.S. Geological Survey, Geologic Quadrangle Map GQ-679, scale 1:24000).

Tschiersch, W.B. Li and O. Meisenberg 2007: Increased indoor thoron concentrations and implication to inhalation dosimetry. Radiat Prot Dosimetry (2007) 127 (1-4): 73-78.

U.S.EPA 1976. Report of Ambient Outdoor Radon and Indoor Radon Progeny Concentrations during

Nov. 1975 at Selected Locations in the Grants Mineral Belt, New Mexico. Office of Radiation Program,

Las Vegas, Nevada.

U.S. EPA. 1986. Guidelines for Carcinogen Risk Assessment. 51 FR 33992-34003.

U.S. EPA. 1989a. *Methods for Evaluating the Attainment ofSoil Cleanup Standards. Volume 1: Soils and Solids.* EP A/540/1-89/003. Statistical Policy Branch, Office of Policy, Planning, and Evaluation, Washington, DC.

U.S. EPA. 1989b. *Exposure Factors Handbook.* EPA/600/8-89/043. Office ofHealth and Environmental Assessment, Washington, DC.

USEPA, 1989c. Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual, Part A, Interim Final. EPA/540/1-89/002, Office of Emergency and Remedial Response, Washington, DC.

U.S.EPA 1989d. Record of Decision. Homestake Mining Company. Radon Operable Unit. Grants, New Mexico.

USEPA, 1990a. Guidance for Data Usability in Risk Assessment. EPA/540/G-90/008. Office of Emergency and Remedial Response, Washington, D.C.

USEPA, 1990b. National Oil and Hazardous Substances Pollution Contingency Plan; Final Rule. 40 CFR Part 300.

U.S. EPA. 1991. *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors.* OSWER 9285.6-03. Office of Emergency and Remedial Response, Washington, DC. NTIS PB91-921314.

U.S. EPA. 1991a. *Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals).* Publication 9285.7-0IB. Office of Emergency and Remedial Response, Washington, DC. NTIS PB92-963333.

U.S. EPA. 1992a. *Statistical Methods for Evaluating the Attainment of Cleanup StandardsVolume2: Ground Water.* Draft. Statistical Policy Branch, Office of Policy, Planning, and Evaluation, Washington, DC.

U.S. EPA. 1992b. *Statistical Methods for Evaluating the Attainment of Cleanup Standards Volume 3: Reference- Based Standards for Soils and Solid Media.* PB94 176831. Statistical Policy Branch, Office of Policy, Planning, and Evaluation, Washington, DC.

U.S. EPA. 1992c. *Guidance for Data Usability in Risk Assessment (Part A).* Publication 9285.7A. Office of Emergency and Remedial Response, Washington, DC.

U.S. EPA. 1992d. *Guidance for Data Usability in Risk Assessment (Part B).* Publication 9285.78. Office of Emergency and Remedial Response, Washington, DC.

U.S. EPA. 1993. *Protocols for Radon and Radon Decay Products Measurements in Homes*. Office of Air and Radiation. EPA 402-R-93-003.

U.S. EPA. 1994. *Estimating Radiogenic Cancer Risks.* EPA 402-R-93-076. Office of Radiation and Indoor Air, Washington, DC.

U.S. EPA 1995. Health Effects Assessment Summary Tables (HEAST). U.S. Environmental Protection Agency, Washington, D.C.

U.S. EPA. 1996. *Radiation Exposure and Risk Assessment Manual: Risk Assessment Using Radionuclide Slope Factors.* EPA 402-R-96-0 16, Office of Radiation and Indoor Air, Washington, DC, June 1996.

U.S. EPA 1997.Office of Solid Waste and Emergency Response, Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination, OSWER No. 9200.4-18.

U.S. EPA 1997a. Clarification of the Role of Applicable or Relevant and Appropriate Requirements in Establishing Preliminary Remediation Goals under CERCLA. Office of Solid Waste and Emergency Response. OSWER No. 9200.4-23

U.S. EPA. 1997b. *Exposure Factors Handbook (Update).* EPA/600/P-95/002F. Office of Research and Development, Washington, DC, August 1997.

U.S. EPA 1997c. Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contaminants. Office of Solid Waste and Emergency Response. OSWER No. 9200.4-18

U.S. EPA. 1997d. *Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination,* OSWER No. 9200.4-18, August 1997.

U.S. EPA. 1998a. *Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual, Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments.* EPA/540/R-97/033.Publication9285.7-01D. NTIS PB97-963305. Office of Emergency and Remedial Response, Washington, DC.

U.S. EPA. 1998e. *Integrated Risk Information System (IRIS).* Cincinnati, OH.

U.S. EPA. 1998f. Health Effects Summary Tables (HEAST); Annual Update, FY1998. Environmental Criteria and Assessment Office, Office of Health and Environmental Assessment, Office of Research and Development, Cincinnati, OH.

U.S. EPA. l999a. *Radiation Risk Assessment at CERCLA Sites: Q&A,* Office of Emergency and Remedial Response and Office of Radiation and Indoor Air. Washington, DC. OSWER Directive 9200.4-31P.

U.S. EPA. 1999b. National Primary Drinking Water Regulations; Radon-222, Notice of proposed rulemaking, Federal Register: Volume 64, Number 211 (November 2, 1999), pp: 59295-59344.

U.S.EPA 2000. Interim Final Evaluation of Facilities Currently or Previously Licensed NRC Sites under CERCLA. Office of Solid Waste and Emergency Response. OSWER No. 9272.0-15P

U.S. EPA. 2000a. *Soil Screening Guidance for Radionuclides: User's Guide.* Office of Emergency and Remedial Response and Office of Radiation and Indoor Air. Washington, DC. OSWER No. 9355.4-16A

U.S. EPA. 2000b. *Soil Screening Guidance for Radionuclides: Technical Background Document.* Office of Emergency and Remedial Response and Office of Radiation and Indoor Air. Washington, DC. OSWER No. 9355.4-16

U.S. EPA, NRC, U.S. DOE, and U.S. Department of Defense. 2000c. *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM). NUREG-1575, EPA 402-R-97-016, Rev.1 Washington, DC.

U.S. EPA 2002. Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites. Office of Solid Waste and Emergency Response. OSWER 9285.7-41.

U.S. EPA. 2002a *Radio nuclide Preliminary Remediation Goals (P RGs) for Superfund* electronic calculator.

U.S. EPA. 2002b *Role of Background in the CERCLA Cleanup Program.* Office of Emergency and Remedial Response. OSWER 9285.6-07P

U.S. EPA. 2004a *Radio nuclide ARAR Dose Compliance Concentrations (DCCs) for Superfund* electronic calculator.

U.S. EPA, NRC, U.S. DOE, and U.S. Department of Defense. 2004b. *Multi-Agency Radiation Laboratory Analytical Protocols(MARLAP).* Washington, DC.

U.S. EPA. 2005. Guidelines for Carcinogen Risk Assessment. 70 FR 17765-17817

U.S. EPA. 2005a. *Superfund Radiation Risk Assessment and How You Can Help: An Overview.*

U.S. EPA. 2005b. *Uniform Federal Policy for Implementing Environmental Quality Systems: Evaluating, Assessing, and Documenting Environmental Data Collection/Use and Technology Programs.* EPA: EPA-505-F-03-001, Washington, DC.

U.S. EPA 2007. *Preliminary Remediation Goals for Radionuclides in Buildings (BPRG)* electronic calculator.

U.S. EPA 2008. *Regional Screening Levels for Chemical Contaminants at Superfund Sites (RSL)* electronic calculator.

U.S. EPA 2009. Protocol for Uranium Home Site Assessment. Grants Mineral Belt uranium Project, Cibola and McKinley Counties, New Mexico. Weston Solutions, San Antonio, Texas.

U.S. EPA 2010. ProUCL version 4.1Statistical Software for Environmental Applications for Data Sets with and without Non-detect Observation, Technical Guidance. EPA/600/R-07/041.

U.S. EPA 2010a. Quality Assurance Sampling Plan for Homestake Mining Company. Structure Assessment, Cibola County, New Mexico. Weston Solutions, San Antonio, Texas.

U.S. EPA 2010 b. Field Sampling Plan. Homestake Mining Co. Superfund Site. Grants, New Mexico.

U.S. EPA 2010 c. Quality Assurance Project Plan. Homestake Mining Co. Superfund Site. Grants, New Mexico.

U.S. EPA 2011. Draft Third Five Year Review Report. Homestake Mining Company Superfund Site. Grants, New Mexico.

U.S.EPA 2011a. Radiological Environmental Ground Scanner Survey. Homestake Site. Grants, New Mexico.

U.S.EPA 2012. Removal Assessment Report for Homestake Mining Company. Grants, New Mexico.

U.S. EPA 2012a. Radiation Risk Assessment at CERCLA Sites Q & A. Office of Superfund Remediation and Technology Innovation. Directive 9200.3-70

U.S. NRC 1977. Regulatory Guide 1.109. Office of Standard Development. Nuclear Regulatory Commission. Washington, DC.

Yu, L et. al., 1993. Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.0. ANL/EAD/LD-2.

Yu, C et. al., 1994. RESRAD-BUILD: A Computer Model for Analyzing the Radiological Doses Resulting from the Remediation and Occupancy of Buildings Contaminated with Radioactive Material. ANL/EAD/LD-3. Argonne National Laboratory. November 1994.