# Health Risk Assessment Work Plan

## Tronox LLC Facility
## Henderson, Nevada

March 10, 2010

*Prepared For:*

Tronox LLC
560 W. Lake Mead Parkway
Henderson, Nevada 89015

*Prepared By:*

Northgate Environmental Management, Inc.
300 Frank H. Ogawa Plaza, Suite 510
Oakland, California 94612

*and*

Exponent, Inc.
500 12th Street, Suite 220
Oakland, CA 94607

| Renee Kalmes, M.S.P.H., C.I.H. | Gregory Brorby, DABT | Deni Chambers, C.E.G., C.Hg. |
|---|---|---|
| Risk Assessor | Risk Assessor | Principal Hydrogeologist |

**TABLE OF CONTENTS**

**TABLES**



**FIGURES**



**APPENDIX**

## ACRONYM LIST

| Acronym | Meaning |
|---|---|
| ADD | Average Daily Dose |
| BCA | Bias Corrected Accelerated |
| BCL | Basic Comparison Level |
| Bgs | Below Ground Surface |
| BIO | Relative Bioavailability |
| BRC | Basic Remediation Company |
| COPC | Chemical of Potential Concern |
| CSM | Conceptual Site Model |
| DQI | Data Quality Indicator |
| DQO | Data Quality Objective |
| DVSR | Data Validation Summary Report |
| EC | Exposure Concentration |
| ECAO | Environmental Criteria and Assessment Office |
| EDA | Exploratory Data Analysis |
| FOD | Frequency of Detection |
| GISdT® | Guided Interactive Statistical Decision Tool |
| HEAST | Health Effects Assessment Summary Tables |
| HI | Hazard Index |
| LADD | Lifetime Average Daily Dose |
| LBCL | Leaching Basic Comparison Level |
| LOU | Letter of Understanding |
| NCEA | National Center for Environmental Assessment |
| NDEP | Nevada Division of Environmental Protection |
| PARCC | Precision, Accuracy, Representativeness, Comparability, and Completeness |
| PCDD | Polychlorinated Dibenzodioxins |
| PCDF | Polychlorinated Dibenzofurans |
| PEF | Particulate Emission Factor |
| PPRTV | Provisional Peer Reviewed Toxicity Value |
| RC | Remediation Concentration |
| RfC | Reference Concentration |
| RfD | Reference Dose |
| SAR | Structure-Activity Relationship |
| SF | Slope Factor |
| SPLP | Synthetic Precipitation Leaching Procedure |
| SRC | Site-Related Chemical |
| TEF | Toxicity Equivalency Factor |
| TEQ | Toxicity Equivalency |
| UCL | Upper Confidence Limit |
| USEPA | U.S. Environmental Protection Agency |

## 1.0 INTRODUCTION

Tronox, LLC (Tronox) proposes to perform a human health risk assessment for the Tronox site (Site) after remediation is completed, with the status of completion to be based upon confirmatory field observations and laboratory analyses. By performing a risk assessment after remediation, environmental conditions will represent a baseline for post-remediation exposures and risks, at that time and into the future. This work plan is limited to describing the proposed methodology for conducting human health risk assessments. Because the future use of the site will remain as an active commercial/industrial facility, ecological habitat is not currently, or will not be in the future, sufficient to warrant an ecological risk assessment.

## 2.0 OBJECTIVES AND OVERVIEW

The objective of the human health risk assessment is to evaluate the potential for adverse human health impacts that may occur as a result of potential exposures to residual concentrations of chemicals in soil, groundwater, and other media of concern following remediation. Findings of the human health risk assessment are intended to support the site closure process.

This section describes the technical approach, guiding principles, and tasks that will be employed to complete the post-remediation human health risk assessment. Tronox's proposed risk assessment approach for the Site follows the basic procedures outlined in the U.S. Environmental Protection Agency's (USEPA's) *Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual* (USEPA 1989) and *Draft Risk Assessment Guidance for Superfund: Volume 3—Part A, Process for Conducting Probabilistic Risk Assessment* (USEPA 2001a). Other guidance documents consulted by Tronox in formulating the proposed risk assessment methodology include:

- Guidelines for Exposure Assessment. USEPA 1992a.
- Exposure Factors Handbook. USEPA 1997.
- Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment). USEPA 2004a.
- Soil Screening Guidance: User's Guide. USEPA 1996a.
- Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. USEPA 2002a.
- Soil Screening Guidance for Radionuclides. USEPA 2000a.
- Technical Support Document for a Protocol to Assess Asbestos-Related Risk. Final Draft. USEPA 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). USEPA 2009b.

This human health risk assessment methodology will be the primary tool used to guide discussions with the Nevada Division of Environmental Protection (NDEP) with regard to the content and level of detail of the human health risk assessment that is needed to support decision-making for the Site.

## 2.1 Human Health Protection

Tronox's goal is to remediate Site soils such that it can be documented that, under a future commercial/industrial land use scenario, there is no significant risk to human health. It should be noted that although ½-acre areas are the target for exposure, sampling might not occur on some of these ½-acre exposure areas. Instead, assumptions of similar concentration distributions across areas larger than ½-acre, as supported by the data, might allow risk assessment to be applied to larger areas, which will be the "decision units" for the risk assessment. A risk-based decision might hence be made simultaneously for many ½-acre exposure areas based on the data and documentation that the exposure areas can be aggregated.

The project-specific target risk levels and remediation goals are presented below.

## 2.2 Risk and Chemical-Specific Goals

1. Post-remediation chemical concentrations and radionuclide activities in Site soils will have a cumulative theoretical upper-bound incremental carcinogenic risk level point of departure of $10^{-6}$. For cases where NDEP concurs this goal to be unfeasible, it is Tronox's understanding that NDEP will re-evaluate the goal in accordance with USEPA guidance (USEPA 1991a, 1995). This point of departure risk goal will be evaluated separately for chemicals, asbestos, and radionuclides.

2. Post-remediation chemical concentrations in Site soils are targeted to have an associated cumulative, non-carcinogenic screening hazard index (HI) of 1.0 or less. If the screening HI is determined to be greater than 1.0, target organ-specific HIs may be calculated for primary and secondary organs. The final risk goal will be to achieve target organ-specific non-carcinogenic HIs of 1.0 or less.

3. The risk-based target goal for lead in soil is 800 mg/kg for industrial/commercial land use. This is based on the USEPA's Adult Lead Model using default input factors for an industrial/commercial worker (USEPA 1996b, NDEP 2009a).

4. Where background levels exceed risk-based levels (e.g., arsenic, radium, and thorium), Site soils are targeted to have risks no greater than those associated with background conditions.

5. Asbestos cancer risks are based on the estimated additional deaths from lung cancer or mesothelioma due to constant lifetime exposure. The risk-based point of departure for asbestos is $10^{-6}$. Risk from asbestos is evaluated separately from other chemicals and radionuclides.

6. The target goal for dioxin/furan toxicity equivalents (TEQ) for commercial and industrial land use is 1 part per billion (ppb). This value is based on the 1998 USEPA OSWER Directive with a modification to address identified uncertainties (10-fold uncertainty factor) regarding cancer potency in humans that results in a screening range of 0.5 to 2 ppb  A single value of 1 ppb was selected (NDEP 2009a).  Risks related to TEQs will only be quantitated and presented if residual concentrations exceed the target goal.  If risks are quantiatated the uncertainty analysis will explain (at a minimum) the portion of the risks that are related to non-detected congeners as well as the risks associated with the NDEP  1 ppb TEQ target goal.

## 3.0 THE HUMAN HEALTH RISK ASSESSMENT PROCESS

Pursuant to NAC 445A, and consistent with USEPA (2001a) and the National Academy of Science (1994) guidance, Tronox proposes to follow a "tiered," or iterative, approach. The tiered approach focuses risk assessments on specific objectives, such as identifying potential areas of concern that need further investigation and/or remediation, and eliminating from further consideration areas that do not pose a risk to human health or the environment.

The risk assessment process described herein consists of two tiers based on USEPA (2001a) guidance. The first tier of the risk assessment process is a deterministic risk assessment approach. The second tier applies a probabilistic risk assessment methodology. The deterministic risk assessment methodology is described in this section. Specific details regarding probabilistic risk assessment methodology will be described in a separate submittal to NDEP following the determination that a probabilistic risk assessment is warranted. This human health risk assessment work plan is a "living" document. As needed, descriptions of additional methodology will be submitted as supplemental components to this work plan.

### 3.1 Conceptual Site Model and Data Usability Evaluation

#### 3.1.1 Conceptual Site Model

The Conceptual Site Model (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. The site history, land uses, climate, physical attributes including geology and hydrogeology, and various field investigations will be fully described for the Site and where appropriate for individual areas-or sources.

##### *3.1.1.1 Sources and Release Mechanisms*

As described in several investigation work plans for the approximately 450-acre Tronox facility, there are at least 70 source areas on the Site, which is located within the Black Mountain Industrial (BMI) Complex in Clark County, Nevada. The Site location is shown in Figure 1. The source area investigations include a Phase A investigation (ENSR, 2006; ENSR 2007) which has already been conducted, and a Phase B investigation that is intended to further characterize soil and groundwater conditions across the Site (ENSR, 2008b; ENSR, 2008c; ENSR, 2008d; ENSR,

2008e). For the Phase B investigation activities, the Site has been subdivided into four areas: Areas I, II, III, and IV. The Phase B investigation does not include Parcels A through D, F, G, and H, which are being independently investigated by the Basic Remediation Company (BRC). Parcel E is land that is jointly used by Montrose Chemical and others, and has not yet been addressed. Investigations of Parcels I and J are being conducted independently from Tronox's Phase B activities, by the tenants of those properties. Phase B investigations are currently ongoing. Areas I, II, III and IV deal with soils. The HRA will include data collected as part of the Phase A and B investigations. It is Tronox's understanding that a full HRA report is not required for Parcel C, D F, G and H soil. Groundwater and vapor intrusion issues will be dealt with on a site-wide basis including the Parcels.

A CSM has been developed for the Tronox facility (formerly Kerr-McGee Facility) (ENSR, 2005). For risk assessment purposes, the following paragraphs provide supplemental information to the previous CSM based on information obtained from the Phase A investigation and subsequent development of the Phase B investigation work plans.

Separate investigation work plans have been prepared for each sub-area, as well as site-wide groundwater and soil gas/vapor intrusion work plans (ENSR 2008a; ENSR, 2008b; ENSR, 2008c; ENSR, 2008d; ENSR, 2008e). The four area-specific Phase B investigation work plans focus on the evaluation of potential source areas for the Site-related chemicals (SRCs). The potential source areas on the Tronox Site were identified in a letter of understanding (LOU) to NDEP dated August 15, 1994. Sixty-nine of the source areas have been designated as LOUs (i.e., LOU 1 through LOU 69). The 70th potential source area, identified as the former U.S. Vanadium site, has not been designated as an LOU.

Potential source areas on the Site are diverse and include but are not limited to: settling ponds, above and below-ground piping, acid drain system, leach plant and associated storage tanks and transfer lines, ammonium perchlorate plant and associated buildings, agricultural division plant, disposal piles, landfills, storm sewers, maintenance shop, cooling tower, transformers, and tailings areas. There are LOUs that contain conveyances that cross over into other sub-areas on the Site. These conveyances have the potential to transport SRCs across the Site.

Based on groundwater depth measurements conducted in May and December 2007, the depth to groundwater across the Site varies from about 27 to 80 feet below ground surface (bgs). It has been noted that groundwater is deepest in the southernmost portion of the Site.

Potential release mechanisms from above-ground source areas such as spills, leaks, or accidents could have released SRCs (e.g., volatile organics, semi-volatile organics, inorganics, pesticides, herbicides, radionuclides) 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 or underground storage tanks, may have released SRCs to the subsurface and subsequent migration 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 outdoor air or into buildings.

The individual Area-Specific Work Plans provide detailed descriptions of the individual LOUs, which include a description of likely related SRCs based on known source areas and the potential impacts to surface soil, subsurface soil, soil gas, and groundwater to identify the need for additional Phase B investigations.

#### *3.1.1.2 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 (USEPA 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 previously discussed, 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 (USEPA 2002a) located within the current Site boundaries. Other potential on-Site receptors, such as visitors or trespassers, do not warrant assessment. As discussed by USEPA (2002a), evaluation of exposures to members of the public under a non-residential land use scenario is not warranted for two reasons: (1) because public access is generally restricted at

industrial sites and (2) while the public may have access to commercial sites, onsite workers have a much higher exposure potential because they spend substantially more time at a site.

Current and future "off-Site receptors" are residential and worker receptors located outside the current Site boundaries who could be exposed to airborne chemicals emitted from the Site during short-term construction projects (USEPA, 2002a). Based on the relative difference in the on-Site construction particulate emission factor (which is on the order of $10^{+6}$ kg/m$^3$) and the off-Site receptor particulate emission factor during construction (which is on the order of $10^{+8}$ kg/m$^3$), 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 receptors. Additionally, perimeter air monitoring will be conducted during remediation and construction activities. Accordingly, off-Site receptors will not be quantitatively evaluated in post-remediation risk assessments and a discussion will be included to provide rationale for this decision, and the associated uncertainties will be included in the uncertainty assessment.

Figure 2 presents the primary exposure pathways for each of the potential receptors following remediation at the Site. These populations and complete/potentially complete exposure pathways for each of the receptors will be evaluated in the post-remediation risk assessments.

- Indoor commercial workers[1]
  - incidental soil ingestion*
  - external exposure from soil†
  - indoor inhalation of VOCs from soil and groundwater[2]
- Outdoor commercial/industrial workers
  - incidental soil ingestion*
  - external exposure from soil†
  - dermal contact with soil
  - outdoor inhalation of dust*‡

[1] In accordance with USEPA, 2002a, dermal absorption is not considered to be a complete exposure pathway for the indoor worker. Soil ingestion is identified by USEPA (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. (USEPA, 2002a, Exhibit 4-1)

[2] 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.

- outdoor inhalation of VOCs from soil and groundwater[3]**

- Construction workers
  - incidental soil ingestion*
  - external exposure from soil†
  - dermal contact with soil
  - outdoor inhalation of dust*‡
  - outdoor inhalation of VOCs from soil and groundwater

* Includes radionuclide exposures.

** Quantitatively evaluated only if warranted based on indoor exposures.

† Only radionuclide exposures.

‡ Includes asbestos exposures.

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. With regard to long-term inhalation of VOCs from soil and groundwater, this pathway will be quantitatively evaluated for the outdoor scenario only if indoor air modeling concentrations warrant further evaluation, since modeled indoor air concentrations will be greater than modeled outdoor air concentrations (see Section 3.3.3).

### 3.1.2 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 will be evaluated in accordance with the *Guidance for Data Usability in Risk Assessment (Parts A and B)* (USEPA 1992b,c) and the *NDEP Supplemental Guidance for Assessing Data Usability for Environmental Investigations at the BMI Facility in Henderson, NV* (NDEP, 2008a).

The USEPA 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. USEPA has established a specific guidance framework to provide risk assessors a consistent basis for making decisions about the minimum quality and quantity of environmental

[3] Pathway will be quantitatively evaluated only if estimated indoor air concentrations indicate the need.

analytical data that are sufficient to support risk assessment decisions (USEPA 1992b, c; NDEP 2008a). The USEPA 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 USEPA 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; and
- Data quality indicators (DQIs): precision, accuracy, representativeness, comparability, and completeness (PARCC).

In addition, a data adequacy evaluation will be conducted. The concept of data adequacy incorporates: (i) an analytical program that seeks to quantify all relevant Site chemicals that have the potential to affect risk calculations; and (ii) a spatial density of sampling points that provides confidence that the Site has been sufficiently characterized and that areas requiring remediation have not been missed. The risk assessment analytical program for the Site represents a broad suite of analyses that cover all chemicals that might be conceivably expected to be present at elevated levels at the Site as a result of historical operations on the Site or adjacent to the Site.

An evaluation of the adequacy of the sampling for use in risk assessment will be presented in the risk assessment report. The evaluation may incorporate the results from three analyses. The first qualitatively evaluates whether there are sufficient data available following the data usability evaluation to assess potential health risks for the media and locations identified in the CSM. The second analysis addresses data quality using traditional classical statistics-based process. The third analysis presents a probabilistic analysis of the data.

## 3.2 Selection of Chemicals of Potential Concern

Chemicals of Potential Concern (COPCs) will be selected for each medium and each decision unit evaluated. The broad suite of analytes used to evaluate the SRCs in the potential source areas is considered to be the current list of COPCs at the Site, based on site characterization conducted to

date. However, in order to ensure that the risk assessment focuses on those chemicals that contribute the greatest to the overall risk (USEPA 1989), three procedures will be used to identify COPCs for quantitative evaluation in the risk assessment:

- Identification of chemicals for which Site concentrations are greater than background concentrations (applicable to metals and radionuclides);
- Identification of chemicals that are frequently detected at the Site; and
- Identification of chemicals that exhibit known or potential hot spots.

Chemicals that are infrequently detected within an area will be discussed on a case-by-case basis with NDEP. A concentration-toxicity screen may also be employed to support COPC selection. NDEP's Basic Comparison Levels (BCLs; NDEP 2009a) may be used in this regard (i.e., when the maximum concentration within a decision unit does not exceed one-tenth of NDEP BCL, the chemical is a candidate for COPC elimination). One exception to this COPC screening procedure is for dioxin (TCDD toxicity equivalents). The target goal for dioxin for a commercial and industrial land use is 1 ppb. Accordingly, the criterion for eliminating dioxin as a COPC is 1 ppb.

The procedure for evaluating COPCs relative to background conditions is presented below. Additional steps of the COPC selection process are detailed in subsequent sections.

### 3.2.1 Evaluation of Site Concentrations Relative to Background Conditions

USEPA (1989, 1992b,c) guidance allows for the elimination of chemicals from further quantitative evaluation if detected levels are not elevated above naturally occurring levels. Typically, for purposes of selecting COPCs for risk assessment, COPCs are chemicals that are shown to be elevated above naturally occurring levels based on statistical analyses. Generally, this approach is applicable to metals and radionuclides, although USEPA identified other classes of chemicals for which background evaluations may be useful (USEPA 1989). For the purpose of selecting COPCs for each sub-area, exploratory data analysis (EDA) including summary statistics tables (*Guidance on the Development of Summary Statistics Tables for the BMI Plant Sites and Common Areas Projects, Henderson, Nevada, NDEP, 2008b*) and plots of the data, and appropriate statistical methods will be employed as the basis for decisions (USEPA 2002c). When the weight-of-evidence of the EDA and results of the statistical analyses indicate that a particular chemical is within background levels, then the chemical will not be identified as a COPC. For radionuclides, NDEP's *Guidance for Evaluating Radionuclide Data for the BMI Plant Sites and Common Areas Projects* (NDEP 2009b) should be adopted to assess secular equilibrium when performing background comparisons.

The comparison of site-related soil concentrations to background levels will be conducted using the existing soils background data sets presented in the *Background Shallow Soil Summary Report, BMI Complex and Common Area Vicinity* (BRC and TIMET 2007), which includes both the Environ (2003) dataset and the BRC/TIMET dataset collected in 2005, and the *Deep Background Summary Report, BMI Complex and Common Area Vicinity* (BRC, 2009 –). Appropriate subsets of these background data must be identified for comparison of Site and background data.

Exploratory data analysis will be performed using summary statistics and plots such as cumulative probability plots and side-by-side box-and-whisker plots to evaluate whether the Site and background data are representative of a single population. The plots give a visual indication of the similarities between the Site and background data sets, and are qualitatively used in the selection of COPCs. The plots and summary statistics are used in conjunction with the results of the statistical background comparison tests to determine, using a weight of evidence approach, which metals and radionucldies have Site concentrations that exceed background

Statistical background comparisons will be performed using the Quantile test, Slippage test, the *t*-test, and the Wilcoxon Rank Sum test with Gehan modification. The Quantile test, Slippage test, and Wilcoxon Rank Sum test are non-parametric. That is, the tests are distribution free; thus an assumption of whether the data are normally or lognormally distributed is not necessary. The computer statistical software program Guided Interactive Statistical Decision Tools (GiSdT®; Neptune and Company 2007) will be used to perform all statistical comparisons.

The Wilcoxon Rank Sum test performs a test for a difference between the sum 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 when 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.

The Quantile test addresses tail effects which 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 central tendency like the Wilcoxon Rank Sum test. The Quantile test will be performed using a defined quantile = 0.80.

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, if 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.

Typically an alpha = 0.05 is used to evaluate a statistically significant result. Since several correlated tests will be conducted, a lower alpha is selected. 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 is selected as a reasonable significance level for the COPC selection. Generally, any chemical that resulted in a *p*-value less than 0.025 in one of four tests will be retained as a COPC. Additionally, these tests are set up with one-sided hypotheses. Consequently, not only are differences between the two samples able to be detected, a directional determination can be made as well (e.g., Site is greater than background).

For radionuclides, if approximate secular equilibrium is exhibited in an isotope decay chain, then background comparisons will be performed to confirm if all the radionuclides in a decay chain are similar to background. If any of the radionculides are greater than background, then all the radionuclides will be carried forward in the risk assessment. If they are not greater than background, then they will not be identified as COPCs and will not be quantitatively evaluated in the risk assessment. If secular equilibrium is not exhibited, then background comparisons will be performed for each radionuclide separately and individual radionuclides will be selected as COPCs depending on the outcome of the background comparisons.

### 3.2.2 Further Selection of COPCs

The COPC selection criteria described in this section will be applied to metals and radionuclide COPCs that are present above background levels, and all other detected chemicals. Initially, as discussed above, the broad-suite analytes will be considered to be potential COPCs at the Site. From this list, a preliminary list of COPCs will be derived for purposes of risk assessment that includes chemicals that are (USEPA 1989):

- Positively identified in at least one sample in a given medium, including: (1) chemicals with no qualifiers attached (excluding non-detect results with unusually high detection limits, if warranted); and (2) chemicals with qualifiers attached that indicate known identities but estimated concentrations (e.g., J-qualified data);

- Detected at levels significantly elevated above levels of the same chemicals detected in associated blank samples. This protocol includes an analyte if it is not a common laboratory contaminant and its concentration is greater than five times the maximum amount detected in any blank; if the chemical is a common laboratory contaminant (as defined by USEPA 1989, 1992b), it is included only if its concentration is greater than 10 times the maximum amount detected in any blank;

- Tentatively identified but presumed to be present because of association with the Site based on historical information; and

- Transformation (e.g., degradation) products of chemicals demonstrated to be present.

The following criteria established by USEPA (1989) for further reducing the number of COPCs may also be considered:

Historical Information – Chemicals likely to be associated with site activities, based on historical information, will not be eliminated, even if the results of other "COPC reduction" steps indicate that such elimination is warranted.

Concentration and Toxicity – Aspects of concentration and toxicity will be considered prior to eliminating a chemical as a COPC. Specifically, if the maximum concentration within a decision unit does not exceed one-tenth of the chemical-specific BCL, the chemical will be a candidate for COPC elimination. One exception to this COPC screening procedure is for dioxin (TCDD toxicity equivalents). The target goal for dioxin for a commercial and industrial land use is 1 ppb. Accordingly, the criterion for eliminating dioxin as a COPC is 1 ppb. In general, Class A carcinogens will be retained as COPCs.

Availability of Toxicity Criteria – Some chemicals have not been assigned toxicity criteria. Prior to eliminating such chemicals, structure-activity relationship (SAR) analysis and applicability of surrogate toxicity values will be considered.

Mobility, Persistence and Bioaccumulation – Chemicals that are highly mobile, are persistent, or tend to bioaccumulate will generally be retained as COPCs.

Special Exposure Routes – For some chemicals under special site-specific scenarios, certain exposure routes need to be considered carefully before eliminating COPCs.

Treatability – Chemicals that are difficult to treat should remain as COPCs because of their importance during the selection of remedial alternatives if needed.

Documentation of Rationale – Rationale for the exclusion of any chemicals from the risk assessment will be documented in the risk assessment report.

Need for Further Reduction of COPCs – The need for further reduction of COPCs will be considered prior to applying additional COPC reduction criteria. It may be appropriate to narrow the number of COPCs included in fate and transport modeling by grouping COPCs with similar fate and transport properties (USEPA, 1989). That is, the modeled behavior of a given COPC will likely reflect that of other COPCs with similar properties. The selection of appropriate COPCs to be included in fate and transport modeling will be discussed with, and approval sought from, NDEP prior to modeling. A discussion of the COPCs that are not included in fate and transport modeling will be presented in the uncertainty section of the risk assessment report.

Frequency of detection (FOD) is another USEPA COPC selection criterion that may warrant further COPC reduction for chemicals not addressed by background comparisons. Chemicals exhibiting a low FOD within a specific exposure area or decision unit generally will not contribute significantly to risk and hazard estimates when hot spots are not present. USEPA (1989) suggests that chemicals with a FOD less than or equal to five percent, with the exception of metals and known human carcinogens, may be considered for elimination. Prior to eliminating a COPC based on the FOD criteria, (1) any elevated detection limits will be addressed; and (2) data distributions within decision units will be considered (e.g., potential hot spots will be assessed). Additionally, the detection of the COPC in all sampled media will be considered. For example, USEPA recommends that a chemical infrequently detected in soil should not be eliminated if it is frequently detected in groundwater and exhibits mobility in soil. As stated above, chemicals that are infrequently detected within an exposure area will be addressed on an exposure area-specific basis and will be discussed on a case-by-case basis with NDEP.

Approval by NDEP – NDEP approval will be sought prior to the elimination of any potential COPCs from the risk assessment.

### 3.2.3 Summary and Presentation of COPCs

For each exposure area, a summary of the site COPC data (i.e., chemical, range of concentration, background levels, FOD, retained/eliminated as COPC, and rationale for elimination) will be presented in table form. Summary statistics tables will be prepared that include (at a minimum) all items in NDEP's *Guidance on the Development of Summary Statistics Tables for the BMI Plant Sites and Common Areas Projects, Henderson, Nevada* (NDEP, 2008b).

## 3.3 Determination of Representative Exposure Concentrations

A representative exposure concentration is a COPC-specific and media-specific concentration value used in the dose equation for each receptor and each exposure pathway. As described below, the methods, rationale, and assumptions employed in deriving the representative exposure concentrations will be consistent with USEPA guidance and will reflect site-specific conditions.

### 3.3.1 Soil

The risk assessment will incorporate representative exposure concentration estimates (e.g., 95 percent upper confidence limit of the mean [UCL; USEPA 2002d; Neptune and Company 2009], as presented below) that specifically relate to potential site-specific human exposure conditions.

NDEP recommends that the approach for estimating a UCL of the mean follow the methods used in the computer statistical software program GiSdT® (Neptune and Company, 2007), or the stand alone software EnviroGiSdT (Neptune and Company, 2009), unless an alternative approach is needed to accommodate any special statistical considerations for a given site (e.g., spatial correlation structure, weighting). The methods presented in GiSdT and EnviroGiSdT are accompanied by a user's guide. GiSdT offers three methods. A normal based *t*-distribution method, a simple bootstrap, and a bias corrected accelerated (BCA) bootstrap. NDEP recommends using the highest of the UCLs from these three methods. If spatial correlations are of concern, then approaches involving kriging may be proposed. If data are not collected randomly, but are instead collected according to a weighted sampling scheme, then weighting methods may be proposed.

If the data are spatially uncorrelated for a particular COPC, the 95 percent UCL will be computed to represent the sub-area-wide exposure point concentration. Based on USEPA (1989) guidance and NDEP's recommendation, non-detects will generally be assigned a value of half the detection limit. In some cases (e.g., very few high detect values and mostly non-detect values), alternative methods for addressing censored data will be evaluated. For radionuclide data, the actual reported value will be used even if it is less than the minimum detectable activity. Data identified in the data usability evaluation as unusable due to elevated reporting limits will not be used in the calculation of representative exposure concentrations. In all instances, if the selected 95 percent UCL does not exceed the maximum value (including detects and detection limits), it will be selected as the exposure point concentration; otherwise, the maximum value will be used as the exposure point concentration.

Representative exposure concentrations for chemicals and radionuclides in soil will be based on the potential exposure depth interval for each of the receptors. For workers who are exposed to surface soils, data from the top two feet of soil will be used (USEPA 2002a). For construction workers and commercial/industrial receptors who may be exposed to contaminants in subsurface soils subsequent to intrusive activities, soil data from the surface to a depth as great as 10 feet bgs will be considered for use in calculating exposure concentrations. For external radiation exposures, data from the surface to 10 feet bgs will be used for all receptors.

Estimation of air exposure concentrations from soil data for asbestos will be evaluated using the methodology described in *Technical Guidance for the Calculation of Asbestos-Related Risk in Soils for the Basic Management Incorporated (BMI) Complex and Common Areas* (NDEP 2009d). This methodology is based on the protocols described in USEPA (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 fibers observed in a sample, multiplied by the analytical sensitivity of the measurement:

$$C_{soil} = f \times AS \quad (1)$$

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

$$Pooled\ AS = 1/\sum_{i-1}^{n} 1/AS_i \quad (2)$$

Two estimates of the asbestos concentration will be evaluated, best estimate and upper bound as defined in USEPA's draft methodology (USEPA 2003a) and NDEP (2009d). The best estimate concentration is similar to a central tendency estimate, while the upper bound concentration is comparable to a reasonable maximum exposure estimate. The calculation of pooled analytical sensitivity and estimation of asbestos air concentrations is discussed more fully in NDEP (2009d).

### 3.3.2 Outdoor and Indoor Dust

Long-term exposure to COPCs bound to dust particles will be evaluated using USEPA's Particulate Emission Factor (PEF) approach (USEPA 2002a). The PEF relates concentrations of a chemical in soil to the concentration of dust particles in the air. The Q/C (Site-Specific

Dispersion Factor [USEPA 2002a]) (see Table 1 and Appendix A) values in this equation will be for Las Vegas, Nevada (Appendix D of USEPA 2002a). The USEPA guidance for dust generated by construction activities (USEPA 2002a) will be used for short-term construction worker exposures (see Table 1). Input soil concentrations for the model will be the exposure point concentrations as described above.

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

Chemicals

$$C_{air} = C_{soil} \times CF_1 \times \left(\frac{1}{PEF}\right) \quad (3)$$

Asbestos

$$C_{air} = C_{soil} \times CF_2 \times \left(\frac{1}{PEF}\right) \times \left(\frac{1}{CF_3}\right) \quad (4)$$

Radionuclides

$$C_{air} = C_{soil} \times CF_2 \times \left(\frac{1}{PEF}\right) \quad (5)$$

where:

$C_{air}$ = air concentration ($\mu g/m^3$, $f/cm^3$, or $pCi/m^3$)

$CF_1$ = conversion factor ($\mu g/mg$)

$CF_2$ = conversion factor ($g/kg$)

$CF_3$ = conversion factor ($cm^3/m^3$)

PEF = particulate emission factor ($m^3/kg$)

For long-term indoor air exposure to COPCs bound to dust particles, an indoor air dust attenuation factor will be used to transfer outdoor air concentrations to indoor air concentrations (see Section 4.2.1). This will be applied to metals, radionuclides, non-volatile organic chemicals, and asbestos.

For exposures to VOCs, and volatile SVOCs, the soil gas measurements as described in the following section will be used and these chemicals will not be evaluated as particulates.

### 3.3.3 Indoor and Outdoor Vapors

Volatile constituents (VOCs and certain SVOCs[4]) in soil and groundwater may infiltrate buildings to be constructed at the Site through cracks in their foundations. Indoor air concentrations for these chemicals will be estimated using soil gas measurements collected at the Site (Soil Gas Data Validation Summary Report (DVSR) submitted to NDEP on October 13, 2008).

The USEPA implementation of the "Johnson and Ettinger model", hereafter referred to as the J&E model (USEPA, 2004b; Johnson and Ettinger, 1991), will be used with soil gas data to estimate exposure point concentrations for organic chemicals for the indoor air exposure pathway.

The J&E model incorporates both convective and diffusive mechanisms for estimating the transport of vapors emanating from subsurface media impacted by VOCs into indoor spaces. The major assumption/limitation of the J&E model is that the model is one-dimensional and transport is directed exclusively into the building. That is, vapors only migrate upward from the impacted subsurface media and into the building. Lateral deflection due to the presence of low permeability units or multi-dimensional diffusive transport that reduces the amount of VOC mass that may enter the indoor space is conservatively ignored (diffusion is, physically and mathematically, a three-dimensional process). Additionally, the model assumes that the vapors are at their peak concentration at the floor slab of the building, regardless of the actual depth below ground surface that the highest VOC concentration was detected.

Other assumptions/limitations of the J&E Model are as follows (USEPA, 2004b):

- Contaminant vapors enter the structure primarily through cracks and openings in the walls and foundation.

[4] VOCs are defined by USEPA as chemicals with a Henry's Law constant of 1 x 10-5 atm-m3/mole or greater and with a molecular weight of less than 200 g/mole (USEPA 1991b),

- Convective transport occurs primarily within the building zone of influence and vapor velocities decrease rapidly with increasing distance from the structure.
- Diffusion dominates vapor transport between the source of contamination and the building zone of influence.
- All vapors originating from below the building will enter the building unless the floors and walls are perfect barriers.
- All soil properties in any horizontal plane are homogenous.
- The contaminant is homogeneously distributed within the zone of contamination.
- The areal extent of contamination is greater than that of the building floor in contact with the soil.
- Vapor transport occurs in the absence of convective water movement within the soil column (i.e., evaporation or infiltration), and in the absence of mechanical dispersion.
- The model does not account for transformation processes (e.g., biodegradation, hydrolysis, etc.).
- The soil layer in contact with the structure floor and walls is isotropic with respect to permeability.
- Both the building ventilation rate and the difference in dynamic pressure between the interior of the structure and the soil surface are constant values.

Inputs to the J&E model include the chemical properties and soil gas concentrations of volatile COPCs, soil properties, and default building properties. The chemical properties are the default values coded into the J&E model as downloaded from the USEPA website (http://www.epa.gov/oswer/riskassessment/airmodel/johnson_ettinger.htm).

Site-specific parameters will be used when available. Default parameter values from ASTM (2000) for commercial buildings, where appropriate, will be used where site-specific data are unavailable.

The need to evaluate long-term exposure to volatile chemicals in outdoor air will be dependent on the results of in the indoor air evaluation, as modeled indoor air concentrations will be orders

of magnitude higher than modeled outdoor air concentrations. If evaluation of long-term outdoor air is warranted, concentrations will be determined by calculating a vapor flux based on the effective diffusion coefficient, soil gas measurements and the depth of the soil gas sample(s). The flux will be converted to an outdoor air concentration using the air dispersion factors (Q/C) developed by USEPA (2002a).

### 3.3.4 Groundwater

As previously discussed, incidental ingestion of or dermal contact with groundwater during construction activities is not considered a complete pathway due to groundwater depth. In addition, the Site will utilize institutional controls to insure that groundwater is not used. Based upon these two issues, groundwater will not be quantitatively evaluated.

## 3.4 Methodology for Evaluating Potential Impacts to Groundwater

The potential impacts of residual levels of COPCs in soil on groundwater quality will be evaluated using a tiered approach. Initially, soil concentration data will be evaluated by comparing to NDEP Leaching BCLs (LBCLs) which are based on a simple soil/water partitioning and groundwater dilution model provided in the USEPA's *Soil Screening Guidance* (USEPA 1996a). The model consists of a series of calculations used to determine COPC concentrations in groundwater that result from their presence in the unsaturated zone. The model simulates non-dispersive mass transport in soil from an infinite source. It assumes steady-state flow conditions, that all sources will infiltrate and desorb contaminants from the soil, and that the infiltrate will mix completely within the groundwater mixing zone directly beneath the Site, resulting in an equilibrium groundwater concentration. Following this evaluation the methods outlined in NDEP's January 16, 2010 *Soil to Groundwater Leaching Guidance* (NDEP, 2010) may be utilized. For example, results from synthetic precipitation leaching procedure (SPLP) will be used to supplement the migration to groundwater evaluation as this method is intended to provide a more realistic assessment of chemical mobility under actual field conditions (i.e, when it rains). The presence of chemicals in groundwater will also be considered. If the results of the screening-level evaluation indicate the potential for future groundwater concentrations to exceed applicable environmental- and health-based standards (e.g., MCLs, NDEP residential water comparison levels), a decision will be made to: (1) proceed with additional vadose zone modeling utilizing more refined modeling tools (e.g., SESOIL or VLEACH vertical migration modeling, development of site-specific dilution factors based on SPLP data; (2) re-evaluate the risk goal in accordance with USEPA guidance; or (3) perform additional soil removal and sampling. Results of this evaluation will also be combined with existing groundwater

concentrations to evaluate whether post-remediation COPC concentrations in soil (if any) could potentially impact groundwater to a cumulative extent greater than applicable standards, or – if existing groundwater concentrations are already above these standards – to determine the incremental increase in concentrations.

## 4.0 TIERED HUMAN HEALTH RISK ASSESSMENT APPROACH

A tiered approach is proposed for the post-remediation risk assessment. The tiered, or iterative approach for the risk assessments follows the USEPA recommendations (USEPA 2001a). The tiered risk assessment approach is applicable for all COPCs, with the exception of lead, as a site-specific remediation goal has been established for lead.

### 4.1 Deterministic Human Health Risk Assessment Methodology

The deterministic risk assessment will follow procedures outlined in the USEPA's *Risk Assessment Guidance for Superfund: Volume I – Human Health Evaluation Manual* (USEPA 1989). Other guidance documents that will be relied on include:

- *Guidelines for Exposure Assessment*. USEPA 1992a.
- *Soil Screening Guidance: Technical Background Document*. USEPA 1996.
- *Exposure Factors Handbook, Volumes I-III*. USEPA 1997.
- *Soil Screening Guidance for Radionuclides.* USEPA 2000a.
- *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*. USEPA 2002a.
- *Technical Support Document for a Protocol to Assess Asbestos-Related Risk. Final Draft.* USEPA 2003a.
- *Child-Specific Exposure Factors Handbook*. USEPA 2006.
- *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment).* USEPA 2009b.
- *Nevada Administrative Code Chapter NAC 445A. Adopted Permanent Regulation of the Nevada State Environmental Commission. LCB File No. R119-96.* NDEP 1996.

Various NDEP guidance documents will also be relied on for the risk assessment (as referenced throughout this Section). In addition, NDEP's BCLs (NDEP 2009a) will be used for comparison of site characterization data to provide for an initial screening evaluation, to assist in the evaluation of data usability, determination of extent of contamination, and initial identification of target remediation goals.

## 4.2 Deterministic Exposure Parameters

The exposure parameters proposed to be used in the deterministic risk assessment are presented in Tables 2 and 3. These generally conservative default values are based on standard USEPA guidance values. Exposure parameters that have significant impact on the results will be discussed in the uncertainty section of the risk assessment.

### 4.2.1 Deterministic Exposure Assessment

Reasonable maximum exposure levels to chemicals will be calculated for each receptor of concern, using the default exposure parameters identified in Tables 2 and 3. A central tendency estimate may also be calculated. As appropriate, site-specific modifications to the default exposure parameters values may be incorporated. The methodology used to estimate the average daily dose (ADD) of the chemicals via each of the complete exposure pathways will be based on USEPA (1989, 1992a) guidance. For chemical carcinogens, lifetime ADD (LADD) estimates are based on chronic lifetime exposure extrapolated over the estimated average 70-year lifetime (USEPA 1989). This is performed in order to be consistent with cancer slope factors, which are based on chronic lifetime exposures. For non-carcinogens, ADD estimates will be averaged over the estimated exposure period. The exposure pathway-specific dose equations are presented below for chemicals, radionuclides, and asbestos.

**Chemicals**

Soil Ingestion:

$$Dose = \frac{C_{soil} \times IR \times CF_4 \times EF \times ED \times BIO}{BW \times AT \times 365\ d/yr} \quad (6)$$

where:

Dose = ADD for non-carcinogens and LADD for carcinogens (mg/kg-day)

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

IR = 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 (years); same as the ED for non-carcinogens ($AT_{nc)}$ and 70 years (average lifetime) for carcinogens ($AT_c$)

With the exception of arsenic (and possibly dioxin/furan TEQs; see below), a relative oral bioavailability (BIO) of 100 percent will be used for all COPCs. Consistent with scientific literature recommendations on arsenic bioavailability (Roberts *et al*. 2001; Ruby *et al*. 1999; USEPA 2001b), an arsenic oral bioavailability of 25 percent will be used. The actual oral bioavailability of arsenic (as well as other metals at the site, for which an oral bioavailability of 100 percent) is likely to be lower than this value.

In regard to dioxin/furan TEQs, Tronox recently submitted a memorandum entitled "Justification for Using an Adjustment Factor for Dioxin Bioavailability in Soil" (Northgate February 2, 2010). Although this memorandum was rejected, further discussions with NDEP led to the development of a protocol for conducting site-specific bioaccessibility testing for dioxin/furans. This protocol was submitted to NDEP (Northgate February 11, 2010), and subsequently revised based on NDEP comments (Northgate February 19, 2010). The revised protocol was accepted by NDEP.

Dermal Contact:

$$Dose = \frac{C_{soil} \times CF_4 \times SA \times AF \times ABS \times EF \times ED}{BW \times AT \times 365\ d/yr} \quad (7)$$

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 = exposure factor (events/year)

ED = exposure duration (years)

BW = body weight (kilograms)

AT = averaging time (years); same as the ED for non-carcinogens ($AT_{nc}$) and 70 years (average lifetime) for carcinogens ($AT_c$)

Chemical-specific dermal absorption values from USEPA guidance (USEPA 2004a [Part E RAGS]) will be used in the risk assessments. USEPA does not recommend absorption factors for VOCs based on the rationale that VOCs are volatilized from the soil on skin and exposure is accounted for via inhalation routes (USEPA 2004a).

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* (USEPA 2009b). The equation for inhalation for outdoor workers and construction workers is:

$$EC = \frac{C_{air-outdoor} \times ET_o \times EF \times ED}{AT} \quad (8)$$

where:

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

$C_{air\text{-}outdoor}$ = concentration of contaminant in outdoor air ($\mu g/m^3$)

$ET_o$ = exposure time outdoors onsite (hr/day)

EF = exposure frequency (days/yr)

ED = exposure duration (year)

AT = averaging time (hours); based on ED for non-carcinogens ($AT_{nc}$) and 70 years (average lifetime) for carcinogens ($AT_c$)

The equation for inhalation for indoor workers is:

$$EC = \frac{[(C_{air-indoor} \times ET_i) + (C_{air-outdoor} \times ET_o \times DF)] \times EF \times ED}{AT} \quad (9)$$

where:

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

$C_{air\text{-}indoor}$ = concentration of contaminant in indoor air (applies to volatile COPCs only) ($\mu g/m^3$)

$ET_i$ = exposure time indoors onsite (hr/day)

$C_{air\text{-}outdoor}$ = concentration of contaminant in outdoor air ($\mu g/m^3$)

$ET_o$ = exposure time outdoors onsite (hr/day)

DF = dilution factor for outdoor to indoor air (unitless)

EF = exposure frequency (day/yr)

ED = exposure duration (years)

AT = averaging time (hours); based on ED for non-carcinogens ($AT_{nc}$) and 70 years (average lifetime) for carcinogens ($AT_c$)

**Radionuclides**

Instead of chemical mass, radionuclide activity (e.g., pCi) is used to quantify the amount of a radionuclide in an environmental medium. The pathway-specific intake equations for radiation cancer risk are presented below.

Soil Ingestion:

$$Intake = C_{soil} \times CF_5 \times IR \times EF \times ED \quad (10)$$

where:

Intake = radionuclide intake from soil ingestion (pCi)

$CF_5$ = conversion factor (g/mg)

$C_{soil}$ = activity concentration of radionuclide in soil (pCi/g)

IR = soil ingestion rate (mg/day)

EF = exposure frequency (days/year)

ED = exposure duration (years).

Inhalation:

The equation for inhalation for outdoor workers and construction workers is:

$$Intake = C_{air-outdoor} \times InhR \times ET_o \times EF \times ED \quad (11)$$

where:

Intake = radionuclide intake from inhalation (pCi)

$C_{air\text{-}outdoor}$ = concentration of radionuclide in outdoor air (pCi/$m^3$)

InhR = inhalation rate ($m^3$/hr)

$ET_o$ = exposure time outdoors onsite (hr/day)

EF = exposure frequency (day/yr)

ED = exposure duration (years)

The equation for inhalation for indoor workers is:

$$Intake = C_{air-outdoor} \times DF \times InhR \times ET_i \times EF \times ED \quad (12)$$

where:

Intake = radionuclide intake from inhalation (pCi)

$C_{a\text{-}outdoor}$ = concentration of radionuclide in outdoor air (pCi/$m^3$)

DF = dilution factor for outdoor indoor air factor (unitless)

InhR = inhalation rate ($m^3$/hr)

$ET_i$ = exposure time indoors onsite (hr/day)

EF = exposure frequency (day/yr)

ED = exposure duration (years)

External Radiation

The external dose for radionuclide exposure will be calculated using the following equation (adapted from USEPA 2000a):

$$Dose = C_{soil} \times [EF/CF_{DY}] \times ED \times ACF \times [ET_o/CF_{HD} + (ET_i/CF_{HD} \times GSF)] \quad (13)$$

where:

Dose = exposure from external radiation (pCi-yr/g)

$C_{soil}$ = exposure concentration term for soil (pCi/g)

$EF$ = exposure frequency (days/year)

$CF_{DY}$ = conversion factor (days/year)

$ED$ = exposure duration (years)

$ACF$ = area correction factor (unitless)

$ET_o$ = exposure time outdoors onsite (unitless)

$CF_{HD}$ = conversion factor (hours/day)

$ET_i$ = exposure time indoors onsite (unitless)

$GSF$ = gamma shielding factor (unitless).

The USEPA model for external radiation assumes that an individual is continually exposed to a non-depleting radiological source that is effectively an infinite slab. The concept of an infinite slab means that the thickness of the contaminated zone and its aerial extent are so large that it behaves as if it were infinite in its physical dimensions. Source areas contaminated to a depth greater than 15 cm with an aerial extent greater than 1,000 $m^2$ will create a radiation field comparable to an infinite slab (USEPA 2000). The area correction factor (ACF) adjusts for smaller source areas. USEPA has derived ACFs for various source area sizes, ranging from 10 to 10,000 $m^2$ (USEPA 2009b). These will be used to assess radiological risks at various site assessment areas at the Site.

The gamma shielding factor (GSF) is a factor that accounts for the shielding effect provided by buildings during times of indoor occupancy or by other site features.

**Asbestos**

Exposure to asbestos fibers in air will be evaluated using the methodology described in NDEP (2009d). The NDEP asbestos risk assessment guidance is based on methods for assessing asbestos risk described in USEPA (2003a), and also associated examples of the implementation of these methods as described in other documents by the authors of USEPA 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 USEPA 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 (Equation 14):

$$EC = \frac{C_{air} \times [ET_o + (ET_i \times DF)] \times EF \times ED}{AT} \quad (14)$$

where:

EC = exposure concentration (fibers/cm$^3$)

$C_a$ = air concentration of asbestos (fibers/cm$^3$)

$ET_o$ = Exposure time outdoors onsite (hours/day)

$ET_i$ = Exposure time indoors onsite (hours/day)

DF = dilution factor for outdoor to indoor air (unitless)

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

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

**Exposure Assessment Results**

Exposure levels of potentially carcinogenic and non-carcinogenic chemicals will be calculated separately because different input parameters apply (i.e., ADD for non-carcinogens and LADD for carcinogens). Exposure levels will be estimated for each relevant exposure pathway (i.e., soil, and air), and for each exposure route (i.e., oral, inhalation, and dermal). Daily doses for the same route of exposure will be summed. The total dose of each chemical is the sum of doses across all applicable exposure routes.

The results of the exposure assessment will be used with information on the toxicity of the COPCs in the risk characterization step of the risk assessment to estimate the potential risks to human health posed by exposure to the COPCs.

### 4.2.2 Determination Whether to Proceed to a Probabilistic Risk Assessment

The decision of whether the deterministic risk assessment results indicate that final Site conditions are protective of human health and the environment will be made based on the non-cancer HI and incremental lifetime cancer risk (separately for chemicals, radionuclides, and asbestos) characterized in the deterministic risk assessment as follows:

- If both the non-cancer HI and the total Site cancer risks are below their respective acceptable levels (i.e., a target organ HI of 1.0 and a cancer risk point of departure (i.e., 10-6), and no hot spots are determined to exist, it will be concluded that probabilistic risk assessment will not be warranted.

- If either the non-cancer HI or the total Site cancer risk is above their respective target levels, a decision will be made to: (1) re-evaluate the risk goal in accordance with USEPA guidance, (2) proceed to a probabilistic risk assessment or (3) evaluate the feasibility of additional soil removal.

In order to assist in the decision to proceed to a probabilistic risk assessment, a quantitative sensitivity analysis may be performed if Tronox considers that performance of a probabilistic risk assessment may be warranted. The final determination of whether a probabilistic risk assessment is warranted will be made by the NDEP based on critical information provided by Tronox. If a probabilistic risk assessment is conducted for a particular exposure area, all chemicals will be included (i.e., no further reduction of COPCs will be conducted).

## 4.3 Probabilistic Human Health Risk Assessment Methodology

The probabilistic risk assessment will follow the procedures outlined in USEPA guidance (1989 and 2001a). It should be noted that the use of probabilistic risk assessment methodology is intended to more explicitly identify and quantify the uncertainty and variability that can be expected in the exposure assessment, and consequently, the risks associated with these exposures. As discussed above, specific details regarding proposed probabilistic risk assessment methodology will be described in a separate submittal to NDEP.

## 5.0 TOXICITY ASSESSMENT

This section identifies how toxicity values to be used for the risk assessment will be obtained. Toxicity values are published by the USEPA in the on-line Integrated Risk Information System (IRIS; USEPA 2009a). Cancer oral slope factors (SFs), which are expressed in units of $(mg/kg\text{-}day)^{-1}$, or inhalation unit risk factors (URFs), which are expressed in units of $(\mu g/m^3)^{-1}$, are chemical-specific and experimentally derived potency values that are used to calculate the risk of cancer resulting from exposure to potentially carcinogenic chemicals. 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 used to quantify the extent of toxic effects other than cancer due to exposure to chemicals. With RfDs and RfCs, a lower value implies a more potent toxicant. These criteria are generally developed by USEPA risk assessment work groups and listed in the USEPA risk assessment guidance documents and databases. Toxicity criteria will not be developed *de novo* by Tronox for elements or compounds that do not have criteria published in IRIS or other sources outlined below. Should COPCs be found which do not have established toxicity criteria, these will be discussed on a case-by-case basis with NDEP and qualitatively addressed in the uncertainty analysis of the risk assessment report. Where appropriate, and only as approved by NDEP, non-carcinogenic surrogate RfDs or RfCs may be applied.

Like any biological reaction, the toxicity of a chemical on humans can be described as a range of possible outcomes (severities and levels that cause an endpoint of concern). The uncertainty in the toxicity outcomes or values is an important source of uncertainty in most risk assessments and would be an appropriate parameter to be modeled probabilistically. However, for the purposes of both the deterministic and probabilistic assessments, the toxicity values used will be point estimates (deterministic). Available toxicity values for all Site COPCs to be used in the risk assessment will be obtained from the USEPA. The following hierarchy for selecting chemical toxicity criteria will be used (based on USEPA 2003b):

1. IRIS
2. USEPA's Provisional Peer Reviewed Toxicity Values (PPRTVs)
3. National Center for Environmental Assessment (NCEA, or other current USEPA sources)
4. Health Effects Assessment Summary Tables (HEAST)

5. USEPA 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. USEPA's Environmental Criteria and Assessment Office (ECAO)

8. Peer-reviewed scientific literature

For carcinogens, the USEPA weight-of-evidence classification will be identified for each carcinogenic COPC. Available RfDs will be obtained for all COPCs, including carcinogens. A list of COPC-specific non-carcinogenic and carcinogenic toxicity criteria, current at the time of the post-remediation risk assessment, will be submitted to NDEP for approval prior to initiation of the risk assessment. Radionuclides toxicity criteria originally published in the *Health Effects Assessment Summary Tables* for radionuclides will be obtained from the USEPA's *Preliminary Remediation Goals for Radionuclides* (USEPA 2007). For some radionuclides, two different toxicity criteria are available: for that radionuclide only, and for the radionuclide and associated short-lived radioactive decay products (i.e., those decay products with radioactive half-lives less than or equal to six months).The toxicity criteria that include radioactive decay products (labeled as "+D" in USEPA (2007) will be used.

Although route-to-route extrapolation is generally inappropriate without adequate toxicological information, route-to-route extrapolation will be applied based on NDEP's approach applied in the derivation of the BCLs (NDEP 2009a). The uncertainties associated with this approach will be addressed in the risk assessment report.

Although USEPA has developed toxicity criteria for the oral and inhalation routes of exposure, it has not developed toxicity criteria for the dermal route of exposure. Typically, a simple route-to-route (oral-to-dermal) extrapolation is assumed such that the available oral toxicity criteria are used to quantify potential systemic effects associated with dermal exposure. However, as noted in USEPA's *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment;* (USEPA 2004a), there is uncertainty associated with this approach because the oral toxicity criteria are based on an administered dose and not an absorbed dose. In general, USEPA (2004a) recommends an adjustment to the oral toxicity criteria to convert an administered dose into an absorbed dose. The adjustment accounts for the absorption efficiency of the chemical in the "critical study" that is the basis of the oral toxicity criterion. If the oral absorption in the critical study is 100 percent,

then the absorbed dose is equivalent to the administered dose and no adjustment is necessary. If the oral absorption of a chemical in the critical study is poor (less than 50 percent), then the absorbed dose is much smaller than the administered dose. In this situation, an adjustment to the oral toxicity criteria is recommended (USEPA, 1989).

For the dioxins/furans, the USEPA toxicity equivalency procedure, developed to describe the cumulative toxicity of these compounds, will be 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 TEQ of a mixture involves multiplying the concentration of individual congeners by their respective TEF. One-half the detection limit will be used for calculating the TEQ 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 will be used to evaluate the 17 chlorinated dibenzo-p-dioxins and chlorinated dibenzofurans. In addition, the WHO 2005 TEF values will be 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).

For carcinogenic PAHs, provisional USEPA guidance for estimating cancer risks will be used (USEPA 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 may be used to modify the SF developed for benzo(a)pyrene for each PAH, or to calculate benzo(a)pyrene equivalent concentrations for each of the PAHs (which would then be used with the benzo(a)pyrene SF). The former approach will be used in the risk assessment. If one carcinogenic PAH is considered a COPC then all seven carcinogenic PAHs will be considered COPCs, regardless of whether or not they are detected at the Site. Although route-to-route extrapolation is inappropriate without adequate toxicological information, route-to-route extrapolation will be applied based on USEPA's approach.

USEPA has not derived toxicity criteria to evaluate the potential non-cancer health hazards associated with exposure to the carcinogenic PAH COPCs. For the human health risk assessment, a toxicological surrogate (i.e., pyrene) will be used to quantify the potential non-carcinogenic effects of the carcinogenic PAHs. This surrogate was selected from a list of six PAHs for which non-cancer oral toxicity criteria have been assigned by the USEPA based on a 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 USEPA, the most sensitive target organs are the liver, kidney, and blood (hematological effects [IRIS], USEPA 2009a; 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 for 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.

The National Research Council of the National Academies published its technical review of the *Health Implications of Perchlorate Ingestion* in January 2005. From this review USEPA has established a final RfD of 0.0007 mg/kg-day, which is currently contained in the IRIS database (USEPA 2009a). This value will be employed in the risk assessment unless IRIS is updated prior to completion of the risk assessment.

Asbestos risks will be assessed in line with the approaches specified in NDEP's (2009d) *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* (USEPA 2003c). The majority of available information indicates that lung cancer and mesothelioma are the most important risks associated with low levels of asbestos (NDEP 2009d, USEPA 2003c). 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 USEPA draft document (USEPA 2003c) studies from environments with asbestos dusts of differing characteristics were reviewed to evaluate asbestos related risks. USEPA 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 will be assumed for this risk assessment. The coefficients are presented in NDEP 2009d; USEPA 2003c)

## 6.0 RISK CHARACTERIZATION

In the last step of a risk assessment, the estimated rate at which a person intakes a COPC is compared with information about the toxicity of that COPC to estimate the potential risks to human health posed by exposure to the COPC. This step is known as risk characterization. In the risk characterization, cancer risks will be evaluated separately from non-cancer adverse health effects. The methods used for assessing cancer risks and non-cancer adverse health effects are discussed below.

### 6.1 Methods for Assessing Cancer Risks

In the risk characterization, carcinogenic risk will be estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to chemicals, radionuclides, or asbestos. Carcinogenic risks for chemicals will be evaluated by multiplying the estimated average exposure rate (i.e., LADD calculated in the exposure assessment) by the chemical's SF. The chemical SF converts estimated daily doses averaged over a lifetime to incremental risk of an individual developing cancer. According to USEPA (1989), this approach is appropriate for theoretical upper-bound incremental lifetime cancer risks of less than $1 \times 10^{-2}$. The following equations will be used to calculate chemical-specific risks and total Site risks:

$$Risk_{oral\ or\ dermal} = LADD \times SF \tag{15}$$

where:

LADD = lifetime average daily dose (mg/kg-d)

SF = cancer slope factor $(mg/kg\text{-}d)^{-1}$

$$Risk_{inhalation} = EC \times URF \tag{16}$$

where:

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

URF = unit risk factor $(\mu g/m^3)^{-1}$

and

$$Total\ Site\ Risk = \sum Chemical\ Risk \quad (17)$$

It will be assumed that cancer risks from various exposure routes are additive. Carcinogenic risk estimates will be evaluated by NDEP in light of site-specific risk management decision criteria.

Radiation cancer risk, like chemical cancer risk, is evaluated as the incremental probability that an individual will develop cancer during their lifetime. Radiation cancer risk is calculated as:

$$Risk = Intake \times SF \quad (18)$$

where:

Intake = average daily intake (pCi)

SF = cancer slope factor $(pCi)^{-1}$

The units in the equation for external irradiation differ, but the equation is analogous:

$$Risk = Intake \times SF \times (1.14 \times 10^{-4}\ yr/hr) \quad (19)$$

where:

Intake = average daily intake (pCi-hr/g)

SF = cancer slope factor (risk/yr per pCi/g)

Radionuclide cancer risks for each exposure pathway are summed to calculate radionuclide cancer risk to an individual.

Asbestos cancer risks are based on the estimated additional deaths from lung cancer or mesothelioma due to constant lifetime exposure. The equation used to calculate asbestos risks based on concentrations of asbestos fibers in air is:

$$Risk = Time\ Weighted\ Airborne\ Concentration\ (f/cm^3)\ \times URF\ (f/cm^3)^{-1} \quad (20)$$

The asbestos URF is calculated according to the methods described in USEPA (2003a) and is based upon separation of fiber type (amphibole and chrysotile), fiber length, and endpoint (mesothelioma and lung cancer). The derivation of the URF is provided in NDEP (2009a).

## 6.2 Methods for Assessing Non-Cancer Health Effects

Non-cancer adverse health effects are estimated by comparing the estimated average exposure rate (i.e., ADDs or exposure concentrations [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:

$$Hazard\ Quotient_{oral\ or\ dermal} = \frac{ADD}{RfD} \quad (21)$$

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:

$$Hazard\ Quotient_{inhalation} = \frac{EC}{RfC} \quad (22)$$

where:

EC = exposure concentration (mg/m$^3$)

RfC = reference concentration ($mg/m^3$)

The ADD-to-RfD or EC to RfC ratio is known as a hazard quotient. If a person's average exposure is less than the RfD (i.e., if the hazard quotient is less than 1), the chemical is considered unlikely to pose a significant non-carcinogenic health hazard to individuals under the given exposure conditions. Unlike carcinogenic risk estimates, a hazard quotient is not expressed as a probability. Therefore, while both cancer and non-cancer risk characterizations indicate a relative potential for adverse effects to occur from exposure to a chemical, a non-cancer adverse health effect estimate is not directly comparable with a cancer risk estimate.

If more than one pathway is evaluated, the hazard quotients for each pathway, for all COPCs, will be summed to determine whether exposure to a combination of pathways poses a health concern. This sum of the hazard quotients is known as an HI.

$$Hazard\ Index = \sum Hazard\ Quotients \quad (23)$$

A total HI that includes all COPCs and all exposure pathways will be presented in the risk assessment. The NDEP non-cancer risk management target is an HI value of less than or equal to 1.0.

For any HI that exceeds 1.0, the potential for adverse health effects will be further evaluated by considering the target organs upon which each chemical could have an adverse effect. Target organ-specific HIs will be assessed only after approval by NDEP. The target organ specific HIs will be summed for all relevant COPCs. The segregation of HI by target organ is consistent with USEPA guidance for non-carcinogens, including metals (USEPA 1989, 2001c).

### 6.3 Assessment of Risks Associated with Background Soil

As indicated in Section 3.2, if statistical analyses indicate that a particular chemical is within background soil levels, then the chemical will not be identified as a COPC. However, in cases where the cumulative (Site) ILCR exceeds $10^{-6}$, the risk associated with background soil levels will be quantitated. Risk associated with background soil levels will be presented separately and will also be discussed as part of the uncertainty analysis.

## 6.4 Uncertainty Analysis

Consistent with USEPA (1989) guidance, for the deterministic risk assessment, a qualitative discussion of the uncertainties associated with the estimation of risks for the Site will be presented in the risk assessment report. The uncertainty analysis will discuss uncertainties associated with each step of the risk assessment, including site characterization data, data usability, selection of COPCs, representative exposure concentrations, fate and transport modeling, exposure assessment, toxicity assessment, and risk characterization. For non-carcinogens (HI), chemical carcinogens (risk), and radionuclides (risk), the relative contribution of specific COPCs and pathways to the risk assessment results will be identified. If a probabilistic risk assessment is performed, the uncertainty analysis will be performed quantitatively. Details will be provided in a separate probabilistic risk assessment methodology submittal to the NDEP.

## 6.5 Data Quality Assessment

Data quality assessment (DQA) is an analysis that is performed after the risk assessment to determine if enough data have been collected to support the risk-based decisions that are being supported by the risk assessment. A DQA of the data used for risk assessment will be presented in the risk assessment report. Sample size calculations will be conducted for a number of chemicals of interest for the Site. 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 2009) that formed the basis for an approximate formula that is based on the normal distribution. Essentially, the formula is the one that would be used if a normal-based test were being performed, but an adjustment is made (multiply by 1.16) to account for the intent to perform a non-parametric test. The formula is as follows:

$$n = 1.16\left[\frac{s^2}{\Delta^2}(z_{1-\alpha} + z_{1-\beta(\mu)})^2 + 0.5z_{1-\alpha}^2\right] \quad (24)$$

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)

$\alpha$ = significance level or Type I error tolerance

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

z = quantile from the standard normal distribution

For each chemical, inputs for the calculations will include an estimate of the variance from the measured data, a desired significance level, and desired power of the test that must be specified at a concentration of interest (which determines the tolerable difference from the threshold value), typically the NDEP BCL. The calculations will cover a range of Type I and Type II error tolerances, and the point at which the Type II error is specified. That is, various combinations of input values will be used, including: values of $\alpha$ of 5%, 10% and 15%; values of $\beta$ of 15%, 20%, and 25%; and a gray region of width 10%, 20% and 30% of the threshold level.

This analysis will be conducted to document that sufficient data were collected for each decision unit at the site.

## 6.6 Interpretation of Findings

The risk characterization results will be presented in tabular format in the risk assessment report. Key exposure (e.g., estimated intakes, important modeling assumptions, summary of exposure pathways for each receptor) and toxicity information (e.g., SFs, RfDs, target organs) will be provided. In addition, the risk characterization results will be discussed in the context of the target risk goals specified in Section 2.2. The cancer risk assessment results for chemicals and radionuclides will be presented for both Site -related cancer risk and background cancer risk estimates. Those COPCs and exposure pathways having the greatest influence on the risk assessment results will be identified. As appropriate, graphical presentation of the results will also be included in the risk assessment report. The format and content of risk assessment reports will follow the guidelines presented in USEPA's *Risk Assessment Guidance for Superfund: Volume I Human Health Evaluation Manual—Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments* (USEPA 2001c) and USEPA's Reviewers Checklist (USEPA 1989) to ensure that essential issues are adequately addressed in each risk assessment.

## 6.7 Risk-Based Remediation Concentration (RCs) for Soil

As previously stated, NDEP's BCLs (NDEP 2009a) will be used as a technical screening tool to assist in the evaluation of data usability, determination of extent of contamination, identification of chemicals of potential concern and identification of target remediation goals. As stated in USEPA and NDEP guidance, risk-based goals (either screening or more refined) are initial

guidelines. These values do not represent final cleanup levels or establish that cleanup to meet these goals is warranted (USEPA 1991b, NDEP 2009a). If appropriate, risk-based remedial goals may be modified in accordance with *USEPA Risk Assessment Guidance for Superfund Volume 1 Part B* (USEPA 1991b) to consider such factors as future land use, exposure assumptions and the media and chemicals of potential concern. The modified goals may be based on deterministic or probabilistic methodologies. In the latter case, specific details regarding proposed probabilistic risk assessment methodology will be described in a separate submittal to NDEP.

## 7.0 REFERENCES


Agency for Toxic Substances and Disease Registry (ATSDR). 1990. Toxicological Profile for Polycyclic Aromatic Hydrocarbons. U.S. Department of Health and Human Services, Public Health Service.

Agency for Toxic Substances and Disease Registry (ATSDR). 1995. Toxicological Profile for Polycyclic Aromatic Hydrocarbons. U.S. Department of Health and Human Services, Public Health Service. August.

American Society for Testing and Materials (ASTM). 2000. Standard Guide for Risk-Based Corrective Action. E2081-00.

Berman, D.W. and Chatfield, E.J. 1990. Interim Superfund Method for the Determination of Asbestos in Ambient Air. Part 2: Technical Background Document, Office of Solid Waste and Remedial Response, U.S. EPA, Washington, D.C., EPA/540/2-90/005b, May.

Berman, D.W. and K. Crump. 1999a. Methodology for Conducting Risk Assessments at Asbestos Superfund Sites—Part 1: Protocol. Interim Version. Prepared for USEPA Region 9, February 15.

Berman, D.W. and K. Crump. 1999b. Methodology for Conducting Risk Assessments at Asbestos Superfund Sites—Part 2: Technical Background Document. Interim Version. Prepared for USEPA Region 9, February 15.

Berman, D.W. and Crump, K.S. 2001. Technical Support Document for a Protocol to Assess Asbestos-Related Risk. Prepared for Mark Raney, Volpe Center, U.S. Department of Transportation, 55 Broadway, Kendall Square, Cambridge, MA 02142. Under EPA Review.

Berman, D.W. and Kolk, A. 2000. Modified Elutriator Method for the Determination of Asbestos in Soils and Bulk Material. May (Revision 1).

BRC and Titanium Metals Corporation (TIMET). 2007. Background Shallow Soil Summary Report, BMI Complex and Common Areas Vicinity. March 16.

BRC 2009. 2008 Deep Soil Background report BMI Common Areas (Eastside).October.

Budinsky RA, Rowland JC, Casteel S,et al. 2008. A pilot study of oral bioavailability of dioxins and furans from contaminated soils: Impact of differential hepatic enzyme activity and species differences. Chemosphere 70:1774-1786.

Cal-EPA. 2005. Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air. California Environmental Protection Agency, Department of Toxic Substances Control, Sacramento, CA.

De Rosa, C.T., Brown, D., Dhara, R. *et al*. 1997. Dioxin and Dioxin-Like Compounds in Soil, Part 1: ATSDR Interim Policy Guidance. Toxicology and Industrial Health 13 759-768.

ENSR Corporation (ENSR). 2005. Conceptual Site Model (CSM). Kerr-McGee Facility, Henderson, Nevada. February.

ENSR Corporation (ENSR). 2006. Phase A Source Area Investigation Work Plan. Tronox LLC Facility, Henderson, Nevada.

ENSR Corporation (ENSR). 2007. Addendum to the Phase A Source Area Investigation Work Plan. Tronox LLC Facility, Henderson, Nevada.

ENSR Corporation (ENSR). 2008a. Phase B Source Area Investigation Work Plan – Soil Gas Survey. Tronox LLC Facility, Henderson, Nevada.

ENSR Corporation (ENSR). 2008b. Phase B Source Area Investigation Work Plan Area I (Northern LOUs), Tronox LLC Facility, Henderson, Nevada, April.

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

ENSR Corporation (ENSR). 2008d. Phase B Source Area Investigation Work Plan Area II (Central LOUs). Tronox LLC Facility, Henderson, Nevada. June.

ENSR Corporation (ENSR). 2008e. Phase B Source Area Investigation Work Plan Area III (Eastern LOUs). Tronox LLC Facility, Henderson, Nevada. June.

Environ. 2003. Risk Assessment for the Water Reclamation Facility Expansion Site, Henderson, Nevada. Prepared for the City of Henderson, Nevada. October.

Finley, B., Fehling, K., Warmerdam, J. and E Morinello. 2009. Oral bioavailability of polychlorinated dibenzo-p-dioxins/dibenzofurans in Industrial Soils. *Human and Eco. Risk Assessment*. 15: 1146-1167.

Johnson, P.C. and R.A. Ettinger. 1991. Heuristic model for predicting the intrusion rate of contaminant vapors into buildings. Environmental Science and Technology, 25:1445-1452.

Kimbrough, R.D., Falk, H., Stehr,P., and Fries, G. 1984. Health implications of 2,3,7,8-tetrachlorodibenzo dioxin (RCDD) contamination of residential soil. *J. Toxicol. Environ. Health* 14, 47-93.

Michigan Environmental Science Board. 2001. Evaluation of the Michigan Department of Environmental Quality's Generic Groundwater and Soil Volatilization to Indoor Air Inhalation Criteria. (A Science Report to Governor John Engler). Michigan Environmental Science Board, Lansing, MI.

National Academy of Science (NAS). 1994. Science and Judgment in Risk Assessment. National Research Council. National Academy Press, Washington, D.C.

Neptune and Company. 2007. Guided Interactive Statistical Decision Tools (GISdT). www.gisdt.org.

Neptune and Company. 2009. Stand Alone Software. Guided Interactive Statistical Decision Tools (GISdT).

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

NDEP. 2008a. *Supplemental Guidance for Assessing Data Usability for Environmental Investigations at the BMI Complex and Common Areas in Henderson, Nevada*. Bureau of Corrective Actions, Special Projects Branch, 2030 East Flamingo Rd, Suite 230, Las Vegas, NV 89119. October 22.

NDEP. 2008b. *Guidance on the Development of Summary Statistic Tables at the BMI Complex and Common Areas in Henderson, Nevada*. Bureau of Corrective Actions, Special Projects Branch, 2030 East Flamingo Rd, Suite 230, Las Vegas, NV 89119. December 10.

NDEP. 2009a. *User's Guide and Background Technical Document for Nevada Division of Environmental Protection (NDEP) Basic Comparison Levels (BCLs) for Human Health for the BMI Complex and Common Areas.* Revision 4-November.

NDEP. 2009b. *Technical Guidance for Evaluating Radionuclide Data for the BMI Plant Sites and Common Areas Projects, Henderson, Nevada*, prepared by Neptune and Company Inc, 8550 W. 14th Avenue, Lakewood, CO for the Nevada Division of Environmental Protection, Bureau of Corrective Actions, Special Projects Branch, 2030 East Flamingo Rd, Suite 230, