ERRATA to Revised
Human Health Risk Assessment for Remediation Zone A
Tronox LLC
Henderson, Nevada

July 23, 2010

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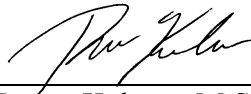300 Frank H. Ogawa Plaza, Suite 510
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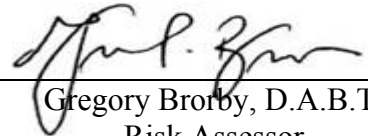Oakland, California 94607

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TABLES

FIGURES

APPENDICES

ACRONYM LIST

Acronym	Meaning
ADD	Average daily dose
BCL	Basic comparison level
Bgs	Below ground surface
BRC	Basic remediation company
CLP	Contact Laboratory Program
COPC	Chemical of potential concern
CSM	Conceptual site model
DQA	Data quality assessment
DQI	Data quality indicator
DQO	Data quality objective
DVSR	Data validation summary report
EC	Exposure concentration
ECD	Electron capture detector
ED	Exposure duration
ECAO	Environmental Criteria And Assessment Office
EDA	Exploratory data analysis
EDD	Electronic data deliverable
EPC	Exposure-point concentration
GC	Gas chromatograph
GISdT®	Guided Interactive Statistical Decision Tool
HCl	Hydrochloric acid
HEAST	Health Effects Assessment Summary Tables
HI	Hazard Index
HRA	Human Health Risk Assessment
IUPAC	International Union of Pure and Applied Chemicals
LADD	Lifetime average daily dose
LOU	Letter of Understanding
MARLAP	Multi-Agency Radiological Laboratory Analytical Protocols Manual
MS	Mass spectrometer
MSD	Matrix spike duplicate
NCEA	National Center for Environmental Assessment
NDEP	Nevada Division of Environmental Protection
OA	Organic acid
OCP	Organochlorine pesticide
OPP	Organophosphate pesticide
PAH	Polycyclic aromatic hydrocarbon
PARCC	Precision, accuracy, representativeness, comparability, and completeness
PCB	Polychlorinated biphenyls
PEF	Particulate emission factor

Acronym	Meaning
PPRTV	Provisional peer-reviewed toxicity value
QA/QC	Quality assurance/quality control
QAPP	Quality Assurance Project Plan
RfC	Reference concentration
RfD	Reference dose
RME	Reasonable maximum exposure
RPD	Relative percent difference
RZ-A	Remediation Zone A
SF	Slope factor
SOP	Standard operating procedure
SQL	Sample quantitation limit
SRC	Site-related chemical
SVOC	Semi-volatile organic compound
TEF	Toxicity equivalency factor
TEQ	Toxicity equivalency
TPH	Total petroleum hydrocarbon
U	Qualified
UCL	Upper confidence limit
URF	Unit risk factor
U.S. EPA	U.S. Environmental Protection Agency
VOC	Volatile organic compound

EXECUTIVE SUMMARY

On behalf of Tronox LLC (Tronox), Northgate Environmental Management, Inc. (Northgate) and Exponent, Inc. (Exponent) have prepared this Human Health Risk Assessment (HRA) for the Remediation Zone A (RZ-A) area at the Tronox facility in Henderson, Nevada (the Site). This HRA has been conducted following the methods presented in the March 9, 2010 HRA Work Plan that was approved by the Nevada Division of Environmental Protection (NDEP) on March 16, 2010 (Northgate, 2010a). The objective of the HRA was to evaluate the potential for adverse health impacts that may occur as a result of potential exposure to soil that contains residual concentrations of chemicals with the upper 10 feet of soil at RZ-A. No remediation is planned for this area; therefore, findings of this HRA are intended to support the site closure process.

Based on the Conceptual Site Model (CSM) for RZ-A, potential exposure to soil was evaluated for future onsite indoor and outdoor commercial workers and future construction workers via direct contact with soil (i.e., incidental ingestion, dermal contact, and inhalation of dust). Potential exposure to residual chemicals in soil vapor and potential for leaching of chemicals to groundwater will be evaluated on a site-wide basis; therefore, these media were not evaluated in this report.

Soil data collected as part of the Phase B Site Investigation for Area IV, of which RZ-A is a part, was evaluated and considered useable for purposes of this HRA. Chemicals of potential concern (COPCs) were selected according to a multi-step process, including comparisons to background for metals and radionuclides, a toxicity screen, frequency of detection, and CSM considerations. Based on this process, seven carcinogenic polycyclic aromatic hydrocarbons (PAHs), hexachlorobenzene (HCB), polychlorinated biphenyls (PCBs), perchlorate, boron, iron, and chrysotile asbestos were selected as COPCs. The results of the HRA can be summarized as follows:

- Noncancer hazard indexes and/or theoretical excess cancer risks associated with direct contact with soil were estimated for all of the COPCs except asbestos based on the maximum detected concentration. The estimated hazard indexes and excess cancer risks were below NDEP's point of departure for noncancer effects (hazard index of 1) and cancer risks (1×10^{-6}) for future onsite indoor and outdoor commercial workers and future construction workers under the conditions evaluated.

- With regard to asbestos, a best estimate and an upper-bound estimate were calculated. The estimated risks for death from lung cancer or mesothelioma for asbestos exposures to future onsite outdoor commercial workers and construction workers are less than or equal to 1×10^{-6} except for upper bound estimates of exposure to amphibole fibers by future

construction workers. Importantly, these latter estimates are based on an observed count of zero amphibole fibers for all samples collected in RZ-A.

Therefore, the results of this HRA indicate that direct contact with residual chemicals in the upper 10 feet of soil in RZ-A should not result in unacceptable risks for all future on-Site receptors. The results of the data quality assessment indicate that a sufficient number of samples were collected in RZ-A to support the conclusions of this HRA. Potential exposure to residual chemicals in soil vapor and potential for leaching of chemicals to groundwater will be evaluated on a site-wide basis, and an addendum to the RZ-A HRA will be prepared to complete the closure process for the RZ-A exposure unit.

1.0   INTRODUCTION

On behalf of Tronox LLC (Tronox), Northgate Environmental Management, Inc. (Northgate) and Exponent, Inc. (Exponent) have prepared this Human Health Risk Assessment (HRA) for the Remediation Zone A (RZ-A) area at the Tronox facility in Henderson, Nevada (the Site). This HRA has been conducted following the methods presented in the March 9, 2010 HRA Work Plan that was approved by the Nevada Division of Environmental Protection (NDEP) on March 16, 2010 (Northgate, 2010a).

1.1   Site Description and History

The approximately 450-acre site, of which RZ-A is a small 29-acre portion at the southern part, is located approximately 13 miles southeast of the city of Las Vegas in an unincorporated area of Clark County, Nevada, and lies in Sections 1, 12, and 13 of Township 22 S, Range 62 E, (see Figure 1). The site is located within the Black Mountain Industrial (BMI) complex, which consists of several facilities, owned and operated by chemical companies, one of which is Tronox.

The BMI complex was first developed by the U.S. government in 1942 as a magnesium plant for World War II operations. Later, a part of the BMI complex was leased by Western Electrochemical Company (WECCO) that would ultimately become the Tronox Site. WECCO produced manganese dioxide, sodium chlorate, sodium perchlorate, and other perchlorates. WECCO also produced ammonium perchlorate (a powerful oxidizer) for the Navy during the early 1950s using a plant that was constructed on the Site by the Navy. WECCO merged with American Potash and Chemical Company (AP&CC) in 1956, with continued production of ammonium perchlorate for the Navy. In 1967, AP&CC merged with Kerr-McGee Corporation (Kerr-McGee) and added production of boron chemicals in the early 1970s. The production processes included elemental boron, boron trichloride (a colorless gas used as a reagent in organic synthesis), and boron tribromide (a colorless fuming liquid compound used in a variety of applications). The production of boron tribromide was discontinued in 1994, and the production of sodium chlorate and ammonium perchlorate was discontinued in 1997 and 1998, respectively. Perchlorate was reclaimed at the Site using existing equipment until early 2002.

In 2005, Kerr-McGee Chemical LLC was renamed Tronox LLC. Tronox's Henderson facility continues to produce electrolytic manganese dioxide, used in the manufacture of alkaline batteries; elemental boron, a component of automotive airbag igniters; and boron trichloride,

used in the pharmaceutical and semiconductor industries and in the manufacture of high-strength boron fibers for products that include sporting equipment and aircraft parts.

During the 1970s, the U.S. Environmental Protection Agency (U.S. EPA), the State of Nevada, and Clark County investigated potential environmental impacts from the BMI companies' operations, including atmospheric emissions, groundwater and surface-water discharges, and soil impacts (Ecology and Environment, 1982). From 1971 to 1976, Kerr-McGee modified its manufacturing process and constructed lined surface impoundments to recycle and evaporate industrial wastewater. In 1976, the facility achieved zero discharge status regarding industrial wastewater management. In 1980, the U.S. EPA requested specific information from the BMI companies regarding their manufacturing and waste management practices by issuing Section 308 letters. In 1993, a Phase I site assessment was completed for the Site and approved by NDEP. In 1994, NDEP issued a Letter of Understanding (LOU) to Kerr-McGee that identified 69 specific areas or items of interest and indicated the level of environmental investigation they wanted Kerr-McGee to conduct. In 1996, Kerr-McGee completed a Phase II site assessment which included field sampling as described in an NDEP approved Phase II Work Plan.

Tronox has continued to undertake environmental investigations to assess environmental conditions at the Henderson facility. A detailed discussion of the specific areas or items of interest identified in the LOU, and a list of the products made, years of production, and approximate waste volumes for WECCO, AP&CC, and Tronox are found in the Conceptual Site Model document (ENSR, 2005).

Background information, including local geology, hydrogeology, and wind direction, is also described in the *Conceptual Site Model (CSM) Report* (ENSR 2005). In general, groundwater is encountered in the fine-grained facies within the uppermost Muddy Creek Formation. The depth to groundwater ranges from about 27 to 80 feet below ground surface (bgs) and is generally deepest in the southernmost portion of the Site (where RZ-A is located). The prevailing wind direction for the site is from the Southwest and the South or West with the Pioneer property located upwind (west) and the Timet property located down-wind (east) from the Site. (see Figure 1 for wind-rose). Based on the prevailing wind direction, no adjacent residential locations are located down-wind from the site.

1.2   Overview of Site Investigation

As described in several investigation work plans, the Site source area investigations include a Phase A investigation (ENSR, 2006; ENSR, 2007a,b) and a Phase B investigation that further

characterized soil and groundwater conditions across the Site . For the Phase B investigation activities, the Site was subdivided into four areas: Areas I, II, III, and IV. Separate investigation work plans were prepared for each area, as well as Site-wide groundwater and soil gas/vapor intrusion work plans (ENSR 2008a; ENSR, 2008b; ENSR, 2008c; ENSR, 2008d; ENSR, 2008e; AECOM, 2008). The four area-specific Phase B investigation work plans focus on the evaluation of potential source areas for the Site-related chemicals (SRCs).

During a meeting on February 22, 2010, NDEP suggested that, for purposes of remediation and health risk assessment evaluations, the Site be divided into five Remediation Zones that are based on geographic groupings of chemical detections and CSM considerations. Figure 2 shows the five remediation zones (named RZ-A through RZ-E), highlighting the location of RZ-A in relation to the Phase B Area I, II, III, and IV investigation areas. RZ-A is located in the southern portion of the Site and is a portion of the area investigated as part of the Phase B Area IV investigation.

1.3   Scope of the RZ-A Risk Assessment

The objective of this HRA is to evaluate the potential for adverse human health impacts that may occur as a result of potential exposures to soil that contains residual concentrations of chemicals within 10 feet (ft) below ground surface (bgs) at RZ-A. Findings of the HRA are intended to support the site closure process. As presented in the approved HRA Work Plan, potential exposure to residual chemicals in soil vapor and potential for leaching of chemicals to groundwater will be evaluated on a site-wide basis; therefore, these media are not evaluated in this report. Following completion of the site-wide soil vapor report and leaching evaluation, an addendum to the RZ-A HRA will be prepared. The cumulative risks from soil and soil vapor will be documented for risk management decisions and to complete the closure process for the RZ-A exposure unit. Additionally, consistent with the HRA Work Plan, because the area will remain as part of an active commercial/industrial facility in the future, ecological habitat is not currently sufficient to warrant an ecological risk assessment, nor will it be in the future.

The HRA follows the basic procedures outlined in the U.S. Environmental Protection Agency's (U.S. EPA's) *Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual* (U.S. EPA, 1989). Other guidance documents consulted in formulating the risk assessment include:

- Guidelines for Exposure Assessment. U.S. EPA 1992a.
- Exposure Factors Handbook. U.S. EPA 1997.

- Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment). U.S. EPA 2004a.

- Soil Screening Guidance: User's Guide. U.S. EPA 1996a.

- Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. U.S. EPA 2002a.

- Soil Screening Guidance for Radionuclides. U.S. EPA 2000a.

- Technical Support Document for a Protocol to Assess Asbestos-Related Risk. Final Draft. U.S. EPA 2003a.

- Nevada Administrative Code Chapter NAC 445A. Adopted Permanent Regulation of the Nevada State Environmental Commission. LCB File No. R119-96. NDEP 1996.

- Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment). U.S. EPA 2009a.

1.4   Organization of Report

The remainder of this assessment is organized as follows:

- **Section 2, Exposure Scenarios and Conceptual Site Model:** This section describes the relationships between the suspected sources of chemicals identified at RZ-A, the mechanisms by which the chemicals might be released and transported in the environment, and the means by which the receptors could come in contact with the chemicals, and presents the CSM for RZ-A.

- **Section 3, Data Evaluation, Usability, and Selection of Chemicals of Potential Concern:** This section discusses the sources of analytical data that are used in the HRA and procedures used to evaluate the data and select the chemicals of potential concern (COPC).

- **Section 4, Exposure Assessment:** This section presents the equations and input values used to calculate potential exposure for each of the identified COPCs.

- **Section 5, Toxicity Assessment:** This section presents the toxicity criteria used to evaluate the COPCs.

- **Section 6, Risk Characterization:** The risk characterization section presents the estimated risks and hazard indexes associated with potential exposure to the

COPCs for the scenarios evaluated. In addition, an uncertainty analysis discusses the relative impact of the primary assumptions used in the assessment.

- **Section 7, Conclusions:** This section summarizes the conclusions of the report.

- **Section 8, References:** This section provides complete references for the literature cited throughout the assessment report.

2.0 EXPOSURE SCENARIOS AND CONCEPTUAL SITE MODEL

The exposure scenarios considered in the HRA are dependent on the relevant exposure pathways and receptor populations for the RZ-A area. The CSM is a tool used in risk assessment to describe relationships between chemicals and potentially exposed human receptor populations, thereby delineating the relationships between the suspected sources of chemicals identified at the Site, the mechanisms by which the chemicals might be released and transported in the environment, and the means by which the receptors could come in contact with the chemicals. The CSM provides a basis for defining data quality objectives (DQOs), guiding site characterization, and developing exposure scenarios.

2.1 Sources and Release Mechanisms

As part of the Phase B investigation, a list of potential SRCs was agreed upon, with NDEP, based on review of historical Site operations and practices, as well as those at the neighboring facilities to the east and west of the Site. Not all the SRCs are related to Site operations, but were included as they may be related to neighboring facilities. The SRCs include:

- Volatile organic chemicals (VOCs)

- Semivolatile organic chemicals (SVOCs)

- Organic acids (OAs)

- Organophosphate pesticides (OPPs)

- Organochlorine pesticides (OCPs)

- Polychlorinated biphenyls (PCBs)

- Dioxin/furans

- Asbestos

- Metals

- Perchlorate

- Cyanide

- Radionuclides

As discussed in the investigation work plans (ENSR, 2008c; AECOM, 2008), the distribution of sampling locations was designed in part to evaluate potential sources within each LOU and to provide general coverage within each area supporting the planned future risk assessment. To

evaluate each source area, the proposed soil borings were placed at locations where constituents were anticipated to occur in soil at the highest concentration for most source areas. Soil borings were also placed in locations outside the boundary of LOUs to gain additional insight into the horizontal extent of constituents in soil.

With regard to RZ-A, investigation of SRCs focused on the following two LOUs that are shown on Figure 3.

