REMEDIAL INVESTIGATION / FEASIBILITY STUDY

AND

PROPOSED PLAN

COLORADO SCHOOL OF MINES RESEARCH INSTITUTE SITE

GOLDEN, CO

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List of Acronyms/Definitions

ACM	Asbestos Containing Materials
ALARA	As Low As Reasonably Achievable (NRC)
ALI	Annual Limit of Intake
ARAR	Applicable or Relevant and Appropriate Requirements
BFI	Browning-Ferris Industries
bgs	Below Ground Surface
BNSF	Burlington Northern Santa Fe Railroad
CDOT	Colorado Department of Transportation
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended
CFR	U.S. Code of Federal Regulations
CO	Colorado
COC	Contaminant of Concern
cpm	Counts Per Minute
CSI	Conservation Services, Inc.
CSM	Colorado School Mines
CSMRI	Colorado School Mines Research Institute (the Site)
CSWP	Characterization Survey Work Plan (URS Corporation)
cy	cubic yard
DAC	Derived Air Concentrations
DCGL	Decision Control Guide Limit
$DCGL_{emc}$	Decision Control Guide Limit, Elevated Measurement Comparison
$DCGL_{w}$	Wilcox rank-sum
DO	Dissolved Oxygen
DoD	U.S. Department of Defense
EE/CA	Engineering Evaluation/Cost Analysis
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FRTR	Federal Remediation Technology Roundtable
FS	Feasibility Study
GPS	Global Positioning System

HI	Hazard Index (EPA)
HQ	Hazard Quotients (EPA)
HSP	Health & Safety Plan
ID	Idaho
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MeV	Mega electron-Volt
MCL	Maximum Contaminant Levels (EPA Drinking Water)
mg/kg	Milligram per Kilogram
mg/L	Milligram per Liter
mrem	Millirem – small unit of radiation dose (one thousandth of a rem)
MTP	Materials Transport Plan
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NOAA	National Oceanic and Atmospheric Administration
NORM	Naturally Occurring Radioactive Material
NPL	National Priority List
NRC	U.S. Nuclear Regulatory Commission
NUREG	US Nuclear Regulatory Commission publication
O&M	Operation and Maintenance
OU	Operable Unit
PAI	Paragon Analytical, Inc.
pCi/g	Pico-Curies per Gram (very small unit of radioactivity)
pCi/l	Pico-Curies per Liter (very small unit of radioactivity)
PID	Photo-Ionization Detector
QAPP	Quality Assurance Program Plan
RA	Remedial Action
RAIS	Risk Assessment Information System
RAO	Remedial Action Objectives
RAOA	Removal Action Options Analysis
RCRA	Resource Conservation and Recovery Act
RESRAD	Pathway analysis computer code developed for implementing U.S. Department of Energy Residual Radioactive Material Guidelines.
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
SAP	Sampling and Analysis Plan

SVOC	Semi-Volatile Organic Compounds
SWMP	Storm Water Management Plan
TCLP	Toxicity Characteristic Leaching Test
TEDE	Total Effective Dose Equivalent
TENORM	Technologically Enhanced Naturally Occurring Radioactive Material
TSCA	Toxic Substances Control Act
UAO	Unilateral Administrative Order (from EPA)
US	United States
EPA	U.S. Environmental Protection Agency
UTM	Universal Transverse Mercator
VOC	Volatile Organic Compounds
WL	Working Level: Any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy.
yr	year

1.0 Introduction

1.1 Executive Summary

A Remedial Investigation and Feasibility Study was conducted on portions of the former CSMRI Site located in Golden, Colorado. The Site was used for mining and metallurgical research for about 70 years. The investigation phase consisted of many tasks including a gamma survey, the collection of 165 surface soil samples, the excavation of 36 test pits (56 samples), the drilling of 28 borings (68 samples), and four consecutive quarters of ground-water samples (seven monitoring wells). All of the sample points/areas were spatially located to allow geostatistical interpretation and to aid future possible remediation. The investigation found soils with elevated radionuclide activities, primarily radium, thorium, and uranium, in the vicinity of the former buildings and some nearby areas. Elevated metals concentrations, primarily arsenic, cadmium, lead, and mercury, also were detected in the Site soils. Uranium concentrations in excess of the Maximum Contaminant Level (MCL) were found in ground-water monitoring wells along with concentrations of chlorinated solvents below the MCL.

The data gathered during the remedial investigation were used to evaluate the risks and hazards associated with radionuclides and metals found in the soils. The baseline risk assessment indicated current site conditions are not protective of human health and the environment.

Using the information gathered during the remedial investigation phase, a number of possible remedial technologies were identified. After a screening process, five remedial alternatives (in addition to the no further action alternative) were identified as part of the feasibility study phase. The alternatives included leaving material on site and using stabilization methods (e.g., capping, solidification, and/or disposal cells) to immobilize the material, a combination of off-site disposal and stabilization, and complete off-site disposal. The ground-water pathway is a major driver of the site alternatives because of the proximity of Clear Creek and the apparent increase in uranium concentrations in a downgradient monitoring well.

This RI/FS proposes complete off-site disposal as the remedial action plan for the Site. Off-site removal best meets the remedy selection criteria of the National Oil and Hazardous Substances Pollution Contingency Plan. Preliminary community outreach efforts have identified a preference for the off-site disposal alternative. The final alternative selection will be made following the public comment period and review by the Colorado Department of Public Health and Environment.

1.2 Regulatory Initiative

This document is the combined Remedial Investigation/Feasibility Study (RI/FS) Report for portions of the former CSMRI site located in Golden, Colorado and unincorporated Jefferson County, Colorado (Figure 1-1). The area of investigation includes portions of the Fenced Area surrounding the former research buildings and the Clay Pits area located to the south of the Fenced Area (see Section 1.4.1 for location description). This RI/FS is being prepared as part of the Colorado School of Mines conducted remedial action in accordance with the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended (CERCLA), and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). This RI/FS proposes a remedy for the investigation area and explains the factual and legal basis for selecting the final remedy for the Site.

1.3 Purpose of Report

The purpose of this report is to:

- describe the current nature and extent of potentially affected surface and subsurface materials remaining at the Site (Chapter 3.0),
- quantify the current and future risk to human health and the environment (Chapters 5.0 and 6.0) resulting from these materials,
- identify and evaluate remedial action alternatives that are feasible for application at the Site (Chapters 7.0 and 8.0),
- propose a remedial action alternative for implementation (Chapter 9.0)

Data collected during the RI, in conjunction with existing data, were used to accomplish each of these objectives.

1.4 Site Background

1.4.1 Site Description

The CSMRI Site has historically included the soil stockpile (material removed from the settling pond) formerly located near the Colorado School of Mines (School) softball field, the Fenced Area (including the settling pond), and the Clay Pits area located south of the intersection of Birch and 12th Streets. For the purposes of this document only, the Site is defined as the Fenced Area (excluding the settling pond) and the Clay Pits area.

The Site is located on the south side of Clear Creek, east of U.S. Highway 6, in the northeast quarter of the northwest quarter of Section 33, Township 3 South, Range 70 West as shown in Figure 1-1. The main entrance to the Site is located about 475 feet northwest of the intersection of Birch and 12th Street in Golden, Colorado. A chain-link fence restricts access to the Site, except for a small area located south of 12th Street known as the Clay Pits area. A settling pond was previously located within the perimeter fence but the pond was cleaned up and closed by the U.S. Environmental Protection Agency (EPA) in 1997 as part of an Emergency Removal Action under CERCLA and is not part of the School's remedial action.

The Site (excluding the Clay Pits area and the former settling pond area) covers an area of about six acres and is currently defined by the shaded area shown in Figure 1-2. The Clay Pits area also is shown in Figure 1-2. In accordance with CERCLA and the NCP, 40 Code of Federal Regulations (CFR) Parts 300.5 and 300.400(e), the term "on-site" refers to the areal extent of contamination and all suitable areas in proximity to the contamination. Consequently, the Site boundary may be modified or expanded to address the needs of the remedial action alternatives.

1.4.2 Site History

Numerous mineral research projects (some of which involved the mineral extraction and beneficiation of materials that contained levels of radionuclides above background) were conducted at the Site from 1912 until approximately 1987. The research projects utilized 17 buildings on the Site that were subsequently removed in the mid-1990s. An impoundment (settling pond) also was situated between the building complex and Clear Creek to store wastewater generated in the laboratories and research facilities. Wastewater discharged from the buildings was transferred to the settling pond through a system of sumps and floor drains in the buildings.

On January 25, 1992, a water main owned by the City of Golden broke on the site and began discharging a large volume of water into the settling pond. EPA's Emergency Response Branch responded in February 1992 and performed a number of activities to stabilize conditions at the site, including:

- excavation of the contaminated sediments and soil,
- stockpiling of the material (the Stockpile),
- decontamination of building drains,
- demolition and removal of several buildings,

- consolidation of existing drums and disposal of compressed gas cylinders,
- sampling of sediments and water, and
- closure of the settling pond

EPA subsequently contacted many of the entities that had sent materials to the Site and requested that the Stockpile be removed off site. This culminated in the issuance of a Unilateral Administrative Order (UAO) on December 22, 1994 to certain entities (the respondents). Among other things, the UAO required the respondents to develop and evaluate disposal options for the Stockpile (approximately 20,000 cubic yards) and ultimately implement the selected disposal alternative. Some of the respondents prepared a *Removal Action Options Analysis* (RAOA) report that was issued on June 12, 1995. The RAOA report identified and evaluated various disposal options for the Stockpile. The Colorado School of Mines and the State of Colorado were the only respondents that subsequently implemented the preferred disposal option. The EPA removal action was completed in 1997.

The School hired AWS Remediation to remove the remaining research buildings from the Site in the mid-1990s. Following demolition of the buildings, the existing pits and basements were backfilled to grade; building foundations and concrete footers were left on-site.

A *Characterization Survey Work Plan* (CSWP) was prepared by URS Corporation (URS) on July 23, 2001. The purpose of the CSWP was to guide field investigation activities to supplement existing data and evaluate the risks associated with the release of residual metals and radioactive materials found in soils within the Fenced Area and the Clay Pits Area. Working in accordance with the CSWP, URS completed the characterization of the concrete and asphalt slabs and issued two Draft Final Reports on February 11, 2002 and May 18, 2002, respectively.

The CSWP identified demolition of the remaining concrete and asphalt materials as an integral part of the Site characterization process. Consequently, in April 2002, the School hired New Horizons Environmental Consultants, Inc. (New Horizons) to remove the remaining concrete and asphalt slabs and to characterize surface and subsurface soils on the Site. New Horizons prepared a comprehensive set of work plans that guided the characterization activities which were conducted at the Site. These plans were subsequently approved by CDPHE and included:

- *Storm-Water Management Plan* (SWMP) dated June 24, 2002

The SWMP identified potential sources of storm-water pollutants and established a variety of Best Management Practices (BMPs) designed to reduce or eliminate possible water quality impacts from these sources during project construction activities.

- *Health & Safety Plan* (HSP) dated July 1, 2002

The HSP established health and safety procedures that were followed by New Horizons' employees, contractors, subcontractors, and visitors while conducting assessment activities at the Site. Specifically, the HSP assigned responsibilities for implementation of New Horizons' corporate health and safety program, established personal protection standards, addressed health and safety issues related to site operations, and provided for contingencies.

- *Sampling and Analysis Plan* (SAP) dated July 1, 2002

The SAP specified the procedures used to obtain field measurements and/or samples of environmental media from the site as part of the site environmental assessment and response.

- *Materials Transport Plan* (MTP) dated July 1, 2002

The MTP described the classification of concrete and asphalt materials that were transported off-site, specified the transportation protocol for each of these materials, and detailed emergency response procedures for the materials in transit.

- *Task Plan* dated July 17, 2002

The Task Plan provided a detailed summary of the various tasks that were conducted during the characterization effort.

In addition, the *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) was used to plan the survey points spacing, select the field instruments and analytical parameters, maintain adequate instrument and procedural quality control, determine the placement of the surface samples, and assist in data interpretation.

During November and December 2002, all remaining concrete and asphalt were removed from the Site and either transported as demolition debris to BFI’s Foothills Landfill (BFI) in Golden, CO (a permitted Subtitle D solid waste facility) or transported to Recycled Materials, Inc.'s (RMI) plant in Arvada, CO for recycling. Detailed documentation regarding the removal of the concrete and asphalt slabs is provided in New Horizons' April 11, 2003 report entitled *Concrete and Asphalt Removal and Disposal [Final Report]*.

During December 2002 and January 2003, New Horizons collected surface and subsurface soil samples, which were analyzed for metals and radionuclides. Quarterly ground-water samples were collected for four quarters beginning in February 2003. The results of the Site investigation are presented in this RI/FS.

1.4.3 Previous Investigations

A number of historical investigations have been completed at both the Fenced Area and the Clay Pits area. Results from these investigations are included in the following reports:

- *Surface Gamma Ray Scanner Survey*, U.S. Environmental Protection Agency, 1982.
- *CSMRI Environmental Assessment*, Jacobs Engineering Group Inc., October 1987.
- *Claypits Report to CDPHE*, Robert MacPherson, October 20, 1988.
- *Preliminary Assessment of Radiological Risks at CSMRI, Creekside*, L. Hersloff, Radiant Energy Management, September 1989.
- *Tailings Pond, CSMRI, Creekside Sampling Report, Industrial Compliance Inc.,* October 1989.
- *Preliminary Assessment of the Potential for Water-Borne Migration of Contaminants in the Claypits,* J. Kunkel, Advanced Science, October 20, 1989.
- *CSM Environmental Sampling & Analysis Program: Claypits Site & CSMRI Facility*, James L. Grant & Associates, August 9, 1990.
- *Characterization Plan for Claypits & CSMRI Creekside and Table Mountain Research Center Sites,* James L. Grant & Associates, March 22, 1991.
- *Preliminary Remedial Alternative Evaluation for the CSM Creekside Stockpile*, SR & K, August 25, 1994.
- *Removal Action Options Analysis (*RAOA*),* Multiple authors, June 12, 1995 (3 vols.).
- *Concrete and Asphalt Characterization Report*, URS Corporation, May 18, 2002.
- *CSMRI Characterization Summary*, New Horizons Environmental Consultants, Inc., August 21, 2003.

1.5 Report Organization

This RI/FS report is organized into 2 volumes. Volume 1 includes the main text, tables, and figures. Volume 2 includes the appendices. Volume 1 includes nine chapters. Chapter 1 describes the regulatory setting and Site background. Chapter 2 broadly portrays the physical characteristics of the Site, Chapter 3 describes site investigations pertinent to the RI. Chapter 4 describes the nature and extent of affected materials. Chapter 5 discusses contaminant fate and transport and Chapter 6 assesses the baseline risk to human health and the environment. Chapter 7 defines remedial action objectives for the Site, identifies general response actions, quantifies volumes or areas of each media of concern, and screens general response actions, potential remedial technologies and process options. Chapter 8 develops and compares the remedial alternatives based on remedial action objectives, the screened technologies, and representative options. Chapter 9 presents an overview of the proposed remedial action alternative.

1.6 Schedule

Depending on the selected alternative, the remedial action is expected to take between four and eight months to complete. Estimated schedules for each alternative can be found in Section 8.0.

2.0 Physical Characteristics of Study Area

2.1 Surface Features and Utilities

In general the Site slopes gently to the north with a major elevation break above the former settling pond (Figure 2-1). The majority of the buildings located on the eastern side of the main driveway had shallow foundations resulting in relatively uniform topography after the concrete removal operations had been completed. Buildings on the western side of the Site had fairly deep foundations and removal operations resulted in significantly deeper excavations. As a safety precaution, a limited amount of soil was moved to stabilize steep slopes in the vicinity of these excavations.

Utilities remaining on the Site at the start of the RI included an overhead electrical line, water mains and a sewer line owned by the City of Golden, and irrigation lines owned by the School. All other utilities had been disconnected prior to the concrete/asphalt removal operation.

The City of Golden attempted to locate all of their utilities on several occasions, but encountered difficulty locating the 16-inch water main that traversed the property from north to south. Consequently, remedial investigation activities in the general vicinity of the water main were purposely limited.

2.2 Meteorology

Information for the local meteorology was gathered from a number of sources. Local weather observation stations in the vicinity of the Site include a National Oceanic and Atmospheric Administration (NOAA) maintained weather station (precipitation) located about 3.5 miles south of the Site (operational record 1975 to present). The RAOA referenced information weather stations in Wheat Ridge (operational record 1981 through 1988), Lakewood Station (operational record 1962 to 2000), and Golden (operational record 1989 to 1995). Average temperatures and precipitation for the area are available from websites such as http://www.weather.com. The RAOA referenced an anemometer that operated during a period from May 1979 to March 1980. The meter was located about 4,000 feet west of the Site in Clear Creek Canyon (Figure 2-2). Wind speeds at the anemometer location are biased by the canyon, but provide directional information relevant to the Site.

2.2.1 Precipitation

Average annual precipitation listed for the Golden area is about 17.1 inches (www.weather.com), but there is significant variability along the Front Range. The NOAA weather station located to the south indicates a precipitation average of 13.4 inches (maximum 18.7 inches, minimum 7.5 inches) over 27 years. For the Front Range area, about 70 percent of the total annual precipitation occurs between April and September due to upslope conditions and thunderstorm activity. The greatest amounts of precipitation typically occur in April, May, and June when the average monthly totals exceed two inches. Precipitation minimums occur in December, January, and February when the average monthly precipitation is generally less than one inch. Front Range evaporation potential exceeds the annual total precipitation. Typical total annual pan-evaporation is about 60 inches and total annual lake evaporation averages about 41 inches. Approximately 71 percent of the evaporation occurs between May and October.

2.2.2 Temperature

The average annual temperature is about 63.2 degrees Fahrenheit (°F). The highest average monthly temperatures typically occur in July and August and range between 68°F and 70°F. In December and January, the lowest average monthly temperatures are generally observed and range between 28°F and 29°F. Area temperatures can range from –26°F to 101°F.

2.2.3 Wind Direction and Speed

Average wind speed information collected from the three weather stations varied little from month to month. The data indicates, however, that maximum winds and wind gusts are higher in the winter than in the summer. Increased wind speeds in the winter are probably due to the passage of storm fronts causing strong downslope conditions. Average annual wind speed in the Denver area is about 9 miles per hour. However, wind speeds are often higher along the foothills near the Site (no site-specific data was located).

Basically, there are two major meteorological conditions that determine the direction of air movements in the Golden area (1) synoptic flows and (2) local flows. Synoptic flows are wind patterns that affect areas on the order of several thousands of square miles that are characterized by meteorological systems on the scale of high and low pressure systems as shown on weather maps. In the absence of a dominant synoptic flow, local flows become the prevalent factor in the air movement. These winds by and large follow the topography of an area with air flows draining from higher elevations toward the lower elevations.

The Site area is in a unique location relative to wind direction that is best represented by the wind direction information from the meteorological monitoring location shown in Figure 2-2. The wind direction information from that location was evaluated and a wind rose developed for that data (Figure 2-2). Wind data is an incomplete data set collected from May 1979 to March 1980 and was used as part of the RAOA evaluation. The wind rose in Figure 2-2 shows the percentage of time that the wind blew from each of the 16 wind directions monitored. The wind was calm for only about 1.4 percent of the time during the measurement period. Based on a review of Figure 2-2 and area weather data, the predominant wind direction is from the west to east and reflective of drainage flows which are common along the Front Range. On an annual basis the wind actually blows from the west approximately 60 percent of the time and from the east approximately 35 percent of the time with minor excursions from the north and south. Midday warming of the plains can generate east to southeast winds, creating an upslope flow along the Front Range. During the night, the cooler air flows down the mountainside across Golden and into the Denver Basin to the east. The nighttime flows can start early in the evening and persist into the midmorning and early afternoon.

2.3 Surface-Water Hydrology/Quality

The Site is located immediately south of Clear Creek, the primary surface-water conveyance in the area. Clear Creek is a perennial tributary of the South Platte River with a drainage basin area above the Site of approximately 400 square miles. The headwaters of Clear Creek are located along the Continental Divide near Loveland Basin Ski Area. From the headwaters the stream drops over 8,000 feet in about 50 miles, passing through steep canyons on its way to the Golden area. East of Golden, Clear Creek flows through the plains for about 14 miles to its confluence with the South Platte River in Denver, Colorado.

Gingery and Associates, Inc. (1979) developed discharge information for flood analysis of Clear Creek. Peak flows calculated for the reach of Clear Creek up to the western edge of the City of Golden are listed below:

Return Period	Peak Flow (cfs)
10-year	3,300
50-year	8,000
100-year	12,500
500-year	25,000

In the vicinity of the Site, the 100-year flood elevation is 5,682 feet (Appendix A). Based on work summarized in Advanced Sciences, Inc. (1989), the 500-year flood level is about 5 feet higher than the 100-year elevation or about 5,687 feet. The elevation at the lowest point of the Site is approximately 5,670 feet (former settling pond area next to Clear Creek), which is in the flood plain. However, the majority of the Site lies between about 5,700 feet and 5,720 feet, which are at least 23 feet above the 100-year elevation and 18 feet above the 500-year elevation.

Chimney Gulch is a small drainage that passes about 100 feet west of the western gate of the Site (Figure 2-2). Chimney Gulch is a tributary of Clear Creek with a drainage basin of approximately 482 acres. This tributary's headwaters begin on Lookout Mountain and its confluence with Clear Creek is about 200 feet northwest of the Site. During most of the year, Chimney Gulch is dry. However, when the Welch Ditch is being used, excess water in the ditch is routinely drained into Chimney Gulch and back into Clear Creek.

Clear Creek passes through an historic mining region of the Colorado Mineral Belt. Several reaches of Clear Creek have been designated EPA Superfund Sites because of the extensive mining operations. Numerous mine adits along the stream contribute to seasonally elevated concentrations of metals, primarily manganese and zinc.

2.4 Geology

The Site is located along the eastern edge of the Rocky Mountain Front Range foothills. The Front Range is a complexly faulted anticlinal arch of primarily Precambrian crystalline rocks that reach elevations of over 14,000 feet. The foothills include the areas where "older" deposits were folded and pushed aside as the "younger" Rocky Mountains uplifted. The foothills rock types range from unconsolidated sediment deposits (25 thousand to 1 million years old) to sedimentary rocks (primarily sandstone and shale – 300 million to 63 million years old) to igneous and metamorphic rocks (over 1 billion years old). These formations remain as horizontal layers beneath Denver and the eastern plains. The Clay Pits area is a surface expression of the unconsolidated sediment deposits (Laramie – Fox Hills Sandstone – these deposits have been tilted almost vertical) and the bedrock underlying the Site is a sedimentary rock (Pierre Shale). The Golden fault, a high-angle reverse fault, is present along the eastern edge of the foothills west of the Site (Figure 2-4).

2.4.1 Bedrock Structure

Figure 2-4 is a Surficial/Bedrock Geologic Map of the area showing the Site location and surrounding features. Weimer (1976) developed a geologic cross-section of the Site vicinity. Weimer's cross section is presented in Figure 2-5 and shows that the geologic strata are overturned and steeply dipping. Measurements of the strike of the beds in the Clay Pits area show a North 37° West trend with dips ranging from about 70° to 80° to the west (James L. Grant & Associates, Inc., April 1990). Further east the beds become vertical and then east dipping. Erosion activity of an earlier Clear Creek along with construction activities appears to have removed the surface expression of the Laramie-Fox Hills sandstone north of the Clay Pits. The Site is located in an area of surficial deposits overlying the Pierre Shale. As shown in Figure 2-4, the Site is located in the Pierre Shale unit, a sequence that is at least 2,000 feet thick at this location.

As evident on Figure 2-4, the Golden fault cuts through the area just west of the Site. Van Horn (1976) characterizes the fault as a moderately to steeply west-dipping reverse fault of large displacement. This fault was extensively evaluated as part of investigations at the Rocky Flats Plant to the north. As a result of these evaluations (summarized in Appendix B of the RAOA) the Golden fault is not an active fault (i.e., movement has not occurred in the past 35,000 years and multiple movements have not occurred in the past 500,000 years).

2.4.2 Bedrock Stratigraphy

The stratigraphic units presented in Figure 2-4 are described below in order of decreasing age, oldest to youngest. These summaries are primarily from Van Horn (1976, 1995 – oral communication for RAOA) and Weimer (1976).

Precambrian (pC) - These metamorphic rocks are resistant but mostly covered by colluvium west of the Site and forms the eastern-most slopes of the Front Range. Although outcrops are present, individual units are generally difficult to follow for any distance. Precambrian rocks in this area are believed to be overlain with angular unconformity by the Fountain Formation.

Fountain Formation (PPf) - This sedimentary unit is not exposed in the immediate vicinity of the Site but is believed to be present on the west side of the Golden fault under the alluvial fan materials shown in Figure 2-4. The Fountain is a pink to reddish-orange, coarse- to fine-grained, arkosic conglomeratic sandstone and conglomerate interbedded with lenticular, dark-reddishbrown, silty, indurated mudstone and pinkish-gray, fine-grained, quartzose sandstone.

Pierre Shale (Kp) – Small areas of Pierre Shale are evident along the western end of the former settling pond, exposed by the erosion action of Clear Creek. Weimer (1976) characterized the unit as consisting of dark gray shale with minor, thin laminae of tan-weathered limonitic siltstone and silty, very fine-grained sandstone. Pierre Shale underlies much of the Site including part of the parking area. The Pierre Shale is estimated to be at least 2,000 feet thick beneath the Site.

Fox Hills Sandstone (Kfh) – In the immediate vicinity, exposures of the Fox Hills are limited because of localized faulting. Where exposed, the sandstone is tan to yellow, fine-grained, subrounded, friable, calcareous sandstone with thin beds or laminae of siltstone and gray montmorillonitic claystone. The exposed thickness of the Fox Hills near 12th Street (Figure 2-4) is about 40 feet; however, the exact thickness is questionable because of faulting and could be as much as 75 feet (Weimer 1976). As shown in Figure 2-4 the Fox Hills underlies a part of the eastern-most practice field and some of the former Site buildings and parking area. The outcrop of this formation is visible to the west of the claypits site.

Laramie Formation (Kl) – The Laramie is well exposed in a clay excavation south of Birch and 12th Street. The thickness of the Laramie is about 350 feet and the formation is subdivided into two stratigraphic units. The lower unit (western-most unit) is about 190 feet thick near 12th Street and consists of four major sandstones that alternate with mineable kaolinitic claystone. The thickness of the individual sandstones and claystones varies from 20 to 40 feet. The sandstones are light gray to buff, fine-to coarse-grained, poorly sorted, subangular, and silty. The kaolinitic claystone units contain light- to medium-gray, blocky weathering claystone with lesser amounts of dark gray to black carbonaceous claystone and thin coal streaks. Additionally, the lower Laramie contains a mineable coal seam. A monument over the Old White Ash coal mine is located at the intersection of Birch and 12th Street. The surface trace of the main worked seam is located to the east of the monument and is 8 feet thick; a second mined seam, 10 to 20 feet to the west of the primary seam, is 3 feet thick (Emmons, et. al., 1896). These seams were mined to a distance of about one-mile north of Clear Creek and several hundred feet south of 12th Street. The surface trace of the coal mine is presented in Figure 2-4.

The upper Laramie is about 160 feet thick and is similar in lithology to the lower Laramie, except that the sandstones are much thinner and finer grained. Neither coal nor carbonaceous shale is associated with the upper Laramie claystone. As is evident from Figure 2-4, the Laramie underlies the western half of Brooks Field and the eastern portion of the Site.

Arapahoe Formation (Ka) – The Arapahoe overlies the Laramie to the east and is 300 to 500 feet thick. It is composed of discontinuous beds of sandstone and claystone. The exposure in the Clay Pits south of Brooks Field show the lower Arapahoe is predominantly a conglomerate and conglomeratic sandstone with minor intercalations of gray claystone and siltstone. The upper Arapahoe is not exposed in the immediate area. As is evident in Figure 2-4, the Arapahoe underlies the eastern half of Brooks Field and part of the eastern Site access road.

Denver Formation (TKdv) – To the east of the Arapahoe lies the Denver Formation, which is not exposed in the immediate vicinity. The Denver consists of light gray to brown tuffaceous silty claystone, tuffaceous arkose, and esitic conglomerate. The base is marked by the first appearance of volcanic material.

2.4.3 Geologic Characteristics of the Surficial Deposits / Soils

The surficial deposits that overlie the bedrock in the vicinity of the Site include the following (the order presented below does not show the age relationship):

- Louviers Alluvium
- Younger Alluvial Fan Colluvium
- Post-Piney Creek Alluvium
- Artificial Fill

More information, e.g., thickness on these surficial deposits can be found in the test pit and boring logs.

Louviers Alluvium (Qlo) – The Louviers forms a well-defined terrace in the Clear Creek valley and is the oldest of the alluvial deposits present in the area shown in Figure 2-4. The deposit is typically a coarse cobbly sand and gravel that is poorly sorted. Generally, there is less than 10 percent silt and clay present. Just east of the area shown in Figure 2-4, the Louviers has sub-round to round pebbles and cobbles of granitic rocks. Boulders as large as one-foot across are present, but the common large size is 6 inches. Based on the subsurface work performed at this location, this unit is about 10 feet thick and extends south under the baseball and practice fields to the approximate location shown where it pinches out against the bedrock. The Louviers is overlain by younger alluvial fan, colluvium, and artificial fill deposits. Locally, the post-Piney Creek Alluvium overlies eroded Louviers deposits.

Younger Alluvial Fan (Qyf) – In the location shown in Figure 2-4, this unit is associated with the current Chimney Gulch drainage and overlies the Louviers. This deposit is believed to have formed before the deposition of the post-Piney Creek Alluvium. The materials present in the deposit associated with the Chimney Gulch drainage consist of a poorly sorted, heterogeneous mixture ranging from boulders to clay. The upper few feet are clayey silt grading downward to coarser materials. The thickness of this unit varies but is expected to be as much as 40 feet in the area mapped in Figure 2-4.

Colluvium (Qco) – Colluvium consists of materials that have been moved down steep slopes by creep and sheet wash, and, at a few places, they represent minor alluvial fan deposits. The colluvial deposits grade into, and interfinger with, alluvial terrace deposits and the younger alluvial fan deposits. It is mostly a massive to crudely bedded sandy to clayey silt but locally either sand or clay can predominate. Colluvial deposits generally overlie very irregularly sloping bedrock surfaces. While this may be typical at many locations, they are known to overlie the Louviers deposits over a portion of the area covered in Figure 2-4 as discussed above.

The subsurface investigation of the Site included 36 test pits and 28 borings (see Section 3.3.4). The majority of the subsurface material would be classified colluvium. The eastern portion of the Site is covered with a clay layer that varies in thickness between 5 and 6 feet. Below the clay is a layer of red, brown sandy clay followed by a layer of orange, red, brown clayey sand. These layers vary in thickness from about one foot to three feet. These differences reflect the origin of the colluvium. Potentially, the clay materials have been derived from the Pierre Shale; the reddish-brown sand from the Fountain Formation (present on the west side of the Golden fault); and the brown sand from the Fox Hills formation.

Underlying the colluvial material is an alluvial cobble zone. The cobble zone consists of a small quantity of pinkish, reddish sand intermixed with numerous flat cobbles/boulders (up to 12 inches). See the following description of the Post-Piney Creek Alluvium. Up to 13 feet of this alluvial material was encountered in the borings. This zone could not be penetrated by the backhoe used for the test pits.

Post-Piney Creek Alluvium (Qpp) – This alluvial unit is present along Clear Creek, and the youngest alluvial unit in the area mapped in Figure 2-4. It consists of coarse sand and gravel deposits.

Artificial Fill (af) – Artificial fills areas were identified during the RAOA and are shown in Figure 2-4. The identified fill was used primarily for highway construction and for enhancing the usable area of the athletic fields and the adjacent area. The fills include tan to brown clay, medium to stiff, silty, sandy, and slightly gravelly (athletic field) and the artificial fill consists of silty clay to clayey sand with some gravel and construction debris (softball field area).

A comparative analysis of the topographic changes in the last several decades was performed as part of the RAOA. The analysis revealed that fills in the baseball field and western-most practice field may have been generated from cuts (up to 15 feet) in the infield portion of the baseball field.

Additional artificial fill was identified during the RI including:

- Sandy, silty cobbles for roadbed construction,
- Imported uniform sand used for fill around foundations and under roads,
- Bricks and miscellaneous building debris mixed with varying mixtures of clay and sand, and
- A variety of bricks, clays and sands, and miscellaneous debris used for roadbeds and fill around building foundations.

The topographic evaluation also shows that the channel of Chimney Gulch formerly may have been located about 130 feet east of its current location, which would place the old channel beneath the western access road.

2.4.3.1 *Soils*

Because of the extensive construction activities on the Site, very little "A" horizon material remained (see Figure 2-3a). Small areas of an "A" horizon were encountered along the northern side of the eastern and western access road. A treed area is located along Clear Creek in the northeastern corner of the Site has a shallow "A" horizon underlain by sandy, silty sub-soils. No additional subsurface investigation was completed in this area for the RI. The majority of the Site is covered with "B" or "C" horizon subsoils that were exposed as the buildings and roads were constructed.

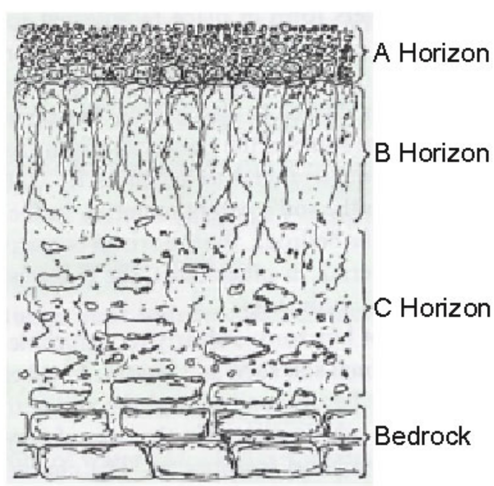

Figure 2-3a Schematic representation of an hypothetical soil profile, with its underlying parent rock. The A horizon is typically referred to as "top soil" (Hillel, 1982)

2.4.4 Water-Bearing Units

In the area shown in Figure 2-4 and 2-4a, ground water is present in the following bedrock units: the Laramie/Fox Hills units, the Arapahoe, and some of the Denver. Ground water is also present in the Louviers Alluvium and post-Piney Creek Alluvium. The Laramie/Fox Hills and the Arapahoe are important aquifers of regional significance and the Louviers Alluvium, post-Piney Creek Alluvium, and the Denver Formation can be locally significant. Regional studies by Robson (1983 and 1984) and Robson, et. al. , (198l a and 1981 b) indicate that the outcrop areas for these units in the area covered in Figure 2-4a are part of the recharge area. Recharge is primarily expected to occur from direct rainfall and snowmelt infiltration and by percolation from Clear Creek directly through the alluvium. However, RI observations suggest the reach of Clear Creek along the northern Site border may be a gaining reach because of the artesian nature of Laramie Fox-Hills aquifer in this area (several seeps are visible in the area).

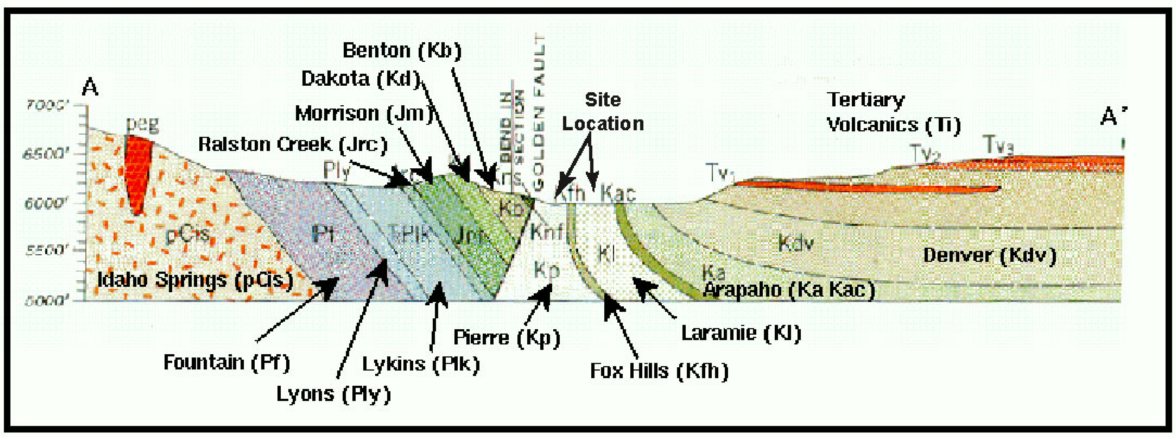

Figure 2-4a Geological cross section in the vicinity of the Site

The most relevant water-bearing unit on the western side of the Site is the alluvial deposit above the weathered Pierre Shale (see Figure 2-3). The Pierre Shale acts as an aquitard, allowing water from infiltration and nearby stream losses to move downgradient to Clear Creek. The Pierre Shale was encountered in four of the borings installed as part of the RI. Depth to the unit varied from about 10-feet below ground surface (bgs) north of the former Building 101N location to about 40-feet bgs near the baseball field. The ground-water zone above the formation varies between about one to four feet above the unit near the former Building 101N location and between about 6- to 15-feet near the baseball field. Ground water was encountered about 30-feet below the baseball field and about 54-feet below the practice fields during the RAOA. More detailed discussions of the subsurface conditions including ground water are provided in Section 4.

The most relevant water-bearing unit on the eastern side of the Site is the Laramie Fox-Hills aquifer (see Figures 2-3 and 2-4a). The outcrop of the Arapahoe formation appears to be located to the east of the Site and does not influence Site hydrology.

2.5 Ground-Water Hydrology

A complex ground-water system underlies the Site because of the area geology (see Section 2.4). Bedrock in the vicinity is a complicated system of nearly vertical sediment deposits overlying Precambrian, crystalline bedrock (see Figure 2.4a). Sediment layers that once were located deep under the Denver Basin were pushed up as a result of the uplift of the Rocky Mountains. The Site is located at the western edge of the Denver Basin aquifer system, which includes the following four aquifers – Dawson, Denver, Arapahoe, and Laramie-Fox Hills. These aquifers are unconfined along these uplifted beds and the potentiometric surface (water table) associated with each aquifer is typically closer to the surface than the majority of the aquifer. The aquifers are confined in the deeper portions of the basin, providing the pressure required to raise the ground water closer to the surface. This artesian effect appears to be occurring in the portion of the Laramie Fox-Hills aquifer that underlies the Site.

Two ground-water-monitoring wells were installed as part of the RI. These wells were used in conjunction with five existing wells to determine ground-water quality and to estimate ground-water flow directions. Because of the very slow recharge rates of several monitoring wells and insufficient information on well screen conditions, ground-water velocities were not determined.

The ground-water direction is governed by the underlying weathered Pierre Shale and appears to be flowing northeasterly toward Clear Creek. The surface expression of the Laramie – Fox Hills Sandstone may influence ground-water movement in the vicinity of the Clay Pits causing a northwestern movement. Weathering has removed any surface expression of the sandstone along Clear Creek so it is difficult to determine if the northwest movement is actually happening.

It appears that the majority of the western Site ground water comes from surface infiltration from the surrounding foothills, surface irrigation of the baseball/softball fields, and the seasonal influence of the nearby Welch ditch. The eastern Site ground water appears to be a mixture of the infiltration water and the Laramie Fox-Hills aquifer.

2.6 Demography and Land Use

2.6.1 Demography

In 2000, the population of the City of Golden was 17,159 based on the U.S. Census. The Golden city limits extend approximately 1.7 miles to the north of the Site, 1.5 miles to the east of the Site, and 3.2 miles south of the Site.

2.6.2 Land Use

Land usage in the vicinity of the Site includes residential, commercial, and rangeland. A large portion of the surrounding area is owned by the State of Colorado and has a variety of university-related uses including athletic fields, classrooms, recreational facilities, maintenance, and administration. Additionally, the City of Golden has offices and a water treatment plant on the north side of Clear Creek across from the Site. The residential, commercial, municipal, and agricultural facilities and their distances from the Site as obtained by direct field reconnaissance and map measurements are as follows:

- West - Condominiums along Clear Creek are located about 1,500 feet west of the Site.
- South - A housing area along Parfet Estates Drive. The closest house is about 1,300 feet from the Site.
- North - A public campground is located about 50 feet from the Site on the north side of Clear Creek. Ponds associated with the City of Golden's water treatment plant are about 200 feet north west of the Site. The City of Golden's offices are about 100 feet to the north. A recreation center is located about 300 feet to the north with a 40-unit apartment building with about 300 feet north of the recreation center (600 feet north of the Site). The dairy originally located 3.6 miles north of the Site is no longer in business.
- East - The CSM football stadium shares the eastern boundary with the Site. There are condominiums on the west side of Maple Drive within 150 feet of the eastern gate. The closest house on 12th Street is about 600 feet from the Site. The closest CSM building is 700 feet to the southeast.

2.6.3 Surface-Water Uses

Surface water diverted from Clear Creek is primarily used for water supply and secondarily for recreation and irrigation purposes. Diversions present within approximately one mile of the Site are shown on Figure 2-5 and are discussed in the following sections.

2.6.3.1 Welch Ditch Diversion

This ditch originates on the southern side of Clear Creek about 1.8 mile upstream of the Site (west). The Welch Ditch passes approximately 900 feet south of the south end of the Site (about 650 feet south of the Clay Pits). The water from the ditch is used for irrigation and there are no domestic uses from the ditch. The ditch is unlined and flows along the side of the hill above the Site to the east, through a tunnel and culverts in the vicinity of the School student housing and the Clay Pits. From here, it flows around the southern perimeter of Golden, along the north side of South Table Mountain above the Coors' brewery, and then to the east into the Federal Center. The ditch is a major source of ground-water recharge for the Site drainage when it is in operation. Overflow from the ditch is diverted down the Chimney Gulch drainage.

2.6.3.2 Church Ditch/City of Golden Diversions

This ditch originates on the northern side of Clear Creek about 0.9 mile upstream of the Site (west). The major water users served by the Church Ditch include the Cities of Broomfield, Northglenn, Thornton, Westminster, and Arvada. Water is used for municipal purposes including drinking water. The City of Golden also diverts some of its municipal water at the Church Ditch headgate and that water is incorporated into the city's drinking water supply. Treatment facilities for Golden are located on the northern side of Clear Creek near the Site.

2.6.3.3 Agricultural Ditch Diversion

This diversion originates on the south side of Clear Creek about 3,000 feet downstream (east) of the Site. The Agricultural Ditch is the first surface-water diversion downstream of the Site. The major water users served by the Agricultural Ditch include a major municipal supplier to the Cities of Lakewood and Wheat Ridge. Some of the water is also used by Arvada, Golden, and unincorporated areas of Jefferson County. There are a number of other smaller industrial and agricultural users as well.

2.6.3.4 Farmers' Highline Canal and Ditch

This diversion originates on the north side of Clear Creek about 3,500 feet downstream (east) of the Site. The major water users served by the Farmers Highline diversion include the cities of Westminster, Thornton, Northglenn, and Arvada. Water is used for municipal purposes including drinking water. Coors and several small irrigation users also divert from the ditch.

2.6.4 Ground-Water Uses

Ground-water wells, applications, and permits were identified for a one-mile radius around the Site from information provided by the Colorado Division of Water Resources. A copy of that information is included in Appendix B. An evaluation of that information shows that there may be as many as 20 wells in use within a 1-mile radius of the Site. The identified uses include 9 for industrial, 10 for domestic, and 1 for household purposes. Yields range from 1 gallon per minute to as much as 85 gallons per minute. The nearest wells are located on the north side of Clear Creek within 500 to 1,000 feet of the Site. The nearest well on the south side of Clear Creek is over 2,000 feet away. All of the 9 industrial use wells are alluvial wells owned by Coors Brewing Company are to the northeast of the Site at distances in excess of about 2,000 feet in locations near Clear Creek. Water taken from the industrial use wells, as well as the domestic and household wells, may be used for drinking water purposes according to the Colorado Division of Water Resources use classification.

2.6.5 National Historic Preservation Act Considerations

Potential historical and archeological resources were previously evaluated during the preparation of the RAOA. The Colorado Historical Society advised that no significant historical or archeological resources are known in the immediate vicinity of the Site. Additionally, the City of Golden's Planning Department also advised that there are no known historical or archeological resources that would affect the FS alternatives evaluation or selection process.

2.7 Ecology

The ecosystem of the area surrounding Golden is a very diverse habitat influenced by a range in elevations that encompasses the plains, foothills, and mountains. The channelization of Clear Creek, construction of artificial ponds, grading projects, changes in vegetation, and other works of man have created new habitats by altering the natural habitat in the vicinity. Extensive residential development also has occurred over the years, and new development is continuing to the north and south of the Site.

The U.S. Fish and Wildlife Service was previously contacted during preparation of the RAOA to determine if sensitive ecosystems or species are present in the area. They indicated that a federally threatened plant species, the Ute Ladies' Tresses Orchid (Spiranthes diluvialis) is present in the Clear Creek area in the vicinity of the Site. The RAOA includes a survey performed by a local botanical expert, recommended by the Fish and Wildlife Service, in an area adjacent to the Site for potential Ute Ladies' Tresses Orchid habitat. The surveyed areas included Chimney Gulch below U.S. Highway 6 and a tributary of Chimney Gulch that runs parallel to U.S. Highway 6 on the north. The results of that survey showed that neither Chimney Gulch nor its tributary provide adequate habitat for Spiranthes diluvialis and that both drainage courses are in poor condition relative to natural habitats. The only portion of the Site that could potentially have suitable habitat would be the lower area along Clear Creek. This area has significant disturbance because of the excavation of the prior settling pond and the installation of the monitoring wells. A wooded area east of the settling pond area is unsuitable habitat for the Ute Ladies' Tresses Orchid because the plant prefers wet meadows. Using published habitat descriptions and the results of the previous investigation it was determined that all on-site habitats were unsuitable for Ute Ladies' Tresses.

3.0 Study Area Investigations

This chapter describes the RI activities that were conducted by New Horizons in 2002 and 2003.

3.1 Surface Features Mapping

Prior to the removal of the concrete floor slabs and asphalt, Flatirons Survey (Flatirons) performed a land survey of the building corners. The location of all visible manholes, drains, and pipelines that penetrated floor slabs were recorded during this survey. After the removal of the concrete and asphalt, additional ground penetrations were identified and recorded. Following surface and subsurface sample collection, Flatirons performed a detailed survey of the Site and surrounding area to produce a topographic map of the area. The topographic map generated from this survey is provided in Figure 2-1.

3.2 Sources - Operations That Produced Contamination

The original operations that generated the elevated material no longer exist on the Site. The Site was used for mining-related research projects and was in operation from 1912 until about 1987. Because buildings and equipment were removed prior to the RI, only the residual affected material (primarily soil) remained on the Site. Source investigations that were conducted as part of the RI included a surface gamma survey, collection of surface samples, excavation of test pits for gamma surveys and sample collection, installation of bore holes for gamma surveys and sample collection, and collection of ground-water samples. Results of these investigations are discussed in the following sections.

3.2.1 Surface Gamma Survey

After the removal of the concrete and asphalt, a surface gamma survey was performed on the majority of the Site. The following describes the survey coverage, procedures, and instrumentation.

3.2.1.1 Gamma Survey Coverage

In accordance with the Sampling and Analysis Plan (SAP) and the CSWP, the Fenced area and the Clay Pits area were surveyed as part of the RI. The area around the former settling pond adjacent to Clear Creek was excluded because it had previously been surveyed and released by EPA during the 1992 response action. In addition, the density of survey locations was limited in the northeast corner of the Site due to dense vegetation and steep slopes, which made this area relatively inaccessible (see Figure 3-1). Several areas of the Site were inaccessible because of unstable slopes that remained after the removal of the concrete and asphalt slabs and sidewalls.

3.2.1.2 Gamma Survey Procedures

The survey consisted of dividing the Site into an approximate 3.3 meter x 3.3 meter (10 feet x 10 feet) grid and recording a 10-second gamma reading inside each grid square. Each survey coordinate was recorded using a global positioning system (GPS) unit. Additional readings were collected in areas that exhibited elevated gamma readings to better define the extent of the anomaly. If the resulting data indicated areas of incomplete coverage, additional points were surveyed to achieve the desired survey density.

3.2.1.3 Instrumentation – Gamma Meter

The gamma survey was performed using Ludlum Model 44-10 gamma detectors in combination with Ludlum Model 2350-1 data loggers. The Model 44-10 is a 2-inch (5.1 cm) x 2-inch (5.1 cm) sodium iodide Tl scintillator detector. During the surface gamma survey, each detector was equipped with a lead-shielded collimator to minimize interference from adjacent radioactive sources (i.e. shine). Data from each data logger was downloaded daily to a master computer database.

Daily efficiency checks were performed on the gamma instruments in accordance with the approved SAP to verify performance of the equipment. Manufacturer calibration certifications and efficiency check documents are provided in Appendix C.

3.2.1.4 Instrumentation - GPS unit

Trimble Pathfinder Pro XRS GPS receiver units were used in conjunction with the gamma meters. The GPS unit was set to record positions only when a sufficient number of satellites were available to guarantee the required accuracy. A 20-second position was collected at each survey location and logged along with the gamma meter reading into the GPS data logger. All data was downloaded at least once a day to a computer database. Because the accuracy of the field data could vary by more than 10 meters, raw data was post-processed using Trimble Pathfinder Office software to calculate differential correction. A base station maintained by CompassCom at the Denver University campus (Denver, CO) provided the data used for the differential correction. Although post-processed data was typically corrected to provide location accuracies of less than one meter, locations measured under obstructions or near power lines may have resulted in accuracies greater than one meter.

All GPS data was collected in Universal Transverse Mercator (UTM), Zone 13 North coordinates and the World Geodetic System of 1984 datum.

3.2.2 Surface Gamma Survey Data Evaluation / Plotting

Prior to the Site gamma survey, gamma measurements were made in areas adjacent to the fenced area and Clay Pits area (see Figure 3-2). These measurements were used to establish the Site background gamma levels.

A total of 3,282 survey points were measured during the surface gamma survey (Table 3-1). The data set included a gamma value and UTM position for each survey point. All gamma data entered into the GPS data logger was cross-checked against the recorded value from the Ludlum data logger using Microsoft Excel®. Each 10-second gamma reading was multiplied by 6 to produce a one-minute count and all location data was post-processed to ensure required accuracy.

Sixty-one data points were surveyed at accessible portions of the Clay Pits (Figure 3-2). All of the Clay Pits area gamma measurements were at or below Site background levels (Table 3-2).

Data exported from the Trimble Pathfinder Office® software was combined with the gamma readings to provide a coordinate file for Surfer® 8 contouring and 3D surface mapping software. Figure 3-1 shows the location of all the gamma survey points in relation to the perimeter fence and the location of the original building slabs.

The effect of overhanging trees and power lines on the accuracy of the GPS unit can be observed along the southern edge of the eastern access road where survey points located inside the perimeter fence plot outside the fence. Also, just south of the old settling pond, 11 survey points appear to be shifted to the north because differential correction files were not available for this area.

3.2.3 Surface Soil Samples

Surface soil samples were collected to determine the type, the extent, and activities/concentrations of the contaminants. The primary focus of the sampling program was metals and radionuclides, but organic compounds were investigated if necessary.

3.2.3.1 Sample Locations

Samples were collected from surface soils at 163 locations on the Site in accordance with the approved SAP and using the guidance provided in MARSSIM (Figure 3-3). The Site was divided into 12 sections with up to 10 samples collected from each section. A GPS unit was used to delineate the section boundaries. Once the boundaries were established, sample locations were selected by randomly placing markers in the area. GPS coordinates were recorded for each sampling location, with location post-processing completed the following day. Because of the irregular shape of the Site, two sections on the Site's eastern side were smaller in area, requiring fewer samples. Additional samples were collected in areas where the gamma survey indicated elevated gamma readings. Four background samples, 2 blank samples (landscaping sand), and 16 duplicate samples were collected in accordance with the approved *Quality Assurance Program Plan* (QAPP).

In addition to the surface samples, two representative composite samples (CSMRI-164 and CSMRI-165) were collected from an existing soil stockpile located near the southern edge of the Site.

3.2.3.2 Sample Collection

Individual grab samples were collected from the designated locations using hand trowels and/or shovels. The sampling tools were decontaminated (brushed off and washed with distilled water) between sample locations. The samples collected from the soil stockpile consisted of 10 equal aliquots for incorporation into a single composite sample.

The Site surface soils consist primarily of clay subsoil. The stockpile consists of a pile of apparent topsoil and a second pile of sandy loess.

Double "ziplock" plastic bags were used as sample containers as specified in the approved SAP. All samples remained in a controlled area until shipment to the laboratory.

3.2.4 Subsurface Soil Investigation

Thirty-six trenches/test pits and 28 borings were used to investigate the subsurface soils at the Site. The test pit subsurface investigation primarily focused on those areas where drains or pipelines had penetrated building flooring (these locations were identified prior to the removal of the concrete and asphalt slabs and relocated by Flatirons after New Horizons completed the removal operations) and other visually suspect areas identified following the concrete and asphalt removal. The borings were primarily focused in those areas with elevated surface gamma readings.

Several areas selected for subsurface sampling were not investigated because of their proximity to active underground water lines. The City of Golden and various utility locate services were contacted to mark pipelines located west of Building 101 and in the vicinity of the former drum storage area next to the baseball fields. Equipment limitations and the age of the pipelines prevented the successful completion of this task. Steep slopes remaining after the removal of concrete and asphalt slabs and sidewalls also limited access to several of the identified investigation sites.

3.2.4.1 Subsurface Soil Test Pits

A backhoe was used to excavate test pits (i.e., pot holes) at 36 locations on the Site (see Figure 3-4). Test pit dimensions varied depending on the site characteristics (pipelines, debris, and soil consistency). The objective was to excavate to at least 10 feet bgs; however, various obstacles prevented completion to this depth on some of the pits. All pits were refilled after the completion of the investigation.

The test pit investigation revealed minimal topsoil remaining on the Site because of building and road construction. In general, the Site was covered with subsoil consisting of silty and/or sandy clay. Under this subsoil layer was a variable thickness layer of tan to brown, high-quality clay followed by a reddish sandy clay layer and an orange to brown clayey sand layer. A cobble zone was located below these layers about 10 feet below the surface on the eastern side of the Site. The zone appeared to be a paleochannel of the original Clear Creek and contained large flat cobbles mixed with a red to pink sand. The cobble zone was at surface level at the excavation site of Building 101N. Detailed logs of the test pits are provided in Appendix D.

Test Pit CP8 revealed evidence of building debris and other pits contained bricks which were likely remnants of an old brick factory that had been located on the Site. Pits along the access roads and to the west of Building 101 showed evidence of backfilling with different layers of imported material. Some of this material appeared to be standard construction grade gravel/ cobbles but some of the material appeared to be building debris and possible mill tailings. Test Pit CP27 contained numerous old laboratory crucibles along with multicolored sand and clay. A distinctly yellow colored material with elevated gamma readings was found in the shallow test pits located to the west of Building 101N. Thin layers of similar material were located in some of the roadbed fill material.

3.2.4.2 Test Pit Sample Collection

Samples were collected from 56 locations in the trenches along with 7 duplicate samples. Sample collection focused on soil layers exhibiting elevated gamma readings but additional samples were collected to characterize general soil types.

Soil samples were collected from a number of depths in each test pit and a gamma survey was performed on the bottoms and sides of each test pit. Samples were typically retrieved using the backhoe bucket, but layer-specific samples were collected with clean hand tools in several shallow test pits. Care was taken to collect samples from the center of the backhoe bucket to minimize the potential for cross-contamination. Double "ziplock" plastic bags were used as sample containers in accordance with the approved SAP.

GPS locations were recorded on the corners of each test pit. Gamma readings were recorded in the test pit logs and on the Ludlum data logger.

3.2.4.3 Borings Investigation

A percussion hammer drill rig was used to advance 28 borings on the Site (see Figure 3-5). The borings were primarily used to investigate areas that indicated elevated gamma readings. Most of the borings were completed to 10 feet bgs. Two of the borings were subsequently converted to ground-water monitoring wells (see Section 3.3.5.1). The uneven ground and active underground pipelines limited the areas available for investigation by this drill rig.

The boring investigation revealed similar soil horizons as those found during the test pit excavations. However, the increased power of the drill rig allowed investigation through and beneath the cobble zone. Detailed logs of the borings are provided in Appendix E. All borings were filled/resealed upon completion of the investigation.

3.2.4.4 Borings Sample Collection

Samples were collected from 68 locations in the borings. Sample collection focused on soil layers that exhibited elevated gamma readings but additional samples were collected to characterize general soil types.

Soil samples were collected from a number of depths within each boring. Gamma measurements were taken at one-foot intervals. The primary method of sample collection was the 2-inch split spoon sampler. Because of the sample volume required by the laboratory and the limited amount produced by the split spoon, no duplicate samples were collected. A limited number of samples were collected from material generated by the drill rig "cyclone". The one duplicate sample was collected from this type of material. Double "ziplock" plastic bags were used to collect samples in accordance with the SAP.

GPS locations were recorded at the center of each boring. Gamma readings were recorded in the boring logs and on the Ludlum data logger. The lead-shielded collimator was removed to allow gamma readings from the sides of the borings.

3.2.4.5 Subsurface Hydrocarbon Investigation

During the installation of the ground-water-monitoring well site initially chosen for the background well (CSMRI-06), an unidentified hydrocarbon was detected in subsurface soils. The hydrocarbon was measurable from a depth of approximately 6 feet to 14 feet bgs. Soil grab samples were collected at 6, 10, and 14 feet to identify the organics present. Grab samples were analyzed for volatile organic compounds (VOCs). Based on the results of VOC analysis, it was determined that additional investigation of the area was required. A backhoe was used excavate test pits in this area and two additional samples were collected from the excavation. Sample results and observations are discussed in Section 4.1.7.

3.2.4.6 Uncovered Concrete Characterization

Portions of walls and floor slabs of Building 103 that had been covered during the original concrete characterization study were subsequently discovered during the concrete removal operations conducted by New Horizons. Test pits CP1 and CP2 were excavated to determine the nature and extent of the these buried Building 103 wall remnants and floor slabs.

Soil samples were not collected from CP1 or CP2, but gamma readings were taken and concrete core samples were collected. Soil overlying these areas appeared to have been moved into the area as part of the on-site soil stockpile operation. The gamma survey of the concrete floors/slabs revealed no evidence of elevated gamma readings. To complete the concrete characterization, core samples of the uncovered floor slabs were collected and analyzed as discussed in Section 4.1.8.

3.2.4.7 Soil Sample Analytical Laboratory

The surface, test pit, and boring soil samples and the concrete core samples were sent to Paragon Analytical, Inc. (PAI) in Fort Collins, CO for analysis. The soil and concrete samples were analyzed for 11 metals, isotopic thorium and uranium (alpha spectroscopy), and 40 common isotopes (gamma spectroscopy) in accordance with the approved CSWP and SAP. Table 3-3 summarizes the analytical methods used by Paragon for sample analysis.

The soil samples collected from the subsurface hydrocarbon investigation area were sent to Evergreen Analytical, Inc. in Wheat Ridge, CO for analysis. Table 3-3 also summarizes the analytical methods used by Evergreen for sample analysis.

3.2.5 Ground-Water Investigation

3.2.5.1 Ground-Water Monitoring Well Installation

Two monitoring wells were installed using two of the borings drilled during the subsurface investigation (Figure 3-5). The purpose of the installation was to provide additional ground-water (upgradient and downgradient) data for the Site. The upgradient well (CSMRI-06) location was positioned along the north-south boundary with the baseball field. The downgradient well (CSMRI-07) was positioned north of the former Building 101N foundation, and above the former settling pond. CSMRI-06 is 43.5 feet deep and CSMRI-07 is 20 feet deep. Four-inch, Schedule 80 PVC piping was used for both wells. Boring logs for the well installations are provided in Appendix E as CB19 and CB20. Detailed monitoring well logs are provided in Appendix F.

Ground water was initially encountered at a depth of about 39 feet in CSMRI-06, with bedrock (Pierre Shale) at 40 feet. The well was completed 3.5 feet into the bedrock to provide a capture volume for ground water. No obvious sign of ground water was visible during the installation of CSMRI-07 but water was present when the well was sampled. The well was completed 4 feet into the Pierre Shale, which was encountered at 16 feet.

3.2.5.2 Ground-Water Sampling

Five existing wells and the two new monitoring wells described in Section 3.3.5.1 were sampled as part of the investigation to determine current ground-water conditions in and near the Site. The existing wells included three wells located along Clear Creek (CSMRI-01, -04, and -05), one background well located south of the Clay Pits (CSMRI-02), and one well located downgradient of the Clay Pits (CSMRI-03) (see Figure 3-6). Three quarters of ground-water sampling have been completed to date.

A Grundfos Rediflo-2 ground-water sampling pump was used to collect the ground-water samples from five of the wells. The wells were purged of at least three well volumes with purging continuing until field parameters stabilized. Two of the wells (CSMRI-02 and CSMRI-07) had recharge rates of 10 to 20-percent per day, making the three-well volume purge impractical. These wells were sampled using a dedicated bailer or a low flow purge using the sampling pump. A WTW Model 340i multi-parameter

meter was used in combination with a flow-through cell to measure field parameters (dissolved oxygen, pH, specific conductance, and temperature). Field parameters were measured from a container for the wells sampled with a bailer, which would affect dissolved oxygen readings. Water purged from the wells was stored in temporary containers until sample analysis was complete.

3.3 Surface Water and Sediments

Because there are no direct surficial pathways for the Site material to be transported into Clear Creek, no stream sediment samples were collected. Erosion and sediment controls (silt fencing and trenches) were installed on the Site shortly after the concrete and asphalt was removed. The Site was stabilized with temporary seeding after the investigation to minimize erosion. The former settling pond area also provides a backup containment system for major storm events.

The removal of the concrete and asphalt did create a ground-water pathway from the Site to Clear Creek. Over time precipitation events will transport the material from the surface deposits in the underlying ground water. The quarterly ground-water samples indicated that this might be happening. However, contaminant activities and concentrations would be difficult to detect after the mixing with Clear Creek. For this reason, no surface water samples were collected as part of the RI.

3.4 Air Monitoring

From October 24, 2002 through January 31, 2003 twenty-six air samples were collected during investigation activities likely to release airborne dust. Activities sampled included excavation of foundations, size reduction of concrete, loading trucks, backhoe operations and drilling.

Fixed area (~ 20 liters per minute [lpm]) and personal lapel samplers (~ 2 lpm) were used to obtain air samples. Fixed samplers were placed downwind and adjacent to the activity being performed. Typically, the lapel sampler was worn for the entire workday. Air samples were counted after three days (to allow for radon daughter decay) using a Ludlum 2929 counter. All alpha activity was conservatively assumed to be Th-230 (the isotope with the most restrictive annual limit of intake).

Measured activities were compared against the Th-230 DAC allowed for workers (10 CFR 20, Appendix B, Table 1). As can be seen in the following summary table, all of the samples were below the regulatory limit. The highest air sampling result occurred during drilling activities. Detailed air sampling results are listed in Appendix G.

Average Activity (μCi/mL)	Maximum Activity (μCi/mL)	Th-230 DAC (μCi/mL)
5.85 E-14	4.80 E-13	3.0 E-12

DAC, Derived air concentration

4.0 Nature and Extent of Affected Materials

Historical site activities left deposits of mining research waste over a large portion of the Site. This Section characterizes the nature and extent of affected material on the Site. Contaminants of concern include:

- Metals – Primarily arsenic, lead, and mercury, but the soil analyses included barium, cadmium, chromium, molybdenum, selenium, silver, vanadium, and zinc.
- Radionuclides – Primarily radium, thorium, and uranium, but gamma spectroscopy was used to examine an additional 38 radioisotopes.

4.1 Soil

This section characterizes the nature and extent of contamination in soil. First, data from gamma surveys was statistically evaluated to determine areas of elevated gamma emitting material. Then surface sampling results were evaluated to show the distribution of the metals and the radioisotopes plotted over the gamma survey data. Test pit samples also were evaluated to show the average vertical distribution of two selected metals (arsenic and lead) and the combined activities of radium and thorium. In addition, boring sample results were evaluated to show the average vertical distribution of two selected metals (arsenic and lead) and the combined activities of radium and thorium.

4.1.1 Surface Gamma Survey Geostatistical Analysis

In order to evaluate the areas of elevated gamma readings, a geostatistics package provided with the Surfer software was used. Geostatistics provides a set of statistical tools for incorporating the spatial coordinates of observations in data processing. Using statistical methods, geostatistics allows one to interpret data between known data points to predict probable values at intermediate points.

A variety of geostatistical methods are available, including kriging, minimum curvature, modified Shepard’s method, natural neighbor, nearest neighbor, polynomial regression, radial basis function, and triangulation with linear interpolation. Kriging was selected for representing the gamma survey because it is a flexible gridding method that typically produces vivid visual maps of data trends.

The kriging option chosen for the analysis was universal (or trend) kriging using a linear variogram model. Block kriging was selected to limit the amount of weight given to single point information. The circular search radius was limited to 40 meters with 8 sectors. Data outside the Site was artificially set at an assumed background gamma reading to limit extrapolation, but the graphs show some residual effect of this type of extrapolation.

4.1.2 Surface Gamma Survey Results

Figure 4-1 shows a contour map of the kriging analysis and the predicted areas of elevated gamma emitting material. The survey readings ranged from 3,594 to 256,848 counts per minute (cpm) with a mean value of 8,585 cpm (lognormal mean of 7,458 cpm) (see Table 3-1). The survey readings have a lognormal distribution with more than 73 percent of the readings falling below the arithmetic mean. Background gamma measurements in the vicinity of the Site (Table 3-2) had a mean value of 4,092 cpm (lognormal mean of 4,045 cpm) with an 95-percent upper confidence level of 5,338 cpm.

URS Greiner Woodward Clyde International-Americas, Inc. (URS) performed a background gamma study for the fenced area in July 2000, using a Lundlum 44-10 detector with a 2221 datalogger, The measurements were made at the base of Lookout Mountain west of the Site. Average background gamma measurements were determined to be 13,728 cpm. URS conducted a second background study in 2002 along the western side of Chimney Gulch. The average gamma measurements for this study were determined to be 18,740 cpm.

Surficial deposits shown in Figure 2-3 indicate that the soils in the area of both URS studies are primarily Mounger alluvial fan and Post-Piney Creek alluvium. Surficial deposits in the vicinity of the Site are shown as Louviers Alluvium. In addition, the majority of the "A" soil horizon has been removed in the vicinity of the former buildings and fill has been used in a number of areas. The background gamma measurements recorded for the RI/FS appear to be more representative of the Site. About 21-percent of the Site was at or below the RI/FS 95-percent upper confidence level for background gamma. The URS background studies would indicate 94- to 96-percent of the Site was below background.

The survey and analysis indicate elevated readings in the following areas:

- Northwestern corner of the former Building 101N: Visual inspection of this area showed an area to the west of the building where artificial fill had been used (Building 101W). There were small irregular patches of a yellow, silty material mixed in with a variety of silty clays and sands. There were no visible signs of unique material along the southern edge of the building, but elevated gamma readings were detected. The former building foundation rested on the alluvial cobble zone and limited areas of the yellow silty material were visible in the cobble material. The highest single point gamma reading in this area was 72,054.

- Driveway area for former Building 101C: Very small areas of the yellow, silty material were visible in several locations, but this material did not appear to be the source of the highest readings. The driveway area had the highest single point gamma reading on the Site (256,848 cpm).

- Three areas along the former Main Street: All of these readings appeared to be associated with trenches that were constructed along the former street for erosion control. A thin layer of the yellow silty material was visible in two of the trenches. There was no unique material visible in the third trench that had a single point gamma reading of 97,818 cpm.

- Northern side of former Building 115N: There were no visible signs of unique material in this area. The majority of the material underlying this building appeared to be artificial fill containing bricks, cobbles, and silty clays and sands. The highest single point gamma reading at this area was 61,764 cpm.

- Paved area east of former Building 115N: Residual material from the removed asphalt made it difficult to determine if unique material existed at this Site. The highest single point gamma reading in this area was 155,268 cpm.

- Two areas along the eastern access road: A previously used wash down pad was adjacent to the area farthest to the east (40,098 cpm). The area to the west appeared to be undisturbed. It was one of a few areas that had an “A” soil horizon on the Site. The highest single point reading at this area was 92,010 cpm.

- One area along the western access road: This area is located to the west of former Building 116. There were no visible signs of unique material in this area. The highest single point reading in this area was 53,298 cpm.

The kriging contour map was used as a background for the plotted sample analytical results to provide information about co-located materials.

4.1.3 Subsurface Gamma Survey Results

Gamma readings were measured and documented along the test pit sidewalls and bottoms using the detector with the lead-shielded collimator (see test pit logs – Appendix D). A longer cable was required to access all test pit areas, which somewhat changed the output of the Ludlum meter (surface and subsurface readings do not directly correlate). As stated previously, test pits were used to examine areas where pipes penetrated floors or other anomalies. Gamma readings were measured where soil characteristics changed, around pipes and debris, and at random locations. In general, the test pits showed elevated gamma readings near some of the test pit surfaces with a significant decrease in counts in the deeper layers. The exception was a layer of silty sand above the cobble zone that had a higher reading. The elevated reading for this material was detected each time the layer was encountered suggesting the readings were related to the deposition layer, not because of Site activities. The sandy, silty soil in this layer had an orange coloration suggesting the presence of iron. An orange or red coloration typically indicates that the material was deposited during reducing conditions that cause the precipitation of iron and other metals - including radionuclides. The color may be an indication of conditions that occurred during the deposition of the layer or the original rock that was weathered to produce the layer.

The collimator was removed during the borings investigation to measure gamma output from the material surrounding the probe. Gamma measurements were made at one-foot intervals to the limit of the detector cable (see boring logs – Appendix E). Borings were concentrated in areas that were known to have elevated surface gamma readings. The borings typically showed a decrease in gamma output with depth, but some of the elevated readings were deeper than the test pit readings. The borings also showed the elevated reading in the layer above the cobble zone (orange material).

4.1.4 Surface Samples Analytical Results

Copies of PAI's analytical data packages are provided in Appendix H. A summary of the surface sample analytical results is provided in Tables 4-1, 4-2 and 4-3. A brief summary of metal concentrations statistics is provided in Table 4-4 (duplicate samples were not included in the summary statistics).

Laboratory flagged qualitative data (metal or isotope detected but at less than the reporting limit) was included in the summary statistics, except "S" flagged data. The "S" indicates interference by another element (probably lead) that results in a false reading. An "S" flag was reported on all of the Cd-109 gamma spectroscopy results, but any Cd-109 present at the time of the Site operations would have decayed into daughter products shortly after the Site was closed. Metals/isotopes reported as undetected were included as half the laboratory detection limit to limit a downward bias of the statistics. Because this data, like most environmental data, has a lognormal distribution rather than a normal distribution, mean concentrations are often dominated by a limited number of elevated concentrations. For example, sample CSM113 contained a lead concentration that was two orders of magnitude greater than the average value (14,000 milligrams per kilogram [mg/kg]). This single value would tend to inflate the mean values. Eliminating this value results in a normal mean of 382 mg/kg (compared to 466 mg/kg) and a lognormal mean of 148 mg/kg (compared to 152 mg/kg). Both the normal mean concentration and the lognormal mean concentrations are provided in Table 4-4 for comparison.

Table 4-5 provides a brief summary of the radioisotope activities determined by alpha spectroscopy. As with the metals data, the isotope activities have a lognormal distribution and a lognormal mean is provided. Summary statistics for the gamma spectroscopy results are provided in Table 4-6. Flagged data and half the detection limit for undetected metals/isotopes were included in the summary statistics for all parameters.

The heterogeneity of the individual soil samples can be seen in the variability of the duplicate samples. Table 4-7 summarizes the percentage difference seen in the metals concentrations and the alpha spectroscopy isotope activities.

Heterogeneity of the Site soil is apparent when comparing metal concentrations and isotope activities of co-located samples. Nine sets of co-located samples were collected on the Site. Information from the gamma survey was used to avoid collecting these samples in areas that were known to have elevated gamma readings. These samples were collected within 3 to 4 meters of one another. Table 4-8 shows range of variability of these samples. The variability for some of the materials is one or two orders of magnitude greater than the duplicate sample variability.

Four background samples were collected to the south of the main Site entrance (Tables 4-1 through 4-3). Sample CSMBKG4 contained lead at the proposed residential soil standard. The sample was collected from an area that had previously been landscaped and contained a significant amount of peat moss. Because peat moss is known to adsorb metals, this sample was not included in the background statistics. To generate a sufficiently large sample set, on-site samples from gamma surveyed areas that were at background or below were screened for metals concentrations. A subset of 14 samples that did not contain metals concentrations near residential standards was added to the background data set (see following table). These samples also were representative of the silty, sandy clay soil type found on the majority of the Site.

Background Sample Locations	
CSM75	CSM130
CSM76	CSM133
CSM78	CSM145
CSM81	CSM146
CSM94	CSMBKG1
CSM120	CSMBKG2
CSM129	CSMBKG3

The background sample set was examined for normality. Histograms indicated irregular distributions for the majority of the constituents. Lognormal statistics were used in an effort to normalize the distribution. Because of the small sample set "T" statistics were used to determine the 95-percent confidence level. The means, lognormal means, and calculated upper limits for background concentrations are presented in Table 4-9. The metal and radionuclide background values are comparable to the values determined during two background characterization studies performed by URS in 2000 and 2002, but are more specific to the soils directly in the vicinity of the Site. The following is a summary of the URS study data.

Metal / Radionuclide	**URS 2000 Study**		**URS 2002 Study**	
	Arithmetic Mean	**95-Percent Confidence Limit**	**Arithmetic Mean**	**95-Percent Confidence Limit**
Arsenic	5.3	13	11.2	30
Cadmium	0.27	0.79	1.7	4.2
Lead	60	140	121	310
Ra-226	0.94	2.3	2.2	4.2
Ra-228	1.1	1.6	2.3	3.5
Th-228	0.51	0.87	2.4	4.3
Th-230	0.58	1.0	1.7	3.1
Th-232	0.84	2.1	2.2	4.0
U-234	0.8	2.1	2.1	3.9
U-235	0.15	0.51	0.1	0.19
U-238	0.74	1.7	2.0	3.6

Notes: Metal units, milligram per kilogram; radionuclide units, picocuries per gram

As previously mentioned, surficial deposits in the area of both URS studies are primarily Mounger alluvial fan and Post-Piney Creek alluvium (see Figure 2-3) while surficial deposits in the vicinity of the Site are Louviers Alluvium. The URS studies are more representative of the "A" soil horizon, which is missing for the majority of the Site. Soil variation associated with locations is evident when the two URS studies are compared.

Figures 4-2 through 4-8 shows the distribution of select metals and select radioisotopes plotted over the gamma survey data. Although some of the metals appear to be primarily co-located with the elevated gamma readings, others appear to be associated with former building locations and/or access roads.

4.1.4.1 Surface Soil Samples Analyzed for Americium and Plutonium

Two surface soil samples were analyzed for americium and plutonium because of oral reports of the presence of small quantities of soil contaminated with plutonium during Site operations. It was reported that the material was tightly controlled and removed prior to the cessation of operations. Two samples were selected to verify that the material left the Site. Surface soil samples CSM-97 and CSM-152 were selected because of the elevated radionuclides found in both samples. The following is a summary of the analytical results.

Sample ID	**Am-241**		**Pu-238**		**Pu-239**	
	Result	TPU	Result	TPU	Result	TPU
CSM-97	ND (<0.025)	±0.035	ND (<0.041)	±0.056	0.060	±0.060
CSM-152	0.046 LT	±0.047	0.048 LT	±0.060	ND (<0.043)	±0.060

Notes: All units in picocuries per gram; TPU, total probability units; ND, not detected; LT, Result is less than requested detection limit but greater than the method detection limit.

In addition to naturally occurring radionuclides, the background concentration in soils includes contributions from global radioactive fallout due to worldwide nuclear weapons testing conducted from 1945 to 1980, and the 1964 atmospheric burnup of a satellite. Plutonium, which does not occur naturally in the environment, is found worldwide from the radioactive fallout.

Nuclear weapons radioactive contamination spread worldwide as atmospheric fallout, which resulted in a fairly even distribution of radionuclide contamination over most of the earth's surface. Peak concentrations of fallout occurred in the 1960s, after which fallout rates declined.

A background radionuclide study that was performed as part of the Rocky Flats Environmental Technology Site – Soils Monitoring Program indicates that the upper confidence level (99-percentile) for fallout related Americium-241 is 0.037 pCi/g and lists the level of Plutonium-238 and -239 at 0.084 pCi/g.

Sample CSM-152 does show Am-241 at an activity greater than the fallout background activity, but the value is flagged “LT”. The “LT” flag indicates that the radionuclide is present but the quantification is in question. The total probability units (TPU) associated with the measurement indicates significant uncertainty in the result. Small activities of plutonium also were detected in samples but at activities below the fallout background activity.

4.1.5 Test Pit Samples Analytical Results

A summary of the test pit soil sample analytical results is provided in Tables 4-10, 4-11 and 4-12. A brief summary of metals concentrations statistics is provided in Table 4-13 (duplicate samples were not included in this summary). Laboratory flagged qualitative data (metal or isotope detected but at less than the reporting limit) was included in the summary statistics. Metals/isotopes reported as undetected were included as half the laboratory detection limit to limit a downward bias of the statistics. As with the surface soil samples, lognormal means also are provided.

Table 4-14 provides a brief summary of the radioisotope activities determined by alpha spectroscopy, including a lognormal mean. Summary statistics for the gamma spectroscopy results are provided in Table 4-15. Heterogeneity of the test pit duplicate samples is compared in Table 4-16. The results show a greater average variation in the isotope samples than was seen in the surface soil samples.

Figures 4-9 and 4-10 show the average vertical distribution of two selected metals (arsenic and lead) and the combined activities of radium and thorium as determined by the test pit soil samples. In general, arsenic and lead concentrations and radium and thorium activities appeared to decrease with depth, with the effect more pronounced in the elevated gamma areas.

To generate Figures 4-9 and 4-10 the test pits were divided into two groups. One group included the test pits excavated in the areas of elevated gamma readings and the other group included test pits excavated outside of these areas. All of the samples collected in the two foot intervals were averaged together to determine an approximate concentration for that interval. Some of the intervals involved small sample sets, which could influence the statistical accuracy of the method. Lognormal means were used to prevent small numbers of elevated concentrations from dominating the statistics.

