

Baseline Human Health Risk Assessment For the Westinghouse Hematite Site

Rev 1

Prepared for:



Westinghouse Electric Company
Hematite Facility
3300 State Road P
Festus, MO 63028

Prepared by:

Integrated Environmental Management, Inc.
2705 North Main Street, Suite 202
Findlay, Ohio 45840
(419) 423-4701

and

Riverfront Environmental
1139 Olive Street, Suite 300
Saint Louis, Missouri 63101
(314) 436-9492

and

Conestoga-Rovers and Associates Inc.
559 West Uwchlan Avenue, Suite 120
Exton, Pennsylvania 19341
(773) 380-9933

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Acronyms, Abbreviations, and Units of Measure¹

ABB	Asea Brown Boveri
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substance and Disease Registry
bls	Below land surface
CDI	Chronic daily intakes
CE	Combustion Engineering, Inc.
CERCLA	Comprehensive Environmental Response Compensation, and Liability Act
COPCs	Constituents of potential concern
CSM	Conceptual site model
CTE	Central tendency exposure
DAD	Dermal absorbed dose
DTL	Default target level
EPC	Exposure point concentration
FGR 13	Federal Guidance Report 13
HEAST	Health Effects Assessment Summary Tables
HI	Hazard Index
HQ	Hazard Quotient
HHRA	Human Health Risk Assessment
IAEA	International Atomic Energy Agency
IEM	Integrated Environmental Management, Inc.
IEUBK	Integrated Exposure Uptake Biokinetic
ILCR	Increased lifetime cancer risk
IRIS	Integrated Risk Information System
LBG	Leggette, Brashears and Graham, Inc.
LOAEL	Lowest observed adverse effect level
MCL	Maximum concentration level
MDNR	Missouri Department of Natural Resources
MPC	Maximum permissible concentration
MRBCA	Missouri Risk-Based Corrective Action
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NOAEL	No observed adverse effect level

¹ Throughout the text of this risk assessment, various equations are presented to illustrate the calculations of exposures and risks. The variables used in these equations are described in the text of the document and are not included in this list of acronyms.

OSWER	Office of Solid Waste and Emergency Response
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PCE	Tetrachloroethylene
Ppb	Parts per billion
ppm	Parts per million
PRG	Preliminary Remediation Goal
PPRTV	Provisional Peer Reviewed Toxicity Value
QA/QC	Quality assurance/quality control
RAGS	Risk Assessment Guidance for Superfund
RESRAD	RESidual RADiation, a computer modeling code
RfC	Reference Concentration
RfD	Reference Dose
RI	Remedial Investigation
RME	Reasonable maximum exposure
SAIC	Science Applications International Corporation
SF	Slope factor
SVOC	Semivolatile organic compounds
TCE	Trichloroethylene
TEDE	Total Effective Dose Equivalent
TPH	Total petroleum hydrocarbon
TV	Toxicity value
UCL	Upper confidence level
UF ₆	Uranium hexafluoride
UNC	United Nuclear Corporation
USNRC	U. S. Nuclear Regulatory Commission
USEPA	U.S. Environmental Protection Agency
VOC	Volatile organic compound
WEC	Westinghouse Electric Company, LLC

1.0 Introduction

This baseline Human Health Risk Assessment (HHRA) evaluates the potential risks to human health for defined populations that may now, or at some time in the future, be exposed to various constituents that were identified in the areas surrounding the Westinghouse Electric Company, LLC (WEC), former fuel cycle facility located near Hematite, Missouri. The HHRA, which considers potential exposures for a reasonably maximally exposed individual under each of several scenarios, concludes that a human health risk from these constituents may if no action were taken. It is important to note that there are several uncertainties identified within the assessment that have a significant impact on the outcome of the calculations and should therefore be considered in determining the need for and type of remedial actions to be undertaken.

The property's future land use has not been determined. Although several potential receptors have been evaluated (e.g. residential, commercial/industrial, agricultural worker, etc.) these are hypothetical scenarios that do not take into account engineering or institutional controls that are currently in place.

Data for this baseline HHRA were provided from the Remedial Investigation (RI) completed in 2004 (Science Applications International Corporation [SAIC], 2007). SAIC also performed the data quality assurance and quality control (QA/QC) and data validation.

Two types of risk are evaluated in this assessment. The first is a total cancer risk from constituents considered. The acceptable level of risk based on U. S. Environmental Protection Agency (USEPA) guidelines is an excess risk of cancer that is not more than one in ten thousand (10^{-4}) to one in one million (10^{-6}) greater than the excess risk of the general population. Cancer risks associated with non-radiological constituents are discussed in Section 6.1. Cancer risks associated with radiological contaminants are discussed in Section 6.3.

Additionally, for radionuclide exposure, a dose assessment that estimates the total radiological exposure is presented in Section 6.3. Regulatory guidance addressing radionuclide contamination is expressed in terms of annual radiation dose, millirem per year (mrem/year).

The second type of risk is a non-cancer health hazard from exposure to non-carcinogenic constituents through various pathways. This type of risk is measured through the use of a hazard quotient (HQ) that is derived primarily through the use of exposure assumptions and reference doses (RfDs) provided in USEPA guidance documents. An HQ is the ratio of a single substance exposure level over a specified time period (e.g., subchronic) to a reference dose (or

concentration) for that substance derived from a similar exposure period. Non-cancer risks are discussed in Section 6.1. Non-cancer risks specific to lead exposures are discussed in Section 6.2. In using the guidance provided by the USEPA, as well as input from other regulatory agencies such as the Missouri Department of Natural Resources (MDNR), the risk values calculated in this report represent a conservative estimate of risk for a reasonably maximally exposed individual. A list of these guidance documents is provided in Section 1.3.

Data were not obtained directly from the burial pits for various reasons including regulatory approvals, safety concerns, heterogeneity of materials, etc. Because of the lack of representative data, the risk associated with the burial pits has been evaluated qualitatively rather than quantitatively. Based upon a review of materials deposited into the burial pits, they are considered to pose an unacceptable risk to human health if left unaddressed.

In this report the terms facility, site and property are defined in the following way:

- Hematite Facility -- the central portion of the property, approximately 18 acres encompassing the historic primary operations area, Site Pond and burial pits areas;
- Hematite Site -- the Hematite Facility and other areas that were the focus of the investigation; and
- Westinghouse Property -- the 228 acres owned by WEC.

Uncertainty is an inherent quality to any risk assessment. The number and significance of the uncertainties associated with this risk assessment demand that a broad spectrum of exposure scenarios be included. Incorporating a number of scenarios representing various populations created a range of risk estimates for consideration in determining the need for and type of remedial action. Given the uncertainties, and the conservatism built into this assessment, the actual risk for average individuals is likely to be much lower than that calculated in this assessment. These uncertainties are discussed in Section 6.5.

1.1 Report Organization

Section 1.0 provides an introduction to this report. Section 2.0 identifies the exposure pathways and potentially exposed populations that are addressed in the HHRA. Section 3.0 addresses the constituents of potential concern (COPCs). The exposure assessment is presented in Section 4.0, including the quantification of exposure concentrations for the COPCs in the applicable media and the presentation of exposure factors for applicable receptors. In Section 5.0, the toxicity of the COPCs is addressed, and the cancer slope factors and non-carcinogenic RfDs that are used in the risk assessment are presented. The risk characterization is presented in Section 6.0. This



characterization includes the presentation of media-specific non-carcinogenic health hazards and carcinogenic risks, an assessment of radiological risk and annual radiation dose, and an evaluation across various media and pathways. Section 7.0 lists the references that are cited in the body of the report.

1.2 Site Background

The baseline HHRA was performed for the former nuclear fuel cycle facility that is located at 3300 Missouri State Road P in Jefferson County near the unincorporated village of Hematite, Missouri. The Westinghouse Property is situated on 228 acres with primary operations historically being conducted within the Facility area (Figure 1). No known activities related to nuclear fuel manufacturing occurred in the outlying acreage of the Property. The relationship between the Site and potential exposure units evaluated in the HHRA is discussed in Section 4.0. The term “Site” is defined in this risk assessment as the Hematite Facility and other areas that were the focus of the investigation. This risk assessment evaluates the entire Site as one exposure unit. The Site includes the Westinghouse Hematite Property and Facility as well as portions of land to the east of the Hematite Property where investigation was conducted.

Nuclear-related operations at the Hematite Facility began with the purchase of the Property (then consisting of farmlands) by Mallinckrodt Chemical Works in 1955. The Hematite Facility became operational in July 1956, producing uranium metals for the nuclear fuel program of the U.S. Navy. Mallinckrodt Chemical Works and related entities operated the Hematite Facility until 1961, when ownership was transferred to a joint venture called United Nuclear Corporation (UNC). UNC continued to produce uranium products for the federal government. In 1971, UNC and Gulf Oil Corporation (Gulf) entered into a joint venture, forming the Gulf United Nuclear Fuels Corporation, (GUNFC) which owned and managed the Hematite Facility until late 1973, when Gulf acquired UNC's interest in GUNFC. General Atomic Company (GAC), a partnership involving Gulf, owned the Hematite Facility from January 1974 through May 1974 when Combustion Engineering Inc. (CE) purchased the Hematite Facility from GAC. Asea Brown Boveri (ABB) purchased the stock of CE in 1989, and CE began operating the Hematite Facility as ABB Combustion Engineering. In April 2000, WEC purchased the nuclear operations of ABB, which included the Facility at Hematite. WEC ceased operations in June 2001 and is proceeding with site decommissioning and remediation.

Throughout its history, the manufacture of uranium metal and compounds from natural and enriched uranium was the primary activity at the Hematite Facility (Leggette, Brashears and Graham, Inc. [LBG], 2003). Operations included the conversion of uranium hexafluoride (UF₆) gas of various uranium 235 enrichments to uranium oxide, uranium carbide, uranium dioxide



pellets, and uranium metal. During the period prior to CE's purchase of the Property in 1974, government projects dominated Hematite facility operations. Many of these operations were classified, and details regarding the exact nature of production processes prior to 1974 are not known. The following are examples of known projects during this time (LBG, 2003):

- production of uranium metal for use in the U. S. Navy's nuclear-powered submarines and destroyers;
- production of specialized uranium oxides for use in the U. S. Army's Army Package Power Reactor;
- production of highly enriched uranium oxides for a General Atomics gas-cooled reactor;
- production of highly enriched uranium metal for materials test reactors utilized by the U. S. Navy;
- production of uranium-beryllium pellets for use in the SL-1, an experimental U. S. military nuclear power reactor that was part of the Army Nuclear Power Program;
- production of high-enrichment uranium zirconia pellets for a naval reactor; and
- production of highly enriched oxides for use in General Atomics nuclear rocket projects.

Although uranium material production was the primary function at the Hematite Facility, records indicate secondary activities such as uranium scrap recovery and a limited amount of work with thorium compounds as part of early research into the use of thorium in the fuel cycle. A detailed list of radioactive feed materials historically used for production is not available. However, previous investigators have compiled a list of chemicals (Table 1.1) used at the Hematite Facility during active operations (LBG 2003).

1.3 Guidance Documents

Procedures and methodologies used in the risk assessment were based on the following guidance, including:



- *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual- Part A* (USEPA 1989a)²
- *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Goals)* (USEPA 1991a)
- *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments)* (USEPA 1998)
- *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment)* (USEPA 2004)
- *Office of Solid Waste and Emergency Response (OSWER) Directive 9285.6-03*, March 1991 (USEPA 1991b)
- *Exposure Factors Handbook*, Office of Research and Development, Washington, D.C. (USEPA 1997a)
- *Health Effects Assessment Summary Tables (HEAST)*, Annual FY 1997 (USEPA 1997b)
- *Risk Characterization Handbook* (USEPA 2000a)
- *Supplemental Guidance to RAGS: Calculating the Concentration Term* (USEPA 1992a)
- *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual, Supplemental Guidance, "Standard Default Exposure Factors"*, Office of Solid Waste and Emergency Response (OSWER) Directive 9285.6-0 (USEPA, 1991c)
- *Evaluating and Identifying Contaminants of Concern for Human Health*, Region VIII Superfund Technical Guidance RA-03, September 1994 (USEPA, 1994)
- *Land Use in the CERCLA Remedy Selection Process*, OSWER Directive 9355.7-04, (USEPA, May 25, 1995).

² The protocol for the assessment of risk associated with ionizing radiation is described by the USEPA in RAGS Part A in Chapter 10 and RAGS Part B in Chapter 4.

2.0 Conceptual Site Model

Risk assessments must first identify what populations might be affected by potential risks in a specific area, both now and in the future. Exposures can only occur when a receptor can directly contact released constituents or when there is a mechanism for the released constituents to be transported to a receptor. Without exposure, there is no risk; therefore the exposure assessment is one of the key elements of a risk assessment. In the case of groundwater, exposure to constituents may occur through ingesting the water when using groundwater as a drinking water source, through inhalation of volatile organic compounds (VOCs) when using groundwater to shower, and through dermal contact when using groundwater to bathe. For soil, exposure to constituents may occur through direct contact, through inhalation of airborne soil particulates, through incidental ingestion of soil during daily activities, and (for radionuclides) through external radiation. Exposure to constituents in surface water/sediment may occur through dermal contact, incidental ingestion, and inhalation during various activities in and around surface waters.