LOU 59: Storm Sewer System

Segments of the storm sewer system lie in RZ-A and run from east to west. Additionally, a north-south line connects the east-west lines near the eastern boundary. From 1941 to 1976, the Site–wide storm water system was used to convey storm water and process effluent from portions of the site to the beta ditch. The process effluent contained classes of chemicals associated with chlorate, perchlorate, elemental boron, and leach plant processes, though none of those processes are thought to have operated in RZ-A. Since 1976, the storm water system has been used only to convey storm water and once-through, non-contact cooling water to the beta ditch. Closure is not being requested for LOU 59 because the storm sewer system is still active (ENSR, 2008c).

LOU 62: State Industries, Inc. Site, including Impoundments and Catch Basin

LOU 62, which is no longer active, consisted of two lined surface impoundments that received spent pickling process wastes, generated during the manufacture of water heaters, from 1974 to 1988. State Industries, Inc. operated from 1969 to late 1988 and manufactured and stored water heaters. Wastes included spent sulfuric acid, borax, soda ash, phosphates, TURCO II H.T.C. soap, and spent cyanide. In 1983, a warehouse was constructed over the westernmost surface impoundment, and the eastern surface impoundment was filled with soil in 1988 (ENSR, 2008c).

Potential release mechanisms from above-ground source areas, such as spills, leaks, or accidents, could have released SRCs to surface soils. These SRCs may have then leached into subsurface soils and eventually migrated to groundwater. In addition, subsurface sources such as below-ground piping may have released SRCs to the subsurface that may subsequently have migrated to groundwater via leaks or accidents.

In addition to the potential primary release mechanisms, secondary release mechanisms may include resuspension of SRCs in surface soils into ambient air. In addition, surface water runoff

and movement along effluent ditches may have allowed SRCs to migrate to other areas in surface soil and leach to subsurface soil/groundwater. Volatile organics detected in the subsurface also have the ability to migrate upward to ambient air or into buildings.

Although all of these pathways are considered in the CSM, the scope of the RZ-A HRA is limited to evaluating direct contact with affected soil within 10 ft bgs. Groundwater and indoor vapor issues will be dealt with on a Site-wide basis and are not included in this HRA.

2.2   Potential Receptors and Exposure Pathways

The identification of potentially exposed populations and exposure pathways is supported by the CSM. For a complete exposure pathway to exist, each of the following elements must be present (U.S. EPA, 1989):

- A source and mechanism for chemical release;

- An environmental transport medium (i.e., air, water, soil);

- A point of potential human contact with the medium; and

- A route of exposure (e.g., inhalation, ingestion, dermal contact).

As discussed previously, the Site is a currently-operating industrial facility. In the future, the Site will continue to be used for industrial and/or commercial purposes. Accordingly, current and future "on-Site receptors" include long-term indoor workers, long-term outdoor workers, and short-term construction workers (U.S. EPA, 2002a). Other potential on-Site receptors, such as visitors or trespassers, do not warrant assessment. As discussed by U.S. EPA (2002a), evaluation of exposures to members of the public under a non-residential land-use scenario is not warranted for two reasons:

1. Public access is generally restricted at industrial sites, and

2. While the public may have access to commercial sites, on-Site workers have a much higher exposure potential, as they spend substantially more time at a site.

Current and future "off-Site receptors" are residential and worker receptors located outside the RZ-A boundaries who could be exposed to airborne chemicals emitted from the Site during short-term construction projects (U.S. EPA, 2002a). Considering the distance from RZ-A to the nearest off-Site residents, and based on the relative difference in the on-Site construction particulate emission factor (which is on the order of 10^{+6} m^3/kg) and the off-Site receptor particulate emission factor during construction (which is on the order of 10^{+8} m^3/kg), versus other exposure factors that

may be higher for the off-Site receptors, the on-Site construction worker exposure will be greater than that of the off-Site receptor. Accordingly, off-Site receptors are not evaluated quantitatively in the HRA. This issue is discussed further in the uncertainty assessment (Section 6.4.6).

2.3 Conceptual Site Model

Based on the source and release mechanisms identified in RZ-A, Figure 4 presents the following exposure pathway and receptor populations that are considered in the HRA:

- Indoor commercial workers[1]
    - Incidental soil ingestion[2]
    - External exposure from soil[3]
    - Indoor inhalation of VOCs from soil and groundwater[4, 5]
- Outdoor commercial/industrial workers
    - Incidental soil ingestion[2]
    - External exposure from soil[3]
    - Dermal contact with soil
    - Outdoor inhalation of dust[2, 6]
    - Outdoor inhalation of VOCs from soil and groundwater[7, 8]

Construction workers
    - Incidental soil ingestion[2]
    - External exposure from soil[3]

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[1] In accordance with U.S. EPA, 2002a, dermal absorption is not considered to be a complete exposure pathway for the indoor worker. Soil ingestion is identified by U.S. EPA (2002a) as a potentially complete exposure pathway for an indoor worker, due to potential for contact through ingestion of soil tracked indoors from outside. Inhalation of indoor dust (particulates) is accommodated via the soil ingestion pathway. (U.S. EPA, 2002a, Exhibit 4-1)

[2] Includes radionuclide exposures; however, as noted in Section 3.6, radionuclides are not selected as COPCs for RZ-A.

[3] Only radionuclide exposures; however, as noted in Section 3.6, radionuclides are not selected as COPCs for RZ-A.

[4] Indoor inhalation of VOCs from soil and groundwater will be evaluated as part of a site-wide assessment based on collected soil-vapor measurements and are not included in the RZ-A evaluation.

[5] Radon is not expected to be an issue for the Site because future use will remain commercial/industrial. In the event it is concluded that Site radionuclide concentrations are greater than background the need for an evaluation of potential radon exposure will be discussed with NDEP.

[6] Includes asbestos exposures.

[7] Pathway will be quantitatively evaluated only if estimated indoor air concentrations indicate the need as part of the site-wide soil gas vapor assessment.

[8] Quantitatively evaluated only if warranted based on indoor exposures.

- Dermal contact with soil

- Outdoor inhalation of dust[2, 5]

- Outdoor inhalation of VOCs from soil and groundwater.

With regard to the direct contact with soil pathways, commercial workers are assumed to come into direct contact with soil between 0 and 2 feet bgs and construction workers are assumed to come into direct contact with soil between 0 and 10 feet bgs, as specified in the approved HRA Work Plan (Northgate, 2010a). As discussed in Section 3.6.1, samples within this depth interval were generally collected from 0.5 to 2 ft bgs and from 10 to 11.5 ft bgs, although a few samples were collected at 2.5, 5, 7, and 9 ft bgs due to location-specific sampling obstacles; samples for asbestos analysis were collected from 0 to 0.17 ft (0 to 2 inches) bgs. This sampling strategy is consistent with the CSM for the site in that the presence of asbestos in near surface soil is likely the result of aerial deposition whereas other chemicals are present in soil as a result of former industrial processes that took place on site. Except for asbestos, data from samples collected from 0.5 to 2 ft bgs are used to represent the 0 to 2 ft bgs interval. Similarly, data collected from 0.5 to 11.5 ft bgs are used to represent the 0 to 10 ft bgs interval. The uncertainty associated with not routinely collecting soil samples between 0 to 0.5 ft bgs and 2 to 10 ft bgs is discussed in the Uncertainty Analysis (Section 6.4). It should be noted that incidental ingestion of or dermal contact with groundwater during short-term construction activities are not considered complete pathways due to groundwater depth being greater than 20 feet bgs.

3.0 DATA EVALUATION

This section discusses the sources of analytical data that are used in the RZ-A HRA and procedures used to evaluate the data and select COPCs.

3.1 Investigation and Data Sources

As discussed in the HRA Work Plan, analytical data collected as part of the Phase A and Phase B investigations are the sources of the data evaluated in the HRA.

- Phase A Source Area Investigation Work Plan, Tronox LLC Facility, Henderson, Nevada Site (ENSR 2006);

- Addendum to the Phase A Source Area Investigation Work Plan, Tronox LLC Facility, Henderson, Nevada Site (ENSR 2007a);

- Phase A Source Area Investigation Results Report, Tronox LLC Facility, Henderson, Nevada (ENSR 2007a);

- Phase B Source Area Investigation Work Plan Area IV (Western and Southern LOUs), Tronox LLC Facility, Henderson, Nevada (ENSR 2008c); and

- Revised Phase B Site Investigation Work Plan for Areas I, II, III and IV, Text, Tables and Figures. Tronox LLC Facility. Henderson, Nevada. (AECOM 2008).

3.2 Soil Sampling Program

As described previously, RZ-A is located in a portion of the area investigated as part of the Phase B Area IV investigation. Area IV soil samples were collected and analyzed in accordance with the *Revised Phase B Investigation Work Plan, Tronox LLC Facility, Henderson, Nevada, December* 2008 (AECOM, 2008) and the *Revised Phase B Quality Assurance Project Plan Tronox LLC Facility, Henderson, Nevada, July 2009* (AECOM and Northgate 2009). In addition, Standard Operating Procedures (SOPs) developed by the Basic Remediation Company (BRC, 2007 and 2009) were used as guidance for field activities involving the installation of borings and collection of soil samples. The following description provides a summary of the activities conducted during collection of soil samples in Area IV, which includes Remediation Zone A (RZ-A). Soil sampling for asbestos analysis is described separately.

Soil sampling activities for RZ-A were conducted by installing temporary borings using Sonic drilling techniques. Samples were collected using a split-spoon sampler as described in SOP 23 (BMI, 2007, 2009). The samples were collected using four 6-inch long, 2.5-inch diameter

stainless steel tubes inserted in a 24-inch long split spoon sampler that was hammered ahead of the bottom of the drill string at the appropriate depths to accommodate sample collection from designated sample depths. The soil in the top tube was discarded leaving 3 tubes of soil for sample collection. Where an EPA SW 846 8260(B) analysis (VOC) was required, a Terracore® sampler was inserted directly into the top of the middle steel tube and the required three samples for extraction and analysis were collected using the sampler and placed in the laboratory supplied and preserved sample bottles (40 ml VOAs). After collecting the sample for VOC analysis, the soil remaining in the middle tube and the tubes above and below the middle tube were emptied into a stainless steel mixing container and homogenized in the field prior to being transferred to appropriate sample containers. Containers were filled based on standard sampling protocol ordering with organic analyses samples collected first in order of decreasing volatility, metals, radionuclides and then wet chemistry analytes. Field sieving was not performed or required as sufficient volume of sample was accounted for in the sample container size that the laboratories were able to meet all extraction requirements for the methods as outlined in the QAPP (AECOM, 2009).

Asbestos samples were collected using the methodology outlined in SOP-12 (BMI, 2007, 2009). All asbestos samples are considered to be surface soil samples. The samples were collected from a generally unpaved area measuring 50 ft by 50 ft and subdivided into four quadrants as required by SOP-12. The asbestos sample includes two separate types of samples, a moisture and silt content sample, which is a grab sample, and the asbestos sample itself, which is a composite sample from the four quadrants described above. The four separate samples are collected using a steel trowel, homogenized in a stainless steel bowl and then placed into two (2) 250 milliliter (ml) containers as required by the method. The moisture and silt sample is a grab sample at the center of the grid and a stainless steel trowel was used to collect approximately 1 liter (L) of the material into a container for submittal to the laboratory. NDEP allowed a modification to this procedure to accommodate locations where there was only minimal soil available. The modification allowed the sampler to use irregularly sized grid locations at varying distances of up to 75 feet from the designated location so that sufficient soil material suitable for analysis by the selected method could be collected. The volume of sample remained the same, two 250 ml asbestos samples and one (1) L moisture and silt sample.

All samples were collected, stored, shipped and handled under proper chain of custody, following the procedures outlined in the BMI SOP's and the applicable sampling and analysis plans.

3.3   Data Review and Selection for RZ-A

Area IV soils were collected from 54 borings, resulting in analyses of 5,999 environmental and 1,266 field quality control (QC) samples (field blank, equipment blank, field duplicate, and matrix spike/MS duplicate [MS; MSD]) for multiple analyses. Within the Area IV investigation area, a total of 20 soil borings are located in RZ-A. The data usability summary specific for RZ-A is discussed in more detail in Section 3.5, following the data usability evaluation findings with regard to Area IV.

3.4   Data Usability Evaluation

The primary objective of the data usability evaluation is to identify appropriate data for use in the risk assessment. All relevant site characterization data were reviewed in accordance with the *Guidance for Data Usability in Risk Assessment (Parts A and B)* (U.S. EPA, 1992b,c) and the *NDEP Supplemental Guidance for Assessing Data Usability for Environmental Investigations at the BMI Facility in Henderson, NV* (NDEP, 2008a). A quality assurance and quality control (QA/QC) review was conducted on 100% of the analytical data, and findings are presented in the March 19, 2010, Data Validation Summary Report (DVSR; Appendix E) to assess the validity (based on data validation) and usability (based on project objectives) of the Phase B, Area IV soil data (Northgate, 2010b), which was approved by NDEP on March 29, 2010. A DVSR for the Phase A data (one location within RZ-A) is contained in Appendix G of the Phase A Report (ENSR 2007b).

The U.S. EPA data usability evaluation framework provides the basis for identifying and evaluating uncertainties in the human health risk assessment with regard to the site characterization data. Data usability is the process of assuring or determining that the quality of data generated meets the intended use. U.S. EPA has established a specific guidance framework to provide risk assessors a consistent basis for making decisions about the minimum quality and quantity of environmental analytical data that are sufficient to support risk assessment decisions (U.S. EPA, 1992b, c; NDEP, 2008a). The U.S. EPA data usability guidance provides an explicit set of data quality criteria that are used to determine the usability of site characterization data in the risk assessment process.

The six U.S. EPA evaluation criteria by which data are judged for usability in risk assessment are:

- Site data report content
- Documentation

- Data sources

- Analytical methods and detection limits

- Data review

- Data quality indicators (DQIs): precision, accuracy, representativeness, comparability, and completeness (PARCC).

A summary of these six criteria for determining data usability is provided below.

Criterion I – Availability of Information Associated with Site Data

The usability analysis of the site characterization data requires the availability of sufficient data for review. The required information is available from documentation associated with the site data and data collection efforts. Data have been validated per the NDEP-approved *Revised Data Validation Summary Report, Phase B Investigation Area IV Soil* (Northgate 2010b). The following lists the information sources and the availability of such information for the data usability process:

- A property description provided in the NDEP-approved work plan (ENSR 2008c; AECOM 2008) identifies the location and features of the property, the characteristics of the vicinity, and contaminant transport mechanisms.

- A site map with sample locations and sampling design and procedures were provided in the NDEP-approved work plan (AECOM 2008, Revised Phase B Site Investigation Work Plan-Text, Tables and Figures).

- The laboratory provided a QA/QC narrative with each analytical data package, and the data review provides a narrative of qualified analytical results. These narratives are included as part of the DVSR (Northgate 2010b).

- Method-specific QC results are provided in each laboratory report, along with associated raw data. The laboratory reports and QC results are included as part of the DVSR (Northgate 2010b).

- Data flags used by the laboratory were defined adequately and are further discussed in below and in Section 3.5.

Criterion II – Documentation Review

The objective of the documentation review is to confirm that the analytical results provided are associated with a specific sample location and collection procedure, using available

documentation. For the purposes of this data usability analysis, the chain-of-custody forms prepared in the field were reviewed and compared to the analytical data results provided by the laboratory to ensure completeness of the data set. Based on the documentation review, all samples analyzed by the laboratory were correlated to the correct geographic location at the property. Field procedures included documentation of sample times, dates, and locations, and other sample-specific information, such as sample depth was also recorded. Information from field forms generated during sample collection activities was imported into the project database.

The analytical data were reported in a format that provides adequate information for evaluation, including appropriate quality control measures and acceptance criteria. Each laboratory report describes the analytical method used, provides results on a sample-by-sample basis along with sample-specific quantitation limits (SQLs), and provides the results of appropriate quality control samples, such as method blanks, laboratory control spike samples, surrogate recoveries, internal standard recoveries, matrix spike samples, second column confirmation, interference checks, and serial dilutions. All laboratory reports contained data equivalent to a Contract Laboratory Program (CLP) deliverable, inclusive of CLP QC summary forms where applicable, and the supporting raw data. Reported sample analysis results were imported into the project database.

Criterion III – Data Sources

The review of data sources is performed to determine whether data from different sources can be combined in the quantitative risk assessment. Although earlier investigations have been conducted at the Site, as agreed upon with NDEP, the HRA includes data collected as part of the Phase A and B investigations. A further discussion of the combined Phase A and Phase B data for RZ-A is presented below and in Section 3.5.

Criterion IV – Analytical Methods and Detection Limits

In addition to the appropriateness of the analytical techniques evaluated as part of Criterion III, it is necessary to evaluate whether the detection limits are low enough to allow adequate characterization of risks. At a minimum, this data usability criterion can be met through the determination that routine U.S. EPA reference analytical methods were used in analyzing samples collected from the property. Table A-2 of the *Revised Phase B Quality Assurance Project Plan (QAPP) Tronox LLC Facility, Henderson, Nevada, July 2009* (AECOM and Northgate, 2009) identifies the analyte list, practical quantitation limits, and method detection limits. Table B-2 of the QAPP identifies the U.S. EPA methods that were used in conducting the laboratory analysis of soil samples. Each of the identified U.S. EPA methods is considered the

most appropriate method for the respective constituent class, and each was approved by NDEP as part of the work plan and project QAPP (AECOM and Northgate, 2009).

The range of detection limits achieved in field samples was compared to the NDEP worker basic comparison levels (BCLs) (NDEP, 2009a). With the exception of two radionuclides (radium 226 and radium 228), all had non-detectable results with method detection limits below NDEP BCLs. Therefore, the detection limits are considered adequate for risk assessment purposes.

Criterion V – Data Review

The data review portion of the data usability process focuses primarily on the quality of the analytical data received from the laboratory. All soil data were subject to data validation performed by Laboratory Data Consultants (LDC). Validation was performed using EPA guidelines (U.S. EPA, 1999, 2004b, 2008, 2009b) or equivalent regional U.S. EPA validation guidelines, such as Region 9 Superfund Data Evaluation/Validation Guidance, R9QA/006.1 (U.S. EPA, 2001a), Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP), Department of Energy guidance, the BMI Plant Site Specific Supplemental Guidance on Data Validation from NDEP (NDEP, 2009b, 2009c), Basic Remediation Company (BRC) Standard Operating Procedure (SOP) 40, and Data Review/Validation (BRC, 2009). These federal EPA guidelines, which were prepared for CLP data, were adapted to reflect the analytical methods and measurement quality objectives established for the individual sampling events and the guidance provided by NDEP.

The data validation summary for the Area IV soils was prepared as a separate deliverable (Northgate, 2010b). Any analytical errors and/or limitations in the data have been addressed, and explanations for data qualification are provided in the respective data tables. The results of LDC's data review for these issues are presented in the Area IV DVSR and are summarized below. Although certain laboratory limits, such as percent recovery and relative percent difference (RPD) between sample and duplicate, were exceeded for certain compounds or analyses, as identified by the laboratory (and confirmed during LDC's review of the data), there does not appear to be a widespread effect on the quality of the analytical results. Furthermore, based on a review of the laboratory narratives (provided in the laboratory reports in each DVSR), the laboratory does not believe that the observed exceedances of laboratory criteria represent a concern. As discussed below, when quality criteria were not met for some analytical results, various data qualifiers were added to indicate limitations and/or bias in the data. The definitions for the data qualifiers, or data validation flags, used during validation are those defined in SOP 40 (BRC, 2009) and the project QAPP (AECOM and Northgate, 2009). Sample results were

rejected based on findings of serious deficiencies in the ability to properly collect or analyze the sample and meet QC criteria. Table 3-12 of the Area IV DVSR lists the rejected data (Northgate, 2010b). Fewer than 0.1% of the data were rejected. As noted below, the only data that were rejected were for samples collected 20 ft bgs for purposes of evaluating the potential for leaching to groundwater; therefore, these data are not applicable to this HRA. Analytical results with other data qualifiers and their potential usability in the HRA are discussed further in the following sections.

Sample/Duplicate Differences Outside Permissible Range or Greater than Permissible Values

The data validation analyst reviewed the sample/duplicate results to determine whether differences in those results suggested potential data quality issues. Specifically, the analyst reviewed:

- Matrix spike/matrix spike duplicate (MS/MSD) RPDs
- Laboratory control sample/laboratory control sample duplicate (LCS/LCSD) RPDs
- Sample/laboratory sample duplicate RPDs
- Sample/field duplicate RPDs

No MS/MSD or LCS/LCSD RPDs were outside acceptance limits. Table 3-9 of the DVSR (Northgate, 2010b) lists the sample data exceeding sample/laboratory duplicate RPD limits, which represents 2.88% of the Area IV soil and SPLP sample data. All samples were qualified as estimated (J/UJ). No data were rejected. Table 3-10 of the DVSR (Northgate, 2010b) lists the sample data exceeding sample/field duplicate RPD limits, which represents 0.61% of the Area IV soil and SPLP sample data. All samples were qualified as estimated (J/UJ). No data were rejected. These flagged data were subjected to further review in terms of data usability for the HRA, as discussed in Section 3.5.

LCS/LCSD and/or MS/MS Recoveries Below Acceptable Criteria

Tables 3-5 and 3-6 of the DVSR (Northgate, 2010b) list the sample data exceeding LCS/LCSD and MS/MSD recovery limits, which represent 2.40% and 3.26% of the Area IV soil and SPLP sample data. All samples were qualified as estimated (J/J-/J+/UJ). No data were rejected. These flagged data were subjected to further review in terms of data usability for the HRA, as discussed in Section 3.5.

Surrogate Percent Recoveries Below Laboratory Control Limit

Table 3-7 of the DVSR (Northgate, 2010b) lists the sample data for which surrogate percent recoveries were below laboratory control limits, which represents 0.75% of the Area IV soil and SPLP sample data. All samples were qualified as estimated (J/J-/J+/UJ). No data were rejected. These flagged data were subjected to further review in terms of data usability for the HRA, as discussed in Section 3.5.

Criterion VI – Data Quality Indicators

Data quality indicators (DQIs) are used to verify that sampling and analytical systems used in support of project activities are in control and that the quality of the data generated for this project is appropriate for making decisions affecting future activities. The DQIs address the field and analytical data quality aspects as they affect uncertainties in the data collected for site characterization and risk assessment. The DQIs include "precision", "accuracy", "representativeness", "comparability", and "completeness" (PARCC). The project QAPP provides the definitions and specific criteria for assessing DQIs using field and laboratory QC samples and is the basis for determining the overall quality of the data set. Data validation activities included the evaluation of PARCC parameters, and all data not meeting the established PARCC criteria were qualified during the validation process using the guidelines presented in the Tronox QAPP.

"Precision" is a measure of the degree of agreement between replicate measurements of the same source or sample. Precision is expressed by RPD between replicate measurements. Replicate measurements can be made on the same sample or on two samples from the same source. Precision is generally assessed using a subset of the measurements made. The precision of the data was evaluated using several laboratory QA/QC procedures. Based on LDC's review of the results of these procedures, there do not appear to be any widespread data usability issues associated with precision.

"Accuracy" measures the level of bias that an analytical method or measurement exhibits. To measure accuracy, a standard or reference material containing a known concentration is analyzed or measured, and the result is compared to the known value. Several QC parameters are used to evaluate the accuracy of reported analytical results:

- Holding times and sample temperatures;
- LCS percent recovery;
- Matrix spike/matrix spike duplicate percent recovery (organics);

- Serial dilution recovery (inorganics);

- Surrogate spike recovery; and

- Blank sample results.

Detailed discussions of and tables with specific exceedances, with respect to precision and accuracy, are provided in the DVSR (Northgate, 2010b) and summarized above. No wide-spread laboratory blank contamination was noted, despite the presence of low levels of common laboratory contaminants (e.g., acetone, 2-butanone, methylene chloride) in a high percentage of the samples (see Table 1). Upon investigation of this issue, it was determined that field practices were the likely cause of this issue, although the detections of these compounds did not impact the overall data quality.

"Representativeness" is the degree to which data accurately and precisely represent a characteristic of the population at a sampling point or an environmental condition (U.S. EPA, 2002b). There is no standard method or formula for evaluating representativeness, which is a qualitative term. "Representativeness" is achieved through selection of sampling locations that are appropriate relative to the objective of the specific sampling task, and by collection of an adequate number of samples from relevant types of locations. For RZ-A, the sampling locations were selected on the basis of both systematic sampling with random point placement within each grid cell and focused samples collected from specific areas to further investigate potential concerns. The samples were analyzed for a broad spectrum of chemical classes across the property. As described in the DVSR report, sample collection information in the chain-of-custody documentation, conformity of laboratory analyses to Work Plan intentions, adherence to documented laboratory procedures to method requirements, and completeness of laboratory data packages were reviewed. Importantly, the data collected during the Tronox Phase B Investigative sampling were analyzed by eight participating laboratories. With 100% of the data validated, some data packages and electronic data deliverable (EDD) were amended prior to finalizing the DVSRs. The percentage of data package amendments and EDD corrections was less than 2% of the entire Phase B dataset.

"Completeness" is a measure of the amount of valid data obtained from a measurement system, compared to the amount expected under normal conditions. "Field completeness" is defined as the percentage of samples actually collected versus those intended to be collected per the Work Plan. The goal stated in the QAPP for this project was greater than 90% field completeness. A comparison of the Work Plan sample tables with the database sample IDs indicates that actual field completeness was 99.94%, exceeding the goal established for the project. Field

completeness was assessed using the total sample locations scheduled in the Work Plan compared to actual number submitted for analysis. Laboratory completeness is defined as percentage of valid data points versus the total expected from the laboratory analyses. "Valid data" are defined as all the data points judged to be usable (i.e., not rejected as a result of the validation process). The objective stated in the QAPP for this project was greater than 95% laboratory completeness. Actual laboratory completeness was 100% on the basis of sample analysis (i.e., all requested analyses were performed and reported by the laboratories), and 99.94% completeness based on valid data.

"Comparability" is a qualitative characteristic expressing the confidence with which one data set can be combined with another for purposes of estimating exposure. In general, comparability of data is maximized by using standard methods for sampling and analysis, reporting data, and data validation. For RZ-A in particular, the vast majority of the site data (42 of 44 samples collected at depths beginning between 0 and 10 ft bgs) were collected as part of a single (Phase B) investigation. All of these samples, as well as the two samples from the Phase A investigation, were collected and analyzed using the same standard methods. Further, as discussed in Section 4.1, with the exception of asbestos, the maximum concentration was used as the exposure point concentration, negating the need for combining the two data sets for purposes of estimating exposure.

3.5   Data Usability and Summary for RZ-A

One hundred percent of the laboratory data for the Phase B Investigation Area IV soil were validated using standardized guidelines and procedures recommended by EPA and NDEP. Based on the validated data, 99.94% of the results for Area IV soil were determined usable for all decision-making purposes. Fewer than 0.1% of the data were rejected. All of the rejected data were associated with samples collected at 20 ft bgs for purposes of evaluating the potential for leaching to groundwater and are, therefore, not applicable to this HRA. In addition, a small percentage of data were qualified as estimated based on one or more data quality indicators and these results were evaluated with respect to usability in the risk assessment. As discussed further below, all soil data that were not rejected during data validation were included. With regard to data qualified as estimated based on recoveries being outside of acceptance criteria, some were qualified as being biased high and others were qualified as being biased low. In cases where the estimated values are biased high, use of these data in the risk assessment could result in calculated risks that are higher than that associated with actual Site conditions. Therefore, these data were included in the HRA without further consideration for samples collected within RZ-A

at depths beginning at 0 to 10 ft bgs. Conversely, where the estimated values are potentially biased low, the calculated risks may be underestimated. Because the possibility of underestimating risk is of more concern, the results associated with the following data quality indicators that could lead to results that are biased low were evaluated further as part of the data usability evaluation for the HRA:

- Holding time exceedences

- Calibration violations indicating a low bias

- MS/MSD or LSC/LSCD recoveries below acceptable criteria

- Surrogate percent recoveries below laboratory control limits

As described below, the estimated values initially discussed above under Criterion V, were considered appropriate for use in the risk assessment.

3.5.1   Holding Time Exceedences

Holding time exceedences can cause the loss of sample constituents due to biodegradation, precipitation, volatilization, and chemical degradation. Table 3-1 of the DVSR (Northgate, 2010b) lists the sample data exceeding holding times, which represents 0.20% of the Area IV soil and SPLP sample data. Of these data, 23 data points representing the OCP analysis from one sample were rejected because the sample was analyzed after two times the method holding time (BRC, 2009). As noted previously, this sample was collected at 20 ft bgs for purposes of evaluating the potential for leaching to groundwater and is, therefore, not applicable to this HRA. The remaining data were qualified as estimated (J-/UJ). The data qualified as estimated (UJ) for samples collected within RZ-A at depths beginning at 0 to 10 ft bgs were included in the HRA. The data qualified as estimated with a low bias (J-) were limited to a single sample (SA121009-0.5B), for which the dioxin analysis was conducted 55 days after sample preparation versus the 30 days required by the method. Although the data for this sample would be considered usable because dioxins are very stable in soil and the reported concentrations are very low relative to the site-specific BCL, this sample is located outside of RZ-A and is not included in this HRA.

3.5.2   Calibration Violations Indicating a Low Bias

Table 3-2 of the DVSR (Northgate, 2010b) lists the sample data with calibration deficiencies, which represents 2.8% of the Area IV soil and SPLP sample data. Of these data, 16 data points were qualified as estimated with a low bias (J-), five for acetone, five for hexachlorobutadiene,

one for MBAS (a surfactant), and five for total organic carbon. The remaining sample data were qualified as estimated (J/UJ) or estimated with a high bias (J+). The data qualified as estimated (J/UJ) or estimated with a high bias (J+) for samples collected within RZ-A at depths beginning at 0 to 10 ft bgs were included in this HRA. The data qualified as estimated with a low bias (J-) for hexachlorobenzene and acetone were from samples collected outside of RZ-A and are not included in this HRA.

3.5.3   LCS/LCS or MS/MSD Recoveries Below Acceptance Criteria

As described above, Table 3-5 of the DVSR (Northgate, 2010b) lists the sample data exceeding LCS/LCSD recovery limits. Of these data, 24 data points were qualified as estimated with a low bias (J-), five for hexachlorobutadiene, 17 for perchlorate, and 2 for 1,2,3,4,7,8,9-heptachlorodibenzofuran. For these data points, the percent recovery ranged from 62 to 77%, fairly close to the lower end of the acceptable range. Therefore, those data for samples collected within RZ-A at depths beginning at 0 to 10 ft bgs were included in this HRA, along with those qualified as estimated (J/UJ) or estimated with a high bias (J+). Table 3-6 of the DVSR (Northgate, 2010b) lists the sample data exceeding MS/MSD recovery limits (see above). Of these data, approximately 350 sample data points were qualified as estimated with a low bias (J-). Those data points with recoveries above 50% (~270 data points) were considered usable without further evaluation. The remaining ~80 data points, which were limited to antimony, chloride, manganese, sulfate, and tungsten, were also considered usable because (1) the LCS/LCSD recoveries for these samples were within acceptable ranges, and (2) the reported concentrations are low relative to the BCLs for these compounds. Therefore, those data for samples collected within RZ-A at depths beginning at 0 to 10 ft bgs were included in this HRA.

3.5.4   Surrogate Percent Recoveries Below Laboratory Control Limit

As described above, Table 3-7 of the DVSR (Northgate, 2010b) lists the sample data for which surrogate percent recoveries were below laboratory control limits. Of these data, only 13 data points were qualified as estimated with a low bias (J-), one each for 2-butanone, 4-methy-2-pentanone, acetone, benzene, beta-BHC, chlorate, chlorobenzene, chloroform, hexachlorobenzene, m, p-xylene, and tetrachloroethene, and two for toluene. For these data points, the percent recovery ranged from 38-82%, fairly close to the lower end of the acceptable range; however, none of the sample locations are located in RZ-A. Data qualified as estimated (J/UJ) or estimated with a high bias (J+) for samples collected within RZ-A at depths beginning at 0 to 10 ft bgs were included in this HRA

3.5.5   Summary of Data for RZ-A

As indicated previously, within the Area IV investigation area, a total of 20 soil borings are located in RZ-A. The list of boring locations, the rationale for soil sample collection, and the list of chemicals analyzed in each of the RZ-A soil borings are summarized in Table A-1 of Appendix A. Table A-1 also identifies the various laboratories that performed the analyses. A complete set of validated data for RZ-A is provided in Tables A-2 through A-13 of Appendix A. A list of data qualifiers is presented in Table A-14. The RZ-A soil sample locations, along with the locations of LOU 59 and LOU 62, are shown in Figure 3.

Based on validated data, data summaries for RZ-A are provided in Table 1 for organics and general chemistry, and in Table 2 for inorganics and radionuclides. The data summaries present the number of samples, frequency of detection, minimum detect, maximum detect, location of maximum detect, minimum non-detect limit, maximum non-detect limit, determined counts of detects above NDEP worker BCLs, and determined counts of non-detects above NDEP worker BCLs. The NDEP worker BCLs shown in the table are the lower of the indoor and outdoor worker values.[9] As shown in the tables, with the exception of two radionuclides (radium 226 and radium 288), no other count of non-detects were found to be above the NDEP Worker BCLs, and this information was used to support the data usability evaluation. As further discussed in Section 3.6.2, NDEP BCLs are used as part of the toxicity screen for determining COPCs.

With regard to the two radionuclides, only 1 of the 42 samples had a reported non-detected concentration.   Both of the radionuclides were retained as potential COPCs and were further evaluated as part of the background comparison evaluation discussed in section 3.6.1.2.

Table 3 presents the soil data summary results for asbestos. A total of 18 surface soil (0 to 0.5 ft bgs) samples were analyzed for asbestos. Results are reported in terms of the number of long fibers (i.e., >10 μm long and <0.4 μm wide) observed in the sample. As shown in the table, no long amphibole fibers were observed in any of the samples. A total of six long chrysotile fibers were observed in three samples; a maximum of three long chrysotile fibers were observed in any one sample.

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[9] Worker BCLs are based on combining human health toxicity values with a standard exposure factor to estimate contaminate concentrations in environmental media that are considered by NDEP to be protective of human exposure (including sensitive sub-groups) over a lifetime. Worker BCLs do not address intrusion of VOCs into indoor air, particulate emission during construction/excavation activities, and groundwater contact from soil-leached chemicals.

With regard to the data review for RZ-A, the following data treatment procedures were incorporated:

- Field duplicates and site samples were treated as independent samples, on the basis of preliminary evaluation indicating that the variance of the duplicates was similar to the variance of the site samples, in consultation with NDEP guidance (NDEP, 2008c; Paul Black, pers. comm., November 11, 2009).

- Only one location (SA02) was sampled in 2006 as part of the Phase A investigation. Therefore, it is not possible to provide a statistical comparison between Phase A and Phase B data. In general, the detected metals, perchlorate, VOCs, and wet chemistry analytes for the SA02 samples and the remaining Phase B samples collected in RZ-A are comparable.

- For the dioxins/furans, the U.S. EPA toxicity equivalency procedure, developed to describe the cumulative toxicity of these compounds, was applied. This procedure involves assigning individual toxicity equivalency factors (TEFs) to the 2,3,7,8 substituted dioxin/furan congeners. TEFs are estimates of the toxicity of dioxin-like compounds relative to the toxicity of 2,3,7,8-TCDD, which is assigned a TEF of 1.0. Calculating the toxicity equivalency (TEQ) of a mixture involves multiplying the concentration of individual congeners by their respective TEF. A value of zero was used for individual congeners that are non-detect in a particular sample. The sum of the TEQ concentrations for the individual congeners is the TEQ concentration for the mixture. The WHO 2005 TEF values were used to evaluate the 17 chlorinated dibenzo-p-dioxins and chlorinated dibenzofurans. In addition, the WHO 2005 TEF values were used to evaluate the 12 dioxin like PCB compounds (PCB -77, PCB-81, PCB-126, PCB-105, PCB-114, PCB-118, PCB-123, PCB-156, PCB-157, PCB-167, PCB-169, PCB 189) (Van den Berg 2006).

- Hexachlorobenzene was analyzed using both EPA Methods 8081 and 8270. EPA Method 8270 uses gas chromatograph/mass spectrometer (GC/MS) technology for positive identification and eliminates matrix interference not overcome by EPA Method 8081, which uses a GC with an electron capture detector (GC/ECD). As part of the data review, results of the two methods were compared. On average, the HCB concentration measured by the two methods is within 10%. However, data reported for HCB are based on EPA Method 8270, because it was deemed to be the superior method.

3.6   Selection of Chemicals of Potential Concern

All chemicals detected in validated soil samples collected from 0–10 ft bgs were used as the initial list of COPCs. However, to ensure that the risk assessment focuses on those chemicals that contribute the most to the overall risk (U.S. EPA, 1989), the following procedures were used to eliminate chemicals for quantitative evaluation in the risk assessment:

- Identification of metals and radionuclides for which Site concentrations are at or less than background concentrations

- Identification of chemicals that will not contribute significantly to risk and hazard estimates based on a toxicity screen.

Each of these procedures is discussed in the following sections.

3.6.1   Evaluation of Site Concentrations Relative to Background

Consistent with U.S. EPA guidance (1989, 1992b,c), site data for metals and radionuclides were evaluated relative to background concentrations to identify those that are not elevated above naturally occurring levels and can, therefore, be eliminated from further quantitative evaluation in the health risk assessment. This evaluation was based on a combination of exploratory data analysis (EDA) and appropriate statistical methods (U.S. EPA, 2002c). When the weight of evidence of the EDA and results of the statistical analyses indicated that a particular chemical is within background levels, then the chemical was not identified as a COPC. For radionuclides, NDEP's *Guidance for Evaluating Radionuclide Data for the BMI Plant Sites and Common Area Projects* (NDEP, 2009c) and *Guidance for Evaluating Secular Equilibrium at the BMI Complex and Common* Areas (NDEP, 2009d) were followed to assess secular equilibrium when performing background comparisons.

Site soil concentrations were compared to background levels using the existing soils background data presented in the *Background Shallow Soil Summary Report, BMI Complex and Common Area Vicinity* (BRC and TIMET, 2007), which includes both the Environ (2003) data set and the BRC/TIMET data set collected in 2005. Specifically, only the subset of shallow background data identified as being from sediments derived from the McCullough Range were used, based on the recommendation from NDEP (NDEP, 2009e). These samples were collected at 0, 5, and 10 ft bgs. The total number of samples in this data set ranged from 81 to 101, depending on analyte, with between approximately 30 and 40 samples for each depth interval (see Tables 4 and 6).

Site data collected from locations within RZ-A at sample starting depths between 0 and 10 ft bgs were included in this evaluation. Samples were generally collected from 0.5 to 2 ft bgs and from 10 to 11.5 ft bgs, although a few samples were collected at 2.5, 5, 7, and 9 ft bgs due to location-specific sampling obstacles. Field duplicates and site samples were treated as independent samples, on the basis of preliminary evaluation indicating that the variance of the duplicates was similar to the variance of the site samples, in consultation with NDEP guidance (NDEP, 2008c; Paul Black, pers. comm., November 11, 2009). The total number of samples in this data set ranged from 42 to 44 samples, depending on analyte, with 21 or 22 samples collected between 0.5 to 2 ft bgs and > 2 to 10 ft bgs (see Tables 4 and 6). Finally, non-detect results were set equal to one-half of the limit of detection for the purposes of this evaluation. The sample quantitation limit (SQL) was used as the detection limit for both the site and background data sets, per NDEP guidance (NDEP, 2008d).

EDA was performed using summary statistics (*Guidance on the Development of Summary Statistics Tables for the BMI Plant Sites and Common Areas Projects, Henderson, Nevada*; NDEP, 2008b) and normal quantile-quantile (Q-Q) plots and side-by-side box-and-whisker plots to qualitatively evaluate whether the Site and background data are representative of a single population. These plots are included in Appendix B (metals) and C (radionuclides). Normal Q-Q plots provide a visual assessment of how closely a dataset follows a normal distribution. Data points that fall on roughly a straight line may be considered to follow a normal distribution. When the highest concentrations fall above the straight line the dataset may follow a lognormal distribution. When both the background and site data are included, the Q-Q plots provide a direct visual comparison of the two distributions. A curve that is higher in the vertical direction indicates a higher distribution of values (U.S. EPA 2002c). No further statistical analysis (normality, outliers) was conducted on the data in the Q-Q plots. Side-by-side box-and-whisker plots provide a visual comparison between the site and background datasets and an easy assessment of whether the bulk of samples from the site are above background. For each dataset, the box in the box-and-whisker plot encompasses the central 50 percent of the results from the 25th to 75th percentiles. Substantial overlap between the boxes for background and site data indicates the site data may not be significantly different from background. The whiskers demarcate one "step" above the 75th percentile and below the 25th percentile. One "step" is defined as 1.5 times the interquartile range (the difference between the 75th and 25th percentiles). Data points above and below the whiskers are considered potential outliers and are shown on the plots as open circles; an "x" on the plot represents non-detect values.

The computer statistical software program Guided Interactive Statistical Decision Tools (GiSdT®; Neptune and Company, 2007) was used to perform all statistical comparisons. Specifically, statistical background comparisons were performed using the Quantile test, Slippage test, t-test, and Wilcoxon Rank Sum test with Gehan modification (this suite of tests is sometimes referred to as Gilbert's Toolbox). The t-test is parametric, which assumes that the data are normally distributed. In contrast, the Wilcoxon Rank Sum test, Quantile test, and Slippage test are non-parametric, which do not require an assumption of whether the data are normally or lognormally distributed (U.S. EPA, 2002c; NDEP, 2009f). These non-parametric tests are described further below.

- The Wilcoxon Rank Sum test performs a test for a difference between the sums of the ranks for two populations. This is a non-parametric method for assessing differences in the centers of the distributions that relies on the relative rankings of data values. Knowledge of the precise form of the population distributions is not necessary. The Wilcoxon Rank Sum test has less power than the two-sample t-test wherein the data are normally distributed, but the assumptions are not as restrictive. The GiSdT® version of the Wilcoxon Rank Sum test uses the Mantel approach for ranking the data, which is equivalent to using the Gehan ranking system. The Gehan ranking system is used to rank non-detects with the rest of the data (NDEP, 2009f).

- The Quantile test addresses tail effects that are not addressed in the Wilcoxon Rank Sum test. The Quantile test looks for differences in the right tails (upper end of the data set), rather than the central tendency like the Wilcoxon Rank Sum test. The Quantile test was performed using a defined quantile = 0.80 (Paul Black, pers. comm., Oct. 7, 2009).

- The Slippage test looks for a shift to the right in the extreme right tail of the background data set versus the extreme right tail of the site data set. This test determines, for each metal and radionuclide, whether the number of site concentrations that are greater than the maximum background concentration is greater than would be expected statistically if the site and background distributions are the same.

An alpha = 0.05 is typically used to evaluate a statistically significant result (U.S. EPA, 2002c). However, as more tests are performed, it is more likely that a statistically significant result will be obtained purely by chance. Given the use of multiple statistical tests, an alpha = 0.025 was selected as a reasonable significance level for determining whether Site data are different from background (NDEP, 2009f). Generally, any chemical that resulted in a p-value less than 0.025 in one of four tests was retained for further consideration in the COPC selection process.

Additionally, because these tests are set up with one-sided hypotheses, not only are differences between the two samples able to be detected, but also, a directional determination can be made as well (e.g., Site is greater than background).

For radionuclides, if approximate secular equilibrium (discussed further below) is exhibited in an isotope decay chain, then background comparisons were performed to confirm whether all the radionuclides in that decay chain are similar to background. If any radionuclide was greater than background, then all the radionuclides in that decay chain were carried forward in the risk assessment. If they were not greater than background, then they were not identified as COPCs and were not evaluated quantitatively in the risk assessment. If secular equilibrium was not exhibited, then background comparisons were performed for each radionuclide separately, and individual radionuclides were selected as COPCs, depending on the outcome of the background comparisons.

3.6.1.1   Metals

For most metals, comparisons between site data and the background data set were based on the combined data for all depth intervals in each data set, as recommended in BRC's Background Soil Summary Report (BRC/TIMET, 2007). For the remaining metals, the site and background data were subdivided by depth interval as follows, also as recommend in the Background Soil Summary Report (BRC/TIMET, 2007):

- Chromium(total), chromium(VI), iron, manganese, potassium, sodium, and zinc — Site data collected between 0 and 2 ft bgs were compared to background data collected at 0 ft bgs, and site data collected between 2 and 10 ft bgs were compared to background data collected at 5 and 10 ft bgs

- Lead — Site data collected between 0 and 2 ft bgs were compared to background data collected at 0 ft bgs, site data collected between 2 and 6 ft bgs were compared to background data collected at 5 ft bgs, and site data collected between 6 and 10 ft bgs were compared to background data collected at 10 ft bgs.

- Uranium — Site data collected between 0 and 6 ft bgs were compared to background data collected at 0 and 5 ft bgs, and site data collected between 6 and 10 ft bgs were compared to background data collected at 10 ft bgs.

The summary statistics for the background and site data for RZ-A are summarized in Table 4, including number of detections, total number of samples, percent detections, minimum detected value, maximum detected value, median, mean, and standard deviation (NDEP, 2008b); Q-Q and box-and-whisker plots are included in Appendix B. Consistent with NDEP guidance, the median,

mean, and standard deviation are based on detected values (NDEP, 2008b). Subsequent to completion of the background comparisons, it was determined that Phase A and Phase B samples were analyzed for metals by different laboratories (Test America-St. Louis and Columbia Analytical-Kelso, respectively). While both adhered to EPA Method 6020, NDEP has indicated that Test America used a 2% hydrochloric acid (HCl) digestion, whereas Columbia Analytical did not. NDEP has indicated that comparisons of the Phase A and Phase B results from across the entire Tronox site suggest that this difference in sample preparation results in slightly elevated results from the Test America (Phase A) analyses for certain metals, including arsenic, when compared to the Phase B data. However, Tronox is currently evaluating this issue with the appropriate laboratories. Because there are only two Phase A samples from one sample location (out of a total of 44 samples), inclusion of the Phase A samples is not expected to affect the overall conclusions of the HRA for RZ-A. However, it is possible that metals data for Phase A and Phase B samples will be evaluated separately for the remaining remediation zones, pending further evaluation of this issue.

The results for the four statistical tests (p-values) are also included in Table 4, as well as a determination as to whether the site data are greater than background. It is important to note that many of the p-values for multiple tests are close to or equal to one, suggesting that the site data are lower than background. This issue is discussed further below. In addition, there are several chemicals for which there is low frequency of detection (less than 25%) in the site or background data set. Finally, chemicals for which only one p-value was less than 0.025 are noted on Table 4. Based on these results, the chemicals identified as being greater than background in RZ-A are listed below, along with any comments as to how the elevated levels might be explained by the CSM.

Metals Greater than Background	Relation to Conceptual Site Model
Antimony	Very low detection frequency in the site data set. One detected value much greater than maximum detected background concentration (RSAT5-0.5B). No explicit relation to CSM for RZ-A.
Boron	Elevated concentrations detected in samples collected within LOU 62 (State Industries, Inc. site, including impoundments and catch basin). Borax (hydrated sodium borate) was identified as a known constituent of the process waste stored in the impoundments (ENSR 2008c).
Cadmium	Very low detection frequency in background data set. No explicit relation to CSM for RZ-A.
Copper	One detected value much greater than maximum detected background concentration (RSAT5-0.5B). No explicit relation to CSM for RZ-A.
Iron	Elevated concentrations detected in samples collected within LOU 62. Iron identified as a known constituent of the process waste stored in the impoundments (ENSR

Metals Greater than Background	Relation to Conceptual Site Model
	2008c).
Lead	Elevated above background only for data collected between 6 and 10 ft bgs; however, highest detected site concentrations detected in samples collected between 0 and 6 ft bgs. One of two highest concentrations was detected in a sample collected within LOU 62; the other was detected in a sample collected from RSAT5-0.5B. No explicit relation to CSM for RZ-A.
Molybdenum	One detected value much greater than maximum detected background concentration (RSAT5-0.5). No explicit relation to CSM for RZ-A.
Platinum	Very low detection frequency in background data set; maximum detected concentration in site data below maximum detected concentration in background data. No explicit relation to CSM for RZ-A.
Potassium	Elevated above background only for data collected between 2 and 10 ft bgs; maximum detected concentration in site data below maximum detected concentration in background data for this depth interval. No explicit relation to CSM for RZ-A.
Selenium	Low frequency of detection in site data set. No explicit relation to CSM for RZ-A.
Silver	Low frequency of detection in both site and background data sets. Two highest detected site concentrations from samples collected within LOU 62. No explicit relation to CSM for RZ-A.
Sodium	Highest detected site concentrations from samples collected within LOU 62. Potentially associated with borax (hydrated sodium borate) that was identified as a known constituent of the process waste stored in the impoundments (ENSR 2008c).
Tin	Very low detection frequency in site data set. Highest detected concentration in site data below maximum detected concentration in background data. No explicit relation to CSM for RZ-A.
Titanium	Maximum detected site concentration is only slightly higher than maximum detected background concentrations (1080 vs. 1010 mg/kg). No explicit relation to CSM for RZ-A.
Tungsten	Not detected in background data set. No explicit relation to CSM for RZ-A.
Uranium	Elevated above background only for data collected between 6 and 10 ft bgs; maximum detected concentration in site data below maximum detected concentration in background data for this depth interval. No explicit relation to CSM for RZ-A.
Vanadium	Maximum detected concentration in site data below maximum detected concentration in background data. No explicit relation to CSM for RZ-A.