4.1.6 Borings Samples Analytical Results

A summary of the borings soil sample analytical results is provided in Tables 4-17 through 4-19. A brief summary of metals concentrations statistics is provided in Table 4-20 (duplicate samples were not included in this summary). Laboratory flagged qualitative data (metal or isotope detected but at less than the reporting limit) was included in the summary statistics. Metals/isotopes reported as undetected were included as half the laboratory detection limit to limit a downward bias of the statistics. As with the surface soil samples, lognormal means are also provided. Table 4-21 provides a brief summary of the radioisotope activities determined by alpha spectroscopy, including a lognormal mean. Summary statistics for the gamma spectroscopy results are provided in Table 4-22.

Figures 4-11 and 4-12 show the average vertical distribution of two selected metals (arsenic and lead) and the combined activities of radium and thorium as determined by the boring soil samples. Because the borings were directed primarily at areas of elevated gamma readings, only three borings were considered to be outside of these gamma-influenced areas. The two data sets represented in the figures include all of the borings and a subset of the elevated gamma areas. All of the samples collected at two foot intervals were averaged together to determine an approximate concentration for that interval. As with the test pits, lognormal means were used to prevent small numbers of elevated concentrations from dominating the statistics. Some of the intervals contained small numbers of samples that could affect the robustness of the statistics.

4.1.7 Subsurface Hydrocarbon Investigation Results

Laboratory results of the subsurface hydrocarbon investigation are summarized in Tables 4-23 and 4-24. Table 4-23 presents the results of VOC testing associated with the original well installation sampling (samples CB-18-“depth”). Low concentrations of trichloroethene and acetone were detected in two of these samples. To evaluate the nature and extent of the VOCs, test pits were excavated to further investigate the soils in this area. Visual inspection of the excavation site showed a darkened layer of clay with a strong odor of hydrocarbons. The upper horizon of the material appeared at a depth of about 5 feet but dipped somewhat as the excavation continued to the north. The material was visible to about 10 feet, the depth of the excavation. A photoionization detector (PID) reported minimal VOC concentrations in the vicinity of the excavation, but elevated concentrations were detected in the headspace of a sample. Two additional samples were collected during the excavation. These samples were analyzed for VOCs and semi-volatile organic compounds (SVOCs) to determine the nature of the material (sample numbers CS-“depth”). Laboratory results are presented in Table 4-26. The two samples contained low concentrations of the acetone and one of the samples contained 2-methylnaphthalene, a component of diesel fuel. None of the compounds were above Colorado proposed soil standards.

4.1.8 Uncovered Concrete Sample Results

Four core samples were collected using a boring machine and sent for analysis to PAI. The samples were crushed and then analyzed for the same metals/isotopes as the soil samples. The results of the analyses are provided in Table 4-25. The concrete samples contained metals concentrations and radioisotope activities at or below the site background concentrations.

4.1.9 Soil Sample TCLP Results

Ten duplicate samples (collected and stored during the RI) were selected from the surface and test pit sample sets to quantify leaching characteristics for the landfill disposal options. Six of the samples were biased to the upper end of the metals concentrations and radionuclide activities to determine worst case values. The remaining samples were randomly selected. The samples were sent to PAI and analyzed using the toxic characteristic leaching procedure for metals and a select list of herbicides, pesticides, SVOCs, and VOCs. A subset of these samples was analyzed for pH, reactive cyanide, and reactive sulfide.

Because the TCLP samples were actually sampled as part of the original soil sampling program (duplicate samples that were stored on site), all of the samples exceeded standard laboratory holding times. SVOC, VOC, and mercury (possible arsenic) concentrations could be affected by the excessive holding time. The SVOC's and VOC's do not appear to be a major concern for the Site because other than the specific subsurface hydrocarbon investigation area near the baseball field (see Section 4.1.7) there were no other indications of additional onsite hydrocarbon material. A small amount of mercury could have volatilized from the samples during the long holding time, but it is unlikely that there would have been a significant change in the TCLP results.

One sample contained lead at a concentration of 12 mg/L (standard is 5 mg/L), but the remaining samples were below the TCLP standards. Using the data from these samples, the average metals concentrations would be below the standards. With the exception of one subsurface sample with a detectable quantity of methyl ethyl ketone (0.040 mg/L -"J" flag), the samples were free of herbicide, pesticides, SVOCs, and VOCs. No reactive cyanide or sulfide was detected and the pH was in the range of 7.5. A summary of the sample results is provided in Tables 4-26 through 4-29.

4.1.10 Summary of Soil Characterization

All of the surface soil samples contained arsenic at concentrations above the proposed Tier 2 soil standards found in the proposed CDPHE Soil Remediation Objectives policy (1997 and 2003). However, background arsenic concentrations vary greatly in different types of geology. The western states typically have geological formations with elevated arsenic concentrations. Clays formed from the weathering of these formations typically adsorb the arsenic compounds, resulting in elevated concentrations. The majority of the Site is covered with a layer of clay and underlying soil layers all have a clay component. The highest arsenic concentrations appear to be around the excavated building formations and around the western side of the site, but there are a number of areas to the east that have concentrations above the background value. Subsurface soil samples indicate that concentrations of arsenic decrease with depth in the vicinity of the buildings (see Figures 4-9 and 4-11) but none of the samples drop below the proposed residential soil standard.

About 21-percent of the surface samples contain lead above CDPHE proposed soil standards. The highest concentrations of lead appear to again be located in the vicinity of the excavated building formations. Lead concentrations decrease significantly with depth suggesting the lead-affected material was imported to the site (see Figures 4-9 and 4-11).

Mercury was detected in all of the surface soil samples, but the species of mercury was not determined. Mercury can occur as inorganic elemental or metallic mercury (Hg^0), mercurous Hg (Hg^{1+}), and mercuric Hg (Hg^{2+}) or as organic methylmercury and ethylmercury. The elemental and organic forms of mercury are considered to carry the greatest risk to human health and the environment. Because of the types of research conducted on the Site and the instruments associated with such research, elemental mercury could be present. But the mercury also could come from mineral ores brought to the site, which would be composed of mercury compounds. About 47-percent of the surface soil samples exceed the CDPHE proposed residential standard for elemental mercury. However, only 3-percent of the samples exceed the CDPHE proposed residential standard if the material consists of mercury compounds. Mercury concentrations also decrease with depth (average concentration of 0.5 mg/kg in the upper 2 feet of soil, compared to average concentrations of less than 0.1 in the underlying layers), which again suggested that the mercury-affected material was imported to the Site.

A small number of the soil samples contained cadmium (about one percent), molybdenum (less than two percent), and vanadium (less than one percent) above CDPHE proposed residential soil standards. All of these samples were co-located with soil that contained elevated concentrations of other metals or radionuclides.

Risk modeling (see Sections 6 and 8**)** indicates that Ra-226 is the primary radionuclide of concern on the site. The majority of the radium-affected material appears to be located in the vicinity of the buildings on the western side of the former Main Street (Buildings 101 and 115) with a limited number of outlying areas (Figure 4-6). Subsurface-soil samples indicate that activities of radium decrease with depth in the vicinity of the former buildings (see Figures 4-10 and 4-12).

Modeling also indicated that Th-230 was a radionuclide of concern over time (decays to radium). As with the radium, thorium appears to be located around the excavated building foundations on the western side of the site (Figure 4-7). Thorium activities also decrease with depth (Figures 4-10 and 4-12) in the vicinity of the former buildings.

Uranium also is considered a radionuclide of concern because it contributes over 30-percent of the activity of the surface soil samples. The uranium appears primarily to be co-located with the radium and thorium in the vicinity of the western former buildings (see Figure 4-8). In general, uranium activities also decrease with depth.

The TCLP results indicate that the affected material is not hazardous waste and may be disposed of in a licensed solid waste landfill.

4.1.11 <u>Applicable Regulatory Classification</u>

The overall objective of this section is to classify and explain the basis and rationale for the regulatory classification of the affected surface and subsurface soil in the Fenced Area of the CSMRI Site (the "Soil"). The appropriate regulatory classification of the Soil is dependent on both the operational history of the research facility and the results of analytical data collected with respect to the Soil. The conclusion of this section is that the Soil is "solid waste" that may be disposed of at a solid waste disposal facility that can demonstrate the ability to safely accept and dispose of the Soil.

The conclusions regarding the regulatory classification of the Soil will be used to determine which specific statutory and regulatory requirements and/or ARARs apply to the Soil. More specifically, the regulatory classification will be used to: (1) determine eligibility for currently licensed or permitted off-site disposal facilities for acceptance of the Soil for disposal, (2) determine engineering design, performance criteria and administrative permitting or licensing requirements for construction of a new disposal facility on site, and (3) determine design and performance criteria for on-site disposal.

Regulatory classification of the Soil is complicated by the fact that the Site operated as a research facility for approximately 70 years (1916 to 1987) involving thousands of projects. Therefore, in order to specifically determine the appropriate regulatory classification it is necessary to evaluate a large "universe" of potential regulatory classifications. Three general overall regulatory schemes could potentially govern the handling of the soil: (1) Solid Waste, (2) Hazardous Waste, and (3) regulated Radioactive Material.

These general regulatory schemes further breakdown into several potential specific material/waste definitions that include:

- Radioactive material,
- Naturally occurring radioactive material (NORM),
- Technologically enhanced naturally occurring radioactive material (TENORM),
- Low-level radioactive waste,
- Special nuclear radioactive material,
- Source material,
- By-product material (11(e)(1) and 11(e)(2)),
- Classified waste,
- Transuranic radioactive material,
- Hazardous waste,
- Mixed waste, and
- Solid waste.

Each of these potential regulatory classifications is discussed in detail in the subsections following the discussion of the operational history.

Some definitions pertaining to radiation control in Colorado include:

"Radioactive material" means any material, solid, liquid, or gas, which emits ionizing radiation spontaneously [§ 25-11-101(3), C.R.S.]

"Naturally occurring radioactive material", or NORM, means any nuclide that is radioactive in its natural physical state and is not manufactured. "Naturally occurring radioactive material" does not include source material, special nuclear material, or by products of fossil fuel combustion, including but not limited to bottom ash, fly ash, and flue gas emission by-products [§ 25-11-101(2.7), C.R.S.]. “Background radiation” includes NORM [6 CCR 1007-1, 1.4].

"Technologically enhanced naturally occurring radioactive material", or TENORM, means naturally occurring radionuclides whose concentrations are increased by or as a result of past or present human practices. TENORM does not include background radiation or the natural radioactivity of rocks or soils. TENORM does not include uranium or thorium in source material as defined in the AEA and US NRC regulations. TENORM is considered a subset of NORM.

"Source material" means material, in any physical or chemical form, including ores, that contain by weight one twentieth of 1 percent (0.05 percent) or more of uranium, thorium or any combination thereof. Source material does not include special nuclear material.

"By-product material" means:

- Any radioactive material, except special nuclear material, yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material (6 CCR 1007-1, 1.4); and
- The tailings or wastes produced by the extraction or concentration of uranium or thorium from ore processed primarily for its source material content, including discrete surface wastes resulting from uranium or thorium solution extraction processes. Underground ore bodies depleted by these solution extraction operations do not constitute "by-product material" within this definition (6 CCR 1007-1, 1.4).

"Waste" means those low-level radioactive wastes that are acceptable for disposal in a land disposal facility. For the purposes of this definition, low-level waste has the same meaning as in the Low-Level Radioactive Waste Policy Act, P.L. 96-573, as amended by P.L. 99-240, effective January 15, 1986; that is, radioactive waste (a) not classified as high-level radioactive waste, spent nuclear fuel, or by-product material as defined in Section 11.e.(2) of the Atomic Energy Act (uranium or thorium tailings and waste) and (b) classified as low-level radioactive waste consistent with existing law and in accordance with (a) by the U.S. Nuclear Regulatory Commission (6 CCR 1007-1, 1.4).

"Waste" is also defined in Part 14 of the radiation regulations as radioactive waste other than:

- Waste generated as a result of the defense activities of the federal government or federal research and development activities;
- High-level waste such as irradiated reactor fuel, liquid waste from reprocessing irradiated reactor fuel, or solids into which any such liquid waste has been converted;
- Waste materials containing transuranic elements with contamination levels greater than one hundred nanocuries (3700 bq) per grain of material;
- By-product material as defined in Section 11(e)(2) of the "Atomic Energy Act of 1954", as amended on November 8, 1978; or
- Waste from mining, milling, smelting, or similar processing of ores and mineral-bearing material primarily for minerals other than radium (6 CCR 1007-1, 14.2).

4.1.11.1 Operational History

The Experimental Plant, also known as "Building 101," was constructed at the Site in 1912. It was a research facility only. Actual mining was not conducted at the Site. There were no production facilities at the Site.

For many years the Experimental Plant was the only building at the Site. Its purpose was to provide a research facility for mining and metallurgy. The Experimental Plant later became one of 17 buildings at the Site.

Mr. Arthur J. Weinig was the director of the Experimental Plant from 1923 to 1949. In 1949, CSMRI was founded as a non-profit organization. CSMRI conducted research for private industry and government at the Site between 1949 and 1987.

The operational history described below is based upon a review of certain CSMRI organizational and financial records, certain documents produced to EPA from various entities identified as potentially responsible parties (PRPs), interviews (including former CSMRI employees), state and national archives, periodicals, and other records. A number of references are made in the following discussion to documents that were provided as attachments to the RAOA (Volume 3, Removal Action Options Analysis report, June 12, 1995).

4.1.11.1.1 Operational History (1912-1920)

The Experimental Plant was seldom used between 1912 and 1916. A 1912 document states that the Plant was not fully equipped when it opened in 1912 (RAOA, Attachment 1 at 5). Upon arrival to the Experimental Plant for the first time, one researcher writes in a May 1916 letter:

> ... the water capacity of the building is absolutely inadequate for any operation, and upon talking to Dr. Phillips, he realized fully that the mill had evidently never been tried out on any scale whatsoever with the view of working same successfully (RAOA, Attachment 2 at 1).

In 1916, the United States Bureau of Mines (BOM) moved its Denver Experiment Station to the School of Mines Physics Building/Engineering Hall, which is not located at the Site (RAOA, Attachment 3 at 4). Although Engineering Hall is separate from the Experimental Plant, BOM used the Experimental Plant (RAOA, Attachment 3 at 4). The attached agreements indicate that the BOM investigations at the Experimental Plant were under the supervision and direction of BOM. Attachment 4, 1916 Agreement at 2 ¶ 3, 1917 Agreement at 1 ¶ 2, 1918 Agreement at 1 ¶ 2, 1919 Agreement at 1 ¶ 2.

BOM used the Experimental Plant in 1916 for the mechanical concentration of over 200,000 pounds of pitchblende ore (RAOA, Attachments 3 at 4). This pitchblende beneficiation project is relevant for purposes of whether wastes emanating from this project are "low-level radioactive waste." (The definition of "low level radioactive waste" in Colorado radiation control regulations excludes (1) waste generated from federal research and development activities; (2) waste generated from federal defense activities; and (3) wastes from the processing of ores for minerals other than radium.)

The pitchblende beneficiation project involved several parties. BOM contracted with a mining company in Colorado, the National Radium Institute in Denver, and a philanthropist (Mr. Alfred Dupont) in Philadelphia (RAOA, Attachment 5). The mining company provided the pitchblende ore to the National Radium Institute in Denver and paid the costs of the research. BOM provided all the labor and supervision for the research in exchange for pure uranium oxide extracted from the pitchblende. BOM used the uranium oxide for experimentation on "its possible utilization for special steels which we (i.e., BOM) hope may find a use in ordnance" (RAOA, Attachment 5). BOM's goal was to research national defense related matters. The National Radium Institute gave the extracted radium to Mr. Dupont who in turn donated the radium to several hospitals for medicinal therapeutic uses (RAOA, Attachment 6).

The various components of the pitchblende work were conducted in different locations. The mining company delivered the pitchblende ore to the National Radium Institute in Denver (RAOA, Attachment 6). BOM brought the pitchblende ore to the Experimental Plant in Golden <u>only</u> for concentration purposes to produce higher-grade material (RAOA, Attachment 2). The concentrates were then delivered to the National Radium Institute in Denver for the extraction of radium and high-grade uranium oxide (RAOA, Attachment 7). The concentration process conducted at the Experimental Plant was mechanical, according to BOM.

BOM also used the Experimental Plant for experiments using a separator for the elimination of impurities from pyrrhotite in order to produce sulfur (RAOA, Attachment 3 at 4-5).

4.1.11.1.2 <u>Operational History (1920-1949)</u>

There is no known information on how the Experimental Plant was used between 1920 and 1923. The Bureau of Mines left Colorado School of Mines in 1920. It is likely that the Experimental Plant was seldom used during this time.

From 1923 to 1949, Mr. Arthur J. Weinig was director of the Experimental Plant. He also ran a consulting business from the Experimental Plant for private industry (RAOA, Attachment 8).

There are few specifics on the type of research conducted at the Experimental Plant under Mr. Weinig's direction. Some understanding of the specifics, however, can be inferred by an understanding of the general use of the facility. In general, Mr. Weinig researched special problems related to mining and metallurgy, including the testing and examination of ores (RAOA, Attachment 19). The School of Mines used the Experimental Plant for laboratory classes during this time period.

Mr. Weinig's clients included Climax Molybdenum Company, American Metal Company, John J. Raskob et. al., London Gold Mining Co., Shenandoah Dives Mining Co., Cuban American Manganese Co., Potash Company of America, Basic Magnesium Inc., and others (RAOA, Attachment 8).

Mr. Weinig had inventions in the following areas: flotation processes for treatment of molybdenum ore, sulfide ore flotation processes, cement manufacturing flotation processes, gold and silver concentrate cyanide treatments, apparatus and process inventions on ball mills, classifiers, screens, tables, meters, flotation machines and cyanidation equipment and a process for treating magnesium ores (RAOA, Attachment 8). Mr. Weinig also wrote a prominent 1933 article, "A Functional Size-Analysis of Ore Grinds" (RAOA, Attachment 8). These types of activities likely occurred at the Experimental Plant during his tenure.

A major client of Mr. Weinig's was Climax Molybdenum Company (Climax). Mr. Weinig assisted Climax to operate the Climax mine near Leadville by working on the design of the flotation mill (RAOA, Attachment 8). Climax's involvement at the Experimental Plant for this time period indicates that much of the research likely involved issues related to the Climax mine near Leadville. Mr. Weinig developed the flotation system for the mine so significant amounts of flotation studies were likely conducted at the Experimental Plant. Also, many of the ores involved in the research were likely associated with molybdenum.

4.1.11.1.3 *Operational History (U.S. Bureau of Mines Operation For 1937-1950)*

The United States Bureau of Mines (BOM) returned to the Site and used portions of the Site for a coal experimental station during the 1937-1950 timeframe (RAOA, Attachment 4 at 5-11). BOM used Building 104, which is adjacent to the Experimental Plant, as well as other adjacent structures and pilot plants for various studies and experiments involving subbituminous coal and lignite (RAOA, Attachment 4 at 5, 12-13). A primary significance of the BOM coal experiment station for waste classification purposes is that by-products of fossil fuel combustion, including ashes, are excluded from the definition of Naturally Occurring Radioactive Material (NORM).

BOM describes 18 different studies during this 14-year time period. BOM's 18 studies focused on coal. Arsenic, thorium, and uranium, which are the contaminants of concern at this Site, are hazardous substances generally common to coal and coal fly ash.

An estimate of the weight of the coal materials used by BOM during this time period is between 20.7 million pounds and 5.8 million pounds. Attachment 3.

4.1.11.1.4 *Operational History (1949-Present)*

In 1949, CSMRI was founded as a non-profit corporation. CSMRI was first incorporated as the Colorado School of Mines Research Foundation, Inc. (CSMRF). In 1969, CSMRF changed its name to the Colorado School of Mines Research Institute (CSMRI). For this report, the organization will be referred to as CSMRI for all time periods.

The CSMRI Articles of Incorporation state that the objects and purposes of CSMRI are, in part, to:

> Promote, prosecute, encourage and aid scientific and technological investigation and research and to provide or assist in providing the means and facilities by which scientific and technological discoveries, inventions and processes may be developed (RAOA, Attachment 9).

To accomplish these objects and purposes, CSMRI was "to conduct research, investigation, studies and tests in the fields related to the mineral industries as well as such other fields as may from time to time be deemed advantageous..." (RAOA, Attachment 9).

CSMRI used the CSMRI research facility for mining research. CSMRI also allowed some portions of the CSMRI research facility to be used by private industry for research that was conducted independently.

Although CSMRI was a fledgling organization in 1949 with few employees, it grew to a large research organization with over 300 employees. By 1987, CSMRI ceased all research operations at the Site and continued closure activities that addressed certain environmental matters at the Site.

In 1992 a City of Golden water main broke at the Site, releasing substantial water into the former tailings pond and into Clear Creek. EPA commenced a CERCLA removal action, resulting in the excavation of the tailings pond and some surrounding soils. Prior to excavation, EPA flushed out remaining mobile contamination from the interior of the buildings into the tailings pond. The excavated materials, which were temporarily stored at the Site by EPA at a location that now has the Colorado School of Mines' softball field, are known as the Stockpile that was the subject of EPA's UAO. The volume of the Stockpile was 22,000 cubic yards.

Unlike the time period from 1920 to 1949, many of the specific projects conducted by CSMRI at the Site between 1949 and the mid-1980s are known. CSMRI's research projects are known through "project files" and corporate records that exist today. There are over 30 large filing cabinets full of CSMRI project files located at CSM. Most of these project files contain detailed records of projects conducted in the 1980s and 1970s, with a few records for the 1960s. The CSMRI annual reports from the 1950s and the early 1960s contain a list of the research projects performed by CSMRI.

After the water main broke in 1992, EPA reviewed the CSMRI project files and created a working "waste-in-list" (the EPA Waste-in-List). The EPA Waste-in-List includes the entities EPA believes to be potentially responsible for the cleanup costs at the Site, as well as a description of the hazardous substances and the type of research performed. The RAOA contains the decade-by-decade summaries of the EPA Waste-in-List (RAOA, Attachments 10-12).

EPA listed 863 projects from the 1960s through the 1980s project files. By far, the majority of projects involved minerals unrelated to uranium, thorium, or radium. Only 89 of these projects, or 10-percent, were described as uranium leaching, separation, process developing, upgrading, or flotation projects. Only nine of these projects, or one-percent, were listed as uranium concentration or extraction projects. The difference between these two categories is that a uranium "leaching" project, for example, can simply be a leaching feasibility or amenability study where the project primary objective is to determine the physical or chemical feasibility of leaching, or process development, as opposed to an actual extraction or concentration project. There was only one project, or less than one-percent, described as a thorium extraction or concentration project. There were no projects for radium extraction. A chart summarizing the results discussed follows:

1960, 1970, 1980 CSMRI PROJECTS
(From EPA's Waste-in-List)

Project Type	Number of Projects	Percent of Total
All Projects	863	100
Total Uranium Projects – Titled "Leaching", "Separation", "Process Developing", "Upgrading", or Floatation"	89	10
Total Uranium Projects Titled "Concentration" or "Extraction"	9	1
Total Thorium Projects – Titled "Leaching", "Separation", "Process Developing", "Upgrading", or Floatation"	0	0
Total Thorium Projects Titled "Concentration" or "Extraction"	1	<1
Total Radium Related Projects	0	0

In addition to summaries of EPA's Waste-in-List, attached to this report are all of the discovered annual reports for projects conducted by CSMRI for specific years during the 1950s and 1960s (RAOA, Attachments 13-20). These lists are copied from CSMRI annual reports and corporate records and are referred to as the "Annual Report Lists."

As compared to the EPA Waste-in-List a lower frequency of uranium, thorium, and radium projects is seen in the Annual Reports. There are 1,408 projects listed in the Annual Report Lists. Of these, only 11 projects, or less than 1-percent, are listed as uranium projects related to leaching, separation, process developing, upgrading, or flotation. Of the 1,408 projects, only one is listed as a uranium concentration project. For thorium, only two are listed as thorium leaching, separation, process development, upgrading, or flotation projects. And there are no projects listed for thorium concentration or extraction. Finally, there are no radium-related projects. Below is a chart summarizing the results discussed:

1952, 1953, 1954, 1958, 1960, 1961, 1962, 1963
(Taken from the Annual Report)

Project Type	Number of Projects	Percent of Total
All Projects	1408	100
Total Uranium Projects – Titled "Leaching", "Separation", "Process Developing", "Upgrading", or Floatation"	11	<1
Total Uranium Projects Titled "Concentration" or "Extraction"	1	<1
Total Thorium Projects – Titled "Leaching", "Separation", "Process Developing", "Upgrading", or Floatation"	2	<1
Total Thorium Projects Titled "Concentration" or "Extraction"	0	0
Total Radium Related Projects	0	0

Combining the Waste-in-List and the Annual Reports indicates that CSMRI conducted at least 2,271 projects from the 1950s to the 1980s. While these two sources of information are not complete for all the projects conducted at the Site by CSMRI, they would pass any statistical test for capturing a representative random sample of all the projects conducted by CSMRI.

Of the 2,271 projects, there are no projects related to radium. Only 100, or 4-percent, are related to uranium leaching, separation, process development, upgrading, and flotation. Only 10 projects, or less than one-percent, are related to uranium concentration or extraction. Of the 2,271 projects, only two are related to thorium leaching, separation, process development, upgrading, and flotation. Only one is related to thorium extraction or concentration. Below is a chart summarizing the results discussed:

1952, 1953, 1954, 1958, And 1960's to 1980's
(Combined Lists)

Project Type	Number of Projects	Percent of Total
All Projects	2271	100
Total Uranium Projects – Titled "Leaching", "Separation", "Process Developing", "Upgrading", or Floatation"	100	4
Total Uranium Projects Titled "Concentration" or "Extraction"	10	<1
Total Thorium Projects – Titled "Leaching", "Separation", "Process Developing", "Upgrading", or Floatation"	2	<1
Total Thorium Projects Titled "Concentration" or "Extraction"	1	<1
Total Radium Related Projects	0	0

These summaries indicate that the vast majority of research conducted at the facility was not conducted for the study of radioactive materials.

When evaluating the two databases and the statistics, the word "uranium" appeared in 240 of the 2,271 total projects, or 11-percent of the total. The 110 uranium related projects listed in the above chart are a subset of the 240 projects. However, the other 130 uranium projects did not fall into the categories of leaching, separation, process development, upgrading, flotation, concentration, or extraction. Instead, these uranium projects were, for example, feasibility studies, literature studies, grinding projects, or projects performed at the sponsor's mining site (not at CSMRI) and should be excluded from the relevant statistics. Similarly, of the 2,271 projects, the word "thorium" appeared in nine projects, or less than one-percent of the total.

Another issue relevant to the waste characterization issue is the disposition of uranium and thorium after the materials were extracted in the few extraction projects. None of the former CSMRI employees interviewed as part of the RAOA recall sending just the extracted materials back to the sponsors. This is further supported by the absence of manifests or licenses to transport extracted materials off-site. The main purpose for conducting extraction research at the Site was to develop the technology and process for extraction. It appears that after the quality of the extracted materials was determined by laboratory analysis, the extracted materials would have been discarded into the tailings pond or wherever all of the waste materials went after completion of the research.

A review of the above-referenced research databases indicates that the vast majority of projects involved copper, lead, nickel, iron, zinc, coal, oil shale, and gold. The research issues varied widely across a broad range of technical mining-related areas, including: development of mining exploration techniques, mineralogical laboratory analyses, refraction techniques, hydraulic transportation methods, rock mechanics, metallurgical processing methods, flotation systems, consulting services to mining sites and mining operations, sulfur studies, pyrometalurgical reactions, liquid ion exchange processing, copper electrolysis, smelting process technologies, halogenation of ores and metallurgical products, fused salt electrolysis, economic feasibility studies, phosphate studies and analysis, handling of limestone, geophysical, petrographic, and stratographic studies, spectrographic studies, x-ray diffraction studies, instrument calibration and construction, fatty acid studies, well log studies, sand heat treatment methods, evaluation of different clays, among other studies. From this partial list it is clear that relatively little work with radiological materials occurred at the Site.

4.1.11.2 Site Licensing History

The CSMRI Site licensing and permitting history shows that the Soil was and should be regulated as solid waste. The Soil is similar to the Stockpile for purposes of regulatory classification. The Stockpile originated from the former impoundment area at the facility and certain adjacent areas. The impoundment area was regulated as a RCRA solid waste facility, not a hazardous waste facility. In addition, the Stockpile was removed from the Site as “solid waste” and disposed of at a solid waste disposal facility in Adams County, Colorado.

CSMRI was careful and conservative when obtaining licenses and permits. In doing so, the regulatory programs that provided facility oversight determined which regulatory program(s) was most appropriate for the Site activities. Governmental regulators concluded that the facility regulation would be under the authority of the Solid Waste Disposal Sites and Facilities Act and associated regulations. This conclusion is supported by the analysis provided in this section showing that the Soil is not hazardous waste.

Prior to this governmental determination CSMRI applied for permits under the RCRA, Subtitle C, which regulates hazardous waste management including the permitting for treatment, storage and disposal facilities of hazardous materials. Obtaining a RCRA hazardous waste permit requires a two part application process. On November 17, 1980 CSMRI applied for and received a Part A permit. On August 24, 1984 EPA requested that CSMRI complete the permitting process by submitting a Part B permit. In undertaking the more detailed Part B application it became apparent that CSMRI had filed the original Part A application in error and that the facility was not subject to RCRA, Subtitle C, hazardous waste regulations. CSMRI submitted a request for exemption from Subtitle C as provided in 40 C.F.R part 261.4(b)(7) (this point is discussed in more detail below). The Colorado Department of Health reviewed this information and determined the facility was exempt from Subtitle C of RCRA. RAOA Attachment 21 contains four letters that discuss the RCRA history at the Site.

Although most of the research at the Site was not related to the study of radioactive materials, CSMRI possessed, and continues to possess, a license for the storage, handling and possession of NORM, source, and by-product material (Colorado Radioactive Materials License Number 617-01S).

The following is a chronological summary of the U.S. Atomic Energy Commission ("U.S. AEC") and the State of Colorado licensing actions at the Colorado School of Mines Research Institute site:

Summary of U.S. AEC Licensing Actions at CSMRI:

Time Period	License Details
Terminated 1948	Weinig had License No. R-120 from the U.S. AEC for source material, which terminated in 1948. V2731, V2732. Weinig's clients also may have had separate licenses from the U.S. AEC for research at the Site. V1436.
1958 -1967	The State of Colorado has records of U.S. Atomic Energy Commission ("U.S. AEC") licensing actions dating from January 1958 through December 1967.
1958 - 1967	U.S. AEC By-product Material License Number: 5-4607-1 (including amendment #1 through amendment #23) dated from January 1958 through December 1967 Issued to: Colorado School of Mines Research Foundation, Inc. Authorized uses: laboratory research; teaching of industrial radioisotopic courses; as a component of a neutron generator for activation analysis; calibration of instruments; measurement of specific gravity of slurry in a pipeline; laboratory tracer studies; monitoring of solutions and slurries; metallurgical studies; neutron generator for activation analysis; experimental curing of thin plastic films deposited on ceramics; studies of molybdenum; geochemical research; to measure wear rate of experimental pipelines and machines and similar laboratory studies; and for the determination of solubility constants.
1966	U.S. AEC Special Nuclear Materials License Number: SNM-972 (for Plutonium), dated August 1966 Issued to: Colorado School of Mines Research Foundation, Inc. Authorized uses: for use in accordance with the procedures described in the licensee's application dated July 20, 1966. Storage only of soil samples.

Summary of State of Colorado Licensing Actions at CSMRI:

Date	License Details
October 24, 1968	Colorado Radioactive Materials License Number: Colo. 08 – 01 (F) Issued to: Colorado School of Mines Research Foundation, Inc. and Colorado School of Mines Authorized uses: Research, development, and teaching.
March 7, 1969	Amendment No. 2 to License Number: Colo. 08 – 01 (F).
May 25, 1971	Amendment No. 2 to License Number: Colo. 08 – 01 (F).
September 29, 1971,	Amendment No. 3 to License Number: Colo. 08 – 01 (F).
February 25, 1972,	Amendment No. 4 to License Number: Colo. 08 – 01 (F).
August 16, 1974	Amendment No. 5 to License Number: Colo. 08 – 01 (F).
October 31, 1975	Amendment No. 6 to License Number: Colo. 08 – 01 (F).
	Note: The State does not have record(s) of licensing actions between November 1975 and March 1985.
April 10, 1985	Colorado Radioactive Materials License Number: Colo. 617-01S Issued to: Colorado School of Mines Research Institute. Authorized uses: Possess, use, and store.
March 25, 1986	Amendment No. 1 to License Number: Colo. 617-01S
September 11, 1990	Amendment No. 2 to License Number: Colo. 617-01S. Issued to: Colorado School of Mines Research Institute Authorized uses: Possess, use, and store.
October 31, 1997	Amendment No. 3 to License No. 617-01
March 30, 2001	Amendment No. 4 to License No. 617-01
February 11, 2002	Amendment No. 5 to License No. 617-01. Issued to: Colorado School of Mines Research Institute Authorized uses: Possess and store naturally occurring, source and by-product.

The Site was licensed by both the Atomic Energy Commission (AEC) and the State of Colorado for numerous types of radioactive materials over several decades. The current license includes NORM, source material, and by-product material. Previous licenses authorized possession and use of any radioactive materials having atomic numbers 3 through 88 inclusive, americium, and plutonium. The scant available records related to plutonium materials indicate that disposal of certain plutonium materials occurred at Rocky Flats west of Denver (RAOA, Attachment 22). The licenses authorizing the use of americium state that the americium was for the calibration of instruments and for gauges. The amounts of americium for these instruments must have been minute. There are no records related to the disposal of americium.

The AEC sponsored some research projects at CSMRI. See Annual Reports (RAOA, Attachments 13-20). In response to EPA's 104(e) request, the successor to the AEC stated that it could find no records related to any AEC-sponsored projects at CSMRI. However, the U.S. Department of Energy (DOE) admitted that the AEC used the Site for research. DOE admitted this several years ago when the

CSMRI Site was considered for remedial action by a federal program administered by DOE. This program, the Formerly Utilized Sites Remedial Action Program (FUSRAP), was created to remediate sites used under the Manhattan Engineer District and the AEC during the early years of nuclear development. In 1987, DOE wrote to CSMRI concluding that the CSMRI Site did not qualify for the FUSRAP program because it could not be determined if the radiological contamination originated from the federal-sponsored work or work conducted under the State radioactive materials license (RAOA, Attachment 23).

There also are numerous general references to defense-related projects at CSMRI, but no files were found during the RAOA investigation and the United States has not produced applicable documents. See April 28, 1995 letter from A. Iatridis to L. Gunderson of EPA.

4.1.11.3 Prior Waste Classifications for Wastes Removed From the Site.

Wastes removed from the Site in the last several years confirm that the Soil is solid waste. The 22,000 cubic yards of stockpiled soils, which originated from the former settling pond, soils near the former pond, and mobile materials from the interior of the buildings, were classified and disposed of as solid waste.

Using the surface soil samples collected during the RI, several categories of "waste" can be considered depending on the selected remedial alternative. Several of the remedial action alternatives (see Sections 7.0 and 8.0) include off-site disposal of the affected material. The following table was generated to provide activity/concentration data to potential off-site disposal facilities. The first table has four categories of waste that include: removal of the highest activity (Ra-226 >15 pCi/g), removal material with Ra-226 greater than 5 pCi/g (but not including the highest activity material), removal of all material with Ra-226 greater than 5 pCi/g, and removal of all the radionuclide and metal affected soil. All data in this table are lognormal means of the data sets selected from the RI surface soil samples.

Metal / Radionuclide	Units	Back-ground	Waste Material Concentrations / Activities (Lognormal Mean)			
			Ra-226 >15 pCi/g	Ra-226 <15 pCi/g & >5 pCi/g	Ra-226 >5 pCi/g	All Material
Arsenic	mg/kg	13	36	34	35	18
Barium	mg/kg	370	230	320	280	230
Cadmium	mg/kg	1.5	1.7	3	2.3	0.68
Chromium	mg/kg	16	19	18	18	16
Lead	mg/kg	86	300	360	330	150
Mercury	mg/kg	0.63	4	2.3	3	0.97
Molybdenum	mg/kg	6.1	40	30	34	14
Selenium	mg/kg	1.7	2.2	2	2.1	1.3
Silver	mg/kg	0.12	2.6	2.2	2.4	0.68
Vanadium	mg/kg	44	61	44	51	39
Zinc	mg/kg	250	440	680	550	320
Ra-226	pCi/g	2.7	29	7.8	14	2.0
Ra-228	pCi/g	2.4	2.3	1.9	2.1	4.1
Th-228	pCi/g	2.7	3	2.1	2.5	1.9
Th-230	pCi/g	1.7	19	6.2	10	3.1
Th-232	pCi/g	2.4	2.7	1.9	2.2	0.17
U-234	pCi/g	1.9	12	4.3	6.8	3.1
U-235	pCi/g	0.098	0.65	0.23	0.37	5.1
U-238	pCi/g	1.6	12	4.5	6.9	1.8

A second table is provided that compares the Site soils to the settling pond soil that was stockpiled by the EPA Emergency Removal Action. All of the statistics for the Stockpile material was provided as arithmetic mean values (RAOA). To allow direct comparison between the Soil and Stockpile, arithmetic means were determined and the following table summarizes the results. As can be seen in the table, the Soil that is the subject of this RI/FS has concentrations and activity levels that are generally lower than the ones found in the Stockpiled soils that were disposed of as solid waste.

Metal / Radionuclide	Units	Waste Material Concentrations / Activities (Arithmetic Mean)		Stockpile Material Concentrations/ Activities (Arithmetic Mean)		
		All Material	**Ra-226 >15 pCi/g**	**EPA Stockpile Data**	**RAOA Composite Sample**	**Combined EPA and RAOA Data**
Arsenic	mg/kg	31	59	75	92	92
Barium	mg/kg	330	260	410	710	510
Cadmium	mg/kg	3.3	4.1	3.4	4.1	4
Chromium	mg/kg	17	20	26	25	28
Lead	mg/kg	470	550	378	328	400
Mercury	mg/kg	5.9	29	8.0	15	17
Molybdenum	mg/kg	38	110	--	<10	--
Selenium	mg/kg	1.9	2.7	--	4	38
Silver	mg/kg	2.7	6.3	3.2	--	5.7
Vanadium	mg/kg	46	85	58	--	61
Zinc	mg/kg	670	750	--	--	--
Ra-226	pCi/g	11	45	30	47	31
Ra-228	pCi/g	2.0	2.7	--	--	<0.9
Th-228	pCi/g	2.8	7.4	--	2.8	1.7
Th-230	pCi/g	9.2	39	30	24	14
Th-232	pCi/g	2.6	7.1	--	3.8	1.6
U-234	pCi/g	6.2	21	--	--	6.3
U-235	pCi/g	0.34	1.2	1.5	--	0.3
U-238	pCi/g	6.2	21	11	--	6.3

The demolition debris from the 17 buildings were removed and disposed of as solid waste. More recently the remaining concrete building slabs and asphalt were removed from the Site and disposed of as solid waste or recycled as solid waste. Miscellaneous containers of research materials also were disposed of at a solid waste landfill, including containers of niobium ore. Therefore, the classification of the remaining Soil as solid waste is consistent with prior classification of different types of materials removed from the Site as solid waste.

4.1.11.4 Summary Of Analytical Data In Regard To Regulatory Classification Of The Soil

The analytical results from sampling of the Soil supports the classification of the Soil as solid waste. The reader is referred back to the previous subsection to review this data. General conclusions regarding the data with respect to possible waste classification are presented below:

4.1.11.4.1 Radiochemistry

The radiochemistry results show that radiological isotopes present in the Soil are essentially in secular equilibrium. Secular equilibrium means that when the original radionuclide has a much longer half-life than the decay products, the decay products will eventually reach the same activity level as the original radionuclide. Using the uranium series as an example, uranium-238 decays to uranium-234 to thorium-

230…(several intermediate products with very short half-live have not been included in this discussion). The soil sample results show that uranium-234 is in equilibrium with uranium-238 – average ratio of U-234 to U-238 is equal to one. However, the average ratio of thorium-230 to uranium-238 is equal to 1.3. The difference can be explained by the solubility of thorium and uranium. Thorium is very insoluble and will remain with the parent rock. Uranium has a much higher solubility and can migrate out of the parent rock. Naturally occurring deposits can have thorium activities that are greater than the uranium because of the solubility issue. Site activities including leaching and floatation also could affect thorium activities in waste material. The ratio of lead-214 with respect to radium-226 is about 0.8, which indicates (0.8 to 1) is present at an activity level of about equal to radium-226 data.

The activity level of radium-226 with respect to thorium-230 (1.3 to 1) and uranium-238 (1.7 to 1) isotopes further supports the conclusion that radium processing was not occurring at the CSMRI Site (also see operational history especially the section regarding the BOM 1916-1920 work at the CSMRI site). Radium does not form any soluble complexes and would not be removed from the parent material without special processing.

Looking at the thorium-232 decay chain, the soil data shows that the thorium-232 and radium-228 activity levels are the same – average ratio of Th-232 to Ra-228 is one. Again this data indicates that these isotopes are in secular equilibrium.

Finally, in looking at the limited number of samples that contained members of the uranium-235 decay chain, there is no evidence of enrichment or depletion of uranium-235 with respect to the contaminated stockpiled soils. In addition, during the years of Site operation the technologies for concentrating Uranium-235 would also concentrate uranium-234 and uranium-233. The data for uranium-234 shows this isotope to be approximately equal in activity to uranium-238. This further supports the fact that there is no known evidence of projects at the Site involving the concentration of uranium for enrichment purposes.

As mentioned above in the operational history section there have been several unsubstantiated rumors that plutonium may have been disposed of at the Site. CSMRI held licenses allowing the possession of americium and plutonium.

It appears, based on the AEC license, that the limited quantity of americium (less than 0.001 microcurie) that may have been at the Site was for instrument calibration (RAOA, Attachment 38). Therefore, the disposal of americium at the Site is very unlikely. The small sample data subset indicates the presence of americium only at background activity (see Section 4.1.4.1).

Historical records indicate that Site use of plutonium was limited to research associated with a project known as Rollercoaster. Project Rollercoaster appears to have involved evaluation of soil samples that contained small amounts of plutonium. The purpose of the project according to a June 10, 1968 letter (RAOA, Attachment 38) was to "determine some of the affects that might be anticipated in an high energy explosion of devices containing nuclear material." The letter also describes that some plutonium in solution (0.1 millicurie) was on-site for use in instrument calibration. As mentioned in the operational history it appears that this plutonium was transported and disposed of at the Rocky Flat plants west of Denver. Nevertheless, to be conservative in the event that there where other unreported experiments using plutonium, two surface samples were analyzed for plutonium. The small sample data subset indicates the presence of plutonium only at background activity (see Section 4.1.4.1).

4.1.11.4.2 *Organic Substances*

The selected TCLP soil samples were free of SVOCs and VOCs, with one minor exception (one "J" value detection of 2-Butanone) and the area near the baseball field. With the groundwater data, a question as to whether the Soil might contain RCRA listed hazardous wastes could be raised. In reviewing the data summary, there are only limited organic compounds detected. This suggests that the TCE and PCE may have been used for small batch research experiments rather than a widely used solvent for degreasing purposes. Moreover, CSMRI's documented compliance history with RCRA suggests that any TCE or PCE used as a solvent or any spills were disposed of at off-site locations (RAOA, Attachment 47).

Based on this data and information on the operational history and previous regulatory determinations for the CSMRI Site it is reasonable to conclude that the TCE and PCE were most likely used in conjunction with the beneficiation of ore during research and experimentation (also see the summary of operational history). At the time of use the TCE and PCE were exempt from regulation under RCRA as provided in the 40 C.F.R. 261.4(b)(7) also commonly known as the "Bevill Amendment" exclusion. This point is discussed in more detail in Section 4.1.11.5.8.

Additionally, based on CSMRI RCRA inspection and compliance history there is no evidence to suggest that TCE or PCE were discarded commercial products, off-specification species, container residues, and spill residues thereof ("U" listed RCRA wastes).

4.1.11.4.3 *Inorganic Substances*

TCLP tests for inorganic substances were conducted on several samples. Results indicate that the majority of the samples contained inorganic substances well below the hazardous waste regulatory concentrations established under RCRA for toxicity.

Based on the above discussion and the results of the data collected on the Soil it is clear that the Soil would not be considered hazardous waste even if RCRA Subtitle C was applicable or relevant and appropriate to the Soil.

4.1.11.5 *Soil Regulatory Classification*

The following discussion will evaluate all reasonable possible regulatory classifications for the Soil. As previously discussed, the universe of possible regulatory classifications include: radioactive material; special nuclear; transuranic; source material; naturally occurring radioactive material (NORM); by-product material (11(e)(1) and 11(e)(2)); Low level radioactive waste; hazardous waste; mixed waste; classified waste; and solid waste. Each of these possible regulatory classifications for the Soil is discussed below in the context of the preceding operational history, analytical results, and regulatory history at the Site.

- Radioactive material,
- Special nuclear material,
- Transuranic waste material,
- Source material,
- Naturally occurring radioactive material (NORM),
- Technically enhanced naturally occurring radioactive material (TENORM),
- By-product material (11(e)(1) and 11(e)(2)),
- Low-level radioactive waste,
- Hazardous waste,
- Mixed waste,
- Classified waste, and
- Solid waste.

The State of Colorado's environmental statutes and regulations regarding the management, storage, treatment, and disposal of solid waste, hazardous waste, and radioactive material are all based on the principle of protecting and improving the health and environment of the people of Colorado. It is important that the regulatory classification(s) applied to the Soil ensures that the most significant hazards of the waste/material are adequately controlled.

4.1.11.5.1 *Radioactive Material*

"Radioactive material" is defined broadly in the Colorado Radiation Control Act. The term means: any material, solid, liquid, or gas, which emits ionizing radiation spontaneously (§ 25-11-101(3), C.R.S.)

"Radioactive material" also is defined broadly under Colorado's radiation control regulations as any solid, liquid or gas which emits radiation spontaneously (RH 1.4). This definition is broader than the U.S. NRC's definition of radioactive material derived from the Uranium Fuel Cycle. The State of Colorado was given "primacy" for Colorado's radiation control program in 1968. With the exception of Nuclear Power Plants and Federal Facilities, the CDPHE has the complete (not delegated) responsibility for the licensing of radioactive material in the State of Colorado. The provisions for licensing of some radioactive material are contained in Part 3 of Colorado's Radiation Control Regulations.

Part 3 of Colorado's Radiation Regulations pertains to the licensing of some radioactive materials with specific exemption of source material, by-product material and certain other specific materials. Because of the presence of naturally occurring deposits of radioactive ores and soils, not all radioactive material in Colorado is required to be licensed under the Radiation Control Act. Moreover, background material is not regulated under the Radiation Control Act, because the regulations provide that a radioactive materials license may be terminated if background levels are achieved.

The analytical data for the Soil show that the Soil has solid material that emits ionizing radiation spontaneously. The Soil, therefore, is radioactive material. However, that does not mean that the Soil is licensed or should be licensed under the Radiation Control Act. The term "radioactive material" does not exclude the Soil from being classified as solid waste.

4.1.11.5.2 *Special Nuclear Material*

Special nuclear material (6 CCR 1007-1, 1.4) is defined as:

- plutonium, uranium-233, uranium enriched in the isotope 233 or in the isotope 235, and any other material that the U.S. Nuclear Regulatory Commission, pursuant to the provision of Section 51 of the Atomic Energy Act of 1954, as amended, determines to be special nuclear material, but does not include source material;
- any material artificially enriched by any of the forgoing but does not include source material.

Comparing the Soil to the special nuclear material definition indicates the following:

- The data indicates that the activity level of uranium-234 and uranium-238 are approximately equal and the Soil is not enriched in uranium-235. Therefore, the Soil does not show enrichment or depletion of key uranium isotopes.
- Plutonium and americium are present at background activities in the Soil.
- The operational history and CERCLA 104(e) information responses do not indicate activity that special nuclear material was disposed of at the Site.

Based on this information, the Soil is not special nuclear material.

4.1.11.5.3 *<u>Transuranic Waste Material</u>*

Although not specifically defined, there is a provision in Part 14 of the radiation control regulations that defines in part, by exclusion, the term "waste" as follows:

3. Waste materials containing transuranic elements with contamination levels greater than one hundred nanocuries (3700 bq) per gram of material;

"Transuranic" is defined as: "radionuclides with atomic numbers greater than 92 (§ 25-11-201(3)(b), C.R.S.).

The licensing history for the CSMRI Site shows a very inclusive range of radioactive substances that could be possessed under the licenses. Specifically, the licenses included any substances with atomic numbers 3 - 88, uranium and thorium bearing substances, plutonium and americium (RAOA, Attachment 38). Plutonium and americium were the only transuranic substances authorized for use at the Site. Therefore, there is no reason to believe that any transuranic elements (other than plutonium and americium) were used or authorized to be used at the Site.

Based on the preceding discussion, and the apparent limited amounts of americium (instrument calibration sources and measuring devices) and plutonium (background), it is concluded that the 3rd provision under the "waste" definition in Part 14 of the Colorado radiation regulations does not apply to the Soil.

Based on this information the Soil is not transuranic material.

4.1.11.5.4 *<u>Source Material</u>*

The radioactive materials license for the Site includes source material. The issue, therefore, is whether the Soil is “source material.” If not, then the Soil is not subject to the Site’s radioactive materials license. "Source material" means material, in any physical or chemical form, including ores, that contain by weight one-twentieth of one-percent (0.05-percent) or more of uranium, thorium or any combination thereof (R.H. 1.4). Source material does not include special nuclear material (R.H. 1.4).

Where "source material" is found in any chemical mixture, compound, solution, or alloy in which the source material is by weight less than 1/20 of 1 percent (0.05) of the mixture, compound, solution, or alloy, the person receiving, possessing, using, owning, or transferring the source material is exempt from the regulatory requirements in Part 3 which otherwise requires licensing (R.H. 3.2.1). Thus, even if source material caused the elevated levels in the Soil, the mixture is exempt from Part 3 of the radiation regulations. Moreover, even if the mixture were not exempt, which it would be, the mixture is a candidate for exemption under section 1.5.1 of the radiation regulations, if such an exemption were applicable.

Under U.S. NRC regulations, the term “source material” has two meanings. It is important not to confuse the two NRC meanings with Colorado regulations. As defined in 10 C.F.R. § 40.4, “source material” means: (1) uranium or thorium, or any combination thereof, in any physical or chemical form or (2) ores which contain by weight 0.05% or more of uranium, thorium, or any combination thereof. Colorado’s regulations adopt the latter NRC meaning; thus excluding from Colorado licensing requirements any source material that contains uranium or thorium regardless of its percentage by weight of the host material.

The combination of uranium and thorium in the analytical data shows that the Soil is less than 0.05 percent by weight. Therefore, the Soil is not source material subject to Colorado radioactive materials licensing requirements.

4.1.11.5.5 *<u>NORM</u>*

The radioactive materials license for the Site also includes NORM. The issue then is whether the Soil is NORM and subject to the license for purposes of disposal. NORM, or "naturally occurring radioactive material," is defined by Colorado statute [§ 25-11-101(2.7), C.R.S.] as:

> any nuclide that is radioactive in its natural physical state and is not manufactured. [NORM] does not include source material, special nuclear material, or by-products of fossil fuel combustion, including but not limited to bottom ash, fly ash, and flue-gas emission by-products.

There are no state regulations implementing the NORM definition, except that “background radiation” includes NORM (R.H. 1.4) (Background radiation is not regulated). Also there are no federal laws regulating NORM. In fact, CDPHE is prohibited from regulating the disposal of NORM [§25-11-104(1)(b), C.R.S.]. This legislative directive indicates that no materials are to be regulated as NORM for disposal until after federal disposal regulations are promulgated.

The Colorado General Assembly recently reaffirmed this statutory policy by expressly acknowledging that NORM (which is unregulated under the radiation control laws), including a subset of NORM known as “technologically enhanced” NORM (or TENORM), may be disposed of as solid waste in solid waste landfills in Colorado without being subject to, or requiring, a radioactive materials license [§ 25-11-201(1)(c), C.R.S.].

The Colorado NORM disposal legislation was enacted in the 1990s, several years after the Experimental Plant ceased to operate. No materials were brought to the Experimental Plant at the time the State of Colorado first had authority to use the term NORM. Thus, NORM cannot apply to the Soil. Colorado did not and does not have authority to regulate the Soil as NORM under the Radiation Control Act. The inclusion of NORM in the CSMRI radioactive materials license is not valid.

Assuming that NORM could apply to the disposal of the Soil, the Soil should not be classified as NORM. The statutory definition of NORM excludes source material and by-products of fossil fuel combustion. As explained above, numerous coal experiments, including combustion, were conducted at the Experimental Plant. Moreover, to the extent the Soil is considered exempt from source material licensing, because the uranium and thorium weight is below the regulatory threshold, the Soil should not be characterized as NORM because two of the exclusions apply to it. Finally, given that the Soil can be disposed of without undue hazard to the public health and safety and property, these materials should be exempt under R.H. 1.5.1.

Based on this information the Soil is not NORM.

4.1.11.5.6 *<u>By-Product Material</u>*

The third category of radioactive materials covered by the radioactive materials license for this Site is by-product material. The issue is whether the Soil is by-product material. Part 18 of Colorado's Radiation Regulations establishes procedures, criteria, and terms and conditions upon which the CDPHE issues licenses for the operation of source material milling facilities and for the disposition of by-product material (R.H. 18.1.1). The state radiation control regulations (R.H. 1.4) define "By-product material" in two ways:

- Any radioactive material, except special nuclear material, yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material; and
- The tailings or wastes produced by the extraction or concentration of uranium or thorium from ore processed primarily for its source material content, including discrete surface wastes resulting from uranium or thorium solution extraction processes. Underground ore bodies depleted by these solution extraction operations do not constitute "by-product material" within this definition.

The State definition is modeled after the federal Atomic Energy Act of 1954 (AEA) and its definition of by-product material [42 U.S.C. § 2014(e)]. Material regulated under the first part of the definition is commonly referred to as "11(e)(1) material," while material regulated by the second part of the definition is commonly referred to as "11(e)(2) material." These references are based on the definitional sections of the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), which amended the AEA and added these two definitions of by-product material.

Because there is no evidence of management or processing of special nuclear material at the Site, the Soil is not 11(e)(1) material.

Whether the Soil is 11(e)(2) material depends in part on the meaning of the phrase "from ore processed primarily for its source material content." Congressional legislative history, case law, Nuclear Regulatory Commission guidance, and prior CDPHE decisions at this Site indicate that 11(e)(2) jurisdiction was not intended to regulate a research facility like the Site. Rather, 11(e)(2) jurisdiction covers licensed full-scale production milling operations that are part of the nuclear fuel cycle**.** The Site, and all wastes generated at the Site, therefore, are not subject to 11(e)(2) jurisdiction and cannot be subject to the radioactive materials license as 11(e)(2) by-product material.

The AEA was enacted in 1954 to promote the development, use, and control of atomic energy (Kerr-McGee, 1990). The AEA gave licensing authority to the Atomic Energy Commission (AEC) to license certain activities involving "special nuclear material," "source material," and "by-product material." By-product material was originally defined in the AEA by the definition currently found in 11(e)(1). The AEA did not regulate waste materials generated from the extraction or concentration of source material.

Congress later enacted UMTRCA in 1978 to regulate source material mill tailings. The House Report for UMTRCA described the need for this legislation (Kerr-McGee at 3, 1990 - emphasis added) as follows:

> Uranium mills are part of the nuclear fuel cycle. They extract uranium from ore for eventual use in nuclear weapons and power plants, leaving radioactive sand-like waste - commonly called uranium mill tailings - in generally unattended piles. As a result of many years of uranium ore processing, about 140 million tons have now accumulated at active and inactive milling sites.

UMTRCA brought these mill tailings into the regulatory scheme by adding the 11(e)(2) definition.

The Nuclear Regulatory Commission (the successor to the AEC) chair at the time, Dr. Joseph Hendrie, who proposed the specific language, stated that the significance of the phrase "processed primarily for its source material content" was that "the language was intended to avoid bringing within NRC jurisdiction radioactive wastes resulting from activities not connected with the nuclear fuel cycle, which would be left to EPA regulation" (Kerr-McGee at 6, 1990 - emphasis added). Dr. Hendrie and the chair of a Congressional committee had the following exchange:

> Mr. Dingell: I am curious about why you include in that word "processed" primarily for source material content. There are other ores that are being processed that do contain thorium and uranium in amounts and I assume equal in value to those you are discussing here.
>
> Is there any reason why we ought not give you the same authority with regard to those ores?
>
> Dr. Hendrie: Mr. Chairman, the intent of the language is to keep NRC's regulatory authority primarily in the field of the nuclear fuel cycle. Not to extend this out into such things as phosphate mining and perhaps even limestone mining which are operations that do disturb the radium-bearing crust of the earth and produce some exposure but those other activities are not connected with the nuclear fuel cycle, EPA is looking at those and those appear to me to be things that ought to be left to EPA regulation under the Resource Conservation and Recovery Act and general authorities (UMTRCA, 1978).

Given the ambiguous language of the 11(e)(2) definition, the United States Court of Appeals in the Kerr-McGee case relied on the legislative history and intent and held that the definition was intended to regulate materials in the course of the nuclear fuel cycle (Kerr-McGee at 6-8).

In partial response to the Kerr-McGee case, the NRC issued guidance that defined the word "ore" as found in the 11(e)(2) definition. 57 Fed. Reg. 20532-20533 [guidance was finalized at 60 Fed. Reg. 49296, September 22, 1995]. The word "ore" is not defined by statute or regulation. The NRC guidance defines "ore" as follows:

> Ore is a natural or native matter that may be mined and treated for the extraction of any of its constituents or any other matter from which source materials is extracted in a licensed uranium or thorium mill (57FR20532-3).

One of the two major considerations of the NRC in drafting this definition of ore was that it should remain:

> tied into the nuclear fuel cycle. Because the extraction of uranium in a licensed mill remains the *primary purpose* of processing the feed material, it excludes secondary uranium side-stream recovery operations at mills processing ore for other metals. Thus, tailings from such side-stream operations at facilities that are not licensed as uranium or thorium mills, would not meet the definition of 11(e)(2) by-product material (57FR20532).

Thus, the 11(e)(2) definition is not intended to cover secondary uranium side-stream operations at mills processing ores for other metals.

The Site Experimental Plant and the research facilities were not a licensed uranium or thorium mill whose "primary purpose was processing feed material" in the nuclear fuel cycle. The Site was not part of the nuclear fuel cycle. The Site was a research center that researched and developed technologies and methods for the full breadth of the mining industry. The 11(e)(2) definition is intended to regulate full-scale production uranium milling operations with enormous amounts of uranium ores as part of the nuclear fuel cycle, not a research center used for many types of research projects with few uranium ore-related projects. Therefore, the 11(e)(2) jurisdiction should not apply to any of the research projects where uranium or thorium were extracted or concentrated from source material. Assuming that the Soil was in fact affected by projects that may be candidates for 11(e)(2) by-product classification, the Soil is not "by-product material."

CDPHE has already agreed that the Experimental Plant at the Site was not a full-scale mill and, therefore, was not subject to 11(e)(2) by-product jurisdiction. When Colorado School of Mines demolished the Experimental Plant building and removed it from the Site as solid waste for disposal at a solid waste disposal facility, even though some of the building materials exhibited radiological characteristics above background levels, CDPHE stated:

> AWS has adequately shown, on pages II-9 through II-16 of the Plan, that the radiologically effected material is not a hazardous waste, low level radioactive waste, source material, NORM, or 11.e.(1) by-product material. Also the Plan argues the materials should not be considered 11.e.(2) by-product because the Experimental Plant was not a "mill" in the usual sense (page II-12 through II-14) even if the four effected areas were the result of "milling" activity. The RCD agrees with this analysis. The analysis of this Plan is not in conflict with arguments presented by the State in its Regulatory Classification of Contaminated Soils in its report of June 12, 1995 for the CSMRI Creekside site. Similarly the RCD has considered the issue of what constitutes milling in relation to another site, and has concluded that crushing and grinding, such as was performed in building 101, is not milling in the usual sense (G. Mallory and D. Simpson, written communication, Apr. 16, 1996).

Therefore, the Soil is not 11(e)(2) by-product material and the Soil is not subject to the radioactive materials license for the Site.

Nevertheless, assuming that any residue from these few uranium and thorium projects could be characterized as 11(e)(2) by-product material, it would be unfair to characterize the soil as 11(e)(2) by-product material for disposal purposes. Given the statistical evaluation of the operational history, the extraction of uranium and thorium was a small part of the research conducted at the Site. Only 11 of 2,271 projects were listed as for uranium or thorium extraction or concentration from Source material. That is less than 1-percent or 0.48-percent of all projects. Thus, it is highly unlikely that the elevated levels of radionuclides were in fact caused solely by 0.48-percent of the total projects conducted. Many ores with mineral values other than uranium and thorium also contain these radionuclides as constituents, and are not classified as source material. The volume of such ores, and the quantity of uranium and thorium associated with these ores, is significantly greater than the volume of source material ores and the source material contained in them.

Furthermore, assuming the selected materials are 11(e)(2) by-product material, these materials are a candidate for exemption from the radiation control regulations because there would be no undue hazard to public health and safety or property by disposal of these materials as proposed by this plan (R.H. 1.5.1).

For these reasons, the identification of the Soil containing elevated concentrations of radioactivity as by-product material is not justified even if some ores classified as source material were utilized in research and development activities at the Site.

Because of the reasons presented in this section the Soil is not by-product material.

Thus, the Soil is not any of the three types of materials regulated by the radioactive materials license for the Site (NORM, source, and by-product). The radioactive materials license does not apply to the Soil. Nonetheless, that conclusion does not end the inquiry into what is the appropriate regulatory classification of the Soil for disposal purposes. Other possible waste classifications should be explored.

4.1.11.5.7 *<u>Low-Level Radioactive Material</u>*

Part 14 of the Colorado radiation regulations establishes licensing requirements for land disposal of low-level radioactive waste. R.H. 14.2 states that: "waste" means radioactive waste other than:

- Waste generated as a result of the defense activities of the federal government of federal research and development activities;
- High level waste such as irradiated reactor fuel, liquid waste from reprocessing irradiated reactor fuel, or solids into which any such liquid waste has been converted;
- Waste materials containing transuranic elements with contamination levels greater than one hundred nanocuries (3700 bq) per gram of material;
- By-product material as defined in Section 11(e)(2) of the "Atomic Energy Act of 1954", as amended on November 8, 1978:* or
- Waste from the mining, milling, smelting, or similar processing of ores and mineral-bearing material primarily for mineral other than radium;*

(* The disposal of these materials is licensed under Part III of the regulations.)

In evaluating the elements of this definition of waste it is apparent that elements 1 and 5 are important with respect to the Soil. Regarding element 1 of the definition, it is clear from the operational history that much of the work conducted at CSMRI was for federal research and development activities, including defense related activities. In fact 33 different federal agencies were clients of CSMRI and many of these clients had multiple projects. This exclusion of federal research and development is especially relevant to the 1916-1920 BOM work. Of equal importance regarding the BOM work is the fact that the pitchblende ore work at the experimental plant was not primarily for the purposes of radium extraction. As discussed in the operational history, the Experimental Plant was only used to grind and separate higher-grade pitchblende ore from lower grade ore. No processing or extraction of radium took place at the Site.

The beneficiated pitchblende ore was sent to the National Radium Institute in Denver. Once at the National Radium Institute the BOM processed the ore, removing uranium oxide for its possible utilization in special steels for ordnance. The National Radium Institute also gave extracted radium to Mr. Dupont who in turn donated the radium to hospitals.

In addition, as shown in the operational history, there are no other known projects that involved radium work. Under element 5 of the definition of waste there is a clear exclusion of ores and mineral-bearing material work on substances other than radium. The operational history shows thousands of projects on ores and mineral-bearing substances that are not for radium processing. Finally, as discussed previously, the analytical data on the Soil supports the operational history in that the data shows the radium isotopes to be approximately equal to or greater than the corresponding uranium and thorium isotopes. No extraction of radium took place at the Site.

Based on the above discussion and the other information presented in this document it is clear that the Soil fits the exclusion under the definition of waste provided in Part 14. Therefore, the Soil is not low level radioactive waste.

4.1.11.5.8 *Hazardous Waste*

The federal statute governing the treatment, storage and disposal of hazardous wastes is the Federal Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act (RCRA) of 1976, as amended. The regulations for implementing the hazardous waste portion of RCRA are known as the Subtitle C regulations. Subtitle C regulations became effective on May 19, 1980.

There are many criteria and exemptions that affect the implementation of Subtitle C of RCRA. Of particular significance with regard to the Soil is an amendment of November 19, 1980 that excluded "solid waste from the extraction, beneficiation and processing of ores and minerals (including coal), including phosphate rock and overburden from mining of uranium ore." This amendment is commonly known as the Bevill Amendment and was put into place until EPA could make a final determination on how to handle certain mining related wastes. Since 1980 there have been several studies and actions to delineate which mining related wastes would remain exempt from being regulated as hazardous waste. From 1980 to 1989 the Bevill exclusion exempted all solid waste from the exploration, mining, milling, smelting, and refining of ores and mineral. In September 1989 EPA promulgated a final rule that removed all but 20 mineral processing wastes from exclusion from being regulated as a hazardous waste. CSMRI operations at the Site ceased by 1987. Currently, all extraction and beneficiation processes relating to ore and mineral bearing substances are still excluded from being regulated as hazardous waste.

Under RCRA Subtitle C a non-exempt waste can be considered hazardous if any of the following factors apply to the substance: it is a listed hazardous waste or it shows the characteristic of ignitability, corrosivity; reactivity; or toxicity. Colorado has been delegated the authority by EPA to administer the federal RCRA program pursuant to state law. Colorado has adopted the above-referenced federal Bevill exclusion and the definitions of hazardous waste.

With regard to the Soil, at the time of disposal all of the activities described in the operational history of the Site indicate that the Soil is covered by the Bevill exemption and is therefore not defined as hazardous waste. This conclusion that the Soil meets the criteria for exemption from regulation as a hazardous waste was previously independently determined by the Colorado Department of Health between 1985 and 1988, (RAOA, Attachment 21), as well as in 1995 when CDPHE approved the disposal of the Stockpiled soils as solid waste.

Notwithstanding the fact that the Soil is excluded from being regulated as hazardous waste a review of the factors that apply to non-exempt materials shows that the Soil still would not be classified as hazardous waste. The TCLP samples indicated the Soil does not contain toxic wastes, sufficient organic material to be ignitable, extreme pH characteristics, or sufficient cyanide or sulfide to be reactive. A single TCLP sample was above the limit for lead, but the sample was intentionally biased to a small area with elevated lead concentrations. The average characteristic of all of the Soil would be below TCLP limits and, therefore, not toxic.

Based on the above discussion, the Soil is not hazardous waste.

4.1.11.5.9 *Mixed Waste*

"Mixed Waste" means a waste that contains both RCRA hazardous waste and source by-product, or special nuclear material subject to the jurisdiction of the AEA. The preceding discussions show that the Soil is not hazardous waste and does not fall within the specific definitions of source, special nuclear, or by-product material subject to AEA jurisdiction. Therefore, the Soil is not mixed waste.

4.1.11.5.10 *Classified Waste*

In the last two years, the Colorado General Assembly enacted a new radioactive materials waste category called "classified material" [§ 25-11-20(1)(a), C.R.S.]. However, this relatively new category of "classified material" is only applicable to material intended to be sent to a "facility" required to be licensed pursuant to the Colorado Radiation Control Act [§§ 25-11-201 (1.6), 25-11-203(1), (2), C.R.S.]. Moreover, nothing in the recent legislation applies to the treatment, storage, management, processing, or disposal of solid waste, which may include NORM and "technologically enhanced" NORM [§ 25-11-201(1)(c), C.R.S]. The School does not intend to send the Soil to a facility required to be licensed pursuant to the Colorado Radiation Control Act. Therefore, the Soil is not "classified material."

4.1.11.5.11 *Solid Waste*

The federal and state solid waste laws and regulations are very broad in scope and can govern almost any discarded material. Under Colorado state regulations (6 CCR 1007-2, 1.2) solid waste means:
"any garbage, refuse, sludge from waste treatment plant, water supply treatment plant, air pollution control facility, or other discarded material..". The contaminated Soil meets this definition because it is discarded material.

The definition of solid waste (6 CCR 1007-2, 1.2) goes on to exclude " ... materials handled at facilities licensed pursuant to the provisions on "Radiation Control Act" in Title 25, Article 11, Colorado Revised Statutes…"

This provision of the definition eliminates duplicative regulation of a single facility. While the Site did have general licenses to handle, store and possess certain radioactive materials, the Soil is not any of the types of radioactive materials that were subject to the licenses and is, therefore, not excluded from the definition of a solid waste. This exclusion language in the solid waste regulation does not exclude all solid wastes handled or generated at a licensed facility. It only excludes those materials that are regulated under the radiation control act and regulations. This is confirmed by the Colorado General Assembly that expressly acknowledged that NORM and TENORM could be disposed of as solid waste without requiring a radioactive materials license [§ 25-11-201(1)(c), C.R.S.].

From the operational history it is apparent that the Site was a mining and mineralogical research facility. The solid waste regulations govern research mining and milling wastes. In fact, the Bevill exemption would not be necessary if research mining and milling wastes were not solid wastes.

The conclusion that the Soil is solid waste is supported by prior CDPHE decisions that found that the Stockpiled soils, the buildings, the concrete and asphalt, and miscellaneous contaminated wastes from research operations were all found to be solid waste that could be disposed of at solid waste landfills in Colorado. The Soil contains lower radionuclide concentrations than the Stockpiled Soils that were disposed of as solid waste, so classification of the Soil as solid waste is consistent with prior regulatory decisions at this Site.

4.1.11.6 Regulatory Waste Classification Conclusion

The preceding discussion outlines complex regulatory, operational and technical information regarding the Soil.

The preceding analysis has shown the following:

- The Soil contains radioactive material at very low concentrations.
- The Soil is NOT special nuclear material, transuranic with respect to plutonium and americium, source material, NORM or TENORM, by-product material, low-level radioactive waste, hazardous waste, mixed waste, or classified waste.
- The Soil is solid waste.

This report recommends that the Soil be classified as solid waste. The two driving factors are the minimal amount of radioactive material in the Soil and the regulatory evaluation of these materials.

Under both federal and state law, broad general authority exists to protect human health and the environment under the regulatory authority of the federal RCRA Subtitle D regulations and the state regulations pertaining to solid waste disposal facilities. These regulations allow those technical measures to be put into place that prevent risks to human health and the environment. In essence the solid waste rules and regulations allow the Soil to be treated and disposed of utilizing a risk-based approach that is consistent with the mandates established in CERCLA and the NCP.

Solid waste disposal sites and facilities must comply with the health laws and standards, rules and regulations of the Colorado Department of Public Health and Environment, the Water Quality Control Commission, the Air Quality Control Commission, and all applicable local laws and ordinance (6 CCR 1007-2, Section 2.1.1). No facility shall constitute a hazard to human health (6 CCR 1007-2, Section 2.1.3). Consequently, in order to ensure protection of human health and the environment, the disposal of the Soil will use some of the additional substantive portions of the radiation control regulations during the handling, transportation, and disposal of the Soil, if necessary.

The Soil consists of materials that do not require a radioactive materials license. The solid waste disposal act and regulations will provide the general framework to be used in determining the appropriate technical and procedural disposal criteria for both on-site and off-site alternatives. The radiation control regulations will be used to augment the technical and procedural requirements of the solid waste regulation to ensure protection of human health and the environment for the radioactive elements in the Soil. The augmentation to the technical requirements of the solid waste regulations will require that the radiation control regulations be used as a guide for determining technical and procedural disposal criteria. This will ensure protection of human health and the environment.

4.2 Ground Water

This section characterizes the nature and extent of contamination in the ground water. Seven ground-water monitoring wells were sampled for three-quarters to determine if material is moving to ground water. Four of the wells are upgradient of the site and three are downgradient. The relative positions of the wells are shown in Figure 3-6.

4.2.1 Ground-Water Analytical Results

Four rounds of quarterly ground-water samples were collected from the Site monitoring wells in 2003. Ground-water samples were forwarded to Paragon Analytical, Inc. for analysis. The samples were analyzed for metals, VOCs, SVOCs, specific radioisotopes (radium, thorium, and uranium), gross alpha and beta particles, and major anions and cations. A summary of the sample results is provided in Tables 4-32 through 4-36. Tables 4-37 through 4-39 provide a limited amount of historical analytical results for comparison.

Low recharge rates for monitoring wells CSMRI-02 and CSMRI-07 make typical purging techniques impractical. The results from these wells may not be representative of formation water.

The field parameters indicate that the ground water in the vicinity of the Site varies seasonally and spatially (Table 4-32). A limited amount of historical field parameter data is provided in Table 4-37 for comparison (data appears inconsistent with current conditions). Specific conductance is about four to six times higher near the Clay Pits area (CSMRI-03) than along the alluvial bedrock of Clear Creek (CSMRI-01) depending on the season. Specific conductivity appears to be increasing in the on-site monitoring wells, potentially reflecting the precipitation driven movement of soluble salts through the previously covered on-site soil. Low dissolved oxygen (DO) concentrations are found in the wells near the former settling pond (CSMRI-04 & -05) and the Clay Pits well (CSMRI-03). The low DO wells also maintain a lower pH than the other sampled wells. Gas bubbles tended to collect in the flow through chamber when the wells CSMRI-03, -04, and -05 were sampled with the highest volume of gas appearing during the sampling of CSMRI-03. Field parameters for wells CSMRI-02 and CSMRI-07 were measured in an open container during the first sampling round because of very slow recharge. A flow through chamber was used during subsequent sampling rounds. The flow through chamber was used for the field parameters measurement of the remaining five wells for all of the sampling rounds.

Small concentrations of chlorinated solvents (tetrachloroethene and trichloroethene) and their degradation products were found in wells CSMRI-04 and CSMRI-05 (Table 4-31) during all four sampling rounds. The trichloroethene MCL (5.0 μg/L) was exceeded in CSMRI-04 during the fourth sampling round (reported value 5.1 μg/L). First and second round CSMRI-05 samples also contained low concentrations (J value) of bromodichloromethane, a compound typically formed during the chlorination of drinking water. The VOC data from the third sampling round appears to indicate laboratory contamination of acetone. Third and fourth round samples showed acetone in all or some of the samples (J, B value – B indicates the compound also was found in the laboratory blank), an obvious sign of laboratory contamination. Acetone (J value) also was detected in well CSMRI-07 during the first round. Analysis of the second round samples did not indicate the presence of acetone. Chloromethane (J value) was detected at similar concentration in four of the wells during the third sampling round suggesting a possible contaminant. A cleaned, polyvinyl chloride manifold was used with the flow through chamber for this round and is a potential source of contamination (manifold was added to allow sample filtration). With the exception of the CDMRI-04 fourth quarter, trichloroethene result, none of the VOCs were above EPA or Colorado Drinking Water Maximum Contaminant Levels (MCLs). No SVOCs were detected during all four quarters of sampling.

The first and second round ground-water samples collected for metals are total metals (see Table 4-33). A decision was made to filter the metals samples after an excessive difference was observed during the second round calculation of the anion/cation balance. Round three and four metals samples were collected using a 0.45-micron capsule filter. The third round results indicate that the lead detected during the first two rounds was probably associated with suspended particles – cadmium and chromium also may have been affected. The second-round CSMRI-02 sample contained lead and chromium at concentrations above the EPA MCLs, but the third round samples suggest this was probably the result of suspended solids. The metal concentration variability between the sample rounds falls within expected ranges for low concentration metals (with the exception of the second-round CSMRI-02 sample). None of the monitoring wells contained metals at or near the current MCLs during the third round (see radionuclide discussion later in this section). A limited amount of historical data for metals is provided in Table 4-38 for comparison.

The samples were analyzed for common anions and cations (see Table 4-34) to determine if the ground water was of a similar type at all locations (the first round did not contain a complete suite of anions and cations). A trilinear diagram of the third sampling round is provided in Figure 4-13 to show the general composition of the water in the monitoring wells. To generate the diagram, major anion (e.g., chloride, fluoride, carbonate, bicarbonate, sulfate, etc.) concentrations are converted to their equivalent charge, summed and compared to the equivalent summed charge of cations (e.g., calcium, magnesium, potassium, sodium, etc.). The sum of the anions should equal the sum of the cations because water is electrically neutral. *Standard Methods for the Examination of Water and Wastewater* allows up to a 5-percent difference in the anion to cation ratio. Two samples collected during the second round of sampling (CSMRI-02 and CSMRI-06) had excessive differences in their anion/cation balances. The laboratory reanalyzed cation portion of the samples and the results are noted in Table 4-34. Cation concentrations for the CSMRI-06 sample changed significantly for the rerun sample (anion/cation balance improved), but there was very little change for CSMRI-02.

The trilinear diagram (Figure 4-15) indicates that the Site ground water is dominated by calcium and magnesium cations, but the anions vary between the sulfates and bicarbonates. Wells CSMRI-04 and CSMRI-07 have similar specific conductance and fall at about the same location on the diagram. The same can be said for wells CSMRI-05 and CSMRI-06. The diagram suggests possible evidence of similar ground-water flow directions. Wells CSMRI-01, CSMRI-02, and CSMRI-03 have different specific conductance and diagram locations compared to the on-site wells, indicating the different formations associated with the ground-water source. The water type for CSMRI-02 appears to be significantly different than the remainder of the monitoring wells, suggesting ground water in this area is not part of the Site ground-water system. As would be expected, monitoring well CSMRI-01 located along Clear Creek appears to be significantly different from the other wells.

Combined radium (226 & 228) concentrations in well CSMRI-02 were at or above the MCL of 5 picocuries per liter for the second and third sampling rounds (Table 4-35). This is consistent with the historical data for the well when it was sampled in 1995 (Table 4-39). All of the other samples were below the radium MCL. Total uranium in well CSMRI-04 was above the listed MCL of 30 micrograms per liter for the second and third rounds. Again historical data shows a similar result (Table 4-39). Total uranium concentrations in monitoring well, CSMRI-07 more than doubled between rounds two and three. The CSMRI-07 third-round uranium concentration is above the uranium MCL.

Gross alpha particles in samples CSMRI-02, -04, and -07 were in excess of the MCL (15 pCi/L) for the third sampling round (gross alpha and beta analyses were added starting the third round). None of the samples exceeded the gross beta particle screening level of 50 pCi/L [5CCR 1003-1 §6.4(2)(a)]. The beta particle MCL is a dose of 4 mrem/yr.

Sample ID	Gross Alpha – Third Round		Gross Beta – Third Round		Gross Alpha – Fourth Round		Gross Beta – Fourth Round	
	Result	TPU	Result	TPU	Result	TPU	Result	TPU
CSMRI-01	ND (<2.2)	±1.1	3.6 LT	±1.6	ND (<2.2)	±1.3	5.3	±1.8
CSMRI-02	26	±4.6	29	±5.0	14	±3.5	13	±3.0
CSMRI-03	14 M3	±3.5	15 M3	±4.0	17 M3	±4.1	16 M3	±4.2
CSMRI-04	41	±6.8	23	±3.9	16	±4.0	9.4	±2.6
CSMRI-05	9.5	±2.8	5.7	±2.1	9.4	±2.7	5.6	±2.0
CSMRI-06	5	±1.8	8	±2.2	4.9	±2.0	8.1	±2.4
CSMRI-07	23	±3.9	16	±2.8	7.4	±2.4	8.1	±2.3

Notes: All units in picocuries per liter; ND, not detected; TPU, total probability units; LT, less than the requested detection limit but greater than the sample specific minimum detection limit (MDC); M3, requested MDC was not met, but reported activity is greater than the reported MDC.

Third-round ground-water samples indicate the possible migration of uranium to the ground water in the vicinity of the former Building 101N. A steady increase in total uranium concentrations is evident in the three rounds of ground-water samples. The same increase is not as evident with other radionuclides or metals. Compound solubility may be affecting solute transport in this area. Above average precipitation during the spring months also potentially influenced solute transport.

4.2.2 Summary of Findings

The findings of the ground-water sampling rounds suggest up to three types of water mixing under the Site producing a complex ground-water system. Water infiltrating into the alluvial material from precipitation, irrigation, and surface-water sources (Welch ditch and Chimney Gulch) travels southwest to northeast along the Pierre Shale aquitard toward Clear Creek. Artesian water from Laramie Fox-Hills aquifer appears to move through the more permeable sandstone in a southeast to northwest direction (although some of this movement may be redirected by paleochannels). And the alluvial channel of Clear Creek moves water in a west to east direction. The three water sources then mix somewhere in the vicinity of the Site.

Using the information provided in Figure 2-3 and the sampling results, monitoring wells CSMRI-03, -04, and -05 all appear to be located in the Laramie Fox-Hills aquifer. The USGS Ground-Water Atlas of the United States describes water in the Laramie-Fox Hills aquifer as sodium bicarbonate or sodium sulfate type that is soft in the central parts of the aquifer and hard to very hard near the margins of the aquifer (USGS, Ground Water Atlas of the United States, Arizona, Colorado, New Mexico, Utah, HA 730-C, http://capp.water.usgs.gov/gwa/ch_c/C-text6.html). The dissolved-solids concentrations of water in this aquifer range from about 200 to 2,000 milligrams per liter with larger concentrations near the aquifer margins. Reducing (oxygen-deficient) conditions present in some parts of the Laramie-Fox Hills aquifer allow hydrogen sulfide and methane gases to exist in the aquifer. When these gasses are present in sufficient concentrations, water pumped from the aquifer may effervesce, have a putrid odor, and be of marginal value for many uses.

The specific conductance, low dissolved oxygen, and gas bubbles observed in CSMRI-03, -04, and -05 all suggest the influence of the Laramie Fox-Hills aquifer. CSMRI-03 appears to be the most representative of the aquifer with CSMRI-04 and –05 showing indications of the mixing process. Increasing nitrate concentrations in monitoring wells CSMRI-06, -07, -05, and –04 reflect a possible infiltration pathway traveling along the top of the Pierre Shale. Seasonal fertilizer application to the athletic fields is a possible nitrate source.

The ground-water sample results suggest the movement of affected material to ground water. Uranium concentrations increased in two of the downgradient wells (CSMRI-04 and -07) during the July sampling round (concentrations were above EPA's Maximum Contaminant Levels [MCL] for total uranium). The uranium concentrations decreased during the October sampling round, which suggests the material was no longer moving to ground water.

The uranium movement is consistent with the precipitation events that occurred during the 2003 season. After an extended dry period a March snowstorm delivered significant precipitation to the area. Spring rains also added to overall soil moisture. Eliminating the Site asphalt and concrete essentially removed a cap that limited the movement of precipitation into the soil column. Removal of the former Building 101N created a depression that now acts as a detention pond during storm events. The bottom of the "pond" is located in the alluvial cobble zone. Calculations showed that precipitation along with the associated ponding would have saturated the soil column and allowed the movement of soluble material and fine particles to ground water. The return of dry weather for the remainder of the summer and fall dried out the soil column, eliminating the ground-water pathway. Metals also appear in the ground water samples but at concentrations at or near the detection levels, making it difficult to predict trends.

The two monitoring wells located along Clear Creek contain relatively consistent, low concentrations of a variety of VOCs. Several of these compounds tend to "pancake" at the bottom of an aquifer resulting in a small continuing source of material for an extended time period. A small quantity of these solvents can produce this result. All of the reported VOC concentrations have been below the MCLs with the exception of the fourth round CSMRI-04 sample, which was 0.1 μg/L above the trichloroethene standard (5.0 μg/L).

5.0 Contaminant Fate and Transport

This section evaluates contaminant fate and transport based on Site physical characteristics and source characteristics.

Prior to the demolition and removal of asphalt and concrete in late 2002, the Site was maintained in a manner such that transport of materials off-site was effectively mitigated. Except for small landscaped areas, floor penetrations (primarily drains), and cracked floor slabs and asphalt, there were no air or surface-water pathways to off-site areas (high ground-water levels potentially could have reached the deeper zones of the affected material). Efforts were made during the removal operations to ensure the affected material was left in the same area that it had been deposited during historical operations. However, removal operations did result in minor relocation of material during excavation and the construction of haul roads. Special procedures (described in the project work plans) were in place during shipping operations to ensure that soil did not migrate onto access roads.

The affected material is currently exposed to wind and water transport, but erosion control measures were installed to minimize off-site migration. These measures included installation of a silt fence along the southern edge of the Site, construction of several trenches to channel storm water into on-site depressions (former building foundations), and temporary seeding to control wind and water erosion. Solute and particle transport (ground-water pathway) and radon diffusion currently are not addressed. A clay layer limits solute transport over most of the Site, but some of the foundations of former Building 101 were completed in the silty/clayey sands and cobble zone.

5.1 Potential Routes of Migration

The potential routes of migration associated with the Site currently include:

- Wind erosion, moving material primarily to the east (prevailing winds are from the west),
- Water erosion, transferring material off-site or into Clear Creek,
- Wind borne diffusion, moving radon and radon decay products off-site (again driven by prevailing west winds),
- Plant material transport, moving material taken up by plants as wind or water borne plant debris,
- Particle transfer, moving material via attachment to personnel and/or vehicle, and

- Solute and particle transport, transferring material into the underlying ground water through percolation and preferential pathways.

Wind and water erosion is currently controlled on the Site by storm-water best management practices. Minimal vegetation is currently growing on the Site, limiting the amount of material that can be transported in this manner. Particle transport is controlled by site-specific safety requirements. Radon diffusion and solute transport is not controlled at this time.

5.2 Contaminant Persistence

The primary contaminants of concern (COC) on the Site include metals and radionuclides. These materials are very persistent in the environment and remedial techniques typically focus on stabilization, removal, or capping. Organic compounds discovered near the baseball field (see Section 4.1.7) included petroleum hydrocarbons and chlorinated solvents. The combination of these materials provided the proper environment for biodegradation of both materials. Current soil concentrations of the organic compounds are below current proposed CDPHE Soil Screening Levels.

5.3 Contaminant Migration

Affected material migration prior to the removal of the asphalt and concrete was minimal, influenced only by minor soil exposure, plant uptake, and water infiltration. An estimated 90-percent of the Site was covered with asphalt or concrete prior to removal operations. Removal and transportation activities did result in some portion of the material being displaced from its original location. Excavation of large foundation blocks and walls required soil to be moved and additional soil was moved to provide access roads for the trucks. Efforts were made to minimize the disturbed areas, but a small amount of material transfer did occur. However, none of the material left the Site.

Demolition and transportation operations during the concrete and asphalt removal generated some airborne particles but operations were halted if wind speeds exceeded specified limits. Perimeter air monitoring was performed during the operations to ensure that off-site transport was minimal. During demolition, transportation, and sampling operations, all equipment was surveyed and cleaned as required. Personnel were required to survey footwear prior to leaving the Site. Erosion control measures were installed to minimize both wind and water affected surface erosion.

5.3.1 Material Migration to Ground-Water

Metals and radionuclides currently present in Site soils provide a continuing source of contaminants to the underlying ground water. Factors including precipitation and ponding, material speciation and solubility, cation exchange capacity, and soil type, pH, and compaction can all affect the movement of the material to ground water. Minor precipitation events can transport material deeper into the soil column where material concentrations increase until a major event transports the material to ground water. Ground-water levels also can raise enough to interact with this material periodically. Sandy soil typically provides minimal resistance to transport of radionuclides and metals, while clays and organic materials can adsorb these materials, slowing the movement to ground water. However, soil acidity and acid rain can reverse the adsorption process (hydrogen cations replace the metal/radionuclide cations), allowing continued material movement. The metal cations also compete with each other for available adsorption sites, continuing downward movement of material through the soil column.

Using arsenic as an example, speciation determines how arsenic compounds interact with the environment. In natural systems, arsenic may occur in four oxidation states: (-3), (0), (+3), and (+5). Movement in environmental matrices is a strong function of speciation and soil type. In a non-absorbing sandy loam, arsenite (As^{3+}) is 5 to 8 times more mobile than arsenate (As^{5+}).

Soil pH also influences arsenic mobility. At a pH of 5.8 arsenate is slightly more mobile than arsenite, but when pH changes from acidic to neutral to basic, arsenite increasingly tends to become the more mobile species. But the mobility of both arsenite and arsenate increases with increasing pH (preliminary data indicates primarily alkaline soils at the site). In strongly adsorbing soils, transport rate and speciation are influenced by organic carbon content and microbial population. Both arsenite and arsenate are transported at a slower rate in strongly adsorbing soils than in sandy soils. Without speciation data, transport models can over or under predict material transport by several orders of magnitude.

The metal and radionuclide affected material identified during the RI were less mobile prior to the removal of the asphalt and concrete "cap". Without the cap the affected material can now migrate to ground water more readily. The on-site ground water is not a drinking water supply so there is no current threat to human health. But the ground water flows into Clear Creek, which is a drinking-water supply for downstream communities. A boundary ground water well (CSMRI-04) had total uranium concentrations above the MCL during two of the quarterly sampling rounds. This well is at the point of compliance. Dilution effects would significantly reduce concentrations in Clear Creek but the CDPHE, Water Quality Control Commission requires that uranium levels in surface water be maintained at the lowest practical level [5 CCR 1002-38, §38.5(3)(b)]. Precipitation events can be expected to continue to move additional material to ground water.

5.3.2 Factors Affecting Migration

Factors that affect the migration of material from the current Site include erosion, plant uptake, and material solubility. Wind and water erosion can be controlled using vegetation, cover material, engineered controls, or an impermeable barrier. Current erosion controls include silt fencing, trenching, and temporary vegetation. Solubility is a function of precipitation, the parent material, and soil properties such as conductivity and pH. Solubility can be controlled primarily through limiting the movement of water through the material. Soil amendments and physically or chemically changing material properties also have been used to control solubility, but these methods are typically expensive and of varying success. No solubility controls are currently in place. Radon generated by the natural decay of the radionuclides diffuses through the soil and migrates to the atmosphere. Radon is typically a problem when a building foundation is in contact with the affected soil and the radon is trapped inside the building. There are no buildings on the Site at this time, although there are two valve pits that are part of the baseball field irrigation system.

5.3.3 Modeling

The U.S. Department of Energy and U.S. Nuclear Regulatory Commission model for site-specific dose assessment of residual radioactivity, RESRAD 6.21 was used to model migration pathways such as wind and water erosion. Because of the limited nature of the ground-water modeling package provided with RESRAD, Visual Modflow Pro in combination with Modflow SURFACT (Waterloo Hydrogeologic) was used in an attempt to model the movement of COCs to ground water. Because only limited number of ground-water system parameters had been identified, the programs were primarily used to examine potential pathways for the contaminants.

Preliminary modeling efforts using Modflow did not converge because of the limited duration of the ground-water-sampling program and the complex nature of the Site hydrology. Accurate modeling of mixing zones is difficult with only a single year of sampling results. The drying and saturating of the soil column that is typical for semiarid regions increased the difficulty of producing an accurate representation of the Site hydrology. Unanswered questions about the multiple parameters associated with the transport portion of the model (e.g., metal species, variable pH, solubilities, accurate representation of the sediment layers) also decreased the probability of an accurate model. Obvious particle pathways (material moves down to the Pierre Shale and then to Clear Creek) were predicted by the preliminary modeling efforts. Rough calculations show that saturating the soil column will move material to ground water either through particle movement or solubility. The exact timing of the contaminant movement and the resulting concentrations are largely dependent on the precipitation amounts. A decision was made to focus resources on the control of the source area rather than expending additional resources to generate a model with a large degree of uncertainty.

6.0 Baseline Risk Assessment

The purpose of the baseline risk assessment is to estimate the risk of leaving the affected material in place (i.e., no action). The risk assessment examines both carcinogenic risks and health hazards associated with the material. Near term land use scenarios could include a recreational area. Foreseeable land use could include the construction of student housing or academic buildings. However, future land use could include an urban resident or potentially a subsistent farmer considering the persistence of the metals and the longevity of the radionuclides (half-life: Ra-226, $1.6x10^3$ years; Th-230, $7.6x10^4$ years). The requirements of 40 CFR §192.02 require that remedies for sites with similar radionuclide contaminants provide up to 1,000 years of protection to human health and the environment (at least 200 years). For a CERCLA NCP baseline risk assessment the conservative subsistence farmer scenario was used as the baseline. To provide an overall picture of relative risk, urban residential and recreational scenarios have been provided for comparison.

6.1 Human Health Evaluation

Acceptable exposures to known or suspected carcinogens are generally those that represent an excess upper-bound lifetime cancer risk to an individual of between 10^{-4} and 10^{-6}. EPA uses the 10^{-6} risk level as the point of departure for determining remediation goals for the National Priority List (NPL) sites. However, the upper boundary of the risk range is not a discrete line at $1x10^{-6}$. A specific risk estimate around 10^{-4} may be considered acceptable if justified based on site-specific conditions (EPA, 1991, OSWER Directive 9355.0-30). EPA references site specific acceptable risks in the range of $3x10^{-4}$, but risks may become unacceptable in the range of $6x10^{-4}$ (EPA, 1997, OSWER No. 9200.4-18).

Noncarcinogens are evaluated by their systemic effect on target organs or systems. EPA defines acceptable human exposure levels (including sensitive subgroups) as those that do not cause adverse effects during a lifetime or part of a lifetime, incorporating an adequate margin of safety. This acceptable exposure level is best approximated by a hazard index (HI) of 1. If a HI is less than 1, adverse effects usually are not expected. As the HI increases beyond 1, the possibility of adverse health effects also increases.

The hazard index is calculated by summing the hazard quotients (HQ) for substances that affect the same target organ or organ system (e.g., respiratory system). The HQ is the ratio of potential exposure to the substance and the level at which no adverse health effects are expected. If the HQ is calculated to be less than 1, then no adverse health effects are expected as a result of exposure. If the HQ is greater than 1, then adverse health effects are possible. The HQ cannot be translated to a probability that adverse health effects will occur, and is often not proportional to risk.

The approach to human health risk assessment for lead differs from that of other metals and contaminants. Risks from lead exposures typically are estimated from long-term exposures, although elevated blood lead (PbB) concentrations also result from short-term exposures. EPA and the CDC have determined that childhood PbB concentrations at or above 10 micrograms of lead per deciliter of blood (μg Pb/dL) present risks to children's health (CDC, 1991). Accordingly, EPA seeks to limit the risk that children will have Pb concentrations above 10 μg Pb/dL.

A variety of tools were used for the baseline risk assessment. Radionuclides risk was modeled using the RESRAD (version 6.2.1) model developed by the Environmental Assessment Division of Argonne National Laboratory for the U.S. Department of Energy and the U.S. Nuclear Regulatory Commission. RESRAD uses the current slope factors referenced in the Health Effects Assessment Summary Tables (HEAST). Health hazards were evaluated using the Risk Assessment Information System (RAIS) developed by Bechtel Jacobs Company LLC for the U.S. Department of Energy, Office of Environmental Management (http://risk.lsd.ornl.gov/index.shtml). RAIS uses the current reference doses and slope factors referenced in the EPA Integrated Risk Information System (IRIS) but for this assessment the information was supplemented by recent publications. The EPA Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK) was used to predict potential blood lead (PbB) concentrations. The model considers several different media through which children can be exposed to lead (EPA, 2003). A preliminary ground-water model was generated using Visual Modflow Pro in combination with Modflow SURFACT (Waterloo Hydrogeologic).

6.2 Exposure Assessment

Currently, the area has minimal exposure pathways because of the limited access to the Site. The area is surrounded with a chain link fence and posted. Since the removal of the asphalt and concrete, access has been limited to several weeks of sample collection and maintenance activities. External, inhalation, and dermal exposures occurred for short periods of time during these activities. Dosimeters and personal air monitors were used to monitor personnel during sampling and maintenance operations. Erosion control measures are in place to limit movement of waterborne particles and air borne particles. There are no drinking water supply wells in the immediate vicinity of the Site.

One pathway that is not currently controlled on the Site is movement of material to the underlying ground water by particle and solute transport. Although the ground water is not used as a drinking water source, it eventually enters the Clear Creek alluvial system. The City of Golden uses Clear Creek as the primary drinking water source, but the surface-water diversion is located about 0.9 mile upstream of the Site. Coors Brewing Company uses alluvial wells located about 0.4 mile downstream from the Site. Additional downstream diversions that supply drinking water include the Agricultural Ditch (0.6-mile) and the Farmer's Ditch (0.7-mile).

For the baseline risk assessment the exposure scenarios examined include a subsistence farmer, an urban resident, and a recreational user. Baseline exposure scenarios were examined for a 30-year period and assumed minimal changes to the current topography (depressions left by the removal of building foundations would remain). Exposure for the subsistence farmer assumes a farmhouse constructed on the existing soil, ground water as the primary drinking water source (including farm animals), and consumption of crops, meat, and milk produced from the local soil. The urban resident assumes a house similar to neighborhood housing but drinking water would come from city water mains and minimal consumption of fruits and vegetables raised in a backyard garden. The recreational receptor assumes regular use by a nearby resident who would use the area for a variety of activities. Factors associated with the exposure scenarios are used in the RESRAD and RAIS models. RESRAD and RAIS sample inputs are provided in Appendix I.

6.3 Soil Radionuclide Risk Characterization

The risk characterization for the Site includes the risk associated with radionuclides and two of the eleven metals (arsenic and chromium – see section 6.4). This section describes the risk calculations performed for eight of the identified radionuclides. Additional radionuclides were identified in the soil samples but the RESRAD option that only uses radionuclides with half-lives of one year or greater was selected. A half-year option also is available but did not seem to be appropriate for a site of this age. Two radionuclides, K-40 and Cd-109, identified by the sample results were not included in the risk analysis. K-40 is present at concentrations within the range of background values. The Cd-109 analytical results are flagged with an "S", which indicates possible interference with another element. With a half-life of 464 days, any Cd-109 that may have been present during Site operations should have decayed to the daughter products by now.

Risk effects of the radionuclides were examined using RESRAD 6.21, the U.S. DOE and NRC model for site-specific dose assessment of residual radioactivity. Risks associated with the scenarios discussed in Section 6.2 were examined using this model. A summary of typical input parameters for the RESRAD model is provided in Appendix I. Actual RESRAD runs for each scenario are provided in Appendix J.

6.3.1 RESRAD Model Description

The RESRAD computer program is a pathway analysis model designed to evaluate the potential radiological dose incurred by an individual who occupies land containing residual radioactive material (Yu, et al., 2001). Version 6.21 of RESRAD was used for this analysis. This version has the capabilities of performing both deterministic and probabilistic dose assessments.

Three primary exposure pathways are considered by the RESRAD model including:

1. Direct exposure to external radiation from the contaminated soil,
2. Internal dose from inhalation of airborne radionuclides including radon progeny, and
3. Internal dose from ingestion of radionuclides, which includes ingestion of:
    - Plant foods grown in the contaminated soil irrigated with contaminated water,
    - Meat and milk from livestock fed with contaminated fodder and water,
    - Drinking water from a contaminated well or pond,
    - Fish from a contaminated pond, and
    - Contaminated soil.

RESRAD has been widely accepted and has a large user base. The models used in the software were designed for and have been successfully applied at sites with relatively complex physical and contamination conditions. In addition, the software has been verified and validated (Yu, 1999; NUREG/CP-0163 [NRC, 1998]).

A number of RESRAD capabilities will be introduced in this section, but are not part of the baseline risk assessment. However, these capabilities are important for the evaluation of the selected alternatives.

6.3.2 Critical Population Group

The critical population group represents the potential individuals that would experience the most conservative radiological exposure from the Site now or in the future. The intent is to identify exposure scenarios for probable future uses of the Site, but not necessarily the worst-case scenario. The "worst-case" scenario could potentially limit the usefulness of the resulting release criteria without providing significantly increased benefits to the public health, public safety, or the environment. However, radionuclides and metals are problematic for defining the critical population group because of their long-term persistence. Baseline risk assessments typically are made using the subsistence farmer scenario.

The definition of the population group or receptor and the site-specific allowable dose is used by RESRAD to determine the derived concentration guideline level (DCGL). Although not determined as part of the baseline risk assessment, the DCGLs are used to determine the site specific cleanup requirements for radionuclides (see Section 8.2). The allowable dose comes from the release criterion determined by regulatory limits expressed in terms of dose (mrem/yr) (Note: release criteria also are evaluated by cancer incidence of cancer mortality risk). A release criterion is typically based on total or committed effective dose equivalent (TEDE or CEDE) and generally cannot be measured directly. Exposure pathway modeling is used to calculate a radionuclide-specific predicted concentration or surface area concentration of specific nuclides that could result in a dose (TEDE or CEDE) equal to the release criterion. RESRAD uses the term DCGL to describe this concentration. Exposure pathway modeling is an analysis of various exposure pathways and scenarios used to convert dose into concentration. Although regulatory guidance may suggest default DCGLs, site-specific modeling is preferred.

The receptor/site specific DCGLs are for individual radionuclides. The calculated value assumes that only one radionuclide is contributing to the dose established for the release criteria. When multiple radionuclides are present on site, the combined dose contributed by all of the radionuclides at their individual DCGL would result in the release criteria (dose) being exceeded. One method to adjust for the multiple radionuclides would be to modify the assumptions made during exposure pathway modeling to account for multiple radionuclides. A second method is to use what is called the sum-of-the-fractions rule to adjust the individual DCGLs. Each radionuclide activity expected at the end of the cleanup is divided by its predicted DCGL for the appropriate receptor. The ratios (fraction) only need to be determined for radionuclides expected to be present at measurable activities after the cleanup. The sum-of-the-fractions the radionuclide (significant) specific activities and DCGLs must be less than or equal one. As previously mentioned, DCGLs were not determined as part of the baseline risk assessment, but are calculated for specific cleanup alternatives (see Section 8.2).

Another important use of RESRAD is the determination area factors for the site cleanup. Using the approach suggested in MARSSIM, area factors should be determined using RESRAD for the small site areas with elevated radionuclide activity. These factors are used to establish DCGLs for elevated measurement comparisons and for the evaluation of scan sensitivities to provide a reasonable level of assurance that any small area of elevated residual activity is not significant. The $DCGL_{emc}$ is established as:

$$DCGL_{emc} = \text{Area Factor} * DCGL$$

During the evaluation of measurement data for each survey unit, any measurement from the unit that is equal to or greater than the DCGL will be investigated by comparison with the $DCGL_{emc}$ using the elevated measurement approach of Section 8.5.1 of MARSSIM to determine if the elevated measurement is acceptable. As with the DCGL, the $DCGL_{emc}$ would be subject to the sum-of-the-fractions rule. Again, $DCGL_{emc}$ were not determined for the baseline risk assessment but are included for specific cleanup alternatives (see Section 8.2).

Two variations of the baseline scenarios were examined to show the importance of the areas with elevated radionuclide activities or metal concentrations. One involved the placement of the receptor only on the area affected by elevated radium-226 activities, also evaluating the co-located metals. The other placed the receptor on areas with lead concentrations above the CDPHE proposed Tier 2 residential standard (400 mg/kg), again evaluating the risk associated with the co-located metals and radionuclides.

6.3.3 Receptor Dose/Risk Assessment

To determine the dose for the theoretical receptor (farmer, resident, recreational user), the RESRAD model defines the property where the individual is exposed for 30 years (6 years as a child and 24 years as an adult). The modeled property consists of an area with Site specific residual radionuclides to an assumed depth. The model incorporates a large number of parameters to numerically simulate the pathways that the radionuclides can use to affect the receptor. A summary of these parameters is provided in Appendix I. For the baseline model, the Site was approximated by a rectangular area with about the same overall surface area as the Site and an average depth of material that was estimated from the RI information. Radionuclide activities used for the model were average activities determined from surface soil samples collected during the RI. Subsurface soil sample activities were not used because the test pits and borings indicated that except for specific areas, the majority of the contamination was located in the upper regions of the soil. Risk associated with ground water was determined using the RAIS model because of ground-water modeling limitations of the RESRAD model.

Two additional radionuclide activity subsets were determined for the baseline scenario variations mentioned in the previous section. The data sets were generated assuming the receptor was exposed to an area with activities or concentrations above a specified limit. The two subsets include one area with combined radium-226 & -228 activities above 5 pCi/g (radium biased) and a second area with lead concentrations above 400 mg/kg (lead biased). Because of the area selection method - surface soil data was sorted using the mentioned cutoffs rather than using actual adjacent sampling locations - the data sets are biased somewhat higher than actual site conditions, but are representative of a combination of small areas. These subsets were selected to show the variability of the site and the possible associated risks.

Exposure pathways evaluated by RESRAD include external gamma (gamma radiation from affected material on the property surface), inhalation (dust and soil particles inhaled during normal activities), ingestion (soil, water, and foodstuffs such as meat, milk, fruits and vegetables), and radon (from diffusion from soil into houses and dissolved in water sources). RESRAD has default values to describe the different pathway parameters, but site specific data is normally used to refine the model for the actual site and receptor. Some of the factors are more sensitive to change than others, such as the time of exposure to external gamma (fraction of time spent outdoors), permeability/porosity of the contaminated material (for radon), and soil ingestion (children typically ingest more soil). The literature references a wide range of assumptions used for the RESRAD parameters. The U.S. Army Corps of Engineers (USACE) White Paper titled Using RESRAD in a CERCLA Radiological Risk Assessment (October, 2002) was used as the basis of the parameter selection for the Site models.

RESRAD includes a diffusion model for estimating radon flow in soil and into habitable structures. Radon is a decay product of radium and radon gas may migrate into structures constructed on soils containing radium. The RESRAD code estimates the movement of radon through on site soils and determines possible indoor concentrations. However, indoor radon concentrations are driven by meteorological conditions, indoor heating and air conditioning practices, local geological characteristics, structural air spaces and airflow conduits, seasonal variances, and other factors that are beyond RESRAD programming. Assumptions made concerning RESRAD input parameters such as the contaminated zone density, contaminant zone total porosity, and cover material porosity can significantly affect the predicted radon dose and risk. Heterogeneous soils such as those found at the Site introduce significant uncertainty into any radon predictions. The USACE White Paper states that indoor radon concentrations using RESRAD (or another other model) may grossly underestimate or overestimate indoor radon concentrations and recommends using radon models only as a last resort.

Radon limits and guidelines are based on concentration and not risk. EPA used an indoor concentration limit of 0.02 Working Level (WL), or about 4 pCi/L. This limit has been adopted by the NRC and the DOE and is typically categorically excluded for radiological dose calculations under these agencies. Risks associated with a concentration of 4 pCi/L (assuming residential exposure) is well above the CERCLA target risk range, and even small fractions of the guideline can produce risks on the order of 10^{-4}. While a qualitative evaluation is preferred, the 0.02 WL guideline does exist and, in some cases, must be evaluated in some detail to satisfy regulators and stakeholders. For example, Title 40 Code of Federal Regulations (CFR) Part 192 specifically limits indoor radon levels to 0.02 WL. Although not a risk limit, the regulatory requirement exists and RESRAD can be used to predict indoor radon levels in both WL and pCi/L concentration.

No specific data was collected for on-site radon because of the variability of the Site and the potential for material removal. Because of the lack of site-specific radon information, a limited number of scenarios were evaluated for radon to determine parameter sensitivity to potential dose effects. The results of the sensitivity analysis showed significant variation in dose by modifying soil parameters that were possible on site. Because of the large variation in predicted doses produced by the sensitivity analysis, the actual Site evaluation disregarded the majority of the radon dose/risk contribution (see Section 6.3.4). The radon pathway was left on for most scenarios, but was minimized by placing the lowest level of the residence below the affected soil (see Section 6.3.4). The radon issue may be re-addressed when the remedial option is determined, with the possible implementation of the suggested radon measurements.

6.3.4 RESRAD Results

A summary of the RESRAD dose and risk predictions for the various scenarios is provided in following table. The two area variations are provided for comparison (see Section 6.3.2, last paragraph).

Scenario	**30-Year Dose (mrem/yr)**	**30-Year Risk**
Current Conditions – Average Soil Activities		
Subsistence Farmer	42	$7.4x10^{-4}$
Urban Resident	35	$6.0X10^{-4}$
Recreational User	0.32	$7.3x10^{-6}$
Current Conditions – Radium Biased Soil Location		
Subsistence Farmer	190	$3.4x10^{-3}$
Urban Resident	64	$1.3x10^{-3}$
Recreational User	1.5	$3.4x10^{-5}$
Current Conditions – Lead Biased Soil Location		
Subsistence Farmer	110	$1.9x10^{-3}$
Urban Resident	37	$8.1x10^{-4}$
Recreational User	0.87	$2.0x10^{-5}$

This summary does not include the risk associated with the on-site metals. A table of the total risk can be found in the following section.

Because of the uncertainty of the RESRAD radon calculation, all of the scenarios were modified to minimize the radon prediction. Using a basement with a floor located beneath the affected soil layer effectively minimizes the influence of the radon without turning the radon pathway completely off. For comparison RESRAD was run for the average soil conditions, assuming slab construction (structure built directly on top of the affected soil). Calculated dose and risk numbers are as follows:

- Subsistence Farmer Dose 220 mrem/yr Risk 3.5×10^{-3}
- Urban Resident Dose 210 mrem/yr Risk 3.4×10^{-3}
- Recreational User Dose 0.46 mrem/yr Risk 9.8×10^{-6}

These scenarios assumed the contaminated soils consist of a sandy clay, but by changing the permeability parameter to reflect more of a clayey sand, the dose for the subsistence farmer drops to 92 mrem/yr and the risk decreases to 1.5×10^{-3}. Adding one meter of clay cover material can further decrease the subsistence farmer dose to 4.8 mrem/yr with an associated risk of 7.5×10^{-5}.

As previously noted and demonstrated above, the RESRAD model can significantly over or under estimate the radon effects, but the radon component should be considered when determining institutional controls (if required). If the radon pathway is not bypassed (lowest level of residence is placed in the affected soil) dose and risk values (assuming a clayey sand soil) are about five times greater than the same scenario without the influence of radon. But changing other model parameters also can significantly affect the predicted dose and risk.

RESRAD predicts significant dose and risk to the subsistence farmer and the urban resident using the baseline soil activities. There is less risk to a recreational user because of the limited time the individual remains on the Site. However, recreational risk values are still above the suggested 1×10^{-6} level listed in 40 CFR 300.430(i)(A)(2) as the point of departure.

6.4 Soil Metals Risk and Toxicity Assessment

This section describes the methods used to determine the risks and hazard quotients associated with the eleven metals present on site. The RAIS model was used to determine to toxicity of nine of the metals, but cadmium and lead were determined using other methods. The literature indicates that radionuclides also have toxicity effects but there are no currently published referenced doses in IRIS. Additional reference material was consulted, but no agreed upon reference dose was identified. Typically health effects for radionuclides focus on cancer risks.

IRIS (and other reference material) lists both cadmium and lead as possible human carcinogens but neither has been assigned slope factors because of ongoing debates about sensitive populations and cancer causing mechanisms. These same debates carry over to the associated hazard quotient determination and currently there is no reference dose provided for either metal. Estimation of the toxicity associated with each metal is discussed in the following sections. Risk estimates are provided for specific species of arsenic and chromium. The remaining seven metals evaluated during the RI are not currently considered carcinogenic.

6.4.1 RAIS Model Description

The Risk Assessment Information System (RAIS) is a web-based system used to disseminate risk tools and supply information for risk assessment activities. Taking advantage of searchable and executable databases, menu-driven queries, and data downloads using the latest Web technologies, the RAIS offers essential tools and information for the risk assessment process and can be tailored to meet site-specific needs. RAIS uses current values listed in the EPA IRIS database to generate the risks and hazards associated with each metal. RAIS input parameters were modified to mimic the RESRAD parameters, but RAIS does not have sufficient flexibility to exactly reflect the RESRAD inputs. RAIS is a top-level risk assessment program used to provide general information about the affected material.

6.4.2 Receptor Risk/Hazard Quotient Assessment

To determine the hazard quotient and risk for the theoretical receptor (subsistent farmer, urban resident, recreational user), the RAIS model defines an individual that is exposed for 30 years (6 years as a child and 24 years as an adult). Exposure pathways include dermal (some metals are absorbed through the skin), ingestion (soil, water, and, foodstuffs) and inhalation (dust and soil particles inhaled during on-site activities). Soil and water concentrations were entered into model along with the exposure parameters. The subsistence farmer scenario included the use of on-site ground water. Average metal concentrations measured in downgradient wells were used as the baseline values. The food exposure route was not used for this top-level risk assessment because of the uncertainty of using generalized food concentration data. It can be assumed that the overall hazard quotient and risk values determined by the model would be biased somewhat low because of this missing component.

The two data subsets described in Section 6.3.3 also were examined for the associated metals. Again, these subsets were selected to show the variability of the Site and assist in the determination of appropriate cleanup levels.

6.4.2.1 Cadmium Assessment

Cadmium can be taken into the body by eating food (and associated soil), drinking water, or breathing air. Gastrointestinal absorption from food or water is the principal source of internally deposited cadmium in the general population. Gastrointestinal absorption is generally quite low, with only about 5-percent of the amount ingested being transferred to the bloodstream. Thirty-percent of cadmium that reaches the blood deposits in the liver, another 30-percent deposits in the kidneys, and the remainder distributes throughout all other organs and tissues of the body (per simplified models that do not reflect intermediate redistribution). Cadmium clears the body with a biological half-life of about 25 years (ANL, Human Health Fact Sheet - Cadmium, November 2001). The literature also mentions a number of studies that have found that cadmium is a major contributor to autoimmune thyroid disease. Acute exposures have documented effects on the gastrointestinal tract, nervous system, kidneys, liver, and cardiovascular system. Chronic exposures have effects on the kidneys and bone with proteinuria, renal stones and Itai-itai disease.

Because of cadmium's similarity to zinc (forms similar cations), the RAIS model was modified for this assessment to use zinc as a surrogate for cadmium. Major differences between the two metals include the gastrointestinal absorption factors (20-percent for zinc, 5-percent for cadmium), target organs, and the biological half-live (280 days for zinc and 25 years for cadmium – literature values range from 14 to 208 years). Using the zinc surrogate method, hazard quotients for the cadmium were estimated to be in the range of $1x10^{-4}$ and do not appear to be a primary driver for the Site. The cadmium hazard quotient also was estimated by modifying the drinking water pathway to simulate soil ingestion (this method would be considered to be conservative because the soil cadmium would not be as bioavailable as the cadmium dissolved in water). This method produced a similar magnitude hazard quotient of $3.5x10^{-4}$. However, these are preliminary estimates and may need to be re-addressed at a later time. Cadmium is typically more mobile than some of the other metals found on site and could be problematic for ground water. On-site cadmium is primarily co-located with the other metals of concern.

6.4.2.2 Lead Assessment

RAIS does not evaluate the hazard quotient for lead because the IRIS database (and other reference material) does not provide a reference dose or slope factor for the metal. While there is a strong correlation between exposure to lead contaminated soils and blood lead concentration, numerous factors make a direct prediction of blood lead concentrations difficult. Soil particle size, lead species, bioavailability, and health of the exposed individual all effect the uptake of lead. Alternative exposure paths such as lead paint and lead pipes in older buildings also influence blood lead concentrations. According to the IRIS website “It appears that some of these effects, particularly changes in the levels of certain blood enzymes and in aspects of children's neurobehavioral development, may occur at blood lead levels so low as to be essentially without a threshold. The Agency's RfD Work Group discussed inorganic lead (and lead compounds) at two meetings (07/08/1985 and 07/22/1985) and considered it inappropriate to develop an RfD for inorganic lead.” Often lead is regulated by the use of the soil standards, however there is significant disagreement about the appropriate concentration. A paper published by the Agency for Toxic Substances and Disease Registry (ASTDR) lists recommended lead soil standards ranging from <100 mg/kg to 1,000 mg/kg (“Impact of Lead-Contaminated Soil on Public Health”, May 1992). The current proposed Tier 2 soil-standard listed by the Colorado Department of Public Health and Environment is 400 mg/kg. The Tier 2 table value for lead is based on current EPA guidance entitled “Revised Interim Soil Lead Guidance for CERCLA and RCRA Corrective Action Facilities”, OSWER Directive 9355.4-12/Jul 94.

The definition of residential properties for lead is somewhat different than other hazardous materials. Residential properties are defined in the recently published Superfund Lead Contaminated Residential Sites Handbook (EPA, OSWER 9285.7-50, August 2003) as any area with high accessibility to sensitive populations, and includes:

- Properties containing single-and multi-family dwellings,
- Apartment complexes,
- Vacant lots in residential areas,
- Schools, day-care centers, and community centers,
- Playgrounds, parks, green ways, and
- Any other areas where children may be exposed to site-related contaminated media.

This document defines sensitive populations as young children (those under 7 years of age, who are most vulnerable to lead poisoning) and pregnant women. Focus is put on children less than 7 years old because blood lead levels typically peak in this age range. This age range is when children are most vulnerable to adverse cognitive effects of lead. Pregnant women are included due to the effects of lead on the fetus (EPA, 2003). This definition of residential property is applicable the evaluation of the current Site.

6.4.3 IEUBK Model Description

EPA has developed the Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK) to predict blood lead (PbB) concentrations in children exposed to lead. The model considers several different media through which children can be exposed to lead (EPA, 2003).

EPA and the CDC have determined that childhood PbB concentrations at or above 10 micrograms of lead per deciliter of blood (μg Pb/dL) present risks to children's health (CDC, 1991). Accordingly, EPA seeks to limit the risk that children will have Pb concentrations above 10 μg Pb/dL. The IEUBK model predicts the geometric mean PbB for a child exposed to lead in various media (or a group of similarly exposed children). The model also calculates the probability that the child's PbB exceeds 10 μg Pb/dL (P10). Preliminary remediation goals (PRGs) generally are determined with the model by adjusting the soil concentration term until the P10 is below 5-percent. Final clean-up level selection for Superfund sites generally is based on the IEUBK model results and the nine criteria analysis per the National Contingency Plan (NCP) (EPA, 1990b), which includes an analysis of ARARs.