A Conceptual Site Model (CSM) has been developed that identifies the exposure medium, exposure points, receptor population and age, and exposure route. The CSM identifies pathways as complete or incomplete, and provides a justification for the designation. The CSM is presented as Table 1.1 (current exposure) and Table 1.2 (potential future exposure).

The Site has been in industrial use for nearly 50 years, and current Site users are industrial workers. The baseline HHRA evaluates risk to such workers, as well as construction workers and trespassers who might come in contact with COPCs at the Site. The residents situated on the facility Property are located outside the Facility and are not potentially exposed to COPCs present at the Site.

WEC is planning to decommission the former fuel cycle facility, dismantle facility structures, and terminate its NRC license. As part of decommissioning planning, WEC is evaluating final end uses of the Site, including unrestricted use. In accordance with USEPA guidance (USEPA, May 25, 1995), the baseline HHRA generally needs only to consider the reasonably anticipated future land use. As stated in the preamble to National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (55 Federal Register 8710), however, more than one future land use assumption may be considered in the baseline HHRA when there is uncertainty regarding the anticipated future land use. In such cases, it can be useful to compare the potential risks associated with several land use scenarios to estimate the impact on human health of decisions regarding land use and how institutional controls should be used to restrict future uses. Consistent with this USEPA guidance, this baseline HHRA examines risks to a wide spectrum of

potential future Site users, including residential, commercial/industrial, recreational, visitor/trespasser, and agricultural.

2.1 Exposure Pathways

During development of the CSM, the following factors were considered:

Medium	Groundwater Surface water/Sediment Surface soil Subsurface soil
Exposure Medium	Groundwater Indoor Air Outdoor Air Surface Water/Sediment Surface Soil (particulates and vapor) Subsurface Soil (particulates and vapor)
Exposure Route	Dermal Ingestion Inhalation
Receptor Population (including current and possible future)	Resident Commercial/Industrial Worker (non-residential) Construction Worker Recreational User Visitor/Trespasser Agricultural Worker (farmer)
Receptor Age	Child Adult Composite Adult ³

Table 1.3 lists the completed exposure pathways as well as a description of the particular data grouping used to prepare the exposure point concentration for each pathway. Table 1.4 lists the specific data points used to prepare the exposure point concentrations. Figures 2 through 5 displays the location of the sampling points according to media.

³ The composite adult is assumed to be a 30-year individual: 6 years as a child and 24 years as adult.

The data were grouped as described below:

- For those exposure scenarios associated with dermal contact, ingestion, or inhalation of groundwater coming into a building through a shower head or tap, the groundwater data was used to calculate the exposure point concentration (EPC). To calculate the discrete risks associated with different hydrogeologic units, the data were grouped according to where the well was screened. Wells screened in the overburden were considered one group, and wells screened in the bedrock were considered a second group.
- For those exposure scenarios associated with inhalation from groundwater, both indoor and outdoor, groundwater data collected from wells screened in the overburden were used to calculate the EPC. Furthermore it is assumed that outdoor exposures of residents or commercial/industrial workers strolling through the floodplain will be similar to that of a visitor or recreational user and are therefore not considered. Data from bedrock wells were not used because the constituents are too deep to create a substantive inhalation risk at the ground surface.
- For those exposure scenarios associated with outdoor inhalation of vapors from groundwater, including construction worker, recreational use, visitor/trespasser, and agricultural user, groundwater data collected from wells screened in the overburden were used to calculate the EPC. Data from bedrock wells were not used because the constituents are considered to be too deep to create a substantive inhalation risk at the ground surface.
- For those exposure scenarios associated with ingestion or dermal contact with surface water or inhalation of vapors from surface water, samples from surface water bodies were used to calculate the EPC.
- For those exposure scenarios associated with residents or commercial/industrial workers contacting surface soil, soil samples from surface soils were used to calculate the EPC. Furthermore it is assumed that outdoor exposures of residents or commercial/industrial workers strolling through the floodplain will be similar to that of a visitor or recreational user, and was therefore not considered.
- For those exposure scenarios associated with construction worker, recreational user, visitor/trespasser, and agricultural worker coming in contact with surface soil, all surface soil samples, including those in the flood plain, were used to calculate the EPC.

- For those exposure scenarios associated with indoor inhalation of vapors from subsurface soils by residents and commercial/industrial workers, subsurface soil samples were used to calculate the EPC. Furthermore, it is assumed that outdoor exposures of residents or commercial/industrial workers strolling through the floodplain will be similar to that of a visitor or recreational user, and was therefore not considered.
- For those exposure scenarios associated with a construction worker coming in contact with subsurface soils, subsurface soil samples to the assumed depth of construction were used to calculate the EPC. The assumed depth of construction is 15 feet.
- For those exposure scenarios associated with a construction worker, agricultural worker, recreational user, or visitor/trespasser coming in contact with outdoor air constituents from subsurface soils, all subsurface soil samples were used to calculate the EPC.

According to the RI, the surface water samples were not filtered prior to analysis, such that the COPC concentrations reported for these samples represent the potential exposure by the swimmer to both surface water and suspended sediment. Data sets using surface water are denoted as “surface water/sediment”. The data from the RI was used to establish the EPC for each exposure scenario. The use of these selected data sets is discussed further in Section 4.2.

Special attention was paid to surface water and sediment samples collected from Joachim Creek since it is an area of frequent current recreational use by nearby residents. There were no instances of COPCs above PRGs in the surface water or sediment of Joachim Creek.

2.2 Exposure Scenarios Considered

The exposure scenarios considered below were divided by receptor and age when applicable. Exposure factors for the receptors considered are presented in Table 4.1. The following paragraphs briefly summarize general assumptions made about each receptor.

Resident Child

The resident child is defined as a potential future receptor with an exposure duration of 6 years, from birth to 6 years of age. In general, the child resident has lower exposure factors than the resident adult with the exception of soil ingestion rate, time spent outdoors, and soil-to-skin adherence factor. The residential water supply is assumed to be from groundwater wells. It is assumed that the resident child bathes, instead of showers, daily for approximately 45 minutes. Dermal exposure to groundwater for the child assumes a bathing scenario in which the entire body is in contact with the water. The resident child is dermally exposed to surface soil

outdoors, groundwater from the tap, groundwater during bathing, and surface water during swimming. Dermal exposure to subsurface soil is not expected, and therefore is not considered. The child incidentally ingests surface soil from the outdoors, ingests groundwater from the tap, and incidentally ingests surface water during swimming. The child breathes outdoor vapors and particulates and indoor vapors from various sources.

Resident Adult

The resident adult is as a potential future receptor with an exposure duration of 24 years, from ages 6 to 30 years of age. In general the adult has higher exposure factors than the resident child with the exception of those previously mentioned in the Resident Child. Again, the residential water supply is assumed to be from groundwater wells. It is assumed that the resident adult showers, instead of bathes, daily for approximately 35 minutes per day. The resident adult is dermally exposed to surface soil outdoors, groundwater from the tap, groundwater during showering, and surface water during swimming. Dermal exposure to subsurface soil is not expected, and therefore is not considered. The adult incidentally ingests surface soil from the outdoors, ingests groundwater from the tap, and incidentally ingests surface water during swimming. The adult inhales outdoor vapors and particulates and indoor vapors from various sources.

Composite Resident Adult

The composite adult is defined as a potential future receptor who is a resident child for 6 years and a resident adult for 24 years. The risk to the composite adult is the addition of risk associated with the resident child and resident adult. The result is a 30-year based risk for a resident from birth to 30 years of age.

Commercial/Industrial Worker

The commercial/industrial worker is defined as an adult receptor (without personal protective equipment) with an exposure duration of 25 years and who works 250 days per year. The baseline HHRA examines both a current and future commercial/industrial worker. The worker spends a majority of the workday indoors and does not perform construction-related or utility work, such as trenching or excavation.

The skin of the current commercial/industrial worker is exposed to surface soil outdoors and surface water. Dermal exposure to surface water is limited to bare hands only. The worker incidentally ingests surface soil and surface water. The worker inhales outdoor vapors and particulates and indoor vapors from various sources.

In addition to these exposure routes, the future commercial/industrial worker is exposed to COPCs through groundwater from the tap. The baseline HHRA assumes that groundwater is developed as the water supply. Accordingly, the future commercial/industrial worker is incidentally dermally exposed to groundwater from the tap and ingests groundwater from the tap.

Construction Worker

The construction worker is defined as an adult receptor with an exposure duration of one year and who works 225 days per year. The exposure to the construction worker is the same under both current and future scenarios.

The construction worker spends the entire workday outdoors. Indoor inhalation pathways are not considered under the construction worker scenario. The worker is dermally exposed to surface soil, subsurface soil to fifteen feet below ground surface and groundwater in the overburden. Dermal exposure to media is limited to the face, hands, and forearms. The worker incidentally ingests surface soil, subsurface soil, and groundwater from contact with these media. It is assumed the construction worker does not obtain drinking water from the Site, either now or in the future. The construction worker inhales outdoor vapors and particulates from various sources.

Recreational Child/Adult

The recreational child and adult are defined as potential future receptors that spend 195 days per year at the site conducting recreational activities. Physically the recreational child and adult are equivalent to their resident counterparts and incur similar outdoor exposures. Indoor pathways are not considered for the recreational receptor, however, because all activities are assumed to be conducted outdoors. Surface water exposures are considered for the recreational receptor. The recreational child and adult swim in surface waters for a duration of 3 hours, 12 days per year. The recreational child and adult do not consume drinking water from the site.

Visitor/Trespasser

The visitor/trespasser is defined as an adult receptor that visits the site 24 days per year for 24 years. The baseline HHRA considers the visitor/trespasser under both current and future scenarios. Physically, the visitor/trespasser is similar to the resident or recreational adult and is exposed to the same outdoor exposures. Indoor pathways, including ingestion or other exposures from groundwater use, are not considered for this receptor since all activities are assumed to be conducted outdoors. Surface water exposures are considered and are similar to those of the recreational or resident adult.

Agricultural

The agricultural worker is defined as a potential future adult receptor that works on the Site for 225 days per year for 30 years. Physically, the agricultural worker is most similar to the construction worker and is exposed to the same outdoor exposures. Indoor pathways, including ingestion or other exposures from groundwater use, are not considered for this receptor because all activities are assumed to be conducted outdoors. Surface water exposures are considered and are similar to those of the construction worker.

Current farming activities involve pasturing livestock, which take place on the northeast corner of the property. This area is relatively unimpacted. Furthermore, exposure factors used in the risk calculations for this receptor represent a farmer that cultivates the land, and grows crops. Pasturing livestock would result in lower exposures, therefore, the calculated risk to the current farmer is considered to be conservative.

3.0 Constituents of Potential Concern

The purpose of the identification of the COPCs for use in the risk assessment is to focus the risk assessment process on the detected constituents that pose a potential threat to human health. Section 3.1 defines the data sets that are used to represent the concentrations of constituents in the exposure media (e.g., surface soil). Section 3.2 describes the screening procedures used to select the COPCs. Section 3.3 presents the identified COPCs for each medium.

3.1 Data Sets

The data used in this risk assessment were collected in 2004 during the site characterization portion of the RI (SAIC, 2007). The data include samples from the following media: surface water/sediment, surface soil, subsurface soil, and groundwater.

In general, the data set includes quantitative results for the following analyses:

- VOCs;
- Semi-volatile organic compounds (SVOCs);
- Pesticides;
- Polychlorinated biphenyls (PCBs);
- Selected radioactive isotopes; and
- Inorganics (heavy metals, cyanide, sulfates, nitrates, etc.).

A select number of samples were also analyzed for the following:

- Dioxins; and
- Total petroleum hydrocarbons (TPH).

The complete data set used for the HHRA is included in the RI report. The sample locations are presented on Figures 1 through 5.

3.2 Data QA/QC and Validation

Data for this HHRA were provided from the RI completed in 2004 (SAIC, 2007). SAIC performed the data QA/QC and validation. Samples were analyzed for a wide range of constituents. Sampling locations were biased toward impacted areas on the site, which resulted in a good representation of the maximum concentrations. Analytical methods used by the

analytical laboratories were equivalent to those approved by USEPA. Procedures used in the field to collect the samples were based on approved field collection methodology. The number of samples collected provided adequate data for competent statistical evaluation.

It was observed that some of the detections for organics may be false positives. A common cause for false positives was a result of contamination of samples with common laboratory contaminants. Among the VOCs, methylene chloride, acetone, 2-butanone and cyclohexane are frequent lab and method blank contaminants. For the RI data set, most of these contaminants were detected in method blanks and data were appropriately qualified with validation code. The laboratory reported standard sample quantitation limits (SQLs) as described in the method requirements.

3.3 Screening Procedures

It is important to focus on constituents that have the potential to cause substantive risk. Screening procedures are used to limit the number of COPCs in each medium. Screening was performed using procedures consistent with USEPA CERLCA guidance (USEPA 1989a). Three screening procedures are used for the risk assessment data sets to assure that the appropriate constituents are being assessed. Screening procedures are described in the following paragraphs.

Table 2.1 presents a summary of the chemical COPCs selected following the screening process. The chemical COPCs were selected following the steps described below:

- Data were grouped by medium (groundwater, surface water/sediment, surface soil and subsurface soil.);⁴
- Detected compounds were extracted from the medium-specific data sets; and
- The highest detected concentrations for each detected compound were compared to the 2004 USEPA Region IX Preliminary Remediation Goals (PRGs) and identified as either being above screening level or below screening level. The 2004 USEPA Region IX PRGs were used to screen compounds because they are considered to be conservative values that are protective of human health.

⁴ Data collected from the flood plain were included in the screening procedure. The screening procedure was an evaluation of the entire data set. However, COPCs were not screened further once EPC sets were developed.

- Constituents detected at maximum concentrations below the respective PRGs were not retained as COPCs. This method of determining COPCs is both protective and conservative because the sampling locations were biased to areas of suspected contamination.⁵
- Additional compounds were eliminated based on the following criteria as described in the USEPA Region VIII Superfund Technical Guidance for Evaluating and Identifying Contaminants of Concern for Human Health (USEPA, 1994), which was based on the USEPA Risk Assessment Guidance for Superfund (RAGS) Part A (USEPA 1989a):
 - Compounds identified as essential nutrients were not retained as COPCs. For the purposes of this HHRA, the following compounds were removed from the list of COPCs: iron, zinc, manganese, and chloride.
 - Those constituents having a frequency of detection of less than 5 percent were not retained as COPCs. The compounds that were screened out due to this criterion were further evaluated to ensure their removal was appropriate. A description of this evaluation follows.

Several compounds were removed from consideration through the screening process because they occurred in less than 5 percent of the total sample population. These compounds were evaluated to ensure that they were not erroneously excluded. The following compounds were detected in less than 5 percent of samples⁶:

Groundwater: 1,1,2-trichloroethane, 1,2-dichloroethane, benzene, chloroethane, chloroform, phenol, and thallium. The majority of these compounds were detected at concentrations only slightly above detection limits, and most of the

⁵ The values for trichloroethylene (TCE) and tetrachloroethylene (PCE) in tap water as presented in the 2004 USEPA Region IX PRGs are based on draft toxicological values. These PRGs are well below maximum contaminant levels (MCLs) for drinking water and are below typical method detection limits for these compounds. TCE and PCE were not screened out of surface water and groundwater data sets and were retained in the risk assessment to maintain data quality objectives.

⁶ Benzo(a)anthracene and benzo(b)fluoranthene were detected in 5.5 percent and 5.8 percent of samples respectively, while benzo(a)pyrene was detected in 4.3 percent of samples. These compounds generally occur together and were treated as a group even though two of the compounds were detected with frequencies slightly above 5 percent.

detections were qualified by the laboratory as estimated values because the concentrations were so low.⁷

Surface Soil: Dibenzo(a,h)anthracene. This compound was detected in three samples. Two of the three samples were qualified by the laboratory as estimated values because the concentrations were so low.

Subsurface Soil: Benzo(a)anthracene, benzo(a)pyrene, and benzo(b)fluoranthene. The majority of detections were qualified by the laboratory as estimates values because the concentrations were so low.⁸

The compounds identified above were excluded from the risk assessment because they occurred in less than, or nearly less than, 5 percent of the samples that were analyzed for those compounds. Based on a review of the data and sample locations, it is believed that excluding these compounds is justified for the following reasons:

- Most of the detections are only slightly above the detection limit, and most are qualified as estimated values by the laboratory.
- Because these compounds are found at such low concentrations and with low frequency, it is unlikely that they would be drivers for remediation.

Table 2.1 summarizes the COPCs selected following the two screening process described above. Tables 2.2 through 2.19 provide a comparison of highest concentrations to USEPA Region IX PRGs. Each table presents a summary of the occurrence, distribution, and selection of COPCs. The frequency of detection is listed as well as the minimum and maximum detected concentrations. The screening toxicity value is presented as well (e.g., the USEPA Region IX PRG) as additional information regarding other potential regulatory values. The last two

⁷ 1,1,2 trichloroethane was identified 5 times in 138 groundwater samples with the maximum concentration at 8 ppb. 1, 2-dichloroethane was identified 9 times in 138 samples with the maximum concentration at 9 ppb. Benzene was identified twice in 138 samples with the maximum concentration at 4.8 ppb. These low frequencies of detection and relatively low concentrations do not justify retaining these compounds in the risk assessment for the given media. If 1,1,2 trichloroethane and 1,2- dichloroethane are breakdown products of TCE, then the results show these compounds are not preferential breakdown products. Furthermore, assessing the risk of TCE, a more toxic compound than 1,1, 2 trichloroethane or 1,2- dichloroethane, is more conservative then assessing risk of projected concentrations of these assumed breakdown products

⁸ PAHs were removed from consideration because of the low concentrations that was detected and their minimal solubility which limits their transport in subsurface soils.

columns indicate whether the constituent was considered to be a COPC for the risk assessment or not and the reason for its inclusion or exclusion. Tables 2.20 through 2.30 present the second tier of the screening process.

Sediment samples were collected from various water bodies across the site, including Joachim Creek, the site pond, and other tributaries. Data from Joachim creek was evaluated separately because unlike the other bodies of water, Joachim Creek contains fish, and is used for recreational purposes. The results from samples collected from sediment in the creek indicated site related constituents did not exceed PRGs.

No screening was performed for radionuclides. USEPA Region IX PRGs are not available for radionuclides. All of the isotopes detected in the RI report were present in the ambient background as a result of naturally occurring and man-made radioactive materials (SAIC, 2007). However, in order to maximize the potential risk calculated for each exposure scenario, the contribution from background was included in the Risk Assessment.

Radioactive isotopes were identified in the water, both groundwater and surface water. The radioactive isotopes that were detected included uranium 238, radium 226 and technetium 99.⁹ Plutonium 239/240 was not detected in the ground water samples at a detection limit of 0.01 pCi/liter. One sample of 32 identified the presence of neptunium 237 at a concentration of 0.02 pCi/liter. The radioactive isotopes identified in the soil, included uranium 238, uranium 235, uranium 234, thorium 232, thorium 230, thorium 228, radium 228, radium 226 and technetium 99.¹⁰ Plutonium 239 and Neptunium 237 were not detected in the surface soil but was detected in the subsurface soil.

The presence of technetium 99 in the soil and groundwater was evaluated in 1996 as well as the RI in 2004. Technetium 99, which decays by beta radiation, is a byproduct of the nuclear fission of uranium-235 and has a half-life of 213,000 years. Technetium 99 contamination was present in commercial UF₆ as a result of US government recycling and re-enrichment activities at the gaseous diffusion plants (LBG, 1999).

⁹ The progeny of thorium that emit gamma radiation were detected and found to be in secular equilibrium with their parent isotope. Thorium 228 and Radium 228 were found to be in secular equilibrium with their parent isotope, Thorium 232, respectively. Progeny of Uranium 238, especially Thorium 230 and Radium 226 were not in secular equilibrium.

¹⁰ Thorium 228 and Radium 228 were found to be in secular equilibrium with their parent isotope, Thorium 232. Progeny of Uranium 238, especially Thorium 230 and Radium 226 were not in secular equilibrium. The observed concentration was used for the calculation of risk in Chapter 6 of this report.

For this risk assessment, it was determined that the key radionuclides would be retained as COPCs and the risk calculated for the HHRA. The key radionuclides that were included in the risk assessment included uranium and progeny, thorium and progeny, technetium, plutonium 239/240 and neptunium 237. For a sample where the radionuclide was reported to be at a concentration below the method detection limit, the detection limit was assigned as the reported concentration to calculate the UCL and the source term for the receptors.

For those radionuclides identified as COPCs, the activities used in the risk assessment are the measured EPCs; the contribution from background was not subtracted. This is a conservative approach such that the calculated risk is the incremental lifetime cancer risk, including the contribution of background. The observed risk is lower than the values calculated in Chapter 6 of this report because of the addition of natural background; this approach provides a conservative estimate of the risk from radionuclides.

4.0 Exposure Assessment

The objective of the exposure assessment is to quantify the type and magnitude of the total exposure by potential receptors to COPCs. These COPCs may be present at, or migrating from the Site or are present off site but may be due to Site-related activities, currently or at some time in the future if no further remedial actions were taken. The potentially exposed populations and exposure pathways to environmental media (e.g., soil, surface water/sediment, and groundwater) were identified in Section 2.0. In Section 4.1, the statistical analyses that are used to determine a conservative EPC are presented. Section 4.2 identifies the exposure pathways for each of the potential receptors being evaluated. In Section 4.3, the equations that are used to determine the Chronic Daily Intakes (CDI) of non-radiological COPCs and the total radiological intake and annual dose are presented, along with the exposure factor assumptions.

This baseline HHRA includes data collected site-wide as a single exposure unit. Evaluating data on a site-wide basis is appropriate to evaluate baseline risk to receptors. This is a conservative approach because sampling was biased toward known impacted areas. As a result, maximum concentrations of COPCs are well represented. Furthermore, exposure point concentrations (EPCs) were calculated using conservative approximations of the mean (i.e. 95 percent upper confidence limit.) Following completion of this site-wide baseline HHRA, individual exposure units will be identified and evaluated.

4.1 Exposure Point Concentrations

For quantitative human health risk assessments, the EPC, which is the concentration term used in the exposure equations, is the arithmetic average of the concentration that is contacted over the exposure period. The EPC is estimated from the arithmetic average concentration for a COPC based on a set of sampling results. Because of the uncertainty associated with estimating the true average concentration at a site, the 95 percent upper confidence limit (UCL) of the arithmetic mean is used for this variable for the reasonable maximum exposure (RME). The 95 percent UCL provides reasonable confidence that the true site average concentration will not be underestimated. The RME is the highest exposure that is reasonably expected to occur at a site and is intended to estimate a conservative exposure case (i.e., well above the average case) that is still within the range of possible exposures. The 95 percent UCL values were calculated using USEPA guidance (OSWER Directive 9285.6-10, USEPA, 2002). Specifically, the UCL was calculated using PRO-UCL, version 3.0, a computer program developed by the USEPA (USEPA, 2004a).

The following describes the EPC calculation process.

- First, the data was organized into EPC sets. An EPC set is a unique grouping of data (as shown in Table 1.3-1.4) and corresponding COPCs by media (as summarized in Table 2.1).
- Second, undetected concentrations were replaced with one-half of the detection limit as a proxy for the concentration.
- Third, the data were censored for outliers. One sample, GW-BD2-121604, was excluded in the EPC calculation because of a spike of PCE concentration in the sample and the resulting highly elevated analytical reporting limit. Inclusion of the data from this sample for compounds (i.e., proxy concentrations set at one-half of the highly elevated reporting limit) would cause the 95 percent UCL of all of the COPCs in groundwater to be overestimated.
- Fourth, the EPC data sets were imported into PRO-UCL, version 3.0. PRO-UCL calculates the 95 percent UCL by ten different methods. The methods assume either a normal, lognormal, gamma, or non-parametric distribution. PRO-UCL also tests the imported data for the appropriate distribution. The output (where is this documented) of PRO-UCL lists the 95 percent UCLs for each of the ten methods and recommends which of the ten UCLs should be used based on the distribution of the data. The recommended UCL was selected as the EPC term. In some instances the EPC data were subsequently modeled to convert the values to the appropriate exposure media. Section 4.1.1 discusses the models used further.

Tables 3.1 through 3.6 provide a summary of EPCs for each COPC contained within the data groupings for their respective completed exposure pathway. These tables include the number of samples for each EPC, the number on non-detects for each EPC, the statistical method used to determine the 95 percent UCL depending on the statistical distribution that fits the data, the 95 percent UCL, and the arithmetic average concentration. The PRO-UCL data output for each calculated value is included in Appendix A.

4.1.1 Exposure Point Concentration Models

Fate and transport models are needed to determine concentrations of COPCs in exposure media that have transferred to other media. For this HHRA, concentrations of COPCs transported to air from soil and groundwater were modeled to quantify potential inhalation risks. Calculation worksheets (Worksheet 3.1-3.8) were developed to show the model equations, input parameters,

and output. These worksheets are contained in Appendix B. The models used for each exposure scenario are discussed further below.

Shower/Bath Water to Indoor Air - Vapors

Henry's Law was used to model the vapor concentrations of VOCs in indoor air from tap water during a shower or bath. Henry's Law describes the volatility of a dilute species (e.g., <10 percent) in solution at equilibrium. The assumption of this model is that the breathing zone of a receptor in a shower or bath is near the interface at which equilibrium exists. Worksheets 3.1 and 3.2 show the calculation for tap water from overburden wells and bedrock wells, respectively.