All of these chemicals were evaluated further in the COPC selection process (Section 3.6.2), regardless of whether the elevated concentrations could be related to the CSM for RZ-A.

As stated previously, in many cases, the *p*-values for one or more of the statistical tests were near or equal to 1. In practice, background comparison tests resulting in *p*-values greater than 0.975 can be considered indicative of the site data being lower than the background data (Paul Black, pers. comm., April 30, 2010). As shown in Table 4, this was the case for a large proportion, but

not all, of metals in RZ-A, including aluminum, arsenic, barium, beryllium, cadmium, chromium (total), chromium (VI), cobalt, magnesium, manganese, strontium, thallium, uranium, and zinc. These results suggest that the McCullough Range subset of the BRC/TIMET (2007) data, may not be representative of background at the Tronox site, at least for these metals. This difference could be to due to a number of reasons, including (1) variations in the lithologic compositions of the alluvial fans derived from the McCullough Range and the relative positions of the background and site samples within the alluvial fan sequences; and (2) differences in analytical preparation techniques, as described previously, because NDEP has indicated that the samples from the background data set were analyzed using HCl digestion sample preparation whereas the majority of the site samples (from Phase B) were not. Additional statistical analysis conducted by NDEP suggests that the metals data for Parcels A/B, which is located in the northern portion of the Tronox Site and analyzed using HCL sample preparation, is also lower than the McCullough Range subset of the BRC/TIMET (2007) data set (NDEP, 2010). Therefore, for purposes of background comparisons for the remaining remediation zones, it is possible that the RZ-A data will be used as the background dataset for data collected on the Tronox site that was analyzed without HCl digestion sample preparation, and the Parcels A/B data will be used as the background dataset for any data collected at the Tronox Site analyzed using HCl digestion sample preparation (NDEP, 2010).

3.6.1.2   Radionuclides

Only data from Phase B sampling were used for the secular equilibrium and background comparison analysis. Phase A radionuclide data were not used because of differences in the analytical methods used (i.e., Phase A samples were analyzed by gamma spectroscopy not prepared using hydrofluoric acid whereas Phase B samples were analyzed by alpha methods) (NDEP, 2009g). Therefore, the results from the two Phase A samples in RZ-A (SA2-0.5 and SA2-10) were removed from the radionuclide data set prior to statistical analysis.

Secular Equilibrium

Secular equilibrium is defined by the International Union of Pure and Applied Chemicals (IUPAC) as "Radioactive equilibrium where the half-life of the precursor isotope is so long that the change of its activity can be ignored during the period of interest and all activities remain constant" (IUPAC, 1997). In other words, the activity of each radionuclide within an isotope decay chain is essentially the same. The analysis of secular equilibrium was performed according to NDEP's *Guidance for Evaluating Radionuclide Data for the BMI Plant Sites and Common Areas Projects* (NDEP, 2009c) and *Guidance for Evaluating Secular Equilibrium at the BMI*

Complex and Common Areas (NDEP, 2009d). The uranium decay series and thorium decay series were broken down by different depth intervals, per the recommendations from NDEP to use the same chemical-specific depth intervals used for the background comparison (BRC/TIMET, 2007). The uranium decay series includes, in order, U-238, U-234, Th-230, and Ra-226. The thorium decay series includes Th-232, Th-228, and Ra-228. The depth intervals used for the uranium decay series were for data collected between 0 and 6 ft bgs, and between 6 and 10 ft bgs The Th-232 chain was analyzed for the single depth interval of 0 to 10 ft bgs.

The results of the equivalence test for secular equilibrium of radionuclides in RZ-A are presented in Table 5a. The table includes the *p*-value, a conclusion about secular equilibrium, the delta used, the sample size, the number of missing data pairs (if any), the mean proportions of radioactivity, lower and upper 95% confidence intervals, and data shifts (the value by which all negative activities are shifted upward toward zero, if this setting was used). The equivalence test analysis was performed using Neptune's EnviroGiSDT statistical analysis tool. The null hypothesis of the test is that the radionuclides within a decay series are not in secular equilibrium. Per NDEP guidance (NDEP, 2009d), the delta value (maximum deviation from equal proportions) was set to 0.10 (based on NDEP evaluations of background data sets) and a decay series was considered to be in secular equilibrium if the p-value was less than the standard significance level of 0.05. As noted in the documentation for the GiSDT software, the upper and lower confidence intervals are included primarily to show which radioisotopes are producing more/less radioactivity than the others, in case secular equilibrium is not shown. As shown in Table 5a, the equivalence test indicates that the uranium decay series is in approximate secular equilibrium in shallow soils between 0 and 6 ft bgs and between 6 and 10 ft bgs. Conversely, the equivalence test indicates that the thorium decay series is not in secular equilibrium in shallow soils between 0 and 10 ft bgs, with a delta value of 0.10. This latter result may be an artifact of the number of samples collected in RZ-A. For example, as also shown in Table 5a, the equivalence test for shallow soils between 0 and 10 ft for the Tronox site as a whole indicates that the thorium decay series is in approximate secular equilibrium. Importantly, the mean proportions of radioactivity between the RZ-A and site-wide data sets are very similar; however, the confidence limits on the mean proportions for RZ-A, which are based on 42 samples, are wider than those for the site-wide data, which are based on 507 samples. The wider the confidence limits on the mean proportions of radioactivity, the more likely that the null hypothesis will not be rejected, given a fixed value for delta, as illustrated in the example provided in NDEP's (2009d) guidance. Further, NDEP's equivalence testing of the Parcel A/B data indicates that the thorium decay series also is in approximate secular equilibrium (NDEP, 2009d).

Secular equilibrium was further evaluated using exploratory data analysis. Box-and-whisker plots (box-plots) of the RZ-A radionuclide results for the isotopes in the uranium decay series and the thorium decay series are presented in Figure 5. Correlation matrices for theses same two decay chains are shown in Table 5b-i. In conjunction with the equivalence testing described above, these exploratory data analysis methods serve as additional lines of evidence for establishing if the decay chains are in secular equilibrium (NDEP, 2009d).

The box-plots in Figure 5 show that, in general, the activities of the isotopes in the uranium decay series (Figure 5a) and thorium decay series (Figure 5b) have comparable mean activities, although for both series, the radium isotopes appear to be slightly lower than the uranium and thorium isotopes. In general, the box plots suggest that the two decays series are in approximate secular equilibrium.

As shown in Table 5bi, the correlation matrices show a positive correlation between the isotopes within each chain, which would be consistent with decay chains in secular equilibrium. The correlations are strongest for the uranium decay chain, where the strongest correlation occurs between U-238 and U-234, and the weakest correlations occurring between Ra-226 and the uranium isotopes. For the thorium decay chain, the strongest correlation is between the Th-232 and Th-228, while weaker correlation is exhibited between Ra-228 and the thorium isotopes. Correlation between Ra-228 and Th-232 is very weak, reflective of the larger scatter in the Ra-228 activities. A similar picture was seen for the decay chain correlations in the Tronox Parcels A/B results (NDEP, 2009d), shown in Table 5b-ii for comparison. For additional comparison, the correlation matrices for the 2005 BRC/TIMET Background data set are presented in Table 5b-iii.

Background Comparison

Comparisons between site data and the background data set for the Th-232 decay series were based on combined data between 0 and 10 ft bgs in each data set, as recommended in BRC's Background Soil Summary Report (BRC/TIMET, 2007). For the U-235 and U-238 decay series, the site and background data were subdivided into two depth intervals, as also recommended in the Background Soil Summary Report (BRC/TIMET, 2007). For these radionuclides, site data collected between 0 and 6 ft bgs were compared to background data collected at 0 and 5 ft bgs, and site data collected between 6 and 10 ft bgs were compared to background data collected at 10 ft bgs. The background comparison tests were carried out using Neptune's EnviroGiSDT statistical analysis tool.

The summary statistics for the background and site radionuclide data for RZ-A are summarized in Table 6, including the number of detections, total number of samples, percent detections, minimum detected value, maximum detected value, median, mean, and standard deviation (NDEP, 2008b); Q-Q and box-and-whisker plots are included in Appendix C.

Consistent with NDEP guidance, the median, mean, and standard deviation are based on detected values (NDEP, 2008b). The results for the four statistical tests (*p*-values) are also included in the table, as well as a determination as to whether the site data are greater than background. Similar to the metals background comparison discussed above, many of the *p*-values for multiple tests are close to or equal to one, suggesting that the site data are lower than the McCullough Range subset of the BRC/TIMET (2007) Shallow Background data set. Based on these results, none of the radionuclides in RZ-A are considered to be above background; therefore, radionuclides were not evaluated further in the COPC selection process. The use of Phase B RZ-A data as the background data set for the remaining remediation zones will be further evaluated and discussed with NDEP.

3.6.2 Evaluation of Site Concentrations relative to toxicity screen

Table 7 contains a list of all chemicals (47 potential COPCs) that were either positively identified in at least one soil sample as presented in Tables 1 through 3[10] or, for metals, were determined to be above background based on evaluation presented in Table 4. Based on the approved methods in the HRA Work Plan, a combination of frequency of detection (chemical is detected in less than 5% of the samples) and a toxicity screen were used to further reduce the initial list of potential COPCs. No chemical was eliminated based solely on frequency of detection.

The chemical toxicity screen used was based on comparison of the maximum detected concentration to a percentage of the BCL. To illustrate this BCL comparison, Table 7 presents the ratio of the BCL divided by the maximum detected soil concentration. A ratio >10 indicates that the maximum detected concentration is less than 10% of the BCL. A ratio of > 100 indicates that the maximum detected concentration is less than 1% of the BCL.

All detected chemicals with the exception of hexachlorobenzene, iron and lead have maximum detected concentrations less than 10% of the BCL (or ratios above 10). The majority of detected chemicals have very large ratios indicating that they would not contribute substantially to overall health risk estimates.

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[10] This included all J-qualified data and non-detect with high detections.

All persistent, bioaccumulative, and toxic chemicals and Class A carcinogens were retained as COPCS with the exception of DDT, DDE, beta BHC. These three chemicals were eliminated as COPCs as their ratio of BCL to maximum detected concentration was greater than 100 (maximum detected concentration is less than 1% BCL), indicating they would not significantly contribute to overall health risk estimates. Benzo(a)pyrene was selected as a COPC and, therefore, per NDEP guidance, all seven carcinogenic PAHs were considered COPCs, regardless of whether they are detected at the Site. As such, dibenzo-a,h-anthracene was retained as a COPC although it was not detected. This methodology allows for evaluation of all carcinogenic PAHs based on the relative potency to benzo(a)pyrene.

There is no BCL for asbestos; however, one or more long chrysotile fibers (> 10 microns [µm] in length and <0.4 µm in width) were detected in 3 of 18 samples analyzed for asbestos. Therefore, long chrysotile fibers were identified as a COPC.

Chemicals such as boron and perchlorate that would normally be eliminated based on the chemical toxicity criteria screen, but are associated with historic site activities (LOUs), were retained.

As stipulated in the approved HRA Work Plan, dioxin was not retained as COPC as the sum of the maximum detected concentration of dioxin/furans TEQ (64.6 pg/g) and the maximum detected concentration of PCB TEQ (0.39 pg/g) is below the NDEP target goal of 1000 pg/g. In addition, the maximum detected lead concentration is below the NDEP target goal of 800 mg/kg and was not retained as COPCs.

There is no NDEP BCL for the non-carcinogenic chemical octachlorstyrene, nor does it appear that a toxicity criterion has previously been developed. Based on a review of readily available toxicology studies, the maximum detected concentration of 0.025 mg/kg is not expected to contribute to overall non-cancer health impacts (Chu et al. 1986; HSDB 2010). The impact of not-retaining octachlorstyrene as a COPC is further discussed in the uncertainty analysis (Section 6.4).

In summary, based on the background comparison for metals and radionuclides, and the toxicity screen evaluation, the following chemicals are identified as COPC for RZ-A and are further evaluated quantitatively in the HRA.

- Asbestos (long chrysotile fibers)
- Benz(a)anthracene

- Benzo(b)fluoranthene
- Benzo(k)fluoranthene
- Benzo(a)pyrene
- Boron
- Chrysene
- Dibenzo(a,h)anthracene
- Hexachlorobenzene
- Indeno(1,2,3-cd)pyrene
- Iron
- Perchlorate
- Total polychlorinated biphenyls (PCBs)

4.0 EXPOSURE ASSESSMENT

The magnitude of exposure for any given receptor is a function of the amount of the constituent in the exposure medium and the frequency, intensity, and duration of contact with that medium. This section presents the equations and assumptions used to calculate potential exposures for each of the identified COPCs.

4.1 Determination of Representative Exposure-Point Concentrations

A representative exposure-point concentration (EPC) is a COPC-specific and medium-specific concentration used in the dose equation for each receptor and each exposure pathway. The methods, rationale, and assumptions employed in deriving the EPCs are discussed below for the relevant environmental media based on the COPCs evaluated in RZ-A.

4.1.1 Soil

Soil EPCs were calculated to estimate direct-contact exposure for future on-Site indoor and outdoor commercial workers and construction workers. The soil EPCs were also used to derive airborne particulate concentrations of non-volatile COPCs. For purposes of this HRA, a screening approach was used that incorporated use of the maximum detected concentration within the 0- to 10-ft bgs interval for each identified COPC, except for asbestos, which is discussed separately below. This is a very conservative assumption, in that representative EPCs should consider the potential exposure depth interval for each receptor. For example, as indicated in the HRA Work Plan, future indoor or outdoor commercial workers' exposure to soil is limited to surface soil; therefore, data from the 0- to 2-ft bgs interval is more appropriate. Additionally, U.S. EPA (1992c) recommends using the 95th upper confidence limit (UCL) of the arithmetic mean concentration for purposes of estimating reasonable maximum or upper-end exposures. Therefore, use of the maximum detected concentration within the entire 0- to 10-ft bgs soil column for evaluating both commercial and construction workers likely overestimates the representative EPCs and is considered a screening approach. The EPCs for the COPCs, except asbestos, are presented in Table 8.

4.1.2 Asbestos

Bulk soil concentrations for asbestos were used to estimate exposure-point concentrations in air according to the methodology described in *Technical Guidance for the Calculation of Asbestos-Related Risk in Soils for the BMI Complex and Common Areas* (NDEP, 2009h). This

methodology is based on the protocols described in U.S. EPA (2003a), and requires estimation of asbestos concentrations in soil to develop exposure-point concentrations in air.

Asbestos concentrations in surface soils are based on the number of long fibers (i.e., >10 μm in length and <0.4 μm in width) observed in a sample, multiplied by the analytical sensitivity of the measurement:

$$C_{soil} = f \times AS$$

where f is the number of long fibers observed (unitless), and AS is the analytical sensitivity (fibers per gram [fibers/g]).[11] If more than one asbestos sample is collected, the analytical sensitivity is pooled across the n samples as follows:

$$Pooled\ AS = 1 \times \frac{1}{\sum_{i=1}^{n} AS_n}$$

Two estimates of the asbestos concentration were calculated (i.e., a best estimate and upper-bound estimate) as defined in U.S. EPA's draft methodology (U.S. EPA, 2003a) and NDEP (2009h). The best-estimate concentration is similar to a central-tendency estimate, whereas the upper-bound concentration is comparable to a reasonable maximum exposure estimate. The pooled analytical sensitivity is multiplied by the number of long chrysotile or amphibole structures to estimate concentration. For the best estimate, the number of long fibers measured is incorporated into the calculation above. The upper bound of the asbestos bulk soil concentration is calculated as the 95% UCL of the Poisson distribution, where the mean equals the number of long structures detected. This value is calculated as follows (NDEP 2009h):

$$95\%\ UCL = \frac{\chi^2_{u,v_b} \left(2 \times (x+1)\right)}{2}$$

The 95% UCL of the Poisson distribution is then multiplied by the pooled analytical sensitivity to estimate the upper-bound concentration.

4.1.3   Outdoor Dust

Long-term exposure to COPCs bound to dust particles was evaluated using U.S. EPA's particulate emission factor (PEF) approach (U.S. EPA, 2002a). The PEF relates concentrations of a chemical in soil to the concentration of dust particles in the air. The Q/C (Site-Specific

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[11] The laboratory results are reported as "structures;" however, the term "fibers" is used herein for simplicity.

Dispersion Factor [U.S. EPA, 2002a]) values are based on the Las Vegas, Nevada, area, as presented in Appendix D of U.S. EPA, 2002a. The U.S. EPA guidance for dust generated by construction activities (U.S. EPA, 2002a) was used for short-term construction worker exposures. Input soil concentrations for the model are the EPCs described above. The remaining model input parameters are summarized in Table 9; the calculations, including all intermediate equations, are included in Appendix D of this report. It should be noted that the PEF for short-term construction workers includes two components, emissions from unpaved roads and emissions from wind erosion, excavation, dozing, grading, and tilling (U.S. EPA, 2002a). These sources of dust emissions are combined into a single PEF for short-term construction workers as follows:

$$PEF_{sc\_total} = \frac{1}{\left(\frac{1}{PEF_{sc_{road}}}\right) + \left(\frac{1}{PEF_{sc}}\right)}$$

where:

$PEF_{sc\text{-}total}$ = total subchronic construction-related PEF (m³/kg)

$PEF_{sc\ road}$ = subchronic PEF for unpaved road traffic

PEF_{sc} = sub-chronic PEF for construction activities

For on-site workers, the PEF is limited to emissions from wind erosion from surface soil, which is calculated according to the Equation 24 in NDEP's (2009h) asbestos guidance, as shown in Appendix D.

The air concentration term for COPCs bound to dust particles is derived from soil concentrations (mg/kg for chemicals and fibers/g for asbestos) by applying the PEF values described above in the following equations:

Chemicals

$$C_{atm} = C_{soil} \times CF_1 \times \left(\frac{1}{PEF}\right)$$

Asbestos

$$C_{air} = C_{soil} \times CF_2 \times \left(\frac{1}{PEF}\right) \times \left(\frac{1}{CF_3}\right)$$

where:

C_{air} = air concentration (μg/m³, f/cm³)

CF_1 = conversion factor (1000 μg/mg)

CF_2 = conversion factor (1000 g/kg)

CF_3 = conversion factor (10^6 cm³/m³)

PEF = particulate emission factor (m³/kg)

For asbestos, the soil bulk concentrations and air concentrations (and subsequent health risks) were calculated using NDEP's "asbestos guidance riskcalcs.xls" spreadsheet. It should be noted that asbestos bulk soil concentrations and corresponding air concentrations were calculated for RZ-A as a whole, and for a subarea represented by sampling locations RSAT5-0.5B, RSAT6-0.5B, and RSAT7-0.5B. The latter subarea was evaluated separately, because long chrysotile fibers were detected only in these three adjacent locations. RZ-A is approximately 29 acres in size. Based on Voronoi/Thiessen polygons, the subarea represented by RSAT5-0.5B, RSAT6-0.5B, and RSAT7-0.5B is approximately 5.2 acres in size (Figure 6).

4.2   Exposure Calculations

Reasonable maximum exposures to chemicals were calculated for future onsite indoor and outdoor commercial workers and future onsite construction workers, using the exposure pathway–specific dose equations presented below and the exposure input parameters presented in Tables 10 and 11, respectively. The dose calculation spreadsheets for each exposure scenario are included in Appendix D. The methodology used to estimate the average daily dose (ADD) via each of the complete exposure pathways is based on U.S. EPA (1989, 1992a) guidance. For chemical carcinogens, lifetime average daily dose (LADD) estimates are based on chronic lifetime exposure extrapolated over the estimated average 70-year lifetime (U.S. EPA, 1989), to be consistent with cancer slope factors, which are based on chronic lifetime exposures. For noncarcinogens, ADD estimates are averaged over the estimated exposure period.

4.2.1 Chemicals

Soil Ingestion:

$$Dose = \frac{C_{soil} \times SIR \times CF_4 \times EF \times ED \times BIO}{BW \times AT}$$

where:

Dose	=	ADD for non-carcinogens and LADD for carcinogens (mg/kg-day)
C_{soil}	=	chemical concentration in soil (mg/kg)
SIR	=	ingestion rate (mg/day)
CF_4	=	conversion factor (10^{-6} kg/mg)
EF	=	exposure frequency (days/year)
ED	=	exposure duration (years)
BIO	=	relative bioavailability (unitless)
BW	=	body weight (kilograms)
AT	=	averaging time (days); equal to the ED × 365 days/year for non-carcinogens (AT_{nc}) and 70 years (average lifetime) × 365 days/year for carcinogens (AT_c)

Dermal Contact:

$$Dose = \frac{C_{soil} \times CF_4 \times SA \times AF \times ABS \times EF \times ED}{BW \times AT}$$

where:

Dose	=	ADD for non-carcinogens and LADD for carcinogens (mg/kg-day)
C_{soil}	=	chemical concentration in soil (mg/kg)
CF_4	=	conversion factor (10^{-6} kg/mg)
SA	=	skin surface area (cm^2/event)
AF	=	soil to skin adherence factor (mg/cm^2)
ABS	=	absorption factor (unitless)

$$EF \quad = \quad \text{exposure factor (events/year)}$$

$$ED \quad = \quad \text{exposure duration (years)}$$

$$BW \quad = \quad \text{body weight (kilograms)}$$

AT = averaging time (days); equal to the ED × 365 days/year for non-carcinogens (AT_{nc}) and 70 years (average lifetime) × 365 days/year for carcinogens (AT_c)

Chemical-specific dermal absorption values from U.S. EPA guidance (U.S. EPA, 2004a [Part E RAGS]) are used in the risk assessment.

Inhalation:

The contaminant concentration in air, rather than contaminant intake, is used as the basis for estimating chemical inhalation risks based on guidance described in *Part F, Supplemental Guidance for Inhalation Risk Assessment* (U.S. EPA, 2009a). As presented in the CSM, indoor dust (particulate) is accommodated via the soil ingestion pathway for indoor workers. The inhalation equation for outdoor workers and construction workers is:

$$EC = \frac{C_{soil} \times CF_1 \times ET_o \times EF \times ED}{AT \times PEF}$$

where:

EC = exposure concentration ($\mu g/m^3$)

C_{soil} = chemical concentration in soil (mg/kg)

CF_1 = conversion factor (1000 $\mu g/m^3$)

ET_o = exposure time outdoors onsite (hr/day)

EF = exposure frequency (days/yr)

ED = exposure duration (year)

AT = averaging time (hours); equal to the ED × 365 days/year × 24 hours/day for non-carcinogens (AT_{nc}) and 70 years (average lifetime) × 365 days/year × 24 hours/day for carcinogens (AT_c)

PEF = particulate emission factor (m^3/kg) – see Table 9

4.2.2 Asbestos

Exposure to asbestos fibers in air was evaluated using the methodology described in NDEP (2009h). The NDEP asbestos risk assessment guidance is based on methods for assessing asbestos risk described in U.S. EPA (2003a), and also on associated examples of the implementation of these methods as described in other documents by the authors of U.S. EPA documents (Berman and Chatfield, 1990; Berman and Crump, 1999a,b, 2001; Berman and Kolk, 2000). The exposure equation for asbestos is analogous to that recommended by U.S. EPA for other inhalation carcinogens. The exposure concentration is a function of the asbestos air concentration, the length of time an individual is exposed, and the averaging time for which carcinogenic effects are evaluated for the unit risk factor. The equation for a time-weighted exposure concentration in air used in performing an asbestos inhalation risk assessment is the same as for chemicals :

$$EC = \frac{C_{air} \times ET_o \times EF \times ED}{AT}$$

where:

EC = exposure concentration (f/cm^3)

C_{air} = air concentration of asbestos (f/cm^3)

ET_o = Exposure time outdoors onsite (hours/day)

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

AT = Averaging time (hours); based on 70 years (average lifetime) (AT_c)

As stated previously, potential exposure to asbestos in soil was evaluated for RZ-A as a whole (approximately 29 acres) and a subarea represented by the three sampling locations where long chrysotile fibers were detected (approximately 5.2 acres). For future onsite commercial workers, no other changes were made; however, for future onsite construction workers, the exposure duration was reduced from 1 year to 0.5 year, to reflect the smaller area over which construction is assumed to occur.

5.0 TOXICITY ASSESSMENT

Cancer oral slope factors (SFs), which are expressed in units of (mg/kg-day)$^{-1}$, or inhalation unit risk factors (URFs), which are expressed in units of (μg/m^3)$^{-1}$, are chemical-specific and experimentally derived potency values that are used to calculate the risk of cancer resulting from exposure to potentially carcinogenic chemicals. The SF and URF are defined as the 95% UCL of the probability of a carcinogenic response per unit daily intake or concentration of a chemical over 70 years. A higher value implies a more potent carcinogenic potential. Non-cancer oral reference doses (RfDs), which are expressed in units of mg/kg-day, and inhalation reference concentrations (RfCs), which are expressed in units of mg/m^3, are experimentally derived "no-effect" levels that are used to quantify the extent of toxic effects other than cancer due to exposure to chemicals. The RfD and RfC are intended to represent the dose or concentration of a chemical that is not expected to cause adverse health effects, assuming daily exposure over a lifetime, even in sensitive individuals, with a substantial margin of safety. With RfDs and RfCs, a lower value implies a more potent toxicant. These criteria are generally developed by U.S. EPA risk assessment work groups and are listed in the U.S. EPA risk assessment guidance documents and databases.

Table 12 presents the toxicity criteria used in this assessment based on the following hierarchy (based on U.S. EPA, 2003b), with the exception of asbestos, which is discussed separately below:

1. IRIS

2. U.S. EPA's Provisional Peer Reviewed Toxicity Values (PPRTVs)

3. National Center for Environmental Assessment (NCEA, or other current U.S. EPA sources)

4. Health Effects Assessment Summary Tables (HEAST)

5. U.S. EPA Criteria Documents (e.g., drinking-water criteria documents, drinking-water Health Advisory summaries, ambient water quality criteria documents, and air quality criteria documents)

6. ATSDR toxicological profiles

7. U.S. EPA's Environmental Criteria and Assessment Office (ECAO)

8. Peer-reviewed scientific literature

For carcinogens, the U.S. EPA weight-of-evidence classification is identified in the table for each carcinogenic COPC. As noted in Table 12, there are several instances where an oral RfD

was used as the basis for the inhalation RfC. Route-to-route extrapolation is generally inappropriate without adequate toxicological information (U.S. EPA, 2009a); however, route-to-route extrapolation was applied based on NDEP's approach to the derivation of BCLs (NDEP 2009a). The uncertainties associated with this approach are addressed in the uncertainty analysis (Section 6.4.7).

For carcinogenic polycyclic aromatic hydrocarbons (PAHs), provisional U.S. EPA guidance for estimating cancer risks was used (U.S. EPA, 1993). The procedure uses information from the scientific literature to estimate the carcinogenic potency of several PAHs relative to benzo(a)pyrene. These relative potencies are used to modify the SF developed for benzo(a)pyrene for each PAH. Further, U.S. EPA has not derived toxicity criteria to evaluate the potential non-cancer health hazards associated with exposure to the carcinogenic PAHs. Per the HRA Work Plan, a toxicological surrogate (i.e., pyrene) was used to quantify the potential non-carcinogenic effects of the carcinogenic PAHs. This surrogate was selected by NDEP consultants (NDEP, 2006) from a list of six PAHs for which non-cancer oral toxicity criteria have been assigned by the U.S. EPA, based on careful consideration of their relevant toxicity data, target organ(s), dose-response information, and structure-activity relationships. From the available oral non-cancer toxicity data reported by the U.S. EPA, the most sensitive target organs are the liver, kidney, and blood (hematological effects [IRIS], U.S. EPA, 2010; ATSDR, 1990, 1995; ORNL, 1993). For the carcinogenic PAHs, the non-cancer target organs were found to be the same, and the reported toxicological thresholds for these effects are generally in the range of those reported for the non-cancer PAHs (ATSDR, 1995). Although naphthalene (2-ring structure) has the most stringent oral non-cancer toxicity criterion (0.02 mg/kg day), pyrene (4-ring structure; oral RfD of 0.03 mg/kg-day) was selected to be the best surrogate, due to (1) non-cancer toxicity endpoints are more consistent with those for carcinogenic PAHs; and (2) the greater number of rings in the pyrene chemical structure (NDEP, 2006).

Asbestos risks were assessed in line with the approaches specified in NDEP's (2009h) *Technical Guidance for the Calculation of Asbestos-Related Risk in Soils for the BMI Complex and Common Areas.* The approach relies on exposure-response coefficients that describe the toxicity of different fiber lengths and types of asbestos. These risk coefficients are adopted from the draft, *Technical Support Documents for a Protocol to Assess Asbestos Related Risk* (U.S. EPA, 2003a). The majority of available information indicates that lung cancer and mesothelioma are the most important risks associated with low levels of asbestos (NDEP, 2009h; U.S. EPA, 2003a). Types and aspect ratios (relative length versus diameter) of asbestos fibers differ, and are known to affect the potency of the material; therefore, deriving conclusions regarding the health

effects related to asbestos exposure is complex. In the U.S. EPA draft document (U.S. EPA, 2003a), studies from environments with asbestos dusts of differing characteristics were reviewed to evaluate asbestos-related risks. U.S. EPA developed an optimal exposure index, which best reconciles the published literature. The index assigns equal potency to fibers longer than 10 µm and thinner than 0.4 µm, and assigns no potency to fibers of other dimensions. The optimal exposure index also assigns unique exposure-response coefficients for chrysotile and amphibole fibers for the endpoints of mesothelioma and lung cancer. Optimum dose-response coefficients, based on the body of available data, were assumed for this risk assessment. These coefficients are used to calculate the factor "R," which is defined as the "Estimated Additional Deaths from Lung Cancer or Mesothelioma per 100,000 persons from Constant Lifetime Exposure to 0.0001 TEM f/cc Longer than 10 µm and Thinner than 0.4 µm" (U.S. EPA, 2003a, Table 8-2 combined lung cancer and mesothelioma risk). This factor is calculated as follows (Equation 8-1 of U.S. EPA, 2003a):

$$R = 0.5\left(\left(0.786(NSM + NSF)\right) + \left(0.214(SM + SF)\right)\right)$$

Where:

NSM = risk for population of non-smoking males

NSF = risk for population of non-smoking females

SM = risk for population of smoking males

SF = risk for population of smoking females

"R" is calculated separately for long chrysotile and long amphibole fibers, reflecting the difference in potency between fiber types. Using the values for NSM, NSF, SM, and SF in Table 8.2 of U.S. EPA (2003a), "R" for chrysotile is 0.5693 and "R" for amphiboles is 63.206. "R" is then used to calculate the URF as follows:

$$URF = \frac{10^{-5}}{0.0001} \times R$$

$$= \frac{1}{10} \times R$$

The numerator, 10^{-5}, and the denominator, 0.0001, reflect that the values in Table 8-2 of U.S. EPA 2003a are based on a risk per 100,000 persons exposed to an asbestos air concentration of 0.0001 f/cc. The resulting URFs are 0.05693 for long chrysotile fibers and 6.3206 for long amphibole fibers. These values were used to estimate risks associated with exposure to asbestos in soil at the site (see Appendix D).

6.0 RISK CHARACTERIZATION

Risk characterization represents the final step in the risk assessment process. In this step, the results of the exposure and toxicity assessments are integrated into quantitative or qualitative estimates of potential health risks. Potential cancer risks and noncancer adverse health effects are characterized separately. In addition, potential cancer risks associated with exposure to asbestos are characterized separately for the other carcinogenic chemicals. This section also contains a qualitative discussion of the uncertainties associated with this assessment.

6.1 Evaluation of Potential Cancer Risks

Carcinogenic risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a given chemical at a given concentration. Carcinogenic risks for chemicals are evaluated by multiplying the estimated average exposure rate (i.e., LADD calculated in the exposure assessment) by the chemical's SF or the estimated average exposure concentration (i.e., EC calculated in the exposure assessment) by the chemical's URF. The SF or URF converts estimated LADDs or ECs averaged over a lifetime to incremental risk of an individual developing cancer. According to U.S. EPA (1989), this approach is appropriate for theoretical upper-bound incremental lifetime cancer risks of less than 1×10^{-2}. Lifetime chemical-specific risks and total Site risks are estimated as follows:

$$Risk_{oral\ or\ dermal} = LADD \times SF$$

where:

$$
\begin{aligned}
LADD &= \text{lifetime average daily dose (mg/kg-d)} \\
SF &= \text{cancer slope factor (mg/kg-d)}^{-1}
\end{aligned}
$$

$$Risk_{inhalation} = EC \times URF$$

where:

$$
\begin{aligned}
EC &= \text{exposure concentration } (\mu g/m^3) \\
URF &= \text{unit risk factor } (\mu g/m^3)^{-1}
\end{aligned}
$$

and

$$Total\ Site\ Risk = \sum Chemical\ Risk$$

The estimated excess cancer risks for each chemical and exposure route are summed, regardless of the type of cancer associated with each chemical, to estimate the total excess cancer risk for the exposed individual.

For most chemicals, the NDEP point of departure is a cumulative incremental cancer risk of 1×10^{-6} (NDEP, 2009a). U.S. EPA considers 1×10^{-6} to 1×10^{-4} to be the target range for acceptable risks at sites where remediation is considered (U.S. EPA, 1990). Estimates of lifetime excess cancer risk associated with exposure to chemicals of less than one-in-one-million (1×10^{-6}) are considered to be so low as to warrant no further investigation or analysis (U.S. EPA, 1990). It should be noted that cancer risks in the 1×10^{-6} to 1×10^{-4} range or higher do not necessarily mean that adverse health effects will be observed. Current methodology for estimating the carcinogenic potential of chemicals is believed to not underestimate the true risk, but could overestimate the true risk by a considerable degree, and the true risk could be as low as zero.

6.1.1 Indoor Commercial Worker

The estimated excess cancer risks associated with exposure of an indoor commercial worker to the COPCs in soil through incidental ingestion are summarized in Table 13, and the calculation spreadsheets are presented in Appendix D. For an indoor commercial worker, the excess cancer risk due to exposure to chemicals in soil is 1×10^{-7}. Hexachlorobenzene is the largest contributor to the overall risk. This value is below the lower end of the generally acceptable risk range, indicating that potential exposure to COPCs in soil by an indoor commercial worker should not pose an unacceptable carcinogenic health risk under the conditions evaluated.

6.1.2 Outdoor Commercial Worker

The estimated excess cancer risks associated with exposure of an outdoor commercial worker to the COPCs in soil through incidental ingestion, dermal absorption, and inhalation are summarized in Table 13, and the calculation spreadsheets are presented in Appendix D. For an outdoor commercial worker, the excess cancer risk due to exposure to chemicals in soil is 3×10^{-7}. Incidental soil ingestion and dermal contact with soil for hexachlorobenzene are the largest contributors to the overall risk; inhalation exposure is inconsequential. This value is below the lower end of the generally acceptable risk range, indicating that potential exposure to

COPCs in soil by an outdoor commercial worker should not pose an unacceptable carcinogenic health risk under the conditions evaluated.

6.1.3 Construction Worker

The estimated excess cancer risks associated with exposure of a construction worker to the COPCs in soil through incidental ingestion, dermal absorption, and inhalation are summarized in Table 14, and the calculation spreadsheets are presented in Appendix D. For a construction worker, the excess cancer risk due to exposure to chemicals in soil is 4×10^{-8}. Incidental soil ingestion and dermal contact with soil for hexachlorobenzene are the largest contributors to the overall risk; inhalation exposure is inconsequential. This value is below the lower end of the generally acceptable risk range, indicating that potential exposure to COPCs in soil by an outdoor commercial worker should not pose an unacceptable carcinogenic health risk under the conditions evaluated.

6.2 Evaluation of Non-Cancer Health Effects

Non-cancer adverse health effects are evaluated by comparing the estimated average exposure rate (i.e., ADDs or ECs estimated in the exposure assessment) with an exposure level at which no adverse health effects are expected to occur for a long period of exposure (i.e., the RfDs and RfCs). ADDs and RfDs are compared by dividing the ADD by the RfD to obtain the ADD:RfD ratio, as follows:

$$Hazard\ Quotient_{oral\ or\ dermal} = \frac{ADD}{RfD}$$

where:

ADD $=$ average daily dose (mg/kg-d)

RfD $=$ reference dose (mg/kg-d)

Similarly, ECs and RfCs are compared by dividing the EC by the RfC to obtain the EC/RfC ratio, as follows:

$$Hazard\ Quotient_{inhalation} = \frac{EC}{RfC}$$

where:

$$EC = \text{exposure concentration (mg/m}^3\text{)}$$

$$RfC = \text{reference concentration (mg/m}^3\text{)}$$

A hazard quotient less than or equal to 1 indicates that the predicted exposure to that chemical should not result in an adverse noncarcinogenic health effect (U.S. EPA, 1989). If more than one pathway is evaluated, the hazard quotients for each pathway, for all COPCs, are summed to determine whether exposure to a combination of pathways poses a health concern. This sum of the hazard quotients is known as a Hazard Index.

$$Hazard\ Index = \sum Hazard\ Quotients$$

The NDEP non-cancer risk management target is a hazard index (HI) value of less than or equal to 1.0 (NDEP, 2009a). It should be noted that HI or HQ values greater than 1 do not necessarily mean that adverse health effects will be observed, because a substantial margin of safety has been incorporated into many of the RfDs and RfCs.

6.2.1   Indoor Commercial Worker

The estimated noncancer hazard quotients and hazard indices associated with exposure of an indoor commercial worker to the COPCs in soil through incidental ingestion are summarized in Table 13, and the calculation spreadsheets are presented in Appendix D. The total hazard index due to exposure to chemicals in soil is 0.04, indicating that potential exposure of indoor commercial workers to COPCs in soil should not pose a potential noncarcinogenic health risk under the conditions evaluated. Iron and perchlorate are the largest contributors to the overall hazard index.

6.2.2   Outdoor Commercial Worker

The estimated noncancer hazard quotients and hazard indices associated with exposure of an outdoor commercial worker to the COPCs in soil through incidental ingestion, dermal absorption, and inhalation are summarized in Table 13, and the calculation spreadsheets are presented in Appendix D. The total hazard index due to exposure to chemicals in soil is 0.08, indicating that potential exposure of outdoor commercial workers to COPCs in soil should not pose a potential noncarcinogenic health risk under the conditions evaluated. Incidental soil ingestion of iron and perchlorate are the largest contributors to the overall hazard index.

6.2.3   Construction Worker

The estimated noncancer hazard quotients and hazard indices associated with exposure of a construction worker to the COPCs in soil through incidental ingestion, dermal absorption, and inhalation are summarized in Table 14, and the calculation spreadsheets are presented in Appendix D. The total hazard index due to exposure to chemicals in soil is 0.3, indicating that potential exposure of construction workers to COPCs in soil should not pose a potential noncarcinogenic health risk under the conditions evaluated. Incidental soil ingestion of iron and perchlorate are the largest contributors to the overall hazard index.

6.3   Asbestos

The equation used to estimate inhalation cancer risk for asbestos is as follows:

$$Risk_{inhalation} = EC \times URF$$

where:

EC =   exposure concentration (f/cm^3)

URF =   unit risk factor (f/ cm^3)$^{-1}$

As noted in NDEP's (2009h) risk assessment guidance, EC is a function of the asbestos air concentration, the length of exposure, and the averaging time. These latter two factors are combined into a "unit risk adjustment factor" (URF adjustment factor) in NDEP's "asbestos guidance risk calcs.xls" spreadsheet, which was used in this HRA. The estimated asbestos air concentrations (calculated as described in Section 4.1.3), URFs, URF adjustment factors, and risks for death from lung cancer or mesothelioma for asbestos exposures to outdoor commercial workers and construction workers are summarized in Table 15, and the calculation spreadsheets are presented in Appendix D.

The upper-bound estimated risks for death from lung cancer or mesothelioma for asbestos exposures to outdoor commercial workers are less than or equal to 1×10^{-6} for both RZ-A as a whole (1×10^{-8} for chrysotile and 1×10^{-7} for amphiboles) , and for the subarea represented by sample locations RSAT5-0.5B, RSAT6-0.5B, and RSAT7-0.5B (4×10^{-8} for chrysotile and 1×10^{-6} for amphiboles). For construction workers, the best estimate and upper-bound estimates range from 2×10^{-7} to 4×10^{-7} for chrysotile, and from zero to 1×10^{-5} for amphiboles for RZ-A as a whole, and from 5×10^{-7} to 1×10^{-6} for chrysotile and from zero to 6×10^{-5} for amphiboles for

RSAT5-0.5B, RSAT6-0.5B, and RSAT7-0.5B. It should be noted that the upper-bound risk estimates are based on an observed count of zero long amphibole structures in the 18 samples collected from RZ-A. It should also be noted that the unit risk factors used to estimate risks from asbestos exposure were intended to evaluate constant lifetime exposures, not short-term exposure such as construction activities (U.S. EPA, 2003a). Therefore, these results indicate that exposures to asbestos in soil in RZ-A should not result in unacceptable risks for all future on-Site receptors.

6.4 Uncertainty Analysis

Uncertainty is inherent in many aspects of the risk assessment process. Uncertainty generally arises from a lack of knowledge as well as variability of (1) site conditions and future site use; (2) toxicity and dose-response of the COPCs; and/or (3) the extent to which an individual may be exposed (if at all) to the chemicals. This lack of knowledge means that assumptions must be made based on information presented in the scientific literature or on professional judgment. Although some assumptions have significant scientific basis, many do not. The assumptions that introduce the greatest amount of uncertainty, and their effects on the findings of this HRA, are summarized in Table 16, and discussed further below. This discussion is qualitative in nature, reflecting the difficulty in quantifying the uncertainty in specific assumptions. In general, assumptions were selected in a manner that purposely biases the process toward health protection.

6.4.1 Uncertainty Associated with Site Characterization Data

Samples cannot be collected from every possible location; therefore, there is always some uncertainty associated with the representativeness of site characterization data. RZ-A is approximately 29 acres in size and contains two LOUs: LOU 62 (State Industries, Inc. site, including impoundments and catch basin) and LOU 59 (storm sewer system in Area IV). Soil samples were collected from 20 locations across the 29 acres; samples collected at 0.5–2.0 ft bgs and 10–11.5 ft bgs were included in this HRA. As presented in Table A-1 of Appendix A, the majority of sampling locations were targeted to the LOUs, and the remaining samples were placed randomly within 4-acre grids for area-wide coverage. Consistent with the CSM for RZ-A, and for the entire Tronox site as a whole, all (or nearly all) soil samples were analyzed for metals, radionuclides, perchlorate, cyanide, SVOCs, VOCs, and TPH. Samples from approximately one-half of the locations were analyzed for dioxins/furans and OCPs, and samples from fewer locations were analyzed for PCBs, OPPs, and OAs. Because most of the sampling locations were targeted, and samples from these locations were analyzed for chemicals

associated with historical operations at RZ-A or the entire Tronox site, the relative uncertainty in the site characterization data is considered to be low. This is true even for chemicals not analyzed in many samples (e.g., OPPs and OAs), because samples from across the Tronox site indicate that these chemicals are not prevalent at the site.

Soil samples were not generally collected from 0 to 0.5 ft bgs (except for asbestos). This is consistent with the CSM that chemicals are present in soil at the site as result of past industrial practices that resulted in released chemicals via spills, leaks or accidents rather than from aerial deposition. Given this CSM and the fact that commercial workers are assumed to have direct contact with soil from 0 to 2 ft bgs (U.S. EPA, 2002a; Northgate 2010a), the absence of data from the 0 to 0.5-ft interval is not expected to affect the conclusion of the HRA. Even for low mobility COPCs, the concentration in the 0 to 0.5-ft interval would have to be substantially higher to greatly affect the average concentration over the entire 0 to 2-ft interval (i.e., the 0 to 0.5-ft interval represents only 25% of the entire 0 to 2-ft interval to which the commercial worker is assumed to be exposed). Further, as noted in Section 6.4.4, the maximum concentration was used as the exposure point concentration, which is a highly conservative assumption because it is very unlikely that receptors will be exposed to the maximum concentration for all COPCs over an extended period of time. For construction workers, who are assumed to have direct contact with soil from 0 to 10 ft bgs, there is some additional uncertainty associated with the fact that samples were generally not collected from 2 to10 ft bgs and exposures were evaluated based on data generally collected from 0.5 to 2 ft bgs and from 10 to 11.5 ft bgs. While it is possible that the estimated risks to construction workers may be over- or underestimated, it is unlikely to be to such a degree as to affect the conclusions of the HRA.

6.4.2   *Uncertainty Associated with Data Usability/Data Evaluation*

For purposes of the Phase B Investigation, the site was divided into four areas, I, II, III, and IV. RZ-A is located within a portion of Area IV. Consistent with the investigation design, the DVSR was completed for the entirety of Area IV rather than for the subset of data within RZ-A. This is not expected to affect the results of the HRA. As discussed in Section 3.4, the results for OCPs from one sample were qualified as rejected (R) because the sample was analyzed greater than two times the method holding time. However, because this sample was collected 20 ft bgs for purposes of evaluating the potential for leaching to groundwater, these data are not applicable to this HRA. Further, a small percentage of the data were qualified as estimated. These data were considered usable for risk assessment purposes. A subset of these samples was qualified as estimated with a low bias. These data were further evaluated to assess the potential impact on the risk assessment results. Inclusion of these data is not expected to result in an underestimate

of the potential risks associated with residual chemicals in soil at the Site because, (1) the number of affected data points was very small relative to the entire data set, and (2) the maximum detected concentration was used as the EPC in the risk assessment calculations.

In addition, the majority of the samples in RZ-A were collected during Phase B; however, samples from one location (SA02) were collected during Phase A. As discussed previously, Phase A samples were analyzed for metals by Test America (St. Louis) and Phase B metals were analyzed by Columbia Analytical (Kelso). While both laboratories adhered to EPA Method 6020, NDEP has indicated that Test America used a 2% hydrochloric acid (HCl) digestion, whereas Columbia Analytical did not. NDEP has indicated that comparisons of the Phase A and Phase B results from across the Tronox site suggest that this difference in sample preparation results in slightly elevated results from the Test America (Phase A) analyses for certain metals, including arsenic, when compared to the Phase B data. Tronox is currently evaluating this issue with the appropriate laboratories. Because there are so few Phase A data in RZ-A relative to Phase B data, inclusion of both data sets is not expected to affect the results of the HRA. Finally, several common laboratory contaminants were detected at low concentrations in many of the samples analyzed for VOCs, although the DVSR did not identify wide-spread blank contamination. The presence of these chemicals in the samples is believed to be associated with field techniques, but is not expected to affect the results of the HRA because the detected concentrations are so low relative to health-based levels for these chemicals.

6.4.3   Uncertainty Associated with Selection of COPCs

Based on comparison to background, a total of 14 metals were identified as being above background. For the majority of these metals, there is no reason to believe they are related to historical Site activities, based on the CSM. No radionuclides were identified as being above background. In addition to the 14 metals, 35 additional chemicals were detected in at least one sample at RZ-A and were included in the COPC selection process. Of these 49 chemicals, 13 were identified as COPCs. For those chemicals that were not selected as COPCs, the maximum detected concentration was generally a factor of 10, if not a factor of 100 or more, lower than the NDEP commercial worker BCL; therefore, exclusion of these chemicals from the quantitative risk assessment may slightly underestimate the potential health risks posed by the site, but to such a small degree as to be inconsequential to the overall results of the HRA. Conversely, some metals may have been selected as COPCs, but may actually be within background. As discussed previously, the results of the background comparisons suggest that some metals and radionuclides are present at concentrations below the BRC/TIMET background data set for the McCollough Range. For some metals, differences between extraction methods may be partially

responsible for the observed difference; however, it is likely that differences in geology also contribute to observed differences. As such, some metals may have been identified incorrectly as being above "background" for RZ-A; however, this would not affect the conclusion of the HRA, because the maximum detected concentrations of these metals are low relative to risk-based levels.

6.4.4   Uncertainty Associated with Exposure-Point Concentrations

The maximum detected concentration was used as the EPC for all of the COPCs except asbestos. This assumption likely overestimates potential health risks, even considering that samples were not collected from 0 to 0.5 ft bgs, because receptors are unlikely to be exposed to the maximum concentration for all COPCs over an extended period of time. With regard to asbestos, two EPCs were calculated—a best estimate and an upper-bound estimate—for the site as a whole and for a subarea within RZ-A. For the site-wide estimates, the EPCs were based on the results from all 18 samples. No long amphibole fibers were counted in any of the samples; up to three long chrysotile fibers were counted in three samples. For the best estimate, the total number of long fibers is multiplied by the pooled analytical sensitivity for all of the samples. Because no long amphibole fibers were counted in any of the samples, the best estimate is zero. The upper bound of the asbestos bulk soil concentration is calculated as the 95% UCL of the Poisson distribution, where the mean equals the number of long structures detected. This value is then multiplied by the pooled analytical sensitivity to estimate the upper-bound concentration. The 95% UCL of the Poisson distribution for zero fibers counted is three fibers; therefore, for long amphibole fibers, the upper-bound EPC assumes that three long amphibole fibers are present, even though none were actually counted. Therefore, the potential risks associated with exposure to asbestos based on the upper-bound EPCs may be overestimated, particularly for long amphibole fibers.

6.4.5   Uncertainty Associated with Fate-and-Transport Modeling

The fate-and-transport modeling in this HRA is limited to estimating PEFs for construction workers and commercial workers. These values were estimated according to U.S. EPA guidance (2002a) based on a combination of site-specific and default input parameters. For most chemicals, inhalation of dust does not contribute significantly to the overall risk estimates, because exposure via ingestion and dermal contact is much higher; therefore, the uncertainty in this input parameter does not affect the conclusions of the HRA. However, for chemicals such as asbestos, which is evaluated as a carcinogen only through the inhalation route, the potential uncertainty in the PEF contributes substantially to the overall uncertainty in the risk estimate. This is particularly important for the construction worker scenario, because the estimated PEF is

large relative to non-construction scenarios. The PEF for construction accounts for several potential sources of dust, including excavating, tilling, and dumping; however, the largest contributor to the overall PEF is driving over unpaved roads. In this case, the majority of the input parameters are based on default values recommended by U.S. EPA (2002a). U.S. EPA provides the basis for most of these values, but not others, including the average weight of the vehicle (8 tonnes) and the number of vehicles that will drive across the area every day (30). The applicability of these and other assumptions to future construction at the Tronox site is unknown; however, it is believed that, in combination, these assumptions are more likely to overestimate, rather than underestimate, potential health risks, potentially to a significant degree.

6.4.6   Uncertainty Associated with Exposure Assessment

The exposure assessment in this HRA is based on a reasonable maximum exposure (RME) scenario, which is defined by EPA as the highest exposure that could reasonably be expected to occur for a given exposure pathway at a site (U.S. EPA, 1989). To achieve this goal, the RME scenario uses highly conservative exposure assumptions. For example, this HRA assumes that a future onsite commercial worker incidentally ingests 100 mg of site soil per day, 225 days per year, for 25 years. These and other upper-bound, default estimates of exposure most likely overestimate the potential health risks associated with the site. It should be noted, however, that the HRA was limited to direct contact with soil. The potential health risks associated with chemicals in soil vapor will be addressed separately for the Tronox site as a whole. Finally, it should be noted that potential health risks were not evaluated quantitatively for off-Site receptors. However, because (1) off-Site receptors would be exposed to lower concentrations than on-Site receptors; and (2) the estimated health risks for on-Site receptors are below levels of concern, potential health risks to off-Site receptors would also be below levels of concern.

6.4.7   Uncertainty Associated with Toxicity Assessment

One of the largest sources of uncertainty in any risk assessment is the limited understanding of toxicity to humans who are exposed to the low concentrations that are generally encountered in the environment. The majority of the available toxicity data are from animal studies; these data are extrapolated using mathematical models or multiple uncertainty factors to predict what might occur in humans. Sources of conservatism in the toxicity criteria used in this HRA include:

- The use of conservative methods and assumptions to extrapolate from high-dose animal studies to predict the possible response in humans at exposure levels far below those administered to animals;

- The assumption that chemicals considered to be carcinogens do not have thresholds (i.e., for all doses greater than zero, some risk is assumed to be present); and

- The fact that epidemiological studies (i.e., human exposure studies) are limited and are not generally considered in a quantitative manner in deriving toxicity values.

In aggregate, these assumptions lead to overestimates of risk, such that the actual risk is unlikely to be higher than the estimated risk, but could be considerably lower and, in fact, could be zero. Chemical-specific uncertainties in toxicity criteria are provided below for chemicals that contribute most to the estimated cancer risks (hexachlorobenzene) and HIs (perchlorate)[12] and asbestos, followed by a discussion regarding chemicals for which route-to-route extrapolations were assumed, surrogate criteria were used, or no criteria were available.

Hexachlorobenzene

The oral slope factor and inhalation unit risk factor for HCB are based on a 2-year chronic feeding study in rats (U.S. EPA, 2010). Significantly increased incidences of kidney and liver tumors were observed in treated animals, and the toxicity criteria were ultimately based on increased liver tumors in females. With regard to their confidence in these criteria, U.S. EPA concluded that significant increases in malignant tumors were observed among an adequate number of animals observed for their lifetime. Additionally, U.S. EPA calculated slope factors from a total of 14 different data sets encompassing 3 species, 4 studies and various endpoints. These values fell within a range of approximately one order of magnitude (U.S. EPA, 2010).

Perchlorate

The oral reference dose for perchlorate is based on a 14-day drinking water study of adult human volunteers (U.S. EPA, 2010). The critical effect from this study is radioactive iodide uptake inhibition in the thyroid. This is not considered to be an adverse effect; therefore, basing the oral RfD on this endpoint is more conservative approach than traditional hazard assessment. U.S. EPA applied an intraspecies uncertainty factor of 10 to the no-observed-effect level (NOEL) to account differences in sensitivity within the human population. U.S. EPA concluded their confidence in the oral RfD is high because it is based on a no-effect level for a well-

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[12] Iron also contributes significantly to the total HI; however, the toxicity criterion for iron is a Provisional Peer Reviewed Toxicity Value (PPRTV) as cited in NDEP's BCL table (NDEP, 2009a). The documentation for the PPRTVs is not readily available to the general public.

characterized precursor effect, accompanied by a 10-fold uncertainty factor for susceptible populations (U.S. EPA 2010).

Asbestos

The potential risk associated with exposure to long chrysotile fibers in soil was assessed based on methodology from U.S. EPA (2003a) as specified in NDEP's (2009h) asbestos risk assessment guidance. This methodology distinguishes between different fiber sizes (greater than 10 µm in length and less than 0.4 µm in width) and types (chrysotile and amphiboles). U.S. EPA (2003a) developed two sets of risk coefficients, one set is "optimized" based on the entirety of the available data and the other set is "conservative" based on a data from a single epidemiology study. Per NDEP (2009h) guidance, the optimized risk coefficients were used in this HRA. In addition, the risk coefficients are intended to assess long-term average exposure, such as on-site workers. Applying this methodology to short-term worker such as construction workers, as was done in this HRA, may result in additional uncertainty in the risk estimates (U.S. EPA 2003a).

Route-to-Route Extrapolation, Surrogate Criteria, and Missing Criteria

For two of the COPCs, hexachlorobenzene and iron, noncancer toxicity criteria have not been developed for the inhalation route of exposure. Per the HRA Work Plan (Northgate, 2010a), the oral toxicity criterion was used as a surrogate, although EPA no longer recommends such route-to-route extrapolation without adequate toxicological information (U.S. EPA, 2009a). Because the estimated noncancer hazard indices are well below a level of concern, this assumption does not affect the conclusions of the HRA. For all of the COPCs, the oral toxicity criteria were used to evaluate the dermal route of exposure, because no dermal-specific criteria have been developed. This route-to-route extrapolation may over- or underestimate the potential health risks associated with this route of exposure. Per the HRA Work Plan (Northgate, 2010a), the RfD for pyrene was used as a surrogate to evaluate the potential noncancer hazard associated with exposure to the carcinogenic PAHs. As before, because the estimated noncancer hazard indices are well below a level of concern, this assumption does not affect the conclusions of the HRA. Finally, toxicity criteria have not been developed for one COPC—octachlorostyrene. This chemical was detected in 3 of 44 samples at a maximum concentration of 0.025 mg/kg. Therefore, this chemical is unlikely to contribute substantially to the overall health risk.

6.4.8   Uncertainty Associated with Risk Characterization

The uncertainties associated with risk characterization are generally the result of the combined uncertainties in the site conditions, exposure assumptions, and toxicity criteria. In this HRA,

potential health risks were quantified for future construction workers and future onsite commercial workers associated with direct contact with soil. Given the highly conservative nature of the exposure parameters used to characterize this pathway, especially for the RME scenario, it is highly unlikely that the same receptor would be exposed at that level over the entire duration of exposure. These conservative estimates of exposure were then combined with even more conservative estimates of acceptable exposure (RfD or RfC) or carcinogenic potency (SF or URF) to estimate the magnitude (noncancer) or likelihood (cancer) of potential effects.

One source of uncertainty that is unique to risk characterization is the assumption that the total risk associated with exposure to multiple chemicals is equal to the sum of the individual risks for each chemical (i.e., the risks are additive). Other possible interactions include synergism, where the total risk is higher than the sum of the individual risks, and antagonism, where the total risk is lower than the sum of the individual risks. Relatively few data are available regarding potential chemical interactions following environmental exposure to chemical mixtures. Some studies have been carried out in rodents that were given simultaneous doses of multiple chemicals. The results of these studies indicated that no interactive effects were observed for mixtures of chemicals that affect different target organs (i.e., each chemical acted independently), whereas antagonism was observed for mixtures of chemicals that affect the same target organ, but by different mechanisms (Risk Commission, 1997).

While there are no data on chemical interactions in humans exposed to chemical mixtures at the dose levels typically observed in environmental exposures, animal studies suggest that synergistic effects will not occur at levels of exposure below their individual effect levels (Seed et al., 1995). As exposure levels approach the individual effect levels, a variety of interactions may occur, including additive, synergistic, and antagonistic interactions (Seed et al., 1995).

EPA guidance for risk assessment of chemical mixtures (U.S. EPA, 1986) recommends assuming an additive effect following exposure to multiple chemicals. Subsequent recommendations by other parties, such as the National Research Council (1988) and the Presidential/Congressional Commission on Risk Assessment and Risk Management (Risk Commission, 1997) have also advocated a default assumption of additivity. As currently practiced, risk assessments of chemical mixtures generally sum cancer risks regardless of tumor type, and sum non-cancer hazard indices regardless of toxic endpoint or mode of action. Given the available experimental data, this approach likely overestimates potential risks associated with simultaneous exposure to multiple chemicals. It should be noted that asbestos risks were evaluated separately from other chemical risks, consistent with the HRA work plan (Northgate, 2010a). These risk estimates are not additive because of differences in the basis for the

carcinogenic toxicity criteria. For chemicals, the SF and URF are defined as the 95% UCL of the probability of a carcinogenic **response** whereas the URFs for asbestos are based on the estimated number of additional **deaths** from lung cancer and mesothelioma.

In summary, these and other assumptions contribute to the overall uncertainty in the results of the HRA. However, given that the largest sources of uncertainty generally result in overestimates of exposure or risk, it is believed that the noncarcinogenic and carcinogenic risks presented in this HRA represent conservative estimates of the risks, if any, posed by residual chemicals at the site.

6.5   Data Quality Assessment

Data quality assessment (DQA) is an analysis that is performed after the risk assessment to determine whether enough data have been collected to support the risk-based decisions that are being supported by the risk assessment. Sample-size calculations were conducted for six analytes [asbestos (long chrysotile fibers), benzo(a)pyrene, HCB, perchlorate, iron, and boron]. The formula used for calculation of sample size is based on a non-parametric test (the Wilcoxon signed rank test), and on simulation studies performed by Pacific Northwest National Laboratories (PNNL, 2001). Essentially, the formula is the one that would be used if a normal-based test (such as a standard t-test) were being performed, but an adjustment is made (multiplier of 1.16) to account for the intent to perform a non-parametric test. The formula is as follows:

$$n = 1.16 \left[\frac{s^2}{\Delta^2} (z_{1-\alpha} + z_{1-\beta(\mu)})^2 + 0.5 z_{1-\alpha}^2 \right]$$

where:

n   =   number of samples

s   =   estimated standard deviation of concentrations/fibers

Δ =   width of the gray region (the difference between the threshold value stated in the null hypothesis and the point at which β is specified)

α =   significance level or Type I error tolerance

$\beta (\mu)$ =   Type II error tolerance

z   =   quantile from the standard normal distribution

For each chemical, inputs for the calculations include an estimate of the variance from the measured data, a desired significance level, and desired power of the test. The power of the test must be specified at a concentration of interest (which determines the tolerable difference from the threshold value), typically the NDEP BCL. The calculations provided in Table 17 cover a range of significance (α) and power ($1-\beta$) levels, including the most commonly used 0.05 significance level and 80% power. Table 17 shows the minimum sample size necessary to detect a 10%, 20% or 30% difference from the threshold value for each combination of significance and power level.

The results in Table 17 indicate that for all chemicals there is sufficient sample size to detect a 10% difference at a 0.05 significance level with 80% power ($1-\beta$). The available sample size (n=44) far exceeds the necessary sample size for all parameters except chrysotile asbestos. Chrysotile asbestos has sufficient sample size (n=18) to detect a change of less than 1 long fiber at the most commonly used significance and power levels.

7.0 CONCLUSIONS

The objective of the HRA was to evaluate the potential for adverse health impacts that may occur as a result of potential exposure to soil that contains residual concentrations of chemicals with the upper 10 feet of soil at RZ-A. No remediation is planned for this area; therefore, findings of this HRA are intended to support the site closure process.

Based on the CSM for RZ-A, potential exposure to soil was evaluated for future onsite indoor and outdoor commercial workers and future construction workers via direct contact with soil (i.e., incidental ingestion, dermal contact, and inhalation of dust). Potential exposure to residual chemicals in soil vapor and potential for leaching of chemicals to groundwater will be evaluated on a site-wide basis; therefore, these media were not evaluated in this report.

Soil data collected as part of the Phase B Site Investigation for Area IV, of which RZ-A is a part, was evaluated and considered useable for purposes of this HRA. COPCs were selected according to a multi-step process, including comparisons to background for metals and radionuclides, a toxicity screen, frequency of detection, and CSM considerations. Based on this process, seven carcinogenic PAHs, HCB, PCBs, perchlorate, boron, iron, and chrysotile asbestos were selected as COPCs. The results of the HRA can be summarized as follows:

- Noncancer hazard indexes and/or theoretical excess cancer risks associated with direct contact with soil were estimated for all of the COPCs except asbestos based on the maximum detected concentration. The estimated hazard indexes and excess cancer risks were below NDEP's point of departure for noncancer effects (hazard index of 1) and cancer risks (1×10^{-6}) for future onsite indoor and outdoor commercial workers and future construction workers under the conditions evaluated.

- With regard to asbestos, a best estimate and an upper-bound estimate were calculated. The estimated risks for death from lung cancer or mesothelioma for asbestos exposures to future onsite outdoor commercial workers and construction workers are less than or equal to 1×10^{-6} except for upper bound estimates of exposure to amphibole fibers by future construction workers. Importantly, these latter estimates are based on an observed count of zero amphibole fibers for all samples collected in RZ-A.

Therefore, the results of this HRA indicate that direct contact with residual chemicals in the upper 10 feet of soil in RZ-A should not result in unacceptable risks for all future on-Site receptors. The results of the data quality assessment indicate that a sufficient number of samples were collected in RZ-A to support the conclusions of this HRA. Potential exposure to residual chemicals in soil vapor and potential for leaching of chemicals to groundwater will be evaluated

on a site-wide basis, and an addendum to the RZ-A HRA will be prepared to complete the closure process for the RZ-A exposure unit.

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