The IEUBK model was used to determine relative risk associated with the on-site lead concentrations. The input parameters do not directly correspond to RESRAD parameters because of the emphasis on a child's initial seven years of the life. For this evaluation, the scenario specific lead concentration was used but the default values were used for the other model parameters. Sensitivity checks showed that the model was relatively sensitive to variation in soil ingestion (10-percent increase in soil ingestion produced a 7-percent increase in blood concentrations), but less sensitive to lead uptake through food consumption (10-percent increase in lead concentrations in food produced a 0.7 percent increase in blood concentrations).

6.4.4 RAIS and IEUBK Results

A summary of the RAIS risk and hazard index predictions for the various scenarios is provided in following table along with the combined metal and radionuclide risk.

Scenario	30-Year Risk (RAIS)	Hazard Index	Combined Risk (RAIS & RESRAD)
Current Conditions – Average Soil Activities			
Subsistence Farmer	$1.5x10^{-4}$	1.8	$1.0x10^{-3}$ [1]
Urban Resident	$1.5x10^{-4}$	1.8	$7.5x10^{-4}$
Recreational User	$1.4x10^{-6}$	0.034	$8.7x10^{-6}$
Current Conditions – Radium Biased Soil Location			
Subsistence Farmer	$2.4x10^{-4}$	3.2	$3.8x10^{-3}$ [1]
Urban Resident	$2.4x10^{-4}$	3.2	$1.5x10^{-3}$
Recreational User	$3.2x10^{-6}$	0.061	$3.7x10^{-5}$
Current Conditions – Lead Biased Soil Location			
Subsistence Farmer	$2.4x10^{-4}$	2.6	$2.3x10^{-3}$ [1]
Urban Resident	$2.3x10^{-4}$	2.6	$1.1x10^{-3}$
Recreational User	$3.2x10^{-6}$	0.035	$2.3x10^{-5}$

[1] Includes the RAIS predicted risk from radionuclides in ground water (see Section 6.5).

The combined risk associated with all of the subsistence farmer and urban residence scenarios are in excess of the $1x10^{-4}$ typically considered to be the upper bound for risk. Hazard quotients for all of the subsistence farmer and urban resident scenarios were above 1. Again because of the limited time the recreational spends on the Site, the risk level is less than $1x10^{-4}$ (but greater than $1x10^{-6}$) and the hazard quotient is less than 1.

Estimated blood lead concentrations predicted by the IEUBK model are provided in the following table.

Scenario	Blood Lead Concentration (µg/dL)
Current Conditions – Average Soil Activities	3.4
Current Conditions – Radium Biased Soil Location	5.6
Current Conditions – Lead Biased Soil Location	13

It is difficult to distinguish between the different receptors for the lead exposure because of the way that residential property is defined. The off-site recreational user could include a neighborhood child that enters the Site for a play area. Soil ingestion during play activities could be a significant fraction of an actual on-site resident. PbB also could be affected by lead concentrations in small areas. The guidance on lead requires small parcels of land be considered during the site investigation, including areas as small as 100 square meters (smaller areas are to be considered if there are play areas) (EPA, OSWER 9285.7-50, August 2003). These small areas could have significantly greater average lead concentrations. Using a number of co-located on-site soil samples generated average lead concentrations as high as 2,200 mg/kg, which produced blood lead concentrations as high as 20 µg/dL.

The proposed CDPHE soil standard for lead is 400 mg/kg. Soil concentrations below this level are generally considered to be protective of human health and the environment (including children). An alternative risk-based standard can be used if risk modeling shows the alternative to be protective. However, additional data collection and modeling is often more costly than meeting the Tier 2 standard through remedial techniques.

6.5 Ground-Water Hazard Index/Risk Assessment

Risk and hazard quotients for the water exposure route (use of on-site ground water) estimated in RAIS using metal concentrations recently measured in the downgradient monitoring wells. The effects of the metals are included in the RAIS results tables (see Section 6.4.4). Risks associated with the radionuclides were determined separately using highest activities measured in the downgradient well (CSMRI-04). The predicted metals and radionuclide risk for an on-site receptor from the consumption of ground water would be about $1.1x10^{-4}$. The ground-water risk value has been included in the combined risk number presented in the table found in Section 6.4.4. These values are only applicable to current site conditions and require an on-site receptor.

Ground-water recharge can be expected to move the affected material into Clear Creek, but dilution effects would make it difficult to detect in the surface water. But dilution effects are not as significant during drought years. Without source removal, the Site would be a long-term contributor of radionuclide and metal loads to Clear Creek. Segment 14 of Clear Creek (the Clear Creek reach near the Site) already has specific limits on cadmium loads.

No controls on the movement of affected material to ground water are assumed for the baseline risk assessment. The full effect of continued exposure to precipitation events is difficult to predict with the limited amount of ground-water information. Without material control ground-water concentrations of metals and radionuclides would be expected to increase the longer the source material remains exposed to the weather.

6.6 Summary of Findings

The baseline risk assessment indicates that taking no future action and leaving the Site in its current condition is not protective of human health and the environment. The subsistence farmer and urban resident would be exposed to excessive risk with current site conditions. Although there are minimal direct risks to the recreational user, the Site would be a continuing problem for the underlying ground water and Clear Creek. Long-term institutional controls would be necessary to protect neighborhood children from exposure. Erosion controls would need to be maintained to minimize the transport of affected sediment to surrounding areas and eventually into Clear Creek. Radionuclides such as radium-226 and thorium-230 are very persistent in the environment, with half-lives of $1.6x10^3$ and $7.5x10^4$ respectively. Environmental factors such as acid rain can affect metal mobility.

The following table summarizes some of the factors used to evaluate the baseline risk assessment. Overall, there are sufficient risks and hazards associated with the Site to warrant remediation.

Scenario	Risk $<10^{-6}$	RISK 10^{-6} TO 10^{-4}	Risk $<10^{-4}$	Dose <15 mrem/yr	Dose <25 mrem/yr	Ra-226 + Ra-228 <5 pCi/g	Hazard Index <1	PbB <10 μg/dL	Soil Lead <1200 mg/kg	Soil Lead <400 mg/kg	Protective of Ground Water	Satisfies ALARA
Current Conditions – Average Soil Activities								Y	Y	Y	N	N
Subsistence Farmer	N	N	N	N	N	N	N					
Urban Resident	N	N	N	N	N	N	N					
Recreational User	N	Y	Y	Y	Y	N	Y					
Current Conditions – Ra Biased Soil Activities								Y	Y	Y	N	N
Subsistence Farmer	N	N	N	N	N	N	N					
Urban Resident	N	N	N	N	N	N	N					
Recreational User	N	Y	Y	Y	Y	N	Y					
Current Conditions – Pb Biased Soil Activities								N	Y	N	N	N
Subsistence Farmer	N	N	N	N	N	N	N					
Urban Resident	N	N	N	N	N	N	N					
Recreational User	N	Y	Y	Y	Y	N	Y					

Notes: Y, meets requirement; N, does not meet requirement

7.0 Development and Screening of Alternatives

The first six sections of the RI/FS describe the remedial investigation phase of the process. The RI indicated that there are sufficient on-site metals and radionuclides to warrant remedial action. The remainder of this document will focus on the feasibility study (FS), which develops, screens, and evaluates available alternatives for remedial actions. The FS process presents the remedial action alternatives to a decision-maker and aids the selection of the appropriate remedy. The primary requirement of the alternative selection is that it shall be protective of human health and the environment by eliminating, reducing, and/or controlling risks posed through each Site pathway.

The purpose of this section is to explain the processes used to identify possible alternatives and screen out alternatives that may be impractical or unworkable at the Site. The development of the alternatives requires:

- Identification of remedial action objectives,
- Identification of potential treatment, resource recovery, and containment technologies that will satisfy the objectives,
- Evaluation of technologies based on effectiveness, implementability, and cost, and
- Generation of alternatives by detailing the technologies and their associated containment or disposal requirements

The alternatives can be designed to address specific contaminated material, a specific area of the site, or the entire site.

Once potential alternatives have been developed, some options may be screened out to reduce the number of alternatives that will be analyzed. The screening process involves evaluating alternatives with respect to their effectiveness, implementability, and cost. It is usually done on a general basis and with limited resources.

7.1 <u>Identification of Remedial Action Objectives</u>

The RI identified elevated activities/concentrations of a number of radionuclides and metals. Based on existing information, site-specific remedial action objectives to protect human health and the environment were developed. The objectives specify the materials and media of concern, the exposure routes and receptors, and an acceptable contaminant (material) level or range of levels for each exposure route (i.e., preliminary remediation goals).

Remedial Action (RA) objectives for the Site are designed to prevent or mitigate further release of affected materials to the surrounding environment and to eliminate or minimize risk to human health and the environment. The affected material is the surface and subsurface soil located in the vicinity of the former buildings. Potential receptor pathways include direct radiation, inhalation, and ingestion of plants and soil. Another pathway is the migration of the affected material to ground water. The following objectives were established for the Site:

- Eliminate or minimize the pathway for dermal contact, inhalation, and ingestion of site specific radionuclides to human receptors, in order to achieve a level of protection in compliance with the National Contingency Plan levels of acceptable cancer risk (10^{-4} to 10^{-6}).
- Develop receptor specific DCGLs to limit unacceptable radiation doses (TEDE to less than 25 mrem/yr and 15 mrem/yr, distinguishable from background) for the radionuclides found in the affected material (i.e., soil). Radium-226, thorium-230, uranium-234, uranium-235, and uranium-238 are present on site at activities above receptor specific DCGLs. A number of additional radionuclides were identified during the RI (radium-228, thorium-228, and thorium-232) but at activities consistent with background.
- Prevent exposure to indoor air concentrations of radon gas and radon decay products greater than 4 picocuries per liter (pCi/L) and 0.02 working level (WL), respectively. Exposure to 4 pCi/L of air for radon corresponds to an approximate annual average exposure of 0.02 WL for radon decay products, when assuming residential land use. As discussed in the baseline risk assessment, there is significant uncertainty in the RESRAD prediction of radon risks. The possibility of radon exposure will be examined for each alternative but actual radon exposures will need to be evaluated after completion of the remedy.
- Prevent long term dermal, inhalation, and ingestion exposures to trace metal affected materials with concentrations greater than the CDPHE Proposed Residential/Unrestricted Land-Use Standards or that generate hazard indexes greater than 1. Because of the relative concentrations and distribution, arsenic, cadmium, lead, and mercury are the primary trace metals of concern. CDPHE proposed Residential Land-Use Standards (Tier 2) for the metals of concern are:

Metal	Proposed Standard (mg/kg)
Arsenic	0.39
Barium	5,277
Cadmium	76.1
Chromium (total – includes Cr VI)	223
Lead	400
Mercury (elemental)	1.1
Mercury (compounds)	23
Molybdenum	390[1]
Selenium	380
Silver	380
Vanadium	550[1]
Zinc	22,825

[1] EPA Region 9 proposed soil standard

- Address specific issues associated with the hazards associated with soil containing elevated concentrations of lead (possible access issues with neighborhood children).
- Prevent off-site migration of affected material that could result in the exposures described above. This includes the ground-water pathway.
- Implement remedial measures that limit ground- and surface-water concentrations to non-zero maximum contaminant level goals (MCLGs), established under the Safe Drinking Water Act. While the affected ground water is not a current drinking water supply it eventually enters Clear Creek, which is used by downstream users for drinking water. Uranium, arsenic, barium, and cadmium are the primary ground-water contaminants of concern.
- Implement remedial actions that reduce exposures from ionizing radiation to levels that are as low as reasonably achievable (ALARA).
- Comply with soil-, location- and action-specific ARARs. (See Section 8.1 and Appendix K for ARAR discussion)

Receptor definition is important for the determination of risks and hazards. Exposure times and multiple pathways place the subsistence farmer at greater risk than an occasional recreational user. The persistence of the affected material would place receptors at risk for over 1,000 years and land use could change significantly in that amount of time. Both the subsistence farmer and the recreational user will be evaluated for each scenario because of the future land use uncertainty.

7.2 Identification of Treatment, Recovery, or Containment Options

NCP requirements detailed in 40 CFR 300.430(e)(ii) & (iii) requires the identification and evaluation of potentially suitable technologies to comply with ARARs and the assembly of suitable technologies into alternative remedial actions.

The initial step of the NCP process is to identify the general action groups. 40 CFR 300.430(e) requires the evaluation of a range of alternatives including:

- No action - may involve no further action if some removal or remedial action has already occurred at the site.
- No treatment – involves little or no treatment, but provide protection of human health and the environment primarily by preventing or controlling exposure to hazardous substances, pollutants, or contaminants. This may be accomplished through engineering controls such as containment, and, as necessary, institutional controls to protect human health and the environment and to assure continued effectiveness of the response action.
- Treatment - identifies treatment(s) that reduces the toxicity, mobility, or volume of the hazardous substances, pollutants, or contaminants. Innovative treatments are to be considered.
- Removal – or off-site disposal involves removal of affected material to a landfill or equivalent location designed to contain such material.

The no further action alternative will be included because some of the on-site material (asphalt and concrete) has been removed during previous activities. The alternative will be evaluated to determine if it is protective of human health and the environment.

The remaining action groups need to be evaluated to determine what is appropriate for this Site. A number of guidance documents and methodologies are available to assist with this process. The primary sources of information used for this portion of the FS include:

- *Remediation Screening Matrix* (http://www.frtr.gov/matrix2/top_page.html) prepared for the U.S. Department of Defense (DoD) and other Federal Agencies participating in the Federal Remediation Technology Roundtable (FRTR).
- Presumptive Remedy for Metals-in-Soil Sites, *U.S. EPA 540-F-98-054, OSWER-9355.0-72FS, PB99-963301, September 1999. Developed in a joint effort between the EPA and the U.S. Department of Energy (DOE).*
- *Contaminants and Remedial Options at Selected Metal-Contaminated Sites*, Office of Research and Development (ORD), U.S. EPA, EPA/540/R-95/512, July 1995.
- *Rules of Thumb for Superfund Remedy Selection*, U.S. EPA, EPA 540-R-97-013, OSWER 9355.0-

69, PB97-963301, August 1997.

According to the program expectations listed in 40 CFR 300.430(a)(1)(iii)(A-F), EPA generally has the following expectations when appropriate remedial alternatives are developed:

- The use of treatment to address the principal threats posed by a site, wherever practicable.
- The use engineering controls, such as containment, for waste that poses a relatively low long-term threat or where treatment is impracticable.
- The use of a combination of methods, as appropriate, to achieve protection of human health and the environment.
- The use of institutional controls, such as water use and deed restrictions, to supplement engineering controls as appropriate for short- and long-term management to prevent or limit exposure to hazardous substances, pollutants or contaminants.
- The consideration of innovative technology when such technology offers the potential for comparable or superior treatment performance or implementability, fewer or lesser adverse impacts than other available approaches, or lower costs for similar levels of performance than demonstrated technologies.
- The return of usable ground waters to their beneficial uses wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site.

Because of the persistent nature of metals and radionuclides, remediation options are typically limited. Current technologies that apply include immobilization, reclamation and recovery, containment, institutional controls, other on-site treatment, and off-site disposal (EPA 540-F-98-054, 1999). Concentrations of the materials do not warrant the consideration of the reclamation and recovery option, reducing the list to the remaining five options.

7.3 Evaluation of Technologies

Immobilization includes processes that change the physical or chemical properties that affect the leaching characteristics of a treated waste or decrease its bioavailability and concentration. This treatment locks metals within a solidified matrix (solidification) and/or converts the waste constituent into a more immobile form, usually by chemical reaction (stabilization). The process involves mixing a reagent (usually cement kiln dust, proprietary agents, cement, fly ash, blast furnace slag, bitumen) and generally solidifying the material with the contaminated soil. Reagents are selected based on soil characteristics and metal contaminants present. The treatment can be performed ex-situ or in-situ, and in either on- or off-site units. Waste minimization is not achieved with this option because of the addition of the stabilization reagents. The literature suggests that the more volatile metals (arsenic and mercury – these metals also are methylated by bacteria and fungi) may continue to migrate out of the completed matrix, but at a slower rate than the untreated soil. Vitrification is another immobilization method that uses an electric current to melt soil at extremely high temperatures to solidify the soil/metals mixture. Vitrification is a very expensive process and can potentially transfer the more volatile metals (arsenic and mercury) to the atmosphere. Soil mixing is using large augers to mix in the concrete/fly ash mix also has been used, but typically requires additional solidification materials and makes verification of cleanup levels more difficult. Immobilized materials generally are managed in a landfill with the associated containment barriers (e.g., caps). All of these methods require some type of institutional control to prevent construction or earthwork that could damage the matrix. The institutional controls will involve long-term operation and maintenance costs.

Containment of wastes in place includes vertical and horizontal barriers. This remedial technology can provide sustained isolation of contaminants and can prevent mobilization of soluble compounds over long periods of time. It also reduces surface water infiltration, provides a stable surface over wastes, limits direct contact, and improves aesthetics. Containment is typically handled with the construction on an engineered on-site waste cell. On-site materials are consolidated and placed in a cell with a clay or synthetic liner. The area is then capped to prevent the migration of precipitation into the cell. Institutional controls are used to prevent damage to the cap. Ground water monitoring is often required to ensure the integrity of the cap and liner. Long-term operation and maintenance costs are associated with this option.

In addition to the stabilization option, a number of on-site treatment technologies exist for removing metals from soils. Soil acid washing, phytoremediation, and electrokinetic separation have been used with varying degrees of success to remove metals from soils.

Acid extraction involves adding an acid and water mixture to the affected soil. This technique is typically performed in an on-site treatment cell to prevent the migration of material to ground water. In this process, soils are first screened to remove coarse solids. Hydrochloric acid is then introduced into the soil in the extraction unit. The residence time in the unit varies depending on the soil type, contaminants, and contaminant concentrations, but generally ranges between 10 and 40 minutes. The soil-leachate mixture is continuously pumped out of the mixing tank, and the soil and leachate are separated using hydrocyclones. The technique is based on the idea that most metals are cations adsorbed to soil particles (primarily clay) and adding the acid increases the mobility of the metals. The leachate from the process is collected and the metals are extracted. However, the technique is often problematic for metal mixtures that exhibit a variety of solubility behaviors in response to pH (e.g., some forms of arsenic are more mobile at high pH). The treatment cell construction in combination with consumable costs makes this option relatively expensive. Hazards associated with the on-site handling of acids also make this option less attractive. If successful, on-site soils can be cleaned to regulatory requirements, allowing unrestricted use of the property.

Phytoremediation uses vegetation to extract metals from the soils. The vegetation is then harvested and disposed of at an approved landfill. The technique has shown promise for several metals, but as with the acid washing technique varying metal solubilities make the extraction process difficult to predict. Sites have tried using chelating agents such as EDTA to improve metal solubilities only to drive the metals to ground water. The technique also requires a number of growing seasons before significant decreases in metal concentrations can be observed. While initial costs for this option are relatively low, the long-term nature of the process can be costly. Institutional controls would be needed to limit access to the Site for the duration of the process. The vegetation also can be an ecological risk to local wildlife. The technique provides no initial control of the ground-water pathway and may accelerate the metals migration if the selected vegetation requires irrigation.

Electrokinetic separation relies upon application of a low-intensity direct current through the soil between ceramic electrodes that are divided into a cathode array and an anode array. This mobilizes charged species, causing ions and water to move toward the electrodes. Metal ions, ammonium ions, and positively charged organic compounds move toward the cathode. Anions such as chloride, cyanide, fluoride, nitrate, and negatively charged organic compounds move toward the anode. The current creates an acid front at the anode and a base front at the cathode. The acid or base front may help to mobilize sorbed metal contaminants for transport to the collection system at the cathode. Limitations of electrokinetic separation include: the requirement of soil moisture contents in excess of 10-percent (can be problematic in a semiarid climate), the presence of buried metallic or insulating material can induce variability in the electrical conductivity making the technique ineffective, the heterogeneity of the soil can be problematic – the technique is most effective in clays, and the oxidation/reduction reactions can produce undesirable products such as chlorine gas. Engineering, equipment, and operational costs make this option relatively expensive. Again the technique provides no initial control of the ground-water pathway. If successful, on-site soils potentially can be cleaned to regulatory requirements, allowing unrestricted use of the property.

Off-site disposal involves the excavation, transportation, and disposal of the affected material. The material is placed in a licensed landfill that can accept all of the materials contained in the soil. Factors to consider for this option include the risks and costs associated with the transportation of the material. Movement of the material can sometimes make community acceptance more difficult. Determining the feasibility of off-site disposal requires knowledge of land disposal restrictions and other regulations developed by state governments. Transportation costs will increase if specialized landfills are required. A major advantage to the off-site disposal option is the ease with which verification samples can be collected, providing an added degree of certainty for achieving remediation goals.

7.4 Generation of Alternatives

After reviewing the remedial action alternatives, a number of technologies were eliminated because of questionable effectiveness and implementability or excessive cost. Vitrification was eliminated because of cost and the potential to off-gas volatile metals. Acid extraction was dismissed because of cost and the uncertainty associated with the technique. Movement and use of large quantities of acid also made this option problematic. Phytoremediation was dismissed because of the long-term requirements of the technology and the continued lack of ground-water protection. Electrokinetic separation was eliminated because of cost and the technique uncertainty. On-site soils are highly heterogeneous and soil moisture is typically low for most of the year.

Five site-specific alternatives were developed that use a combination of techniques to protect human health and the environment. The options were arranged according to the amount of excavation required to complete the process and included treatment and non-treatment options. The five alternatives include:

Alternative	Description	Excavation Required?	Institutional Controls Required?
1	No further action	No	Yes
2A	Engineered cap	No	Yes
2B	Engineered cap and slurry wall	No[1]	Yes
3A	Engineered cap with partial removal[2] (areas with combined radium activity >15 pCi/g)	Yes	Yes
3B	Engineered cap with partial removal[3] (areas with combined radium activity >5 pCi/g)	Yes	Yes
4A	On-site solidification with engineered cap	Yes	Yes
4B	On-site engineered disposal cell	Yes	Yes
5A	Off-site disposal at solid waste facility	Yes	No
5B	Off-site disposal at solid waste facility and portion to specialized waste facility	Yes	No

[1] Some excavation required to install slurry wall
[2] Estimated removed volume between 500 and 1,000 cubic yards
[3] Estimated removed volume about 5,000 cubic yards

The following describes the details of the implementation of each option. A detailed analysis of the risks/hazards and compliance with the ARAR's is provided in Section 8.0.

7.4.1 Common Alternative Elements

Elements that are common to all of the RA alternatives (except for Alternative 1 - No Further Action) are presented below.

7.4.1.1 Work Plan Preparation

Once the RA is selected, a Work Plan will be submitted to the CDPHE. The elements of that Work Plan will vary with the selected alternative but will, at a minimum, include the following:

- Materials handling and storage including on-site handling and excavation of the elevated materials, equipment to be used, work/staging areas, and equipment and personnel decontamination areas.
- Confirmatory sampling, analysis, and disposal plans for the elevated material including sampling methodology, air monitoring, radiation monitoring, equipment and personnel decontamination criteria and procedures, analytical procedures, quality assurance/quality control, and data validation.
- Health and safety plan update including training and medical monitoring requirements for workers, personal protective equipment, evacuation procedures, emergency response, Site security, access, and organization and responsibility.
- Storm-water pollution prevention plan designed to limit erosion and sediment movement, prevent on-site spills of fuel and other hazardous materials, and prevent off-site migration of affected

materials.

- Engineering designs including, at a minimum, specifications, plans, final configuration of the affected areas, dust suppression, erosion control, backfill, and revegetation.
- Community participation plan including measures to be taken for dissemination of information to relevant agencies, organizations, groups, and communities; schedule of public meetings; and measures to receive comments regarding the RA.
- Transportation approaches including work force access, deliveries of supplies and materials, and equipment access to and from the Site including proposed routes, placarding, dust suppression, and permit requirements.
- Reporting requirements including periodic reports detailing Site activities, project schedule, summary of materials handled, health and safety activities, and injury/accidents on the Site, and a final report providing the details of the RA and results of all confirmatory samples.

7.4.1.2 Mobilization Activities

Mobilization activities for each alternative will typically include the following:

- Installation of trailers for Site personnel and equipment associated with the RA contractor, project management, health and safety, personnel decontamination, and oversight activities,
- Modification of temporary fencing system to accommodate work area needs,
- Installation of temporary utilities such as electricity, telephone, etc., as necessary,
- Modification of the Site security and access system,
- Construction of a temporary access road from U.S. Highway 6 to the Site if appropriate,
- Implementation of a vehicle parking policy,
- Construction of an equipment and vehicle decontamination pad, and
- Construction of a storm-water management system including temporary erosion and sedimentation control measures (silt fences, catch basins, etc.).

7.4.2 Dust Suppression/Perimeter Air Monitoring

Regardless of the RA alternative selected, dust suppression activities and perimeter air monitoring will be performed. Dust control procedures that will be used during excavation and handling of materials will typically include the following:

- Using water hoses with mist or fog nozzles to spray light applications of water over the work area during excavation activities (water discharge will be carefully controlled to minimize material migration).

- Using water hoses or water trucks to spray areas that are extensively used by equipment and enforcing reduced speed limits for construction equipment.
- Minimizing use of disturbed areas during extended non-operational periods.
- Storm-water BMPs will be used to control stockpiles and prevent off-site migration.
- Temporary stabilization BMPs may be used during non-operational periods to prevent wind and water erosion.

Fresh water or water collected during storm-water management will be used for dust control on areas containing contaminated soil. Only fresh water will be used on areas that are uncontaminated.

A perimeter air monitoring system will be designed and installed. With the exception of Alternative 1, the system will require electricity (generators or an electric line) around the perimeter of the Site and will consist of high-volume particulate air samplers to monitor particulate emissions and regulated air samplers to monitor radioactivity emissions. Alternative 1 will use a passive canister type air monitoring system for gamma and radon measurement.

7.4.3 Alternative 1 – No Further Action

Alternative 1 provides a comparative baseline against which other alternatives can be evaluated. Under Alternative 1, the affected soils would remain as is without any removal, treatment, containment, or mitigating technologies being implemented. Only institutional controls would be implemented. Institutional controls are items that limit the accessibility of the Site. Items may be physical barriers such as fencing, signs, monitoring and surveillance systems, or deed restrictions put on the land so that it may not be used for activities that would disturb the affected material. Institutional controls will be used to limit the accessibility of a site where no work was performed (no action). Specifically, the following institutional controls and air and ground-water-monitoring activities will occur as part of this alternative:

- Relocation of the water main by the City of Golden.
- Maintenance of the perimeter security fencing that currently surrounds the Site to prevent public access.
- Maintenance of erosion and sediment controls to minimize off-site migration of affected materials.
- Continuation of other institutional controls such as prohibition of construction and selected land uses on or immediately adjacent to the facility.
- Continuation of an air-monitoring program to provide information regarding potential exposures

to nearby residents or users of the adjacent recreational facilities and to use in the periodic reviews.

- Redesign and enhancement of ground-water monitoring system along with implementation of a long-term ground-water-monitoring program to provide information regarding potential contamination of the ground water and to use in the periodic reviews.

Metals and radionuclides migration to ground water and incursions by neighborhood children (external radiation and radionuclide and lead ingestion exposures) present the highest risks for this scenario.

7.4.4 Alternatives 2A and 2B – Engineered cap with and without slurry wall

Alternative 2 involves the use of an engineered cap to prevent exposure to metals and radionuclides and to control surface water infiltration, preventing material migration to ground water. Alternative 2A examines only a cap while alternative 2B adds a slurry wall to ensure protection of ground water. The cap was assumed to cover the entire Site because of the widespread presence of elevated arsenic concentrations.

If the slurry wall option is selected the first operation would be the slurry wall installation. Again because of the widespread presence of arsenic, it was assumed the wall would be installed around the entire Site. The slurry wall is installed using excavation or trenching equipment to make a trench in the soil overlying the bedrock. The trench is continued some distance (usually three feet) into the bedrock to ensure containment. The trench is then filled with a clay/water slurry (sometimes concrete is added) that forms a barrier to ground-water movement. It is necessary to surround the Site to divert upgradient ground water around the Site (no ground water would pass under the Site) and to prevent downgradient ground water from backing into the Site during years when flooding occurs. The overlying cap prevents precipitation infiltration.

Fill material will be required to bring the existing Site to a grade appropriate for the installation of the cap. Current Site topography would be inappropriate for a cap because of drainage issues. Depressions formed by the removal of several of the building foundations would need to be filled and the base material would need to be contoured to ensure drainage off of the cap (no ponding is permitted). Borrow areas have been identified on nearby State property, eliminating the need to transport material on roads to the Site, but fill material may need to be imported if the School decides not to disturb these areas.

The nearby borrow area also contains clay suitable for capping material (Hollingsworth Associates, Inc., 2003) at sufficient quantities to cap the entire Site. A cap thickness of three feet is proposed (estimated volume of clay - 25,000 cubic yards). The cap would be installed in 6-inch lifts and compacted to engineering requirements. Geotechnical samples would be collected to verify compliance with compaction requirements. The fill material and cap would be surveyed to ensure sufficient material has been placed in all areas. Caps are often covered with topsoil and planted with suitable vegetation to limit erosion.

Both alternatives would require long-term institutional controls to ensure the integrity of the cap. Limited use could be made of the area, such as parks and recreational areas, but construction of structures would be discouraged because of the possibility of compromising the cap. Controls would include the redesign and enhancement of the ground-water monitoring system along with implementation of a long-term ground-water-monitoring program to provide information regarding potential contamination of the ground water and to use in the periodic reviews. Subsurface markers/barriers are also recommended above areas contaminated with lead to warn future excavators of the risk (*Superfund Lead-Contaminated Residential Sites Handbook*, U.S. EPA, OSWER 9285.7-50, 2003).

Additional borings and samples may be required for alternative 2A to ensure material has not migrated to areas that potentially can be reached when ground-water levels are high. Soil under the foundation of Building 101N contained elevated radionuclides and metals and is the lowest point on the Site. The significant precipitation event associated with the March snowstorm and the “pond” formed by the depression may have driven additional materials further down into the soil column.

7.4.5 Alternatives 3A and 3B – Engineered cap with partial material removal

Alternative 3 again involves the use of an engineered cap to prevent exposure to metals and radionuclides and to control surface water infiltration, preventing material migration to ground water. The difference in this option is the removal of some of the radionuclide containing material. Alternative 3A would address the areas with combined radium activities in excess of 15 pCi/g. Removal activities would be focused on the areas with elevated gamma radiation as shown in Figure 4-1. An estimated 500 to 1,000 cubic yards would be removed in this alternative. Alternative 3B would address areas with combined radium activities in excess of 5 pCi/g. Kriging of surface samples predict that radium activities in this range can be found on about half of the Site. An estimated 5,000 cubic yards would be removed for this alternative.

As discussed in the Alternatives 2A and 2B section, fill would be required to prepare the Site for a cap. And the capping requirements are the same as Alternative 2. Again it is assumed that the School borrow area would be used for both the fill and cap material. Both alternatives assume cap constructed of three feet of clay, placed in 6-inch lifts.

Alternative 3 has an excavation and removal component. Because the material is not uniformly distributed, soil would be excavated and stockpiled until confirmation sampling is complete. The soil stockpile would then be shipped to an appropriate landfill. Both versions of this alternative would require the construction of the temporary access road to U.S. Highway 6 in order to avoid transporting affected material through the historic district of downtown Golden. The transportation route from U.S. Highway 6 would be dependent on the landfill selection.

The stockpiled material would be loaded onto trucks with a front-end loader or excavator. Following loading, each truck would be decontaminated as required prior to travel to the appropriate landfill. Each truck would have a capacity of 20 tons or approximately 13.3 cubic yards, assuming a weight of 1.5 tons per cubic yard for affected material. Alternative 3A would require between 40 and 80 truckloads to transport the material to the landfill. Alternative 3B would require about 380 truckloads.

Assuming 40 minutes to load each truck, 12 trucks could be loaded during an eight-hour shift. On average, a loaded truck would leave the Site every 40 minutes and an empty truck would enter the Site (total of 24 inward and outward-bound trucks per day). An average of 1,200 tons of affected material would be removed per week. Estimated transport times were determined assuming the closest solid waste landfill. Transportation times may increase if other facilities are selected.

Based on an average of 60 trucks per week, Alternative 3A would require about one to two weeks to transport the material. Alternative 3B would require between six and seven weeks. Additional time would be required for Site preparation, mobilization, excavation, and demobilization activities. Fill and capping operations would require additional time.

Both alternatives would require long-term institutional controls to ensure the integrity of the cap. Limited use could be made of the area, such as parks and recreational areas, but construction of structures would be discouraged because of the possibility of compromising the cap. Controls would include the redesign and enhancement of the ground-water monitoring system along with implementation of a long-term ground-water-monitoring program to provide information regarding potential contamination of the ground water and to use in the periodic reviews. Subsurface markers/barriers are also recommended above areas contaminated with lead to warn future excavators of the risk (U.S. EPA, OSWER 9285.7-50, 2003).

Confirmation samples will be collected to ensure the radium activity limits have been met. However, these alternatives only address radium. Elevated metal concentrations may remain in excavated areas and additional borings and samples may be required to ensure material has not migrated to areas that potentially can be reached by high ground-water levels. Soil in the area around the former Building 101N contains both elevated radionuclides and metals. Metals may have been driven deeper in the soil column by the March 2003 precipitation event.

7.4.6 Alternatives 4A and 4B – On-site solidification with engineered cap or on-site engineered disposal cell

Both versions of Alternative 4 require capping, but for this alternative the cap would only cover limited areas. Alternative 4A involves the consolidation and stabilization of on-site soils using concrete and fly ash. Alternative 4B includes the consolidation of material and the construction of an engineered disposal cell. Alternative 4 assumes that all of the affected on-site material (about 10,000 cubic yards) will be solidified or placed in a disposal cell. Confirmation sampling will be performed to ensure both metal and radionuclide limits are achieved.

Alternative 4A will require a pilot test to determine the appropriate mixture of concrete, fly ash, and soil. Additional soil tests including particle size, Atterberg limits, moisture content, sulfate content, organic content, density, permeability, unconfined compressive strength, leachability, pH, and microstructure analysis will be required to determine the proper mixture. Leachability testing will be performed to determine the degree of contaminant immobilization.

Once the proper mixture is determined, on-site materials will need to be excavated and segregated into soil types. Some crushing of cobbles may be required. An area at a high enough elevation to remain above ground-water fluctuations will be selected for the final placement of the solidified material. Operational concrete and fly ash will be stockpiled on site and a batch processor will be brought in to mix the materials. A water supply also will be required. Batches of material will be placed in lifts and solidification will be verified with test cores.

Once the solidification of the structure has been confirmed, a clay cap (depth of three feet) will be constructed over the structure to limit leaching effects. Assuming a structure depth of 10-feet, a square structure would be about 180 feet on a side. The structure and cap footprint would require institutional controls on about 0.85 acre of land if one assumes 2:1 slope from the top of the cap. Long-term cap maintenance and ground-water monitoring in the vicinity of the solidified matrix would be required. The remaining property would be available for unrestricted use although a limited ground-water-monitoring program may be required to monitor the natural attenuation of current metal concentrations and radionuclide activities. Some backfill would be required to bring the Site to a useable elevation and to provide storm-water control.

Transportation requirements for this option include materials and equipment. The U.S. Highway 6 temporary access would be the preferred route to avoid movement of large equipment through local neighborhoods.

Alternative 4B requires the construction of an engineered disposal cell. An area above ground-water fluctuations would be selected for the construction of the cell. Allowing a material depth of 10 feet and a 4:1 slope into the cell to allow for equipment movement, the footprint of the cell would be about one acre. Geotechnical testing would be required to verify proper placement of the cell and a clay sub-liner would be installed. A geosynthetic liner will be installed over the clay to ensure containment. The affected material will then be excavated from the Site and placed in the cell. Once the removal operation is complete, a clay cap (3-feet deep) will be installed over the material. Again institutional controls would be required for the one-acre cell to ensure the integrity of the cap and to monitor ground water in the vicinity of the cell. Limited ground-water monitoring may be required to monitor the natural attenuation of current metal concentrations and radionuclide activities. Backfill would be required to bring the Site to a useable elevation and to provide storm-water control.

As with Alternative 4A, the U.S. Highway 6 temporary access would be the preferred route to avoid movement of large equipment through local neighborhoods.

Variations of Alternative 4 could include the solidification or containment of a portion of the affected material. However, solidification or containment of all of the material does allow for unrestricted use of the majority of the property.

7.4.7 Alternatives 5A and 5B – Off-site disposal at solid-waste landfill or combination of solid-waste

and specialized landfills

Alternative 5 involves the excavation and removal of all of the affected material to an approved landfill. Alternative 5A assumes all of the material can be placed in a local solid-waste landfill. Alternative 5B assumes that landfill acceptance criteria may require some of the material to be transported to a specialized landfill. Both versions of this alternative would require the construction of the temporary access road to U.S. Highway 6. The transportation route from U.S. Highway 6 would be dependent on the landfill selection.

Excavated material would be stockpiled prior to shipping to maximize the use of the trucks (eliminates waiting time for trucks). The stockpiled material would be loaded onto trucks with a front-end loader or excavator. Following loading, each truck would be decontaminated as required prior to travel to the appropriate landfill. Each truck would have a capacity of 20 tons or approximately 13.3 cubic yards, assuming a weight of 1.5 tons per cubic yard for affected material. Alternative 5A would require about 760 truckloads to transport the material to the landfill. Alternative 5B would require between 680 and 720 truckloads to the solid-waste facility and 40 to 80 truckloads to the specialized waste facility (or shipping site). Estimated transport times were determined assuming the closest solid-waste landfill. Transportation times may increase if other facilities are selected.

Assuming 40 minutes to load each truck, 12 trucks could be loaded during an eight-hour shift. On average, a loaded truck would leave the Site every 40 minutes and an empty truck would enter the Site (total of 24 inward and outward-bound trucks per day). An average of 1,200 tons of affected material would be removed per week.

Based on an average of 60 trucks per week, Alternative 3A would require about 12 to 13 weeks to transport the material. Alternative 3B may require additional time because of the separation of material for shipment. Additional time would be required for Site preparation, mobilization, excavation, and demobilization activities.

Upon completion of the off-site disposal, all of the property would have unrestricted use. Backfill material would be required to bring the site to a useable elevation and for storm-water control.

Variations of Alternative 5 could include the off-site disposal of a portion of the affected material. However, complete removal allows for unrestricted use of the entire property.

8.0 Detailed Analysis of Alternatives

Section 121 of the Superfund statute (the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)) established five principal requirements for the selection of remedies. The remedies must:

- protect human health and the environment;
- comply with applicable or relevant and appropriate requirements (ARARs) unless a waiver is justified;
- be cost-effective;
- utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable; and
- satisfy a preference for treatment as a principal element, or provide an explanation in the ROD as to why this preference was not met.

The five CERCLA requirements are further refined in 40 CFR §300.430(e)(9)(iii) into nine criteria for evaluating remedial alternatives to ensure that all of the important considerations are factored into remedy selection decisions. These criteria are derived from the statutory requirements of Section 121, as well as technical and policy considerations that have proven to be important for selecting among remedial alternatives. The nine criteria analysis comprises two steps: an individual evaluation of each alternative with respect to each criterion; and a comparison of options to determine the relative performance of the alternatives and identify major trade-offs among them (i.e., relative advantages and disadvantages). The following describes the nine criteria.

- *Overall protection of human health and the environment,*

Alternatives are assessed to determine whether they can adequately protect human health and the environment, in both the short- and long-term, from unacceptable risks posed by hazardous substances, pollutants, or contaminants present at the site by eliminating, reducing, or controlling exposures to levels established during development of remediation goals consistent with 40 CFR §300.430(e)(2)(i). Overall protection of human health and the environment draws on the assessments of other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

- *Compliance with ARARs*

The alternatives are assessed to determine whether they attain applicable or relevant and appropriate requirements under federal environmental laws and state environmental or facility siting laws or provide grounds for invoking one of the waivers under paragraph 40 CFR 300.430(f)(1)(ii)(C).

- *Long-term effectiveness and permanence*

Alternatives are assessed for the long-term effectiveness and permanence they afford, along with the degree of certainty that the alternative will prove successful. Factors that must be considered include the following:

- Magnitude of residual risk remaining from untreated waste or treatment residuals remaining at the conclusion of the remedial activities. The characteristics of the residuals should be considered to the degree that they remain hazardous, taking into account their volume, toxicity, mobility, and propensity to bioaccumulate.
- Adequacy and reliability of controls such as containment systems and institutional controls that are necessary to manage treatment residuals and untreated waste. This factor addresses in particular the uncertainties associated with land disposal for providing long-term protection from residuals; the assessment of the potential need to replace technical components of the alternative, such as a cap, a slurry wall, or a treatment system; and the potential exposure pathways and risks posed should the remedial action need replacement.

- *Reduction of toxicity, mobility, or volume through treatment*

Evaluates which alternatives employ recycling or treatment that reduces toxicity, mobility, or volume, including how treatment is used to address the principal threats posed by the site. Factors that are evaluated include the following:

- The treatment or recycling processes the alternatives employ and materials they will treat;
- The amount of hazardous substances, pollutants, or contaminants that will be destroyed, treated, or recycled;
- The degree of expected reduction in toxicity, mobility, or volume of the waste due to treatment or recycling and the specification of which reduction(s) are occurring;
- The degree to which the treatment is irreversible;
- The type and quantity of residuals that will remain following treatment, considering the persistence, toxicity, mobility, and propensity to bioaccumulate of such hazardous substances and their constituents; and
- The degree to which treatment reduces the inherent hazards posed by principal threats at the

site.

- *Short-term effectiveness*

The short-term effects of alternatives must be assessed considering the following:

- Short-term risks that might be posed to the community during implementation of an alternative;
- Potential impacts on workers during remedial action and the effectiveness and reliability of protective measures;
- Potential environmental impacts of the remedial action and the effectiveness and reliability of mitigative measures during implementation; and
- Time until protection is achieved.

- *Implementability*

The ease or difficulty of implementing the alternatives must be assessed by considering the following types of factors as appropriate:

a) Technical feasibility, including technical difficulties and unknowns associated with the construction and operation of a technology, the reliability of the technology, ease of undertaking additional remedial actions, and the ability to monitor the effectiveness of the remedy.

b) Administrative feasibility, including activities needed to coordinate with other offices and agencies and the ability and time required to obtain any necessary approvals and permits from other agencies (for off-site actions);

c) Availability of services and materials, including the availability of adequate off-site treatment, storage capacity, and disposal capacity and services; the availability of necessary equipment and specialists, and provisions to ensure any necessary additional resources; the availability of services and materials; and availability of prospective technologies.

- *Cost*

The types of costs that shall be assessed include the following:

- Capital costs, including both direct and indirect costs;
- Annual operation and maintenance costs; and
- Net present value of capital and O&M costs.

- *State acceptance*

Assessment of State of Colorado concerns may not be completed until comments on the RI/FS are received but may be discussed, to the extent possible, in the proposed plan issued for public comment. The state concerns that shall be assessed include the following:

a) The state's position and key concerns related to the preferred alternative and other alternatives; and
b) State comments on ARARs or the proposed use of waivers.

- *Community acceptance*

This assessment includes determining which components of the alternatives interested persons in the community support, have reservations about, or oppose. This assessment may not be completed until comments on the proposed plan are received.

Of the nine criteria previously listed, the first two criteria are considered threshold criteria that must be attained by the selected remedial action. The next five criteria are the primary balancing criteria, which are considered together to identify significant trade-offs and determine the optimal alternative among those having passed the threshold criteria. The final two criteria are modifying criteria, which are evaluated following public comment on the RI/FS and Proposed Plan.

8.1 Site Disposition ARARs

A significant number of Applicable or Relevant and Appropriate Requirements apply to the Site because of the nature of the materials of concern. EPA typically regulates metal contaminants, but the U.S. Nuclear Regulatory Commission (NRC) regulates radionuclides. The primary focus for EPA is the risk or hazard associated with the material, while the NRC focus on the radioactive material dose. Different types of land use result in a variety of possible exposures and require different levels of cleanup protection. Multiple chemical and physical variables associated with metals in soil also complicate the regulatory picture making the development of numerical standards problematic. Ecological risk assessment is a developing science that adds uncertainties to the current decision making process.

Primary ARARs for the Site are those that define the acceptable dose, risk, and hazard standards associated with the current conditions and final disposition of the property. Additional ARARs apply material handling standards required during excavation or removal operations. The following ARARs for soils and ground and surface water were determined to be major decision drivers for Site disposition. Additional ARARs that apply to other remedial operations, such as excavation and transportation, are summarized in Appendix K.

Media	Site Specific Applicable or Relevant and Appropriate Requirements and To Be Considered
Soil	10 CFR §20.1402 and 1403, NRC Standards for Protection Against Radiation, Radiological Criteria for Unrestricted and Restricted Use – Requires that exposures to on-site receptors do not result in a dose in excess of 25 mrem/yr.
	6 CCR 1007-1, §4.61.2 – 4.61.3, Colorado Radiation Control regulations, Radiological Criteria for Unrestricted and Restricted Use - Requires that exposures to on-site receptors do not result in a dose in excess of 25 mrem/yr.
	EPA Memorandum, Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination, OSWER No. 9200.4-18, August 1997 – Uses a risk-based approach to recommend limiting exposures to less than 15 mrem/yr.
	EPA Memorandum, Reassessment of Radium and Thorium Soil Concentrations and Annual Dose Rates, July 22, 1996 – Initial discussion that resulted in the recommended 15 mrem/yr dose.
	EPA Memorandum, Use of Soil Cleanup Criteria in 40 CFR 192 as Remediation Goals for CERCLA Sites, Directive No. 9200.4-25, February 1998 – Clarification of the use of 40 CFR 192 for the development of radionuclide soil standards.
	EPA Memorandum, Use of Soil Cleanup Criteria in 40 CFR 192 as Remediation Goals for CERCLA Sites, Directive No. 9200.4-25, February 1998 – Clarification of the use of 40 CFR 192 for the development of radionuclide soil standards.
	40 CFR §192.12, Subpart B—Standards for Cleanup of Land and Buildings Contaminated with Residual Radioactive Materials from Inactive Uranium Processing Sites, Standards – Limits radium-226 surface activities (up to 15 cm) to 5 pCi/g and subsurface activities (greater than 15 cm) to 15 pCi/g. For occupied or habitable structures it requires that remedial efforts result in an annual radon decay product concentration (including background) of less than 0.2 WL (in any case the concentration should not exceed 0.3 WL). And interior gamma shall not exceed background by more than 20 microroentgens per hour.
	40 CFR §192.02, Subpart A—Standards for the Control of Residual Radioactive Materials from Inactive Uranium Processing Sites, Standards – Specifies that the control of residual radioactive materials and their listed constituents shall be designed to be effective for up to one thousand years, and in any case for at least 200 years. Also imposes limits on acceptable radon air concentrations and requires ground-water monitoring when necessary.
	CDPHE, Proposed Soil Remediation Objectives Policy Document, December 1997
	CDPHE, Revised Proposed Residential/Unrestricted Land-Use Standards, 2003
	EPA Region 9 Memorandum, Region 9 PRGs Table 2002 Update, October 2002 – Describes risk based approach to soil cleanup and provides table of preliminary remediation goals for soils. CDPHE recommends the use of these PRGs for materials not covered by their proposed soil standards.
Ground and Surface Water	40 CFR §192.02 Standards, §192.03 Monitoring, §192.04 Corrective Action, Subpart A—Standards for the Control of Residual Radioactive Materials from Inactive Uranium Processing Sites – Details the requirements specific to ground water.
	40 CFR §192.20 Guidance for implementation, §192.20 Criteria for applying supplemental standards, Subpart C – Implementation – Additional ground water requirements.
	40 CFR 141.11, National Primary Drinking Water Regulations, Maximum contaminant levels for inorganic chemicals
	40 CFR 141.15, National Primary Drinking Water Regulations, Maximum contaminant levels for radium-226, radium-228, and gross alpha particle radioactivity in community water systems.
	40 CFR 141.51, National Primary Drinking Water Regulations, Maximum contaminant level goals for inorganic contaminants.
	40 CFR 141.55, National Primary Drinking Water Regulations, Maximum contaminant level goals for radionuclides.
	5 CCR 1003-1, Art. 5, Colorado Primary Drinking Water Regulations, Maximum contaminant levels for inorganic chemicals
	5 CCR 1002-41, Colorado Department Of Health, Water Quality Control Commission Regulation No. 41, Basic Standards for Ground Water
	5 CCR 1002-8, §3.1.1, Colorado Department Of Health, Water Quality Control Commission Regulation No. 8, Establishes basic standards, anti-degradation standard, and system for classifying State water.
	5 CCR 1002-38, Colorado Department Of Health, Water Quality Control Commission Regulation No. 38, Classifications And Numeric Standards South Platte River Basin, Laramie River Basin, Republican River Basin, Smoky Hill River Basin
	5 CCR 1002-31, Colorado Department Of Public Health And Environment, Water Quality Control Commission, Regulation No. 31, The Basic Standards And Methodologies For Surface Water, Section 31.8 Antidegradation Rule.

8.2 Analysis of Alternatives

This section presents the results of the analysis of each alternative with respect to the nine evaluation criteria.

8.2.1 Alternative 1 – No Further Action

Under Alternative 1, the affected soils would remain in place and a comprehensive, long-term program would be required to monitor air and ground-water quality. If this alternative were selected, enhanced storm-water controls would be needed and long-term maintenance of the Site perimeter would be required to limit access. This alternative provides a baseline for comparison purposes.

8.2.1.1 Alternative 1 - Protection of Human Health and the Environment

Alternative 1, the No Further Action Alternative, does not provide adequate protection of human health and the environment because it does not address the risks associated with potential skin contact, inhalation, or ingestion of contaminants from the elevated material. If the 40 CFR §192.02(a) requirement of 1,000 years (or at least 200 years) of protection is provided, the no further action alternative is not appropriate. In that amount of time land use could revert to the subsistence farmer modeled in the baseline risk assessment. The predicted dose was up to 190 mrem/yr and could be up to five times higher if the RESRAD predicted radon concentrations are applied. Total risk from radionuclides and metals was up to $3.8x10^{-3}$ (disregarding radon) and the hazard index was predicted to be as high as 3.8. Lead contaminated soil could increase blood lead concentration up to 20 μg/dL. Even recreational use produced risks as high as $3.7x10^{-5}$. DCGLs were not determined for this alternative because the affected material will be left in place.

Even with an effective erosion and sediment control program, wind borne particles would migrate off of the Site. Metals and radionuclides would be absorbed by vegetation, which again can migrate off site in the form of leaves and debris.

A major weakness in the no further action alternative is the failure to address the ground-water pathway. While institutional controls and deed restrictions could be applied to the land surface, contaminates would continue to migrate to ground water. Total uranium concentrations in two of the on-site monitoring wells increased above the MCL during a year of quarterly sampling, apparently in response to a major precipitation event in March 2003. With sufficient time and proper conditions a significant portion of the radionuclides and metals could migrate into the ground water and eventually into Clear Creek. Using the surface water antidegradation rule (5 CCR 1002-31.8) for Clear Creek and the ground water uranium concentration standard [5 CCR 1002-38.5(3)(b)], the Site would fail to provide adequate protection of human health and the environment.

8.2.1.2 *Alternative 1 - Compliance with ARARs*

Assuming the subsistence farmer receptor, the no further action alternative fails to meet the ARARs presented in Section 8.1. The ground and surface water ARARs also are not met under any of the land use scenarios.

8.2.1.3 *Alternative 1 - Long-term Effectiveness and Permanence*

The alternative would provide no reduction in risk (except through institutional controls) and does not reduce toxicity, mobility, or volume of Site contaminants. It would be a long-term source of possible contamination to ground and surface water.

8.2.1.4 *Alternative 1 - Reduction of Toxicity, Mobility, or Volume through Treatment*

No treatment is associated with no further action, resulting in no reduction of toxicity, mobility, or volume.

8.2.1.5 *Alternative 1 - Short Term Effectiveness*

The short-term effects of the no further action alternative would be unchanged from the current risks posed by the elevated material. Because no excavation is required, there would be minimal risk to workers. No elevated short-term risks would result from the implementation of this alternative. However, the existing potential for human and environmental exposure would not be reduced and remedial action objectives would not be achieved.

8.2.1.6 *Alternative 1 - Implementability*

Alternative 1 is technically feasible; however, the administrative feasibility of this alternative is problematic because it would not likely meet the criteria for radioactive materials license termination.

8.2.1.7 *Alternative 1 - Cost*

Cost elements associated with the no further action alternative include the installation of additional ground-water monitoring wells, long-term maintenance of fencing and storm-water controls, and long-term monitoring of the ground water. Assuming 100 years of maintenance and monitoring, the total present value of these requirements is estimated at $2,108,000. There also is the cost of loss in property value. Cost breakdown data for all of the alternatives are provided in Section 8.3.7.

8.2.1.8 Alternative 1 - State Acceptance

State acceptance is unlikely because of possible metals and radionuclide exposure and lack of ground water protection.

8.2.1.9 Alternative 1 - Community Acceptance

Comments received during an open house conducted by the School indicated that local residents preferred the removal of the material from the Site, so community acceptance of no further action would be unlikely.

8.2.2 Alternative 2 – 2A Engineered Cap Covering Entire Site or 2B Engineered Cap with Slurry Wall

Alternative 2 was designed to eliminate direct receptor exposure to the affected material and address the precipitation infiltration pathway. Alternative 2A is the cap only option, which effectively addresses the exposure and infiltration pathways. A weakness of Alternative 2A is the potential fluctuation of ground-water levels, which potentially could reach the lower portions of the affected soil. The affected material in the vicinity of the former Building 101N is the most susceptible to ground-water fluctuations, because of its low elevation and permeable soils. Alternative 2B adds a slurry wall to the cap to address the ground-water fluctuation concerns. However, a weakness in the slurry wall option is the presence of a City of Golden water main and several irrigation pipelines that could compromise wall integrity in the event of a leak. A City of Golden water main break in 1992 led to the EPA removal action and many of the City water lines are old. Thus, a future water main break is not unlikely.

The alternative would require an engineering design, installation of the slurry wall (2B only), movement of fill and capping material from the School borrow area or and off-site location, and grading, compaction, and testing of the fill / cap. The ground water monitoring network also would need to be upgraded. In accordance with 40 CFR §192.02(a), a long-term maintenance plan would be required to maintain cap integrity along with long-term ground water monitoring. Deed restrictions would be required that limited excavation and ensured the integrity of the cap. While construction has been allowed for some capped sites, it makes cap maintenance problematic. Structures and paved areas hinder visual inspection of the cap and utility installation and maintenance (e.g., electrical and water lines) can compromise the cap. There also would be the requirement to permanently mark the lead-affected soil areas (EPA, OSWER 9285.7-50, August 2003). Radon abatement systems would be required for any on-site structures.

8.2.2.1 Alternative 2 - Protection of Human Health and the Environment

Standard exposure pathways would be eliminated with the cap installation because the material would be inaccessible to receptors. RESRAD predicts essentially no dose or risk for the subsistence farmer scenario (numerical RESRAD predictions provided below). RESRAD also predicts essentially no dose or risk for the recreational user. The only remaining pathway for metals exposure would be through ground water use (subsistence farmer), but institutional controls should be designed to prevent this use. However, if ground water were used and the activities/concentrations remain the same as current levels, a hazard index of 0.39 and as associated risk of 6.6×10^{-6} could be expected. Radium-226 would be a continuing source of radon gas but site specific concentrations would need to be determined by measurement. DCGLs were not determined for these alternatives because the material stays in place. With the exception of the uncertainties associated with the ground water (2A only) and radon pathways, the alternative would satisfy the ALARA principle.

Alternative / Receptor	RESRAD Dose[1] (mrem/yr)	RESRAD Risk[1]	Hazard Index	RAIS Risk	Combined Risk[1,3] (RESRAD & RAIS)
2A&B – Farmhouse on Cap	3.7×10^{-23}	9.5×10^{-28}	0.39 (2,3)	6.6×10^{-6} (2,3)	6.6×10^{-6}
2A&B – Recreational User on Cap	6.9×10^{-25}	0	0 (2)	0 (2)	6.9×10^{-25}

[1] Radon pathway not included in risk or dose assessment
[2] Assumes clean cap and fill material
[3] Ground-water pathway at current concentrations

Uncertainties associated with this option in regard to protection of human health and the environment include the ground water and radon pathways. Although borings and test pits were used to evaluate the vertical extent of the material during the RI, exact delineation of the material is not possible without excavation and confirmation sampling. Two test borings (CB27 and CB28) did show the presence of radionuclide and metals at depth that potentially could be reached by ground water during wet years (insufficient water-level data to confirm this possibility). MCLs would likely be exceeded at the point of compliance wells. Alternative 2A could require a future ground-water treatment system if sufficient material is accessible to the ground-water fluctuations. Long-term water quality standards for Clear Creek could be affected by continuing migration of materials, although concentrations would be expected to be at or below current detection limits because of dilution effects. Elevated radon concentration can be addressed through the use of radon mitigation systems.

Strong institutional controls would be required to prevent the degradation of the cap or excavation of the affected material. Failure to maintain the institutional controls could jeopardize future protection of human health and the environment.

8.2.2.2 Alternative 2 - Compliance with ARARs

The alternative complies with most of the ARARs listed in Section 8.1, but there is some uncertainty associated with the cap only alternative (2A) because of ground water concerns. A possible water main break also could affect the ground water protection for Alternative 2B. If the institutional controls include the requirement for radon mitigation for any structure, the ARARs likely would be met.

8.2.2.3 Alternative 2 -Long-term Effectiveness and Permanence

If the cap is maintained the alternative(s) would be effective, however permanence is more difficult to predict. Using the 1,000-year life recommended by 40 CFR §192.02, it would be difficult to anticipate the permanence of the remedy. While cap designs are advertised as having life spans of this magnitude, there are no existing examples of this type of performance. A number of claims are made about caps providing a radon barrier but this is highly dependent on maintaining moisture content. Semiarid climates make prescribed moisture content difficult to maintain.

8.2.2.4 Alternative 2 - Reduction of Toxicity, Mobility, or Volume through Treatment

This alternative does not reduce the toxicity, mobility, or volume of elevated material through treatment. The alternative does remove receptor pathways to reduce dose, risk, and hazard issues. The mobility factor is addressed by eliminating wind and water erosion and infiltration. However, mobility could be affected by ground-water fluctuations in Alternative 2A. Mobility also could be an issue for Alternative 2B if there were a pipeline break. Because of the failure to address the reduction of the toxicity or volume, the remedy could be problematic in the future.

8.2.2.5 Alternative 2 - Short Term Effectiveness

Earth moving activities pose an elevated short-term exposure risk to on-site workers and nearby residents due to airborne particulate generation. Radiation exposure risk would be minimal because the majority of the operations would be performed from enclosed construction equipment and the appropriate safety measures. Affected material dust generation could be a problem during filling operations and to a lesser degree during the slurry wall installation (if appropriate). Risks associated with inhalation of fugitive dusts are controllable through air monitoring, the use of proper health and safety equipment and dust suppression techniques. Air monitoring also would be used to identify potential off-site risks to the neighboring community.

If the on-site borrow area is used there would be minimal off-site truck traffic – primarily mobilization and demobilization. Access to U.S. Highway 6 would eliminate the need to move equipment through nearby residential areas. Otherwise equipment would be transported through the 12th Street Historic District and residential area. Some noise would be expected with the operation that could be noticed by nearby residents.

8.2.2.6 Alternative 2 - Implementability

The technical feasibility of capping the Site and installing a slurry wall relies on the use of conventional technology. Necessary equipment is readily available for implementation of this alternative. The alternative is administratively feasible, but long-term institutional controls must be considered. Permits may be required for on-site disposal.

8.2.2.7 Alternative 2 - Cost

Cost elements associated with Alternative 2 include the installation of the cap (and slurry wall), the installation of additional ground-water monitoring wells, long-term maintenance of the cap, and long-term ground-water monitoring. Assuming 100 years of maintenance and monitoring, the total present value of these requirements is estimated at $3,723,000 for Alternative 2A and $4,617,000 for Alternative 2 B. In addition to the above net present value costs, there is a cost associated with the loss in property value because of the remaining contaminants (see Section 8.3.7.1) and the land use restrictions. The estimated schedule is about four months for both Alternative 2A and 2B. Cost breakdown data for all of the alternatives are provided in Section 8.3.7.

8.2.2.8 Alternative 2 - State Acceptance

Although the alternative meets the requirements of the ARARs, recent problems associated with on-site disposal with the Shattuck Chemical Superfund Site in nearby Denver may reduce CDPHE acceptance.

8.2.2.9 Alternative 2 - Community Acceptance

Comments received during an open house conducted by the School indicated that local residents preferred the removal of the material.

8.2.3 Alternative 3 – 3A Radium-226 >15 pCi/g Removal or 3B Radium-226 >5 pCi/g Removal and Engineered Cap Covering Entire Site (both 3A and 3B)

This alternative is a variation of Alternative 2. Instead of leaving all of the material on-site, a portion would be removed and placed in a licensed disposal facility. The purpose of removal is to lower the overall risk of the Site. Alternative 3A uses a 15 pCi/g cutoff to determine the amount of material to be removed. The >15 pCi/g material is mostly located where the gamma survey showed elevated gamma radiation (see Figure 4-1). An estimated 500 to 1,000 cubic yards of material falls in this range. Alternative 3B uses a removal cutoff of 5 pCi/g. The majority of this material is located around the former buildings and covers about half of the Site. An estimated 5,000 cubic yards of material would be removed by this alternative.

Following the excavation and removal operations, Alternative 3 would require construction of an engineered cap to limit potential exposure to remaining metals and radionuclides. Cap construction would require an engineering design, movement of fill and capping material from the School borrow area or and off-site location, and grading, compaction, and testing of the fill / cap. The ground-water-monitoring network also would need to be upgraded. In accordance with 40 CFR §192.02(a), a long-term maintenance plan would be required to maintain cap integrity along with long-term ground water monitoring. Deed restrictions would be required that limited excavation and ensured the integrity of the cap. While construction has been allowed for some capped sites, it makes cap maintenance problematic. There also would be the requirement to permanently mark the lead-affected soil areas (EPA, OSWER 9285.7-50, August 2003). Radon abatement systems may be required for any on-site structures (Alternative 3A only).

8.2.3.1 Alternative 3 - Protection of Human Health and the Environment

Standard exposure pathways would be eliminated with the cap installation because the material would be inaccessible to receptors. RESRAD predicts essentially no dose or risk for the subsistence farmer scenario for both Alternative 3A and 3B (numerical RESRAD predictions provided below). RESRAD also predicts essentially no dose or risk for the recreational user for both alternatives. The only remaining pathway for metals exposure would be through ground water use (subsistence farmer), but institutional controls should be designed to prevent this use. However, if ground water were used and the activities/concentrations remain the same as current levels, a hazard index of 0.39 and as associated risk of 6.6×10^{-6} could be expected (primarily arsenic). Radium-226 would be a continuing source of radon gas but site specific concentrations would need to be determined by measurement. DCGLs were not determined for these alternatives because of the designated limits of 15 pCi/g or 5 pCi/g of Ra-226.

Alternative / Receptor	RESRAD Dose[1] (mrem/yr)	RESRAD Risk[1]	Hazard Index	RAIS Risk	Combined Risk[1,3] (RESRAD & RAIS)
3A – Farmhouse on Cap	1.7×10^{-23}	4.3×10^{-28}	0.39 (2,3)	6.6×10^{-6} (2,3)	6.6×10^{-6}
3A – Recreational User on Cap	3.1×10^{-25}	0	0 (2)	0 (2)	3.1×10^{-25}
3B – Farmhouse on Cap	7.9×10^{-24}	2.0×10^{-28}	0.39 (2,3)	6.6×10^{-6} (2,3)	6.6×10^{-6}
3B – Recreational User on Cap	1.5×10^{-25}	0	0 (2)	0 (2)	1.5×10^{-25}

[1] Radon pathway not included in risk or dose assessment
[2] Assumes clean cap and fill material
[3] Ground-water pathway at current concentrations

Alternative 3 would reduce the uncertainty associated with radionuclide material deeper in the soil column. Confirmation sampling would determine the limit of the material. Alternative 3A may leave some radionuclides in soil column that could be affected by future ground-water fluctuations (the alternatives include a cap but no slurry wall). Both alternatives do not address metals in the soil column, which could result in continued uncertainty for the ground water (i.e., meeting ground-water ARARs).

Strong institutional controls would be required to prevent the degradation of the cap or excavation of the affected material. Failure to maintain the institutional controls could jeopardize future protection of human health and the environment.

8.2.3.2 Alternative 3 - Compliance with ARARs

The alternative complies with most of the ARARs listed in Section 8.1, but some uncertainty remains for the ground water. Long-term ground water monitoring would be necessary to address that uncertainty. If the institutional controls include the requirement for radon mitigation for any structure, most of the ARARs would be met.

8.2.3.3 Alternative 3 - Long-term Effectiveness and Permanence

If the cap is maintained the alternative(s) would be effective, however permanence is more difficult to predict. Using the 1,000-year life recommended by 40 CFR §192.02, it would be difficult to anticipate the permanence of the remedy. The advantage of Alternative 3 is that a significant portion of the radionuclides would be removed from the Site reducing the overall toxicity, mobility, and volume. While cap designs are advertised as having life spans of this magnitude, there are no existing examples of this type of performance. A number of claims are made about caps providing a radon barrier (a concern for Alternative 3A) but this is highly dependent on maintaining moisture content. Semiarid climates make prescribed moisture content difficult to maintain.

8.2.3.4 Alternative 3 - Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative 3 does reduce the volume of the material and addresses the mobility issue, but by removal not treatment. The toxicity issue is addressed somewhat by the removal of a portion of the material, but again not through treatment.

8.2.3.5 Alternative 3 – Short-Term Effectiveness

Excavation and transport activities pose an elevated short-term exposure risk to on-site workers, transportation workers, and nearby residents due to airborne particulate generation. Direct exposure of workers during implementation of this alternative would be minimized through use of appropriate safety measures and procedural controls. The following table summarizes RESRAD predicted worker doses and risks associated with excavation activities. Conservative parameters were used in the model to predict upper limits for the operation. Assumptions included direct access to the soil when in fact workers will spend most of their time in excavation equipment. Area factors also must be considered for the worker exposure.

Worker Exposure	Dose (mrem/yr)	Risk
Entire Site – 6 months	2.0	4.2×10^{-5}
Elevated Areas – 1 month	1.4	3.2×10^{-5}

Hazards associated with metals would be expected to be minimal during remedial operations. Assuming two months of excavation operations in the elevated areas the RAIS model produced a hazard index of 0.28 and a risk of 2.0×10^{-7} (primarily arsenic through dermal and inhalation pathways). Again these values would be mitigated by material handling equipment and safety equipment. Risks associated with inhalation of fugitive dusts are controllable through air monitoring, the use of appropriate health and safety equipment and dust suppression techniques. Air monitoring also would be used to identify potential off-site risks to the neighboring community.

A low to moderate risk to the local area would be associated with the truck traffic required to move equipment and material (i.e., traffic accidents). Access to State Highway 6 would limit the risk to the immediate neighborhood, but could affect the local county (or counties). A somewhat higher risk is associated with transportation of the material through the neighborhood.

Based on worker risk assessment evaluations, there is a minimal short-term risk of potential adverse health consequences during a transportation-related accident. Exposure times would result in a risk significantly lower than the $1x10^{-6}$ threshold (assumes cleanup operations are completed within 24-hours and the only receptors are emergency response personnel). Typically access to transportation related spills is not allowed to members of the general public.

An accident involving an overturned truckload of affected material would have a small environmental risk if the material were to enter a drainage channel. However, the environmental risk would be limited because of the nature of the material (soil versus liquid) and containment procedures followed by emergency response teams.

Access to U.S. Highway 6 would eliminate the need to transport material and equipment through nearby residential areas. In the event that access to U.S. Highway 6 is not available, truck traffic through the 12th Street Historic District will likely result in public annoyance due to short-term noise and vibration in a residential area. Some operational noise would be expected that could be noticed by nearby residents.

8.2.3.6 Alternative 3 - Implementability

The technical feasibility of material excavation and a Site cap relies on the use of conventional technology. Necessary equipment and materials are readily available for implementation of this alternative.

Factors involving the administrative feasibility of the alternative include obtaining approval from the Colorado Department of Transportation (CDOT) for access to State Highway 6 and meeting the landfill acceptance criteria requirements. An application has been made to CDOT and a determination is expected by early January 2004. Local landfills have indicated a willingness to accept the material but a risk assessment will need to be performed to ensure acceptance criteria are met. Permits also may be required for on-site disposal.

8.2.3.7 Alternative 3 - Cost

Cost elements associated with Alternative 3 include material excavation and transportation to an off-site facility, installation of the cap, installation of additional or replacement ground-water monitoring wells, long-term maintenance of the cap, and long-term ground-water monitoring. Assuming 100 years of maintenance and monitoring, the total present value of these requirements is estimated at $4,083,000 for Alternative 3A and $5,180,000 for Alternative 3B. In addition to the above net present value costs, there is a cost associated with the loss in property value because of the remaining contaminants (see Section 8.3.7.1) and the land use restrictions. The estimated schedule is about five months for Alternative 3A and eight months for Alternative 3B. Cost breakdown data for all of the alternatives are provided in Section 8.3.7.

8.2.3.8 Alternative 3 - State Acceptance

Although the alternative meets the requirements of the ARARs, recent problems associated with on-site disposal at the Shattuck Chemical Superfund Site in nearby Denver may reduce CDPHE acceptance. In-state solid-waste landfill acceptance criteria may be an issue with CDPHE.

8.2.3.9 Alternative 3 - Community Acceptance

Comments received during an open house conducted by the School indicated that local residents preferred the removal of the material. This alternative removes a portion of the material.

8.2.4 Alternative 4 – 4A On-Site Solidification with Engineered Cap or 4B On-Site Disposal with Engineered Cell and Cap

All of the affected soil would be consolidated for these options and disposed of on site using solidified matrix (soil/concrete/fly ash mixture) or an engineered disposal cell. An engineered cap would be placed over both alternatives. An estimated 10,000 cubic yards of soil would be solidified or placed in the disposal cell. Alternative 4 assumes soils with radionuclides above DCGLs and metals above proposed residential soil standards would be consolidated. Arsenic would be the exception because the naturally occurring background concentrations are above the proposed soil standard. Arsenic would be removed to background concentrations.

Alternative 4A would begin with the solidification operation preparation. A properly sized area would be excavated to hold the total volume of the consolidated material and concrete / fly ash mixture. The required equipment would be mobilized to the Site and required materials would be stockpiled. The affected soil would then be excavated and sorted for use in the process. Once the solidification has been completed, the area would be re-graded and a cap would be installed using the material from the School borrow area or and an off-site location. Fill would need to be placed over the remaining site to bring the area to a useable grade and control storm-water. A ground-water-monitoring network would need to be placed around the solidified matrix.

Institutional controls would include deed restrictions for the 0.85-acre of land affected by the solidified matrix. The remainder of the property would be cleaned to a level that allowed unrestricted use. Deed restrictions associated with the solidified matrix would include limiting construction activities and excavation and ensure the integrity of the cap. While construction has been allowed for some capped sites, it makes cap maintenance problematic. In accordance with 40 CFR §192.02(a), a long-term maintenance plan would be required to maintain cap integrity along with long-term ground water monitoring. Deed restrictions also should include a requirement for radon evaluation prior to the construction of any structure above the solidified matrix.

Alternative 4B would begin with the engineering and placement of a disposal cell. A properly sized area would be excavated to hold the cell. A clay liner base would be installed followed by a geosynthetic liner. The affected soil would then be excavated and transferred into the cell. Once all of the material is in the disposal cell, a second geosynthetic liner will be placed over the cell (encapsulating the material) and a cap will be installed using the material from the School borrow area or an off-site location. Once the encapsulation has been completed, the area would be re-graded. Fill would need to be placed over the remaining Site to bring the area to a useable grade and control storm-water.

Institutional controls for both alternatives would include deed restrictions for the 0.85-acre of land affected by the solidified matrix or the 1.0-acre of land affected by the disposal cell. The remainder of the property would be available for unrestricted use. Deed restrictions associated with the solidified matrix or disposal cell would include limiting construction activities and excavation and ensure the integrity of the cap. While construction has been allowed for some capped sites, it makes cap maintenance problematic. In accordance with 40 CFR §192.02(a), a long-term maintenance plan would be required to maintain cap integrity along with long-term ground water monitoring. Deed restrictions also should include a requirement for radon evaluation prior to the construction of any structure above the solidified matrix or disposal cell.

8.2.4.1 *Alternative 4 - Protection of Human Health and the Environment*

Solidification or disposal cell placement coupled with an engineered cap would eliminate the standard exposure pathways. Assuming a farmhouse built directly over the solidified matrix (Alternative 4A), RESRAD predicts essentially no dose (see table in this section) and no excess cancer risk for the subsistence farmer receptor. This assumes clean cap and cover material was used over the solidified material. The radium-226 would be a continuing source of radon gas but site specific concentrations would need to be determined by measurement. Radon abatement systems should be a requirement for any structure or building construction should be prohibited above the solidified matrix. Alternative 4A would produce no dose or risk for the recreational user assuming clean cap and fill material is used.

Again assuming a farmhouse built directly over the disposal cell (Alternative 4B), RESRAD predicts essentially no dose (see table in this section) and no excess cancer risk for the subsistence farmer receptor. Clean cap and cover materials were assumed. As with 4A, radium-226 would be a continuing source of radon gas but site specific concentrations would need to be determined by measurement. Radon abatement systems should be a requirement for any structure or building construction should be prohibited above the solidified material. Alternative 4B would produce no dose or risk for the recreational user assuming clean cap and fill material is used.

If clean cap and cover materials are used the hazard index and risk associated with metals would be would be expected to be zero for both Alternative 4A and 4B.

Alternative / Receptor	RESRAD Dose (mrem/yr)	RESRAD Risk[1]	Hazard Index	RAIS Risk	Combined Risk[1] (RESRAD & RAIS)
4A – Farmhouse over Solidification	$2.1x10^{-26}$	0	0 [(2)]	0 [(2)]	$2.1x10^{-26}$
4B – Farmhouse over Disposal Cell	$1.9 x10^{-26}$	0	0 [(2)]	0 [(2)]	$1.9 x10^{-26}$
4A&B – Subsistence Farmer – After Removal	$6.0x10^{-2}$	$1.1x10^{-6}$	0.58	$3.5x10^{-5}$	$3.6x10^{-5}$
4A&B – Recreational User – After Removal	$4.8x10^{-4}$	$1.1x10^{-8}$	0.022	$6.6x10^{-7}$	$6.7x10^{-7}$

[1] Radon pathway not included in risk or dose assessment
[2] Assumes clean cap and fill material

RESRAD predicted a dose of $6.0x10^{-2}$ mrem/yr and a risk of $1.1x10^{-6}$ (subsistence farmer) for the remainder of the property after material removal. This assumes no backfilling of the Site. The predicted recreational user dose and risk are $4.8x10^{-4}$ mrem/yr and $1.1x10^{-8}$ respectively. Radon doses and risks were not calculated because of the associated uncertainties. Site specific measurements would be recommended because of the natural background radioactivity of some Colorado soils.

To produce a material removal data set for the RESRAD model, surface soil samples that contained combined radium above 5 pCi/g and metals (except arsenic) above proposed residential soil standards were eliminated from the data set. Samples containing arsenic concentrations above background also were eliminated. The lognormal average activities of the remaining samples were used for the RESRAD input parameters. Except for thorium-230 (remaining activity 0.13 pCi/g), all of the radionuclide activities were zero after subtracting background activities. However, a small amount of activity was left in the model (0.0001 to 0.001 pCi/g) because cleanups rarely accomplish complete removal. Actual activities and concentrations following cleanup will be verified by confirmation sampling.

An after-cleanup metals data set was generated in the same fashion as the radionuclide data set. RAIS predicted a risk of $3.5x10^{-5}$ and a hazard index of 0.58 for the subsistence farmer, primarily due to the remaining arsenic. A risk of $6.7x10^{-7}$ and a hazard index of 0.022 were predicted for the recreational user, again primarily driven by arsenic.

Ground-water use would be one pathway (subsistence farmer) that could remain after the remedial operation. Typically there is a time delay prior to noticeable decreases in ground-water activities or concentrations after the removal operations have been completed (natural attenuation). If the ground water were used during this period of time, there would be associated risks and hazards. Using average ground-water activities and concentrations from the one-year ground-water-monitoring program produces a combined metals and radionuclide risk as high as $1.3x10^{-4}$ and a hazard index of 0.70 (primarily radionuclides and arsenic). It is unlikely that the ground water would be used as a drinking water source in the foreseeable future because of the local water distribution system. The poor drinking water quality of the Laramie Fox-Hills aquifer would probably minimize the potential for future use.

DCGLs for the removal of affected soil were calculated and are listed below:

Radionuclide	**Subsistence Farmer (15 mrem/yr)**	**Recreational User (15 mrem/yr)**	**Subsistence Farmer (25 mrem/yr)**	**Recreational User (25 mrem/yr)**
Radium-226	0.84	120	1.4	190
Radium-228	1.4	140	2.4	230
Thorium-228	2.7	150	4.6	260
Thorium-230	3.8	360	6.4	600
Thorium-232	0.96	83	1.6	140
Uranium-234	14	42,000	24	71,000
Uranium-235	3.2	1,700	5.3	2,800
Uranium-238	15	7,300	25	12,000

Note: All units in picocuries per gram

The DCGLs are driven by the receptor definition and the specified basic radiation dose limit. The recreational user can obviously tolerate significantly higher on-site radionuclide activities because of the limited amount of time spent on the Site. However, the DCGLs for the subsistence farmer are much lower because of exposure time and multiple pathways. The DCGL table shows the difference between the 15 and 25 mrem/yr allowable doses. To provide unrestricted use of the Site after cleanup the subsistence farmer using the 15 mrem/yr dose was assumed for the soil removal operation. Actual activities and concentrations following cleanup will be verified by confirmation sampling. Because there are multiple on-site radionuclides, the sum-of-the-fractions rule will apply during cleanup activities.

MARSSIM defined area factors were determined for the portions of the Site where elevated gamma readings were measured and analytical results indicated elevated activities. A 20-m x 20-m area in the vicinity of the former Building 101N was used to determine Site specific area factors. An initial DCGL (1.227 pCi/g) was determined for the Building 101N area using the average of actual sample activities. Radium-226 was selected as the radionuclide of concern. The following area factors were determined using a 15 mrem/yr dose.

Source Area (m^2)	Dose Rate (mrem/yr)	Area Factor	$DCGL_W$ (pCi/g)
400	14.98	1	1.227
225	11.69	1.28	1.227
100	8.607	1.74	1.227
36	6.242	2.40	1.227
25	5.518	2.71	1.227
16	4.689	3.19	1.227
9	3.516	4.26	1.227
4	2.261	6.63	1.227
1	0.644	23.3	1.227

The area factors are used in combination with confirmation sampling to determine if the required cleanup activities have been met.

Institutional controls for the disposal area would be required to prevent the degradation of the cap or excavation into the solidified structure or disposal cell. Failure to maintain the institutional controls could jeopardize future protection of human health and the environment.

8.2.4.2 Alternative 4 - Compliance with ARARs

Alternative 4 complies with all the ARARs listed in Section 8.1, with the exception of ground water requirements and potentially the radon standard (if a structure is built on top of the on-site disposal areas). Ground-water radionuclide activities and metals concentrations would be expected to decrease with time once the source material is removed. Short-term restrictions on ground-water use coupled with a limited ground-water-monitoring program would be needed to meet ARARs and provide unrestricted use of property not affected by the disposal areas. Long-term ground-water monitoring would be required for the disposal areas. Alternative 4 probably would not be considered ALARA because of the costs associated with the option.

8.2.4.3 Alternative 4 - Long-term Effectiveness and Permanence

If the cap is maintained the alternative(s) would be effective, however permanence is more difficult to predict. Using the 1,000-year life recommended by 40 CFR §192.02, it would be difficult to anticipate the permanence of the remedy. The solidified material would be more resistant to damage than the disposal cell, but loss of the cap would be problematic for both 4A and 4B. Cap designs are advertised as having life spans of this magnitude, there are no existing examples of this type of performance. A number of claims are made about caps providing a radon barrier but this is highly dependent on maintaining moisture content. Semiarid climates make prescribed moisture content difficult to maintain. The long-term integrity of the solidified matrix for Alternative 4A also is uncertain.

8.2.4.4 Alternative 4 - Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative 4A addresses the toxicity (reduces bioavailability) and mobility of the material through treatment (solidification), but the volume actually increases (typically 20-percent or more). Alternative 4B addresses the mobility and toxicity but not through treatment. There is no volume reduction.

8.2.4.5 Alternative 4 - Short Term Effectiveness

Excavation activities pose an elevated short-term exposure risk to on-site workers, transportation workers, and nearby residents due to airborne particulate generation. Alternative 4A potentially would generate additional air particulate because of mixing and grinding operations. Direct exposure of workers during implementation of this alternative would be minimized through use of appropriate safety measures and procedural controls. The following table summarizes RESRAD predicted worker doses and risks associated with excavation activities. Conservative parameters were used in the model to predict upper limits for the operation. Assumptions included direct access to the soil when in fact workers will spend most of their time in excavation equipment. Area factors also must be considered for the worker exposure.

Worker Exposure	Dose (mrem/yr)	Risk
Entire Site – 6 months	2.0	4.2×10^{-5}
Elevated Areas – 1 month	1.4	3.2×10^{-5}

Hazards associated with metals would be expected to be minimal during remedial operations. Assuming two months of excavation operations in the elevated areas the RAIS model produced a hazard index of 0.28 and a risk of 2.0×10^{-7} (primarily arsenic through dermal and inhalation pathways). Again these values would be mitigated by material handling equipment and safety equipment. Risks associated with inhalation of fugitive dusts are controllable through air monitoring, the use of appropriate health and safety equipment and dust suppression techniques. Air monitoring also would be used to identify potential off-site risks to the neighboring community.

A low to moderate risk to the local area would be associated with the truck traffic required to move equipment and supplies to the Site (i.e., traffic accidents). Access to State Highway 6 would limit the risk to the immediate neighborhood, but could affect the local county (or counties). A somewhat higher risk is associated with transportation of equipment and supplies through the neighborhood.

8.2.4.6 *Alternative 4 - Implementability*

The technical feasibility of material consolidation into an on-site disposal cell cap relies on the use of conventional technology. Necessary equipment and supplies are readily available for implementation of this alternative. The solidification alternative can be more problematic. This technology has been used successfully on a number of sites but there have been failures because of improper determination of the necessary mix of soil and concrete. Pilot tests would be necessary to determine the proper mixture, but these tests can be inconclusive if there is significant soil heterogeneity. A pilot test was completed for the Stockpile (RAOA), but the soil type was not consistent with Site soils (Stockpile was mostly sand, Site soils have significant clay). If the mixture is accurately determined, the necessary equipment and supplies are readily available. Pilot tests were not completed as part of the FS because of the known higher costs of the solidification alternative.

The alternative is administratively feasible, but long-term institutional controls for the disposal areas must be considered. Permits may be required for on-site disposal.

8.2.4.7 *Alternative 4 - Cost*

Cost elements associated with Alternative 4A include material excavation and consolidation, mobilization and demobilization of the equipment needed to produce the solidified structure, materials, installation of the cap, re-grading of the Site, installation of the ground-water monitoring wells, long-term maintenance of the cap, and long-term ground-water monitoring. Assuming 100 years of maintenance and monitoring, the total present value of these requirements is estimated at $5,568,000. In addition to the above net present value cost, there is a cost associated with the loss in property value because of the remaining contaminants (see Section 8.3.7.1) and the land use restrictions. The estimated schedule for Alternative 4A is about eight months.

Cost elements associated with Alternative 4B include material excavation and consolidation, construction of the disposal cell, materials, installation of the cap, re-grading of the Site, installation of the ground-water monitoring wells, long-term maintenance of the cap, and long-term ground-water monitoring. Assuming 100 years of maintenance and monitoring, the total present value of these requirements is estimated at $5,095,000. In addition to the above net present value cost, there is a cost associated with the loss in property value because of the remaining contaminants and the land use restrictions. The estimated schedule for Alternative 4B is about seven months.

Cost breakdown data for all of the alternatives are provided in Section 8.3.7.

8.2.4.8 Alternative 4 - State Acceptance

Although the alternative meets the requirements of the ARARs, recent problems associated with on-site disposal with the Shattuck Chemical Superfund Site in nearby Denver, may reduce CDPHE acceptance.

Alternative 4A would undergo close CDPHE scrutiny because of the Shattuck Site. EPA selected on-site stabilization and solidification for soils (concrete and fly ash) and natural attenuation for ground water in the 1992 Record of Decision for the Shattuck Site. At the time, this met the statutory preference for a remedy although it increased the mass of materials and created a monolith. EPA conducted a five-year-review of the Shattuck Site and found deficiencies in the monolith cover design, the integrity of the monolith, and the monolith's compliance program. Based on these findings, EPA could not be assured of the long-term protection of the original remedy. In addition to the technical concerns raised by the five-year review, the State, Denver, elected officials, and the local community requested that EPA consider other alternatives to the on-site remedy to allow for unrestricted use of the Site. The monolith is now being demolished and shipped out of state.

8.2.4.9 Alternative 4 - Community Acceptance

Comments received during an open house conducted by the School indicated that local residents preferred the removal of the material.

8.2.5 Alternative 5 – 5A Excavation and Off-Site Disposal All Affected Material Using - One Landfill or 5B Excavation and Off-Site Disposal All Affected Material - Using Two Landfills

Alternative 5 is the excavation and removal of all of the radionuclide and metal affected soil using site-specific DCGLs and proposed residential soil standards as cleanup levels. Arsenic would be the exception because the naturally occurring background concentrations are above the proposed soil standard. Arsenic would be removed to background concentrations.

The material would be consolidated into stockpiles and then shipped to a licensed disposal facility. Alternative 5A uses a single landfill for all of the material. The assumption used for Alternative 5B is that a portion of the material may not meet landfill acceptance criteria and an alternative landfill would be used for that portion. An estimated 10,000 cubic yards of material would be removed from the Site for both alternatives. Alternative 5B assumes a to-be-determined quantity that would go to a specialized landfill.

8.2.5.1 Alternative 5 - Protection of Human Health and the Environment

Both Alternative 5A and 5B assume complete removal of the affected material. The RESRAD predicts a dose of 6.0×10^{-2} mrem/yr and a risk of 1.1×10^{-6} (subsistence farmer) for the remainder of the property after material removal. These dose and risk levels assume no backfilling of the Site. Re-grading operations required for storm-water control, safety, and Site restoration (to allow beneficial use of the Site) would reduce the dose and risk even further (assuming clean fill). Doses and risks associated with radon were not calculated because of the variability previously mentioned. Radon doses and risks were not calculated because of the associated uncertainties. Site specific measurements would be recommended because of the natural background radioactivity of some Colorado soils. The removal of the majority of the radium-226 should significantly reduce radon concentrations.

Alternative / Receptor	RESRAD Dose (mrem/yr)	RESRAD Risk[1]	Hazard Index	RAIS Risk	Combined Risk[1] (RESRAD & RAIS)
5A&B – Subsistence Farmer – After Removal	6.0×10^{-2}	1.1×10^{-6}	0.58	3.5×10^{-5}	3.6×10^{-5}
5A&B – Recreational User – After Removal	4.8×10^{-4}	1.1×10^{-8}	0.022	6.6×10^{-7}	6.7×10^{-7}

[1] Radon pathway not included in risk or dose assessment
[2] Assumes clean cap and fill material

To produce a material removal data set for the RESRAD model, surface soil samples that contained combined radium above 5 pCi/g and metals (except arsenic) above proposed residential soil standards were eliminated from the data set. Samples containing arsenic concentrations above background also were eliminated. The lognormal average activities of the remaining samples were used for the RESRAD input parameters. Except for thorium-230 (remaining activity 0.13 pCi/g), all of the radionuclide activities were zero after subtracting background activities. However, a small amount of activity was left in the model (0.0001 to 0.001 pCi/g) because cleanups rarely accomplish complete removal. Actual activities and concentrations following cleanup will be verified by confirmation sampling.

An after-cleanup metals data set was generated in the same fashion as the radionuclide data set. RAIS predicted a risk of 3.5×10^{-5} and a hazard index of 0.58 for the subsistence farmer, primarily due to the remaining arsenic. A risk of 6.7×10^{-7} and a hazard index of 0.022 were predicted for the recreational user, again primarily driven by arsenic.

Ground-water use would be one pathway (subsistence farmer) that could remain after the remedial operation. Typically there is a time delay prior to noticeable decreases in ground-water activities or concentrations after the removal operations have been completed (natural attenuation). If the ground water were used during this period of time, there would be associated risks and hazards. Using average ground-water activities and concentrations from the one-year ground-water-monitoring program produces a combined metals and radionuclide risk as high as 1.3×10^{-4} and a hazard index of 0.70 (primarily radionuclides and arsenic). It is unlikely that the ground water would be used as a drinking water source in the foreseeable future because of the local water distribution system. The poor drinking water quality of the Laramie Fox-Hills aquifer also would probably minimize the potential for future use.

DCGLs for the removal of affected soil were calculated and are listed below:

Radionuclide	Subsistence Farmer – 15 mrem/yr	Recreational User – 15 mrem/yr	Subsistence Farmer – 25 mrem/yr	Recreational User – 25 mrem/yr
Radium-226	0.84	120	1.4	190
Radium-228	1.4	140	2.4	230
Thorium-228	2.7	150	4.6	260
Thorium-230	3.8	360	6.4	600
Thorium-232	0.96	83	1.6	140
Uranium-234	14	42,000	24	71,000
Uranium-235	3.2	1,700	5.3	2,800
Uranium-238	15	7,300	25	12,000

Note: All units in picocuries per gram

The DCGLs are driven by the receptor definition and the specified basic radiation dose limit. The recreational user can obviously tolerate significantly higher on-site activities because of the limited amount of time spent on the Site. However, the DCGLs for the subsistence farmer are much lower because of exposure time and multiple pathways. The DCGL table shows the difference between the 15 and 25 mrem/yr allowable doses. To provide unrestricted use of the Site after cleanup the subsistence farmer using the 15 mrem/yr dose was assumed for the soil removal operation. Actual activities and concentrations following cleanup will be verified by confirmation sampling. Because there are multiple on-site radionuclides, the sum-of-the-fractions rule will apply during cleanup activities.

MARSSIM defined area factors were determined for the portions of the Site where elevated gamma readings were measured and analytical results indicated elevated activities. A 20-m x 20-m area in the vicinity of the former Building 101N was used to determine Site specific area factors. An initial DCGL (1.227 pCi/g) was determined for the Building 101N area using the average of actual sample activities. Radium-226 was selected as the radionuclide of concern. The following area factors were determined using a 15 mrem/yr dose.

Source Area (m^2)	**Dose Rate (mrem/yr)**	**Area Factor**	**$DCGL_W$ (pCi/g)**
400	14.98	1	1.227
225	11.69	1.28	
100	8.607	1.74	
36	6.242	2.40	
25	5.518	2.71	
16	4.689	3.19	
9	3.516	4.26	
4	2.261	6.63	
1	0.644	23.3	

The area factors are used in combination with confirmation sampling to determine if the required cleanup activities have been met.

8.2.5.2 Alternative 5 - Compliance with ARARs

Alternative 5 complies with all of the ARARs listed in Section 8.1, with the possible exception of some requirements for short term ground-water monitoring. Landfill disposal criteria need to be addressed to determine which alternative would be appropriate for off-site disposal. Of all the alternatives considered, Alternative 5 appears to meet ALARA requirements.

8.2.5.3 Alternative 5 – Long-Term Effectiveness and Permanence

Disposal at a solid waste landfill successfully mitigates the potential long-term effects associated with the elevated metals and radionuclides on the Site. This alternative provides unrestricted use for the entire property.

8.2.5.4 Alternative 5 - Reduction of Toxicity, Mobility, or Volume through Treatment

This alternative does not reduce the toxicity, mobility, or volume of affected material through treatment. All of the material is moved to an off-site landfill where it can be properly managed, but no treatment would be expected.

8.2.5.5 Alternative 5 - Short Term Effectiveness

Excavation and transport activities pose an elevated short-term exposure risk to on-site workers, transportation workers, and nearby residents due to airborne particulate generation. Direct exposure of workers during implementation of this alternative would be minimized through use of appropriate safety measures and procedural controls. The following table summarizes RESRAD predicted worker doses and risks associated with excavation activities. Conservative parameters were used in the model to predict upper limits for the operation. Assumptions included direct access to the soil when in fact workers will spend most of their time in excavation equipment. Area factors also must be considered for the worker exposure.

Worker Exposure	Dose (mrem/yr)	Risk
Entire Site – 6 months	2.0	$4.2x10^{-5}$
Elevated Areas – 1 month	1.4	$3.2x10^{-5}$

Hazards associated with metals would be expected to be minimal during remedial operations. Assuming two months of excavation operations in the elevated areas the RAIS model produced a hazard index of 0.28 and a risk of $2.0x10^{-7}$ (primarily arsenic through dermal and inhalation pathways). Again these values would be mitigated by material handling equipment and safety equipment. Risks associated with inhalation of fugitive dusts are controllable through air monitoring, the use of appropriate health and safety equipment and dust suppression techniques. Air monitoring also would be used to identify potential off-site risks to the neighboring community.

A low to moderate risk to the local area would be associated with the truck traffic required to move equipment and material (i.e., traffic accidents). Access to State Highway 6 would limit the risk to the immediate neighborhood, but could affect the local county (or counties). A somewhat higher risk is associated with transportation of the material through the neighborhood.

Based on worker risk assessment evaluations, there is a minimal short-term risk of potential adverse health consequences during a transportation-related accident. Exposure times would result in a risk significantly lower than the $1x10^{-6}$ threshold (assumes cleanup operations are completed within 24-hours and the only receptors are emergency response personnel). Typically access to transportation related spills is not allowed to members of the general public.

An accident involving an overturned truckload of affected material would have a small environmental risk if the material were to enter a drainage channel. However, the environmental risk would be limited because of the nature of the material (soil versus liquid) and containment procedures followed by emergency response teams.

Access to U.S. Highway 6 would eliminate the need to transport material and equipment through nearby residential areas. In the event that access to U.S. Highway 6 is not available, truck traffic through the 12th Street Historic District will likely result in public annoyance due to short-term noise and vibration in a residential area. Some operational noise would be expected that could be noticed by nearby residents.

8.2.5.6 Alternative 5 - Implementability

The technical feasibility of off-site disposal at a solid waste landfill relies on use of conventional excavation and transport technology. Necessary equipment is readily available for implementation of this alternative.

Factors involving the administrative feasibility of the alternative include obtaining approval from the Colorado Department of Transportation (CDOT) for access to State Highway 6 and meeting the landfill acceptance criteria requirements. An application has been made to CDOT and a determination is expected by early January 2004. Some local landfills have indicated a willingness to accept the material but a risk assessment will need to be performed to ensure acceptance criteria are met.

8.2.5.7 Alternative 5 - Cost

Cost elements associated with Alternative 5A include material excavation and stockpiling, transportation, and re-grading of the Site. After the source removal a limited amount of ground-water monitoring may be required. The total present value of these cost elements is estimated at $3,380,000. Property values are not be significantly affected by this alternative because the land will be available for unrestricted use (see Section 8.3.7.1). The estimated schedule for Alternative 5A is about six months.

Cost elements associated with Alternative 5B include material excavation and stockpiling, separation of specific soils, transportation to two locations, and re-grading of the Site. After the source removal a limited amount of ground-water monitoring may be required. The total present value of these cost elements is estimated at $3,714,000. Property values are not significantly affected by this alternative because the land will be available for unrestricted use (see Section 8.3.7.1). The estimated schedule for Alternative 5B is about six months.

Cost breakdown data for all of the alternatives are provided in Section 8.3.7.

8.2.5.8 Alternative 5 - State Acceptance

Although the alternative meets the requirements of the ARARs, in-state landfill acceptance criteria may be an issue with CDPHE.

8.2.5.9 Alternative 5 - Community Acceptance

Comments received during an open house conducted by the School indicated that local residents preferred this alternative.

8.3 Comparative Analysis of Alternatives

The purpose of this section is to evaluate the relative performance of each alternative in relation to the other alternatives. A brief summary of the alternatives and the nine evaluation criteria is presented in the following table. A detailed evaluation of the alternatives follows.

Alternative	**Protective of Human Health & Environment**	ARAR COMPLIANCE	**Long-term Effectiveness and Permanence**	**Reduction of Toxicity, Mobility, or Volume through Treatment**	**Short-term Effectiveness**	**Implementability (Feasibility)**	**Cost Ranking[1]**	**Cost Ranking[2]**	**State Acceptance**	**Community Acceptance**
1 - No further action	N	N	N	N	N	L	1	3	N	N
2A - Engineered cap	U	U	U	N	Y	M	4	5	U	U
2B - Engineered cap and slurry wall	U	U	U	N	Y	M	6	8	U	U
3A - Engineered cap with partial removal (areas with combined radium activity >15 pCi/g)	U	U	U	N	Y	M	5	7	U	U
3B - Engineered cap with partial removal (areas with combined radium activity >5 pCi/g)	U	U	U	N	Y	M	8	9	U	U
4A - On-site solidification with engineered cap	Y	U	U	Y	Y	M	9	6	U	U
4B - On-site engineered disposal cell	Y	U	U	N	Y	H	7	4	U	U
5A - Off-site disposal at solid waste facility	Y	Y	Y	N	Y	H	2	1	U	Y
5B - Off-site disposal at solid waste facility and portion to special waste facility	Y	Y	Y	N	Y	H	3	2	U	Y

Notes: Evaluation based on subsistence farmer; Y, addresses criteria; N, does not address criteria; U, uncertainty associated with this element; Implementability factors, highly feasible (H) through problematic (L); Rankings range lowest to highest cost
[1] Cost rankings do not include the loss in property value (see Section 8.3.7.1)
2 Cost ranking includes loss in property value (see Section 8.3.7.1).

8.3.1 Protection of Human Health and the Environment

Alternative 1, the no further action alternative, does not provide adequate protection of human health and the environment because it does not adequately address the exposure pathways. It can be argued that the security fence adequately addresses direct contact, but the alternative does not address the migration of metals and radionuclides to ground water. Unauthorized Site access by neighborhood children also is a possibility with this alternative. Trespassers have already breached the existing security fence on a number of occasions.

Alternatives 2 through 5 effectively address the direct exposure pathways by either preventing access to the material using caps and a variety of containment options or by removing the material from the Site. However, there are uncertainties associated with the ground-water pathway for Alternatives 2A, 3A and 3B. Ground-water fluctuations and the presence of a City of Golden water main provide potential mechanisms for migration of affected material. The following table summarizes some of the factors associated with the protection of human health and the environment criteria. Factors associated with the ARARs criteria also are included.

A short-term ground-water-monitoring program may be required for Alternatives 4 and 5 because of residual metals and radionuclides remaining in the ground-water system. The solidified matrix or disposal cell associated with Alternative 4 would require long-term ground-water monitoring.

Alternative	**Risk <10^{-6}**	**RISK 10^{-6} TO 10^{-4}**	**Risk <10^{-4}**	**Dose <15 mrem/yr**	**Dose <25 mrem/yr**	**Ra-226 + Ra-228 <5 pCi/g**	**Hazard Index <1**	**PbB >10 µg/dL**	**Soil Lead <1200 mg/kg**	**Soil Lead <400 mg/kg**	**Protective of Ground Water**	**Satisfies ALARA**
1 - No further action	N	N	N	N	N	N	N	N	N	N	N	N
2A - Engineered cap	Y	Y	Y	Y	Y	N1	Y	Y	N1	N1	U	U
2B - Engineered cap and slurry wall	Y	Y	Y	Y	Y	N1	Y	Y	N1	N1	U	U
3A - Engineered cap with partial removal (areas with combined radium activity >15 pCi/g)	Y	Y	Y	Y	Y	N1	Y	Y	N1	N1	U	U
3B - Engineered cap with partial removal (areas with combined radium activity >5 pCi/g)	Y	Y	Y	Y	Y	Y	Y	Y	N1	N1	U	U
4A - On-site solidification with engineered cap	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	U	U
4B - On-site engineered disposal cell	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	U	U
5A - Off-site disposal at solid waste facility	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y1	Y
5B - Off-site disposal at solid waste facility and portion to special waste facility	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y1	Y

Notes: Evaluation based on subsistence farmer; Y, meets requirement; N, does not meet requirement; N1, exposure is controlled but material remains in soil, U, uncertainty associated with this element; Y1, short-term ground-water monitoring may be required.

The alternative that would provide the most protection to human health and the environment in the vicinity of the Site is Alternative 5.

8.3.2 <u>Compliance with ARARs</u>

Alternative 1 does not meet the ARARs that have been identified for the Site. Alternative 2A, 3A, and

3B comply with ARARs by limiting access to the affected material, but a source remains for possible migration to ground water. The capping material would eliminate the infiltration of precipitation, but ground-water fluctuations could be problematic. Alternatives 4 and 5 are compliant with ARARs either by consolidating and containing the affected material on site or by removal of the affected material.

Alternatives 4 and 5 have the least uncertainty associated with the site-specific ARARs.

8.3.3 Long-Term Effectiveness and Permanence

8.3.3.1 Magnitude of Residual Risk

Alternative 1 has no long-term effectiveness or permanence because the material would remain in place and be a continuing source of hazard and risk to human health and the environment. This alternative would have the largest remaining risk for the Site and surrounding area. Although fencing may prevent direct contact, wind and water erosion would move the material off site. Precipitation would continue to cause the material to migrate to ground water. Access by neighborhood children would be a continuing problem.

The remaining alternatives would sufficiently address residual risk although there is some uncertainty associated with the ground-water pathway for Alternatives 2A, 3A, and 3B. All of the alternatives that involve a cap would have a degree of uncertainty associated with long-term permanence. Cap breakdown could result in significant risks to human health and the environment.

8.3.3.2 Adequacy and Reliability of Controls

Alternatives 2 through 4 rely on containment systems and institutional controls to ensure protection of human health and the environment. A number of uncertainties are associated with these types of controls and need to be addresses when evaluating the Alternatives.

The provision in 40 CFR §192.02 that requires the controls measures to be effective for 1,000 years (at least 200 years) when certain radionuclides are involved. Long-term effectiveness of caps can be compromised by failure to implement institutional controls and the lack of maintenance. In addition to human activities, freeze-thaw cycles, vegetation and burrowing animals can compromise cap material. Slurry walls (Alternative 2B) also can be compromised by human activities (e.g., pipeline leaks). The literature references to problems with the leaching of mercury and arsenic from solidified matrixes (Alternative 4A). The magnitude of this effect would be site specific but could be problematic in the long term.

8.3.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative 4A is the only alternative that addresses the material through treatment. Toxicity and mobility are addressed because the matrix prevents material migration and reduces toxicity through reduced bioavailability. Properly maintained the solidified matrix would be expected to remain intact for an extended period of time. But as mentioned in Section 7.3, there is some question about the leaching of arsenic and mercury.

Alternatives 2 through 4 use caps to address toxicity and mobility by limiting contact and infiltration. On-site volumes are reduced or eliminated in Alternatives 3 and 5, with the complete removal of affected material for Alternative 5. Alternatives 3 and 5 produce no net reduction in metals or radionuclides, just relocation.

8.3.5 Short-Term Effectiveness

8.3.5.1 Risks to Community

All of the alternatives except Alternative 1 (no-further action) involve some short-term risk to the surrounding community. A low to moderate risk would be associated with the truck traffic required to move equipment or material (i.e., traffic accidents). Access to State Highway 6 would limit the risk to the immediate neighborhood, but could affect the local county (or counties). A somewhat higher risk is associated with transportation of the material through the neighborhood. Based on the number of trucks required to complete the task, Alternatives 5A and 5B would be the highest risk, followed by Alternatives 3B and 3A.

Based on worker risk assessment evaluations (see section 8.3.5.2), there is a minimal short-term risk of potential adverse health consequences during a transportation-related accident. Exposure times would result in a risk significantly lower than the $1x10^{-6}$ threshold (assumes cleanup operations are completed within 24-hours and the only receptors are emergency response personnel). Typically access is not allowed to members of the general public.

The potential for air emissions during implementation of the selected remedial action will be controlled by dust control measures (e.g., limiting operations during high velocity winds and use of water spray). Control measures will be monitored by the installation of perimeter air monitoring to evaluate controls on a day-to-day basis.

Alternative 5 followed by Alternative 3B have the highest short-term risk for the surrounding community because of the number of loads of affected soil. The risk applies only to traffic accidents, not to exposure to affected soils. The remaining alternatives would have a lesser effect on the community because of limited transportation operations.

8.3.5.2 *Risks to Workers*

A summary of short-term dose and risk to workers is provided below. The assessment assumes an average of 6 months of exposure to the Site materials. A second set of values is provided for the time spent in the areas of elevated concentrations. These values are provided to show the magnitude of the risk. Values for specific alternatives could be expected to be somewhat higher or lower but by less than an order of magnitude. The primary pathway is the radiation exposure route, but this would be limited by the amount of time spent in material handling equipment and required safety equipment. Crushing operations associated with Alternative 4A would generate the greatest inhalation risk, but again would be controlled by safety equipment. Personal air monitoring equipment will be used to monitor workers during all on-site operations.

Worker Exposure	Dose (mrem/yr)	Risk
Entire Site – 6 months	2.0	$4.2x10^{-5}$
Elevated Areas – 1 month	1.4	$3.2x10^{-5}$

Hazards associated with metals would be expected to be minimal during remedial operations. Assuming two months of excavation operations in the elevated areas produced hazard index of 0.28 and a risk of $2.0x10^{-7}$. Again these values would be mitigated by material handling equipment and safety equipment.

Worker exposure would be the greatest for Alternative 4A because of the mixing and grinding operations. Alternatives 4B, 5A, and 5B would have lesser risk followed by Alternative 3A and 3B (less soil excavation). Alternative 2A and 2B would have limited risk because the soil is not excavated.

8.3.5.3 *Environmental Effects*

Storm-water controls will be used to prevent affected material from leaving the Site and affecting environmental receptors. The largest short-term risk to the environment is a delay in schedule that would allow addition material to migrate to ground water and eventually to Clear Creek. Extended schedule delays also could result in the re-vegetation of the Site along with a variety of insect or animal receptors. Materials such as mercury do bioaccumulate and could be a long-term risk. Alternative 1 is the primary example of environmental risk.

A limited environmental risk is associated with transportation of the material to off-site landfills. An accident involving an overturned truckload of affected soil would have a small environmental risk if the material were to enter a drainage channel. However, the environmental risk would be limited because of the nature of the material (soil versus liquid) and containment procedures followed by emergency response teams.

8.3.5.4 Timeline

Estimated schedules for the Alternatives are provided below:

Alternative	**Description**	**Estimated Schedule (months)**
1	No further action	NA
2A	Engineered cap	4
2B	Engineered cap and slurry wall	4
3A	Engineered cap with partial removal[2] (areas with combined radium activity >15 pCi/g)	5
3B	Engineered cap with partial removal[3] (areas with combined radium activity >5 pCi/g)	8
4A	On-site solidification with engineered cap	8
4B	On-site engineered disposal cell	7
5A	Off-site disposal at solid waste facility	6
5B	Off-site disposal at solid waste facility and portion to specialized waste facility	6

8.3.6 Implementability

8.3.6.1 Technical Feasibility

Alternative 1, No-Further Action alternative, is relatively easy to implement because it is limited to maintenance and monitoring.

Alternatives 2 through 5 are all technically feasible. Each alternative involves standard construction and earth moving techniques. Alternative 4A has the most uncertainty because a concrete/soil mixture would need to be determined. Proper installation of a disposal cell can be problematic (Alternative 4B). Alternatives 2 through 5 are sensitive to weather conditions especially during the winter months. Inclement weather conditions will reduce the ability to work efficiently. Wet or frozen soils typically require additional handling time depending on the type of equipment used. Compaction operations are especially problematic during when soils are wet or frozen. Weather also can affect the placement of material at off-site disposal locations.

8.3.6.2 Administrative Feasibility

Alternatives 2 through 5 require truck access to the Site. Both the State Highway 6 and 12th Street access are being evaluated awaiting approval by the CDOT for the State Highway 6 access. This approval will not affect the comparative analysis because it is an element common to each alternative.

Alternative 1, the no-action/institutional controls could require a license for leaving the material on site. However, CERCLA typically exempts on-site remedies from licensing requirements, although certain substantive requirements must be met. The administrative feasibility for this alternative is high because of the continuing requirements of the monitoring and institutional controls.

Alternatives 2, 3, and 4 may require a license to leave the material in place or in on-site solidification or disposal cells. Again the CERCLA exemption may apply, but have substantive requirements. The administrative feasibility for the leaving the material in place is medium to high because of the continuing requirements of the monitoring and institutional controls.

Existing solid waste landfills are authorized to accept wastes similar to the Site material. The landfills must demonstrate the ability to protect human health and the environment by following applicable local certificate of designation procedures and typically do not need additional permits to accept the elevated materials. The administrative feasibility for these sites to accept the elevated materials is medium to high.

8.3.6.3 Availability of Services and Materials

No limitations would be expected for the availability of any of the services or materials anticipated for any of the Alternatives, with one exception. As previously mentioned, access to and from the Site to U.S. Highway 6 may not be available due to the high traffic, limited sight distance, and sharp curve at the point where an access would be required. If this access is not provided by CDOT, then the construction traffic for any remediation alternative will have to be routed through the nearby community.

8.3.7 Cost

8.3.7.1 Detailed Cost Estimate

Cost estimates have been prepared for each of the remedial alternatives under consideration. Detailed cost estimates for each alternative are provided in Appendix L. The summarized cost information for each alternative is presented in the following table**.** Detailed cost information for the off-site disposal alternatives were provided by the disposal facility and details are confidential business information claimed by the disposal facilities. A number of vendors were contacted for specific tasks such as transportation, surveying, geotechnical testing, liner installation, slurry wall installation, and consumables. Average industry costs were used for solidification equipment, monitoring well installation, and equipment rental.

Cost Breakout	**Alternative Cost**								
	1	**2A**	**2B**	**3A**	**3B**	**4A**	**4B**	**5A**	**5B**
Mobilization	12.1	91.3	91.3	79.0	91.3	115.7	100.3	90.5	90.5
Construction Costs	61.1	921.7	1,815	1,099	1,531	2,371	2,007	1,700	1,791
Equipment Costs	0.5	483.7	483.7	471.1	652.4	566.3	598.0	304.9	352.9
Land Development	0	532.5	532.5	532.5	622.6	524.4	524.8	724.1	724.1
Disposal Costs	0	21.2	21.2	228.1	609.5	21.2	21.2	211.9	408.2
Engineering Costs	5.5	63.9	63.9	63.9	63.9	346.0	216.9	42.9	42.9
O & M (Present Value)	2,017	1,126	1,126	1,126	1,126	1,126	1,126	226.3	226.3
Demobilization	11.6	84.1	84.1	84.1	84.1	99.2	102.3	78.7	78.2
Repair (Present Value)	0	398.4	398.4	398.4	398.4	398.4	398.4	0	0
Total	$2,108	$3,723	$4,617	$4,083	$5,180	$5,568	$5,095	$3,380	$3,714
Rank	1	4	6	5	8	9	7	2	3
Ratio to Least Expensive	1	1.77	2.2	1.9	2.5	2.6	2.4	1.6	1.76

Note: All costs in thousands of dollars.

Based on an appraisal performed on behalf of the Colorado School of Mines in December 2003 (Dyco Real Estate, Inc., December 17, 2003) the value of the CSMRI Site (without the Parfet property – Parfet property consists primarily of the previously described treed portion of the Site) was $2.4 million when considered for its highest and best use (i.e. residential development). However, this value would be for a site that never had any contamination. A “stigma” factor would need to be applied to the highest and best use value. For purposes of comparison a 20-percent stigma value was applied to the property. Application of the stigma value would result in an estimated property value of $1.92 million. The appraisal considered the property to be of no marketable value if contamination remained on Site and it were to be utilized solely for recreational use. A partial property value loss would be applied to Alternative 4 for the loss of a percentage of land (disposal area). This value was estimated as the value of 22 possible housing units or $352,000 (includes stigma factor). The loss in value to the State of

Colorado and to Parfet is an additional factor and cost that should be considered under Alternatives 1 through 4. The following table summarizes the effect of including those costs. The addition of the property value also changes the relative ranking of the alternatives, with both versions of Alternative 5 being the most cost-effective alternatives. A copy of the Site appraisal document is included in Appendix L.

Cost Breakout Including Property Value Loss	**Alternative Cost**								
	1	**2A**	**2B**	**3A**	**3B**	**4A**	**4B**	**5A**	**5B**
Cleanup Cost	$2,108	$3,723	$4,617	$4,083	$5,180	$5,568	$5,095	$3,380	$3,714
Property Value Loss	1,920	1,920	1,920	1,920	1,920	352	352	0	0
Total	$4,028	$5,643	$6,537	$6,003	$7,100	$5,920	$5,447	$3,380	$3,714
Rank	3	5	8	7	9	6	4	1	2
Ratio to Least Expensive	1.2	1.7	1.9	1.78	2.1	1.75	1.6	1	1.1

Note: All costs in thousands of dollars.

8.3.7.2 Cost Minimization/AlternativeRisk

Cost risks associated with the various alternatives include weather delays (Alternatives 2 through 5), construction delays associated with access to U.S. Highway 6 (Alternatives 3 and 5), inability to determine a proper solidification mixture (pilot test for Alternative 4A), subcontractor problems (Alternatives 2 through 5), transportation problems (Alternatives 3 and 5), and landfill selection issues (Alternative 3 and 5). Alternatives 2 through 4 could have additional cost risks associated with licensing applications. Alternatives 3 and 5 have possible risks associated with meeting landfill acceptance criteria. Depending on the weight assigned to each of the risks it would appear that Alternatives 3, 4A, and 5 have the highest number of potential cost risks. However, with the exception of the Alternative 4A pilot test, none of the identified risks appear to be capable of stopping the remedial action.

8.3.8 State Acceptance

Alternative 1 can be expected to be unacceptable to CDPHE. Although the remaining alternative meets the requirements of most of the ARARs, on-site disposal may be problematic because of the recent action at the Shattuck site (Alternatives 2, 3, and 4). In-state landfill acceptance criteria also may be an issue with CDPHE (Alternatives 3 and 5).

8.3.9 Community Acceptance

Comments received during an open house conducted by the School indicated that local residents preferred the removal of the material. Alternative 5 would have the highest community acceptance followed by Alternative 3.

8.4 Summary

Although Alternative 1 is the most cost-effective alternative, it is not protective, does not comply with ARARs, and is the least likely to be accepted by CDPHE and the community. Alternatives 2 through 4 have long-term maintenance and monitoring issues, technical uncertainty, and elevated costs. Alternative 5 appears to be the preferred option because of the lack of maintenance and monitoring, elimination of uncertainties, and the lowest cost (excluding Alternatives 1 if the property value is not considered). Alternative 5 also is the preferred alternative of the School, CDPHE, and the community. The landfill acceptance criteria will need to be resolved for this alternative.

9.0 Remedy Selection

9.1 Criteria Review

Regulation 40 CFR §300.430(f) indicates that the cleanup remedies selected shall reflect the scope and purpose of the actions being undertaken and how the action relates to long-term, comprehensive response at the site. As discussed in the introduction of Section 8.0 the nine evaluation criteria are divided into three groups. The groups are defined as follows:

- *Threshold criteria.* Overall protection of human health and the environment and compliance with ARARs (unless a specific ARAR is waived) are threshold requirements that each alternative must meet in order to be eligible for selection.
- *Primary balancing criteria.* The five primary balancing criteria are long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost.
- *Modifying criteria.* State and community acceptance are modifying criteria that shall be considered in remedy selection.

9.2 Remedy Selection Process

Regulations 40 CFR §300.430(e) and (f) and §300.515(e) require the participation of the State (CDPHE) in discussions of the alternatives addressed in the FS prior to preparation of the proposed plan and ROD. The School met with CDPHE to present a preliminary copy of the RI/FS and to discuss the proposed alternatives. Information collected during this meeting was used to generate a Proposed Plan that is part of this RI/FS package. As presented in the Proposed Plan, CDPHE preferred the off-site disposal alternative (Alternative 5). Specifics of the alternative (Alternative 5A or 5B) will be addressed at the completion of the public comment period.

9.3 Proposed Plan

The Proposed Plan for the CSMRI Site is provided in Appendix M. The plan includes information about the public comment period, the upcoming public meeting, and the location of the administrative record.

9.4 Incorporation of RI/FS and Proposed Plan Comments

Additional components of the community relations required by 40 CFR §300.430(f)(3) after the release of the RI/FS and Proposed Plan include:

- Keeping a transcript of the public meeting held during the public comment period and make the transcript available to the public.
- Prepare a written summary of significant comments, criticisms, and new relevant information submitted during the public comment period and the School response to each issue.

This information shall be made available in the record of decision.

Following the publication of the Proposed Plan and before documenting the selected remedy in a record of decision, any new information that significantly changes the basic features of the remedy (e.g., scope, performance, or cost) will be provided to CPDHE. The new information will be documented in the ROD. If CDPHE determines that additional public comment is required to review the changes, a revised RI/FS and/or Proposed Plan will be resubmitted to the public for comment.

9.5 Final Remedy Selection

Following the public comment period and after all comments are received from CDPHE, the final remedy shall be selected. The final remedy will address all comments and concerns submitted by the public and CDPHE.

9.6 Record of Decision

A Record of Decision (ROD) will be produced to document the final remedy selection. The ROD will be generated in accordance with 40 CFR 300.430 §(f)(5). The ROD becomes the official Site cleanup document after CDPHE approval.

9.6.1 Evaluation of Record of Decision - Community Relations

Following the CDPHE approval the ROD the public will be notified of its completion. Prior to the start of the remedial action a notice of the RODs availability will be published in local newspapers and a copy will be available in the Administrative Record locations.

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