Groundwater to Indoor Air - Vapors

To model indoor air vapor concentrations of VOCs, EPA's 2004 Johnson-Ettinger Model was used. The model simultaneously calculates the carcinogenic and noncarcinogenic risk for each COPC. Worksheets 8.1 and 8.2 in Appendix G contain summary tables for the output of the model. The corresponding calculation worksheet for each COPC is listed on Worksheets 8.1 and 8.2.

Groundwater to Outdoor Air - Vapors

To model outdoor air vapor concentrations of COPCs, chemical-specific volatilization factors were developed based on the method described by MDNR (MRBCA, 2005) and ASTM methods (ASTM E1739-95).¹¹ The volatilization factors describe the fraction of each COPC in groundwater that volatilizes to outdoor air. Worksheet 3.3 shows the calculation for groundwater in the overburden to outdoor air. Worksheet 3.7 shows the calculation of several effective diffusivities, which are needed to calculate the volatilization factors.

Surface Soil to Outdoor Air - Vapors

To model outdoor air vapor concentrations of COPCs, chemical-specific volatilization factors were developed based on the method described in the *Soil Screening Guide* (USEPA 1996b). The volatilization factors describe the fraction of each COPC in surface soil that volatilize to

¹¹ The vapor models used are valid when concentrations of contaminants are below the aqueous solubility limit or the soil saturation concentration. For PCE, only one groundwater and two soil samples exceeded the respective limits. However, the 95 percent UCLs used in the models are below the solubility and soil saturation limits.

outdoor air. Worksheet 3.4 shows the calculation for surface soil to outdoor air. Worksheet 3.8 shows the calculation of the apparent diffusivities of the COPCs, which are needed to calculate the volatilization factors.

Surface or Exposed Subsurface Soil to Outdoor Air - Particulates

To model outdoor air particulate concentrations of COPCs, a generic particulate emission factor was developed based on the method described in the *Soil Screening Guide* (USEPA 1996b). The particulate emission factor describes the fraction of each COPC in surface or exposed subsurface soil that becomes airborne in particulate form. Worksheet 3.5 shows the calculation of the particulate emission factor.

Subsurface Soil to Outdoor Air - Vapors

To model outdoor air vapor concentrations of COPCs, chemical-specific volatilization factors were developed based on the method described in the *Soil Screening Guide* (USEPA 1996b). The volatilization factors describe the fraction of each COPC in exposed subsurface soil that volatilize to outdoor air. Though this approach may overestimate the outdoor air concentrations due to undisturbed subsurface soil, the resulting risk associated with this model is below levels of concern (see Section 6.1 and 6.2 for more discussion of results). Worksheets 3.6 shows the calculation for subsurface soil to outdoor air. Worksheet 3.7 shows the calculation of the apparent diffusivities of the COPCs, which are needed to calculate the volatilization factors.

Subsurface Soil to Indoor Air - Vapors

To model indoor air vapor concentrations of VOCs, EPA's 2004 Johnson-Ettinger Model was used. The model simultaneously calculates the carcinogenic and noncarcinogenic risk for each COPC. Worksheets 8.3 and 8.4 in Appendix G contain summary tables for the output of the model. The corresponding calculation worksheet for each COPC is listed on Worksheets 8.3 and 8.4.

4.2 Exposure Equations and Parameters

Environmental medium-specific exposure algorithms were developed for each of the identified exposure route/pathways. Exposure algorithms are used to estimate chronic daily intake of non-radiological COPCs by receptors (e.g., industrial workers, adult and young child residents) in

potentially exposed populations. The exposure to radiological COPCs is assessed using basically the same algorithms and assumptions.

A Chronic Daily Intakes (CDI) is an exposure expressed as mass of a substance contacted per unit body weight per unit time, averaged over a long period of time (as a Superfund program guideline, seven years to a lifetime). For each exposure activity, the CDI, expressed as mg/kg-day, was an averaged daily dose of a COPC ingested or absorbed by a receptor. The averaged dose received by a receptor was the critical point estimate for determining the extent of health risk/hazard associated with exposure to each constituent.

Table 4.1 provides a summary of exposure factors used in estimating exposure intakes. As Table 4.1 illustrates, the Exposure Assessment has been completed using standardized variables selected from a variety of credible, peer reviewed sources, using the following decision hierarchy:

- 1) USEPA Guidance Documents (USEPA 1989; USEPA 1991; USEPA 1997; USEPA 2002; USEPA 2004);
- 2) Missouri Risk-Based Corrective Action Draft Program Document (MRBCA, 2005); and
- 3) Virginia Department of Environmental Quality Voluntary Remediation Program Document.

As seen in Table 4.1, the vast majority of exposure factor values have been adopted from well established, peer reviewed documents published by USEPA. State-derived exposure factors have been referenced only when the USEPA documents do not provide established values.

The following sections discuss the exposure equations to calculate receptor intakes. Tables 5.1-5.3 summarize the intakes calculated for each receptor. Worksheets 5.1-5.47 display the calculations for each receptor and exposure pathway intake. These worksheets are contained in Appendix C.

4.2.1 Inhalation of Outdoor Air: Vapors and Particulates

The exposure equation for the inhalation of outdoor air accounts for exposure to vapors and particulates from soil, groundwater, and surface water sources. The exposure equation can account for these different sources since the exposure medium (outdoor air) is the same for the sources. The intake equation for outdoor air exposure is

$$Intake = \frac{IR_{AO} \times EF \times ED \times ET_{OUT}}{BW \times AT}$$

where

IR_{AO} = outdoor inhalation rate of the receptor (m^3 /hour)

EF = exposure frequency (days/year)

ED = exposure duration (years)

ET_{OUT} = exposure time that the receptor is outdoors (hours/day)

BW = body weight of the receptor (kg)

AT = averaging time (days).

Therefore, the CDI for each receptor and COPC is calculated by

$$CDI = Intake \times Conc_{COPC}$$

where

$Conc_{COPC}$ = concentration of the COPC in air (mg/m^3) from each exposure source.

4.2.2 Incidental Ingestion of Soil

The exposure equation for the incidental ingestion of soil accounts for typical intakes of soil during normal daily activities according to each receptor. The intake equation for incidental ingestion of soil is

$$Intake = \frac{IR_{SOIL} \times EF \times ED \times FI \times CF}{BW \times AT}$$

where

IR_{SOIL} = ingestion rate of soil for the receptor (mg/day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

FI = fraction of soil ingestion from source (unitless)

CF = conversion factor (kg/mg)

BW = body weight of the receptor (kg)

AT = averaging time (days).

Therefore, the CDI for each receptor and COPC is calculated by

$$CDI = Intake \times Conc_{COPC}$$

where

$Conc_{COPC}$ = concentration of the COPC in surface soil (ppm) or subsurface soil depending upon the receptor.

4.2.3 Dermal Contact with Soil

The intake equation for dermal contact with soil is

$$Intake = \frac{SA_{SOIL} \times EF \times ED \times ET_{SOIL} \times CF \times AF}{BW \times AT}$$

where

SA_{SOIL} = skin surface area available for contact with soil (cm²/day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

ET_{SOIL} = exposure time for dermal contact with soil (hours/day)

CF = conversion factor (kg/mg)

AF = soil to skin adherence factor (mg/cm²)

BW = body weight of the receptor (kg)

AT = averaging time (days).

Therefore, the dermal absorbed dose (DAD) for each receptor and COPC is calculated by

$$DAD = Intake \times Conc_{COPC} \times ABS$$

where

$Conc_{COPC}$ = concentration of the COPC in surface soil (ppm) or subsurface soil depending upon the receptor

ABS = chemical-specific absorption factor (unitless).

4.2.4 Ingestion of Groundwater

The exposure equation for the ingestion of groundwater describes intakes of groundwater at the tap. The intake equation for ingestion of groundwater is

$$Intake = \frac{IR_W \times EF \times ED}{BW \times AT}$$

where

IR_W = ingestion rate of water for the receptor (L/day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = body weight of the receptor (kg)

AT = averaging time (days).

Therefore, the CDI for each receptor and COPC is calculated by

$$CDI = Intake \times Conc_{COPC}$$

where

$Conc_{COPC}$ = concentration of the COPC in groundwater (ppb) according to each water bearing zone (overburden or bedrock).

4.2.5 Dermal Contact with Water

The exposure equation for dermal contact with groundwater describes different exposure scenarios for each receptor. For residents, the exposure equation describes the shower/bath scenario, where the full body is exposed and the hand-washing scenario, where only the hands are exposed. For commercial and industrial workers, the exposure equation describes typical contact with water at the tap on the job. For construction workers, the exposure equation describes incidental contact with groundwater when during excavation or other construction-related activities. The intake equation for dermal contact with groundwater is

$$DAD = \frac{DA_{EVENT} \times SA_W \times EF \times ED \times EV}{BW \times AT}$$

where

DAD = dermally absorbed dose (mg/kg-day)

DA_{EVENT} = absorbed dose per event (mg/cm²-event)

SA_W = skin surface area available for contact with water (cm²/day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

EV = event frequency (events/day)

BW = body weight of the receptor (kg)

AT = averaging time (days).

The DA_{EVENT} is calculated according to the type of COPC.

For organics:

$$\text{If } t_{EVENT} \leq t^*, \text{ then: } DA_{EVENT} = 2 \times FA \times K_P \times C_{COPC} \sqrt{\frac{6 \times \tau_{EVENT} \times t_{EVENT}}{\pi}}$$

$$\text{If } t_{EVENT} > t^*, \text{ then: } DA_{EVENT} = FA \times K_P \times C_{COPC} \left[\frac{t_{EVENT}}{1+B} + 2 \times \tau_{EVENT} \left(\frac{1+3B+3B^2}{1+B^2} \right) \right]$$

where

t_{EVENT} = event duration (hr/event)

t^* = time to reach steady-state (hr)

FA = fraction absorbed water (dimensionless)

K_P = dermal permeability coefficient of compound in water (cm/hr)

τ_{EVENT} = lag time per event (hr/event)

$Conc_{COPC}$ = concentration of the COPC in groundwater (ppb)

B = ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis (dimensionless).

For inorganics:

$$DA_{EVENT} = K_P \times C_{COPC} \times t_{EVENT}$$

where

t_{EVENT} = event duration (hr/event)

K_P = dermal permeability coefficient of compound in water (cm/hr)

$Conc_{COPC}$ = concentration of the COPC in groundwater (ppb).

where

t_{EVENT} = event duration (hr/event)

K_P = dermal permeability coefficient of compound in water (cm/hr)

$Conc_{COPC}$ = concentration of the COPC in groundwater (ppb)

Note: Event duration (t_{EVENT}) and event frequency (EV) are derived from the event time (ET) for dermal contact with water, which is shown on Table 4.1. The relationship is as follows:

$$ET = t_{EVENT} \times EV$$

4.2.6 Inhalation of Indoor Vapors

The exposure equation for the inhalation of indoor air accounts for exposure to vapors from soil and groundwater that travel through foundation cracks into the structure. The exposure equation can account for these different sources because the exposure medium (indoor air) is the same for the sources. The intake equation for outdoor air exposure is

$$Intake = \frac{IR_{AI} \times EF \times ED \times ET_{IN}}{BW \times AT}$$

where

IR_{AI} = indoor inhalation rate of the receptor (m^3 /hour)

EF = exposure frequency (days/year)

ED = exposure duration (years)

ET_{IN} = exposure time that the receptor is indoors (hours/day)

BW = body weight of the receptor (kg)

AT = averaging time (days).

Therefore, the CDI for each receptor and COPC is calculated by

$$CDI = Intake \times Conc_{COPC}$$

where

$Conc_{COPC}$ = concentration of the COPC in air (mg/m^3) from each exposure source.

4.2.7 Inhalation of Indoor Vapors from Tap Water

The exposure equation for the inhalation of indoor air accounts for exposure to vapors from tap water during bathing or showering. The intake equation for this exposure is

$$Intake = \frac{IR_{AI} \times EF \times ED \times ET_W}{BW \times AT}$$

where

IR_{AI} = indoor inhalation rate of the receptor (m^3 /hour)

EF = exposure frequency (days/year)

ED = exposure duration (years)

ET_W = exposure time that the receptor is bathing or showering (hours/day)

BW = body weight of the receptor (kg)

AT = averaging time (days).

Therefore, the CDI for each receptor and COPC is calculated by

$$CDI = Intake \times Conc_{COPC}$$

where

Conc_{COPC} = concentration of the COPC in air (mg/m³) from the tap water source.

4.2.8 Incidental Ingestion of Surface Water

The exposure equation for incidental ingestion of surface water describes surface water intake for a swimming scenario. The intake equation for incidental ingestion of surface water is

$$Intake = \frac{IR_{SW} \times EF_{SW} \times ED \times ET_{SW}}{BW \times AT}$$

where

IR_{SW} = ingestion rate of water for the receptor (L/hour)

EF_{SW} = exposure frequency (days/year)

ED = exposure duration (years)

ET_{SW} = exposure time for swimming (hours)

BW = body weight of the receptor (kg)

AT = averaging time (days).

Therefore, the CDI for each receptor and COPC is calculated by

$$CDI = Intake \times Conc_{COPC}$$

where

Conc_{COPC} = concentration of the COPC in surface water (ppb).

4.2.9 Dermal Contact with Surface Water

The exposure equation for dermal contact with surface water describes exposure to surface water for a swimming scenario or incidental contact depending on receptor. The intake equation for dermal contact with surface water is

$$DAD = \frac{DA_{EVENT} \times SA_W \times EF \times ED \times EV}{BW \times AT}$$

where

DAD = dermally absorbed dose (mg/kg-day)

DA_{EVENT} = absorbed dose per event (mg/cm²-event)

SA_W = skin surface area available for contact with water (cm²/day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

EV = event frequency (events/day)

BW = body weight of the receptor (kg)

AT = averaging time (days).

The DA_{EVENT} is calculated according to the type of COPC.

For organics:

$$\text{If } t_{EVENT} \leq t^*, \text{ then: } DA_{EVENT} = 2 \times FA \times K_P \times C_{COPC} \sqrt{\frac{6 \times \tau_{EVENT} \times t_{EVENT}}{\pi}}$$

$$\text{If } t_{EVENT} > t^*, \text{ then: } DA_{EVENT} = FA \times K_P \times C_{COPC} \left[\frac{t_{EVENT}}{1+B} + 2 \times \tau_{EVENT} \left(\frac{1+3B+3B^2}{1+B^2} \right) \right]$$

where

t_{EVENT} = event duration (hr/event)

t* = time to reach steady-state (hr)

FA = fraction absorbed water (dimensionless)

K_P = dermal permeability coefficient of compound in water (cm/hr)

τ_{EVENT} = lag time per event (hr/event)

Conc_{COPC} = concentration of the COPC in groundwater (ppb)

B = ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis (dimensionless).

For inorganics:

$$DA_{EVENT} = K_P \times C_{COPC} \times t_{EVENT}$$

where

t_{EVENT} = event duration (hr/event)

K_P = dermal permeability coefficient of compound in water (cm/hr)

$\text{Conc}_{\text{COPC}}$ = concentration of the COPC in groundwater (ppb).

where

t_{EVENT} = event duration (hr/event)

K_p = dermal permeability coefficient of compound in water (cm/hr)

$\text{Conc}_{\text{COPC}}$ = concentration of the COPC in groundwater (ppb)

The Event duration (t_{EVENT}) and event frequency (EV) are derived from the event time (ET) for dermal contact with water, which is shown on Table 4.1. The relationship is as follows:

$$ET = t_{\text{EVENT}} \times EV$$

4.2.10 Radionuclide Exposure

Pathways for exposure to radionuclides are available from some of the same pathways as described for chemical COPCs as defined in the previous sections. Radionuclides were encountered in the groundwater, surface water, surface soil and subsurface soil. The radionuclides were present in the form of solids in the soil or water; technetium 99 was found to be soluble in water. The major pathways for exposure were ingestion, inhalation, and direct external exposure. The radionuclides were assumed to be absorbed through the skin.

USEPA presents methods for estimating risk to human health for radionuclide exposure (USEPA, 1989a, USEPA, 1991) and recommends the use of appropriate models and site-specific information to refine the risk assessments. The ingestion pathway was evaluated as described in Section 4.3.2 and 4.3.4 for water and soil, respectively. One appropriate computer model that can be used is the RESRAD (RESidual RADiation) Model. RESRAD is a computer code developed by Argonne National Laboratory that calculates radiation dose and excess lifetime cancer risk. Both the external gamma radiation and inhalation of airborne soil and sediment particulates pathways were modeled using the RESRAD computer program (Argonne, 2001). The inhalation rate was the same as that used for the chemical risk assessment: 20 m³/day or 7,200 m³/year (USEPA 1997a). The exposure frequency for inhalation and external gamma radiation was 350 days a year. This time is divided between indoors and outdoors. It was assumed that, on average, half of each day was spent indoors at the home, one quarter of each day was spent outdoors, and one quarter of each day was spent away from the home.

Other RESRAD input parameters used in the external gamma and inhalation pathways were the same as used previously. This approach was used for the exposure scenarios involving the surface soil for both the resident and construction worker. Potential exposures to surface soil were evaluated using samples from the RI collected at a depth of 0 to 15 cm. This depth was

then used in the subsequent risk assessments including an input parameter for RESRAD. USNRC and USEPA defines surface soil as the top 15 centimeters. The top 15 cm was also considered in terms of contribution to pathways such as dust inhalation, ingestion and particulates. USEPA defines surface soil as the top 2 centimeters, as defined by Urban Soil Lead Abatement Project (USEPA, 1993). In the Soil Screening Guidance, the USEPA explained that additional sampling beyond 2 cm may be appropriate for surface soils under a future residential use scenario in areas where major soil disturbances could reasonably be expected as a result of landscaping, gardening, or construction activities. It is important to be cognizant of local residential construction practices when determining the depth of surface soil sampling and to weigh the likelihood of that area being developed (USEPA, 1996b).

The dermal uptake of radionuclides, which have low permeability constants, was not an important route of uptake for radionuclides (USEPA, 1989a). Dermal uptake of radionuclides is not evaluated in this risk assessment. Likewise, radionuclides present at WEC were not volatile and inhalation of groundwater was not considered a significant exposure route. The radiation dose, and resulting risk, was calculated by the ingestion pathway.

5.0 Toxicity Assessment

The toxicity assessment evaluates the potential for the COPCs to cause adverse health effects in exposed individuals and establishes a relationship between exposure to a constituent and the increased likelihood and severity of induced adverse health effects. Two broad categories of chemically induced disease states were considered, including cancer and non-cancer health effects. Both categories were evaluated in the toxicity assessment for each identified COPC. In the same way that an exposure assessment attempts to define the chronic lifetime dosage of COPCs received by an individual in a given scenario, the toxicity assessment links adverse effects associated with exposure to the particular COPC. Establishing an association between exposure to a constituent and the possible adverse effects is the goal of toxicology. The dose received determines the magnitude of any anticipated adverse effects related to the constituent's inherent toxicity.

5.1 Chemical Toxicity

Toxicity values are used in risk characterization to quantify the probability of observing cancer and non-cancer effects in a potentially exposed population. Two types of toxicity values are used to express a COPCs dose-response-effect relationship:

- Slope Factor (SF) is a plausible upper-bound estimate of the probability of a response per unit intake of a chemical over a lifetime. The slope factor is used to estimate an upper-bound probability of an individual developing cancer as a result of a lifetime of exposure to a particular level of a potential carcinogen. The slope factor is expressed in the units of $(\text{mg}/\text{kg}\text{-day})^{-1}$ for non-radiological contaminants and $(\text{pCi})^{-1}$ for radiological contaminants for estimating the likelihood of carcinogenic effects; and
- Reference Dose (RfD), reported in $\text{mg}/\text{kg}\text{-day}$, or Reference Concentration (RfC), expressed in mg/m^3 , are estimates of the amount of exposure to which a person (including sensitive subpopulations) could be exposed to on a daily basis where adverse non-carcinogenic health effects (e.g., organ damage, biochemical alterations, birth defects) would not be expected. RfDs and RfCs are used in estimating possible non-carcinogenic effects from non-radiological contaminants.

In general, SF and RfD values are derived from long-term animal studies. These studies incorporate uncertainty factors to compensate for extrapolation of observed adverse effects in laboratory animals to estimate possible adverse effects in humans. Where available, the SF and RfD values for studies involving humans may be used to reduce uncertainty.

For this toxicity assessment, toxicity values (TVs) such as SFs, cancer classifications, RfDs were selected from a variety of credible sources, each presenting varying degrees of confidence, with final selection based on the following hierarchy recommended by the USEPA (USEPA, 2003), including:

- Tier 1 - USEPA's IRIS (Integrated Risk Information System);
- Tier 2 - USEPA's Provisional Peer Reviewed Toxicity Values (PPRTVs); and
- Tier 3 - Additional EPA sources (e.g., historic HEAST and NCEA provisional values) and non-EPA sources of toxicity information (e.g., California EPA or Missouri RBCA toxicity values).

When Tier 1 and Tier 2 sources failed to yield a published toxicity value (TV), those published within USEPA Region IX 2004 PRG Tables, which include California EPA TVs as a peer reviewed Tier 3 source, were adopted for use. This decision was based on the premise that a Tier 3 source introduces a relatively higher degree of uncertainty, as they have yet to attain the level of confidence provided by the more established Tier 1 and 2 sources, and making use of USEPA Region IX TVs offers a more protective approach to human health. If USEPA Region IX tables did not offer a TV, additional sources such as the MRBCA tables were referenced for default TVs.

Because toxicity values for dermal exposure are rarely available (appropriate toxicity data are scarce), the oral RfD and SF are adjusted to an absorbed dose, using constituent-specific oral absorption efficiency, as recommended by and provided within the USEPA RAGS Part E (USEPA, 2004b), to derive an adjusted RfD and SF to assess dermal exposure. Table 6.1 displays constituent-specific absorption efficiencies for dermal exposure.

Carcinogenic and non-carcinogenic toxicity effects information for the COPCs are listed in Table 6.1 as well. COPC property information is listed in Table 6.2. Carcinogenic toxicity information for radiological COPCs is listed in Table 6.3.

Cancer risks are expressed as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen (i.e., excess individual lifetime cancer risk). In carcinogen assessment, USEPA evaluates the available data to determine the likelihood that an agent is a human carcinogen. Under the revised carcinogen risk assessment

guidelines (USEPA 1999a), standard descriptors are used as part of the weight-of-evidence narrative. These standard descriptors are summarized as follows:

Carcinogenic to humans – when there is convincing evidence demonstrating causality between human exposure and cancer, or when there is compelling evidence of causality in animals and mechanistic information in animals and humans demonstrating similar modes of action.

Likely to be carcinogenic to humans – when the available data are adequate to demonstrate carcinogenic potential to humans.

Suggestive evidence of carcinogenicity, but not sufficient to assess human carcinogenic potential – when the evidence from either human or animal data is only suggestive of carcinogenicity. In such cases data is insufficient to determine dose-responses or to determine human carcinogenic potential.

Data are inadequate for an assessment of human carcinogenic potential – when available data are inadequate to perform an assessment. Often there is either a lack of pertinent or useful data or there is evidence of conflicting data.

Not likely to be carcinogenic to humans – when the data are considered sufficiently strong for making a conclusion that there is no carcinogenic human hazard concern.

Most of the available toxicity information (e.g. IRIS) was developed prior to the implementation of the revised cancer guidelines. This toxicity information is based on a USEPA's previous classification scheme of the overall weight-of-evidence:

Group A - Human Carcinogen - Sufficient evidence from epidemiological studies substantiated by causal association between exposure and carcinogenicity.

Group B1 - Probable Human Carcinogen - Limited evidence of carcinogenicity in humans from available epidemiological data.

Group B2 - Probable Human Carcinogen - Sufficient evidence of carcinogenicity in animals, but inadequate or no evidence in humans.

Group C - Possible Human Carcinogen - Limited evidence of carcinogenicity in animals.

Group D - Not Classified - Inadequate evidence of carcinogenicity in animals to support classification.

Group E - Not a Human Carcinogen - No evidence of carcinogenicity in at least two adequate animal tests in different species or in both epidemiological and animal studies.

Based on the evidence that a constituent is a known or likely to be a human carcinogen, the USEPA calculates a toxicity value that defines a quantitative relationship between dose and response (i.e., SF). An SF converts estimated daily intakes averaged over a human lifetime of exposure directly to incremental risk of an individual developing cancer. A critical assumption of this approach is that the dose-response relationship is a linear relationship in the low-dose portion of the dose-response curve. Under this assumption, the SF is a constant, and risk is directly related to intake. Thus, the linear form of the carcinogenic risk equation is usually applicable for estimating site risks. This linear low-dose equation is defined for non-radiological contaminants as:

$$Risk = CDI \times SF$$

where:

Risk = a unitless probability (e.g., 1×10^{-6}) of an individual developing cancer over a lifetime

CDI = chronic daily intake averaged over 70 years (mg/kg-day)

SF = slope factor, expressed in (mg/kg-day)⁻¹

The collective carcinogenic risk from exposure to several non-radiological constituents is calculated by adding the individual cancer risks for each constituent in the medium identified in each appropriate exposure pathway assessment and then summing the total carcinogen risk for all relevant exposure pathways.

$$Risk_T = \sum Risk_{ij}$$

where:

Risk_T = the total cancer risk, expressed as a unitless probability, and

Risk_{ij} = the risk estimate for the ith constituent in the jth exposure medium pathway

The resulting summation of constituent-specific cancer risks is a very conservative upper-bound estimate of cancer risk for the following reason. Each SF is an upper 95th percentile estimate of

potency, and, because percentiles of probability distributions are not strictly additive, the total cancer risk estimate becomes more conservative as the number of cancer risk estimates increases. While this may appear to be overly conservative, this method is used to ensure that carcinogenic risks will not be underestimated. Likewise, the increased lifetime cancer risk from radiological constituents is given by the following equation:

$$Risk = Intake \times SF$$

where:

Risk = a unitless probability (e.g., 1×10^{-6}) of an individual developing cancer over a lifetime

Intake = total lifetime intake above background (pCi)

SF = slope factor, expressed in (pCi)⁻¹

The total cancer risk from both radiological and non-radiological constituents is calculated by summing the individual cancer risks for all contaminants (both radiological and non-radiological) across all exposure media and pathways.

To evaluate non-carcinogenic effects, a chronic RfD or RfC is an estimate of the daily exposure to a human population, including any sensitive subpopulation that is unlikely to cause an increased incidence of deleterious health effects during a lifetime of exposure. Chronic RfD or RfC values are specifically developed to be protective for long-term exposure to a constituent.

To characterize low-dose exposure effects, the "no observed adverse effect level" (NOAEL) and the "lowest observed adverse effect level" (LOAEL) are evaluated. The NOAEL is an exposure level where there are no statistically or biologically significant increases in the frequency or severity of adverse effects in the exposed population. The LOAEL is the lowest exposure dose in a dose-response experiment at which there are statistically or biologically significant increases in severity or frequency of adverse effects in the exposed population.

For non-carcinogenic constituents, the measure used to describe the potential for non-carcinogenic toxicity to occur in an individual is evaluated by comparing the estimated exposure level over a specified time period (e.g., lifetime) with the appropriate non-cancer toxicity value (i.e., RfD or RfC).

This ratio of exposure to toxicity is called a non-cancer hazard quotient (HQ):



$$HQ = \frac{CDI}{RfD}$$

where:

HQ = hazard quotient

CDI = chronic daily intake (mg/kg-day)

RfD = Reference Dose

The non-carcinogenic HQ assumes that there is a level of exposure (i.e., RfD or RfC) below which it is unlikely for even sensitive subpopulations to experience adverse health effects.

For assessing the health impacts of several non-carcinogenic constituents, RfDs or RfCs are compared to exposure-specific intake rates of each COPC. A summation of these HQs is termed the hazard index (HI). The aggregate HI is expressed as:

$$HI_T = \sum \frac{CDI_{ij}}{RfD_j}$$

where:

HI_T = total hazard index for exposure scenarios for an individual

CDI_{ij} = chronic daily exposure for the i^{th} constituent in the j^{th} exposure pathway

RfD_i = Reference dose for the i^{th} constituent

Accordingly, the HI is the sum of HQs for substances that affect the same target organ or organ system. Because different COPC may cause similar adverse health effects, it is often appropriate to combine hazard quotients associated with different substances. If this ratio of the daily intake to the RfD or RfC exceeds 1.0 (unity) for the defined exposure scenario, this provides an indication that the exposed receptor may be subject to an adverse health impact and that further investigation should be undertaken. If the ratio is below unity, then it is generally assumed that no adverse impact to human health has or will occur.

The HI approach does have limitations and should be interpreted carefully based on the known aspects of additive toxic effects from exposure to mixtures of chemicals. First, because both the HQ and HI are ratios, after unity has been exceeded, the magnitude of the index has little bearing on the potential severity of adverse effects that may be anticipated. An HI of five does not indicate the non-cancer hazard is greater than a HI of three. Secondly, it is inappropriate to sum non-cancer HQs for constituents that do not have similar toxic modes of action or that do not

affect the same organ system. Additionally, there may be synergistic effects, which, though not directly affecting the same organ system, may increase the risk from one constituent based on the presence or effect of some other constituent.

5.2 Radiological Toxicity

The USEPA published radionuclide-specific risk coefficients or slope factors in Federal Guidance Report No. 13 (FGR 13) (USEPA, 1999b). These factors were used to convert EPC to radiation dose and cancer risk. It includes separate coefficients for water and food ingestion, inhalation, and external exposure for over 800 radionuclides.

The dose conversion factors and slope factors for the isotopes used in this risk assessment are provided in Table 6.3. These risk coefficients are recommended for use whenever a quantitative risk assessment is required.^{12, 13} Values from FGR 13 are provided for both ingestion of tap water as well as dietary intake. While the factors are similar regardless of the source of intake, the dietary values were higher than those provided for the ingestion of tap water, except for a young child. The slope factors for a child, ages 0-5, were higher for tap water compared to dietary ingestion. A resident child was described in Section 2.2 as a child six (6) years of age. Consequently, the calculation of risk in Table 6.3 and Worksheets 7.84 through 7.103 used the greatest slope factor (risk per microcurie) from FGR 13 for either tap water or dietary ingestion. This provided a conservative or slightly higher risk than using the slope factors for both the tap water and dietary ingestion.

A mortality risk coefficient is an estimate of the risk of dying of cancer as a result of intakes of the radionuclide or external exposure to its emitted radiations for an average member of the U.S. population. The coefficient is normalized to a unit activity intake by inhaled or ingested or per unit time-integrated activity concentration in air or soil. A morbidity risk coefficient is an estimate of the risk of experiencing a radiogenic cancer as a result intakes of the radionuclide or external exposure to its emitted radiations for an average member of the U.S. population. The coefficient is normalized to a unit activity intake by inhaled or ingested or per unit time-integrated activity concentration in air or soil. The risk coefficients apply to an average member of the public, in the sense that estimates of risk are averaged over the age and gender

¹² The risk coefficient for a given radionuclide, environmental medium, and mode of exposure, is the estimated probability of radiogenic cancer mortality or morbidity, per unit activity intake for internal exposures or per unit exposure for external exposures.

¹³ The time integral of the effective dose rate is calculated over a fixed time period following a unit activity intake of a radionuclide. The integration time is 50 years for adults and from intake to 70 years for children.

distributions of a hypothetical close stationary population whose survival functions and cancer mortality rates are based on recent data for the United States. The risk coefficients tabulated in FGR-13 are applicable to either chronic or acute exposure to a radionuclide. That is, a coefficient may be interpreted either as the average risk per unit exposure to members of the population throughout life to a constant concentration of the radionuclide in an environmental medium or as the average risk per unit exposure to members of a population acutely exposed to the radionuclide in the environmental medium. For purpose of computing the risk coefficients, it is assumed that the concentration of the radionuclide in the environmental remains constant and that all persons in the population are exposed to that environmental medium throughout their lifetimes.

The cancer risk coefficients in FGR 13 are calculated using the more recent age-specific dose models developed for ICRP Publication 72 and its supporting publications with the age-specific radiation carcinogenesis models adopted by USEPA (ICRP, 1996). The Interagency Steering Committee on Radiation Standards (ISCORS) compared the estimate of radiation risk, (FGR 13) with the previous methods of estimating radiation exposure (FGR 11 and FGR 12) (ISCORS, 2002), and concluded that the risk coefficients published in FGR 13 should be used for situations in which a radiation risk assessment was required to make risk management decisions. The results provided in Chapter 6.3 of this report reflect the use of the risk coefficients from FGR 13. The input parameters for RESRAD also included cancer risk coefficients from FGR 13. The radiation dose conversion factors were selected from FGR 13 and provided in this assessment as a point of comparison. The risks from radioactive materials were calculated using slope factors from FGR 13 rather than converting a risk from radiation dose.

Because radiation exposure, if high enough, is associated with an increased risk of cancer, the radiological risk of interest is the risk of incurring fatal cancer. Hypothetically, the risk of harm caused by radiation exposure increases as the exposure increases.¹⁴ However, no effects have ever been observed at levels below 5,000 millirem delivered over a one year period.^{15,16} In fact, the effects seen when humans are exposed to 100,000 millirem over a very short time period are

¹⁴ This linear relationship between dose and effect is clearly demonstrated in populations that have received large, acute exposures.

¹⁵ Health Physics Society, “*Radiation Risk in Perspective*”, Position Statement of the Health Physics Society, January, 1996 (revised August, 2004).

¹⁶ Health Physics Society, “*Compensation for Diseases that Might be Caused by Radiation Must Consider the Dose*”, Position Statement of the Health Physics Society, March, 2000 (Reaffirmed, March, 2001).

temporary and reversible. It takes a short-term dose on the order of 500,000 millirem (without medical intervention) to cause death.¹⁷

The radiation dose potential to even the maximally-exposed individual is far too low to result in demonstrable health effects. Nonetheless, the LNT, or "Linear No Threshold" hypothesis provides a useful risk assessment tool. In essence, this hypothesis states that since scientists have observed a linear relationship between radiation dose and effect at high doses and dose rates, and since a "radiation free" environment to test the theory at low doses (taken to be 20,000 millirem TEDE or less) does not exist, for radiation protection purposes it is reasonably conservative to assume that the relationship is indeed linear. While the LNT hypothesis leads to the obvious conclusion that any radiation dose, no matter how small, may be capable of causing some biological damage or detriment - a conclusion that is not supported with facts - it nonetheless offers a conservative risk coefficient that is useful for this assessment.

¹⁷ International Commission on Radiological Protection, ICRP Publication 60, "1990 Recommendations of the International Commission", Pergamon Press, 1991.

6.0 Risk Characterization

6.1 Health Hazards and Non-Radiological Cancer Risks

Sections 6.1.1 through 6.1.12 explain the human health hazards and non-radiological cancer risks associated with each exposure medium and route. Table 7.1 presents a summary of risks for each exposure pathway and receptor. Worksheets 7.1 through 7.83 present the incremental cancer risks and HQs for each COPC, exposure pathway, and receptor. These worksheets are presented in Appendix D.

6.1.1 Ingestion of Groundwater

Future residents and commercial/industrial workers may ingest impacted drinking water if domestic wells are installed at the Site and water from these wells is used in lieu of the public water supply currently available at the Site. Similar exposures could also occur if, in the future, current institutional controls are lost and off-site residents or commercial/industrial workers would ingest groundwater from impacted bedrock downgradient of the Site.

For these receptors, the total cancer risk for ingestion of groundwater from bedrock wells is in the order of 10^{-2} . This risk exceeds the acceptable range of 10^{-6} to 10^{-4} for ILCR. The respective total HQs exceed unity by one to two orders of magnitude for ingestion of groundwater.

6.1.2 Dermal Contact with Groundwater

Future residents and commercial/industrial workers may come into contact with impacted tap water if domestic wells are installed at the Site and water from these wells is used in lieu of the public water supply currently available at the Site. Similar exposures could also occur if, in the future, current institutional controls are lost and off-site residents or commercial/industrial workers would use groundwater withdrawn from impacted bedrock downgradient of the Site.

For residents, the total cancer risk for dermal contact with groundwater is in the order of 10^{-3} . This risk exceeds the acceptable range of 10^{-6} to 10^{-4} for ILCR. For commercial/industrial workers, the total cancer risk for dermal contact with groundwater is in the order of 10^{-4} . This risk is at the upper limit for an acceptable ILCR. For residents and commercial/industrial workers, the respective total HQs exceed unity by at most one order of magnitude for dermal contact with groundwater.

Construction workers may come into contact with impacted overburden groundwater during construction-related activities at the Site. The total cancer risk for dermal contact with groundwater from overburden is in the order of 10^{-5} . This risk is within the acceptable range of 10^{-6} to 10^{-4} for ILCR. The respective total HQ, however, exceeds unity.

6.1.3 Inhalation of Indoor Air Vapors during Bathing or Showering

Future potential residents may inhale vapors from groundwater during bathing or showering if domestic wells are installed at the Site and water from these wells is used in lieu of the public water supply currently available at the Site. Similar exposures could also occur if, in the future, current institutional controls are lost and off-site residents would use groundwater withdrawn from impacted bedrock down-gradient of the Site.

For residents, the total cancer risk for inhalation of indoor air vapors from groundwater during bathing or showering is in the order of 10^{-1} . This risk exceeds the acceptable range of 10^{-6} to 10^{-4} for ILCR. The respective total HQs exceed unity by two to three orders of magnitude for this exposure route.

6.1.4 Inhalation of Indoor Air Vapors from Groundwater

Future residents and commercial/industrial workers may inhale vapors from overburden groundwater when buildings are built atop an impacted area. For residents, the total cancer risk for indoor inhalation from overburden groundwater is in the order of 10^{-4} . This risk exceeds the acceptable range of 10^{-6} to 10^{-4} for ILCR. For commercial/industrial workers, the total cancer risk for indoor inhalation from overburden groundwater is in the order of 10^{-4} . This risk is at the upper limit for an acceptable ILCR. For residents and commercial/industrial workers, the respective total HQs are in the order of 10^{-1} .

6.1.5 Inhalation of Outdoor Air Vapors from Groundwater

All of the receptors considered in this HHRA may inhale outdoor vapors from overburden groundwater when conducting outdoor activities at the site. For the receptors, the total cancer risk for outdoor inhalation from overburden groundwater is in the range of 10^{-7} to 10^{-5} . These risks are below or within the acceptable range of 10^{-6} to 10^{-4} for ILCR. The respective total HQs for each receptor are in the range of 10^{-2} to 10^{-4} , which are well below unity. Accordingly, outdoor inhalation of vapors from groundwater is not a human health hazard for any of the receptors for this HHRA.

6.1.6 Incidental Ingestion of Soil

All of the receptors considered in this HHRA may incidentally ingest surface soil during outdoor activities. For the receptors considered, the total cancer risk for incidental ingestion of surface

soil is in the range of 10^{-6} to 10^{-5} . These risks are within the acceptable range of 10^{-6} to 10^{-4} for ILCR. The respective total HQs for each receptor are below unity, with the exception of the resident child with a HQ at 1.27.

Construction workers may come into contact with impacted subsurface soil during construction-related activities at the site. The total cancer risk for incidental ingestion of subsurface soil by a construction worker is of the order 10^{-7} . This risk is below the acceptable range of 10^{-6} to 10^{-4} for ILCR. The respective total HQ is below unity by two orders of magnitude.

6.1.7 Dermal Contact with Soil

All of the receptors considered in this HHRA may come into contact with impacted surface soil during outdoor activities. For the receptors, the total cancer risks for dermal contact with surface soil are in the range of 10^{-7} to 10^{-5} . These risks are below or within the acceptable range of 10^{-6} to 10^{-4} for ILCR. The respective total HQs are below unity by one to three orders of magnitude.

Construction workers may come into contact with impacted subsurface soil during construction-related activities at the site. The total cancer risk for dermal contact with subsurface soil is in the order of 10^{-10} . This risk is within the acceptable range of 10^{-6} to 10^{-4} for ILCR. The respective total HQ is below unity by three orders of magnitude.

6.1.8 Inhalation of Indoor Air Vapors from Soil

Future residents and commercial/industrial workers may inhale vapors from subsurface soils when buildings are built atop an impacted area. For residents and commercial/industrial workers, the total cancer risk for indoor inhalation from subsurface soil is in the order of 10^{-5} . These risks are within the acceptable range of 10^{-6} to 10^{-4} for ILCR. The respective total HQs are below unity by two orders of magnitude.

6.1.9 Inhalation of Outdoor Air Vapors from Soil

All of the receptors considered in this HHRA may inhale outdoor vapors from surface soil when conducting outdoor activities at the site. For the receptors considered, the total cancer risks for outdoor inhalation from surface soil range from 10^{-10} to 10^{-8} . These risks are below the acceptable range of 10^{-6} to 10^{-4} for ILCR. The respective total HQs are zero because non-cancer toxicological values for this pathway and COPCs are not available.

All of the receptors considered in this HHRA may inhale outdoor vapors from subsurface soil when conducting outdoor activities at the site. For the receptors considered, the total cancer risks for outdoor inhalation of vapors from subsurface soil range from 10^{-9} to 10^{-7} . These risks

are below the acceptable range of 10^{-6} to 10^{-4} for ILCR. The respective total HQs are below unity by three to five orders of magnitude.

6.1.10 Inhalation of Outdoor Air Particulates from Soil

All of the receptors considered in this HHRA may inhale outdoor particulates from surface soil when conducting outdoor activities at the site. For the receptors considered, the total cancer risks for outdoor inhalation of particulates from surface soil range from 10^{-10} to 10^{-8} . These risks are below the acceptable range of 10^{-6} to 10^{-4} for ILCR. The respective total HQs are below unity by three to five orders of magnitude.

Construction and agricultural workers may inhale outdoor particulates from subsurface soil when conducting job-related activities at the site. For a construction worker, the total cancer risk for outdoor inhalation of particulates from subsurface soil is in the order of 10^{-10} . For an agricultural worker, the total cancer risk for outdoor inhalation of particulates from subsurface soil is in the order of 10^{-9} . These risks are below the acceptable range of 10^{-6} to 10^{-4} for ILCR. The respective total HQs are well below unity at 10^{-9} .

6.1.11 Incidental Ingestion of Surface Water/Sediment

All of the receptors considered in this HHRA may incidentally ingest surface water/sediment during outdoor activities. For the receptors considered, the total cancer risk for incidental ingestion of surface water/sediment ranges from 10^{-9} to 10^{-7} . These risks are below the acceptable range of 10^{-6} to 10^{-4} for ILCR. The respective total HQs for each receptor are two to three orders of magnitude below unity.

6.1.12 Dermal Contact with Surface Water/Sediment

All of the receptors considered in this HHRA may come into contact with impacted surface water/sediment during outdoor activities. For these receptors, the total cancer risks for dermal contact with surface water/sediment are in the range of 10^{-8} to 10^{-6} . These risks are below or within the acceptable range of 10^{-6} to 10^{-4} for ILCR. The respective total HQs are below unity by two to three orders of magnitude.

6.2 Lead Health Hazards

The health hazards associated with lead were evaluated apart from the main portion of the risk assessment due to the sensitive population effected by exposure to lead. As recommended by the USEPA (USEPA, 1998a) the Integrated Exposure Uptake Biokinetic (IEUBK) model was used to evaluate blood-lead levels in children from six months to seven years of age.

The exposure routes considered in this model were ingestion of surface soil and groundwater and inhalation of dust. Site-specific soil (EPC set 6) and groundwater concentrations (EPC set 1, groundwater in overburden, was used for the calculation – lead was not detected in bedrock groundwater data) were input into the model. IEUBK model default exposure factors were used. The model was run with a time step of once a day.

The text output and probability density plot is presented in Appendix E. The text output displays the total lead intake and the corresponding blood-lead level for each year childhood year. The probability density plot shows the likelihood of exposures given the site-specific soil and groundwater concentrations. The blood-lead level of concern of 10 microgram per deciliter (ug/dL) is also shown on the plot. The USEPA (1998a) has established a recommended health protection goal concerning blood-lead levels for children. The goal is for children to have a <5 percent chance of exceeding a blood-lead concentration of 10 ug/dL. The probability density plot for the site shows that a child will have a 1.032 percent chance of exceeding a blood-lead concentration of 10 ug/dL. This probability is below USEPA's recommended health protection goal. This indicates that the site does not pose an unacceptable lead health hazard to children. Children are more sensitive to lead health hazards in the environment than adults, therefore, the lead health hazard to adults was not evaluated.

6.3 Radiological Risk Assessment

The total dose and total cancer risks associated with radiation exposure from environmental media under current and future land-use scenarios are presented in this section. The total dose is expressed as the annual Total Effective Dose Equivalent (TEDE), which is the sum of the dose from all sources both internal and external averaged over the exposure period and expressed in mrem/yr. In this section, the dose and risk from the applicable pathways are summed to present an assessment of the total dose (i.e., TEDE) and risk. The total radiological dose and risk estimates based on RME exposure factors are presented in Tables 7.1; the worksheets to calculate the radiation risk for each scenario is provided in Appendix D, Table 7.84 through 7.103.¹⁸

The exposure to radioactive materials is characterized by the CSM and the exposure equations described in Section 4.2 of this report. Several receptors had potential exposures to external radiation and the inhalation of dust; these pathways were modeled using a computer code. Specifically, the computer code RESRAD was used to calculate radiological doses for the

¹⁸ The radiation exposure was calculated for the entire exposure period in the Tables provided in Appendix D. For the purposes of comparison, the radiation dose was divided by the assumed duration of exposure and presented as a dose rate in units of millirem per year.

inhalation and external gamma radiation pathways evaluated, and to estimate corresponding ILCR for the identified potentially exposed populations for those pathways (Argonne, 2001). RESRAD evaluated exposure through inhalation of soil particulates and dusts, and external gamma exposure from radionuclides in soil for each of the potentially exposed populations. In this section, dose and risk estimates are presented for exposures to the reasonable maximum exposed individuals. The results were calculated in a deterministic manner in order to be comparable with the risks calculated for the chemical COPCs. There was no attempt to develop a range of results using the probabilistic modules available in the RESRAD code.

6.3.1 Ingestion of Groundwater

Future residents may be exposed to contaminants in groundwater if they use private wells as their drinking water and household-use source. Dermal uptake of radionuclides from groundwater does not represent a significant exposure pathway because of the low permeability of radionuclides through the skin barrier.

The annual radiation doses from groundwater for future residents are summarized in Table 7.1. These range from 0.3 to 2.9 mrem/yr. The potential RME annual doses for the bedrock wells for future on-site resident adults, young children, and construction workers are 1.0, 0.9 and 0.3 mrem/yr, respectively.

The increased lifetime cancer risk from radionuclides in groundwater for future on-site resident adult, young child, and construction worker are summarized in Appendix D, Tables 7.84 through 7.89 for the reasonable maximum exposed individuals. The increased lifetime cancer risk from radionuclides in groundwater from the bedrock wells based on RME exposure factors for the future on-site resident adults, young children, and construction workers are 3×10^{-5} , 1×10^{-5} and 1×10^{-5} , respectively. The potential uncertainty in the risk assessment concerning the use of the data from an extended area and various well depths is addressed in Section 6.5 of this report.

6.3.2 Ingestion of Surface Water

Future residents may be exposed to contaminants in the surface water if they wade in the Joachim Creek or swim in the site pond. Dermal uptake of radionuclides from surface water does not represent a significant exposure pathway because of the low permeability of radionuclides through the skin barrier.

The annual radiation doses from surface water for future on-site or off-site residents are summarized in Table 7.90 and 7.94. The RME results for the future on-site resident adults and young children are 0.3 and 0.3 mrem/yr, respectively.

The increased lifetime cancer risks from radionuclides in surface water for future on-site resident adults, and young children, are summarized in Appendix D, Tables 7.90 through 7.91. The increased lifetime cancer risks from radionuclides in surface water based on RME results for the future on-site resident adults, and young children are 1×10^{-6} and 2×10^{-6} respectively.

6.3.3 Ingestion of Surface Soil

Incidental ingestion of soil can expose future on-site residents to contaminants present in soil. Construction workers may also come into contact with radionuclides in contaminated soil during intrusive activities. The annual radiation dose from soil for future on-site residents and future construction workers are summarized in Appendix D, Table 7.95 to 7.102. Dermal uptake of radionuclides from soil does not represent a significant exposure pathway because of the low permeability of radionuclides through the skin barrier. The annual radiological dose ranges from 0.1 to 7 mrem/yr. The potential RME annual doses for the surface soil future on-site resident adults, young children, and construction workers are 0.9, 3.4 and 1.9 mrem/yr, respectively. The increased lifetime cancer risk from these radionuclides in surface soil for these potential receptors is provided in Tables 7.95 through 7.97. The ILCR from radionuclides in surface soil based on RME exposure factors for future on-site resident adults, young children and construction workers are 9×10^{-6} , 6×10^{-5} and 8×10^{-7} , respectively.

The potential radiation exposure was estimated for other receptors who may come in contact with the surface soil through incidental contact during normal work tasks. These receptors included the construction worker, an industrial worker, a trespasser, recreational residents and a farmer. These exposure scenarios are provided in Chapter 2 of this report. As shown in Table 7.97, the industrial worker was estimated to receive 0.6 mrem/yr or a potential risk of 7×10^{-6} . As shown in Table 7.99 and 7.100, the recreational resident (adult and child) was estimated to receive from 0.5 mrem/yr to 2 mrem/yr. The corresponding ILCR was estimated to be 3×10^{-5} . As shown in Table 7.101, the trespasser was estimated to receive less than 0.1 mrem/yr or a corresponding ILCR of 6×10^{-7} . As shown in Table 7.102, the farmer was estimated to receive 1 mrem/yr or a corresponding ILCR of 1×10^{-5} .

6.3.4 External Radiation

The radioactive constituents in the surface soil may present a potential exposure from external radiation to receptors that reside or work at the site. The radiation dose and risk assessments for external radiation were calculated using the RESRAD program, with the summary reports presented in Appendix F. The annual external radiation exposure ranges from 170 to 180 mrem/yr. Exposures were estimated for the future on-site residents, and future construction

workers. The potential RME results from direct radiation for the surface soil for future on-site residents (adults and young children) and construction worker are 170, 180 and 9 mrem/yr, respectively. The increased lifetime cancer risk from this pathway is provided in Table 7.1 for the reasonable maximum exposed individuals. The ILCR external radiation based on RME exposure factors for the future on-site residents (adult and young child) and a construction worker are 2×10^{-3} , 8×10^{-4} , and 2×10^{-4} , respectively.

6.3.5 Inhalation of Airborne Dust and Particulates

The radiological contaminants in the surface soil may be inhaled as airborne particulates. The dose and risk assessments for inhalation were calculated using the RESRAD program, with summary reports presented in Appendix F. The inhalation pathway represents a minimal airborne exposure potential. The annual radiological dose ranges from 0.6 to 6 mrem/yr. Exposures were estimated for the future on-site residents, and future construction workers. The potential RME results for the surface soil for future on-site resident adults, young children, and construction worker are 6, 3, and 0.6 mrem/yr, respectively. The increased lifetime cancer risk from radionuclides in surface soil for these potential receptors is shown in Tables 7.1 for the future on-site resident adults, young children and construction workers are 8×10^{-6} , 1×10^{-6} and 2×10^{-7} , respectively.

6.3.6 Subsurface Soil

Construction workers may come into contact with residual radioactivity in soil during intrusive activities at the facility. The workers may ingest the soil during the normal performance of their work assignments. The worker is dermally exposed to surface soil, subsurface soil to fifteen feet below ground surface and groundwater in the overburden. Dermal exposure to media is limited to the face, hands, and forearms. The worker incidentally ingests surface soil and subsurface soil from contact with these media. The annual radiation dose for future construction workers, summarized in Table 7.103, is estimated to be 7 mrem/yr. The ILCR from radionuclides in subsurface soil for the construction worker is 9×10^{-7} .

6.4 Total Cancer Risks and Health Hazards

To establish the RME, the non-radiological risks were summed across the completed pathway for each receptor. Table 8.1 presents this information, and the sections below explain the total cancer risks and health hazards for each receptor group further.

6.4.1 Resident

Total risks were calculated for the resident child, resident adult, and the composite adult. The composite adult describes a 30-year risk for a resident starting from birth to 30 years of age. The total cancer risks for the resident child and adult are in the order of 10^{-1} . The total cancer risk for the composite adult is above 10^0 over a 30-year period. These total cancer risks exceed the acceptable range of 10^{-6} to 10^{-4} for ILCR. The HQs for the resident child, adult, and composite adult exceed unity by three orders of magnitude. The majority of the risk is associated with ingestion of tap water, dermal contact of tap water, and indoor inhalation of vapors.¹⁹ The risk associated with the ingestion of groundwater from the overburden was not included in the summation of risk. The hydraulic conductivity of the overburden is too low to provide an adequate supply of water. The quality of the water is poor and not potable.

6.4.2 Commercial/Industrial Worker

The total cancer risk calculated for an adult commercial/industrial worker is in the order of 10^{-2} . This total cancer risk exceeds the acceptable range of 10^{-6} to 10^{-4} for ILCR. The HQ for this receptor exceeds unity by two orders of magnitude. The majority of the risk is associated with ingestion of tap water, dermal contact of tap water, and indoor inhalation of vapors. The risk associated with the ingestion of groundwater from the overburden was not included in the summation of risk.

6.4.3 Construction Worker

The total cancer risk calculated for an adult construction worker is in the order of 10^{-5} . This total cancer risk is within the acceptable range of 10^{-6} to 10^{-4} for ILCR. The HQ for this receptor exceeds unity by less than one order of magnitude. The majority of the risk is associated with dermal contact with overburden groundwater.

6.4.4 Recreational

Total risks were calculated for the recreational child, recreational adult, and the recreational composite adult. The composite adult describes a 30-year risk for a recreational individual starting from birth to 30 years of age. The total cancer risks for the recreational child and adult are in the order of 10^{-6} , respectively. The total cancer risk for the recreational composite adult is on the order of 10^{-5} . These total cancer risks are within the acceptable range of 10^{-6} to 10^{-4} for ILCR. The HQs for the recreational child, adult, and composite adult are below unity by one to two orders of magnitude.

¹⁹ The risk for this scenario is the addition of whole body during bathing and hands during hand washing.

6.4.5 Visitor/Trespasser

The total cancer risk calculated for a child visitor/trespasser is in the order of 10^{-7} . The total cancer risk calculated for an adult visitor/trespasser is in the order of 10^{-6} . The total cancer risk calculated for a composite adult is in the order of 10^{-6} . This total cancer risk is within the acceptable range of 10^{-6} to 10^{-4} for ILCR. The HQ for this receptor is below unity by two orders of magnitude.

6.4.6 Agricultural Worker

The total cancer risk calculated for an adult agricultural worker is in the order of 10^{-4} . This total cancer risk is within the acceptable range of 10^{-6} to 10^{-4} for ILCR. The HQ for this receptor is below unity by one order of magnitude.

6.5 Uncertainty

Uncertainties in the risk assessment are discussed in this section. Uncertainties may be present in the identification of COPCs, may be associated with the exposure assessment and the toxicity assessment, or may be a result of the risk characterization. In a human health risk assessment, uncertainty relates to both the variability of the available data and to the absence of a value for a parameter of interest (e.g., exposure point concentration, exposure factors).

6.5.1 Analytical Data

With regard to analytical data, for example, uncertainty can exist in data collection, data analysis and validation, statistical analysis of the data, and screening of the data. Samples were collected from known and suspected areas of contamination (i.e., “biased sampling”), to delineate the nature and extent of contamination. Although this sampling methodology provided a reasonable estimation of the level of contamination at known or suspected contaminated areas, the possibility exists that the data sets formed by these samples do not accurately represent the level of contamination and instead overestimate the concentrations to which receptors are potentially exposed.

Blank contamination was another source of potential uncertainty with regard to laboratory analysis. Blank contamination can occur during sample collection, sample preparation, or sample analysis, and may result in false positive results in the database. To eliminate this possibility, contaminants detected in samples at concentrations less than five times the concentration detected in the associated blank were treated as non-detects. Common laboratory contaminants (acetone, 2-butanone, and methylene chloride) detected in samples at concentrations less than ten times the concentration detected in the associated blank were also treated as nondetects. This reduced the likelihood of false positive results affecting the

quantitative risk assessment; however, it may have eliminated some low-level positive detections in the database.

The analysis of radionuclides provided an estimate of counting error associated with the decay of the radioactive isotope. For the purposes of this assessment, the counting error was not used to modify the statistical analysis of the data. The 95% UCL was calculated for both the radioactive and chemical COPCs; an estimate of the distribution of the specific dataset was made to eliminate some of the uncertainty of the mean or mode of the data.

6.5.2 Exposure Point Concentrations

The statistical analysis of the data introduced some additional uncertainty. Statistical analysis showed that the data exhibited wide ranges of values and variability for certain COPCs. The large variability may be the result of combining samples collected from known areas of contamination (biased samples) and samples collected randomly. While combining samples provides a more accurate representation of the site-wide contamination than either sampling scheme by itself, combining sample types does introduce a high degree of variability into the data set. The exposure point concentrations used in the exposure assessment for the RME receptors are based on 95 percent UCLs of the mean. These UCL values provide a conservative estimate of the true average concentration, and, therefore, they tend to overestimate the potential exposure.

6.5.3 Exposure Factors

Uncertainties related to the conservative aspect of the risk analysis process and methodologies are especially apparent in the exposure assessment. The USEPA model for conducting human health risk assessments presently requires the use of point estimates for all parameters (e.g., chemical concentration, body weight, length of residence) to establish risk estimates for exposure scenarios. Single-point estimates, however, do not demonstrate the similarity or variability of the data. Therefore, uncertainty analysis is limited to qualitative statements about the confidence placed in critical data or default input parameters used in the exposure assessment used to establish the baseline human health risk assessment.

USEPA default values for many of the RME parameters, such as those for ingestion rates of environmental media, exposure duration, and frequency of events, tends to overestimate exposure in the current and future land-use scenarios. Consequently, the use of these default values provides a conservative result.

In exposure pathways that estimate uptake by ingestion, it was assumed that 100 percent of the ingested COPCs were absorbed. This assumption may be valid for organic, lipophilic COPCs, but this assumption overestimates intake of most inorganic COPCs. Thus, for metals, the fraction of inorganic constituents actually absorbed by ingestion is likely to be overestimated in the CDI dose rate uptake of COPCs in all environmental media. As demonstrated in many animal studies and in limited human studies measuring bioavailability of metals after ingestion, less than 10 percent of most metals, even in soluble form, are absorbed from the alimentary tract into the body. This one assumption may overestimate ingested metals intake in all media by an order of magnitude.

Dermal uptake of COPCs by direct dermal contact to soil, sediment, or water is an exposure pathway with inherent uncertainty. Dermal uptake is directly proportional to the length of time for each exposure event. While dermal absorption coefficients for estimating absorbed doses from direct skin contact with water are available or can be calculated (USEPA 2001), some constituents, such as dissolved metals, are generally poorly absorbed through skin contact and use of calculated values for metals and certain other COPCs that are based on dermal absorption of water significantly overestimate exposures via this pathway.

Dermal uptake from soil/sediment is even more uncertain. Quantitative exposure assessment of COPCs in soil/sediment by direct dermal contact is limited to the constituents for which absorption factors were available. Dermal uptake of other COPCs is underestimated in these dermal exposure pathways. However, uptake of metals by dermal exposure to soil/sediment is considered a minor contributing pathway to the total estimated dosage of metals in impacted media. Transfer of metals from soil to skin as an absorbed dose appears to be on the order of 0.1 to 1.0 percent of the available dose in soil (USEPA 2004b).

6.5.5 Uncertainties in Toxicity Assessment

Toxicity assessment relies upon the use of toxicity values (carcinogenic SF, non-carcinogenic RfDs, or RfCs) developed by USEPA to evaluate potential chronic toxicity of COPCs. These toxicity values may be estimated from human data, but the process is largely dependent upon laboratory animal data generated from a variety of toxicology and safety testing studies conducted on constituents.

Toxicity values are not available for all COPCs. Therefore, health risks/hazards cannot be quantitatively assessed for all constituents, and the total risk/hazard for the Site may be underestimated in such circumstances. The carcinogen toxicity values, SFs, are derived from cancer bioassay or epidemiologic dose-response data to estimate carcinogenic risk at constituent

concentrations that may be several orders of magnitude lower than the given dose or estimated exposure observed in the studies that form the basis of the assessment. Thus, extrapolations are made in projecting potential effects at low doses from data on effects at high doses; all these extrapolations add to the uncertainty. A number of uncertainties are associated with this methodology.

The extrapolation of observed carcinogenic effects at high doses used in animal cancer studies to possible cancer effects at substantially lower doses is based on the hypothesis that there is no threshold dose for carcinogens. The extrapolation of carcinogenic and non-carcinogenic effects in animals to effects in humans may not be appropriate for all constituents.

While USEPA recommends standard weight-of-evidence descriptors for carcinogens, the cancer risk algorithm does not utilize this weight-of-evidence and sums all carcinogenic risks equally, whether a COPC is a known human carcinogen or only a suspect carcinogen. Each of these three uncertainty factors tends to overestimate cancer risk. There are also questions concerning the summation of cancer risks when different constituents have specific target organs or induce quite different neoplastic disease states.

The toxicological information for trichloroethylene (TCE) is under review. USEPA recommends using the upper end of the slope factor range for susceptible populations having risk factors for TCE-induced cancer. The upper-end slope factor was used in this risk assessment to assure that risk to susceptible individuals is not underestimated. However, risks to the general exposed population may be overestimated.

Toxicity values derived to estimate chronic dosages that may induce non-cancer adverse effects also have a number of limitations. Unlike cancer risk assessment, by convention non-cancer adverse effects are assumed to occur in a dose-response manner only after a threshold dose has been exceeded. This assumption is the basis for the use of the RfD or RfC in estimating the HI. If this ratio is greater than 1.0, such exposures may be considered hazardous. The HI can only be used to qualitatively rank the possibility of adverse non-cancer effects occurring. The HI used to describe non-cancer health hazards has an inherent uncertainty. For example, RfDs are derived from NOAEL or LOAEL dose rates determined from animal studies or human exposure investigations. Depending on the quality of the available data, the NOAEL or LOAEL is divided by an uncertainty factor ranging from 1 to 10,000. Large uncertainty factors used in extrapolating animal effects to human effects may over-estimate non-cancer hazards.

The HI approach assumes that all non-cancer adverse effects to the same organ or systems are additive. While this approach may be sound for assessing a series of constituents that have

similar modes of action and act on the same target organ, it may not be appropriate when there are different modes of action. Summation of HIs to calculate a total HI for an exposure scenario can generate a very large number. The HI is a ratio of estimated exposure compared to a "safe" exposure dose. A health hazard is indicated if this ratio exceeds one. The magnitude of a calculated HI greater than one has little bearing on the potential severity of adverse effects.

A number of factors contributed to uncertainties in this risk characterization. These uncertainties are attributable to the risk characterization procedure itself and to several site-specific factors. Quantitative risk characterization is largely dependent upon laboratory-derived animal toxicity values (carcinogenic slope factors, non-carcinogenic RfDs, and RfCs) for the constituents of potential concern. Toxicity values are not available for all COPCs; therefore, risks/hazards cannot be quantitatively characterized for these constituents and the total calculated risk/hazard for the site may be underestimated. Additionally, toxicity values derived from animal studies are given the same weight as toxicity values derived from human data.

COPCs with different carcinogenic weights of evidence are summed in this risk characterization. The carcinogenic risk equation for multiple substances sums all carcinogens equally, giving as much weight to Group B1 or B2 carcinogens as to Group A carcinogens. This tends to overestimate calculated carcinogenic risks.

7.0 References

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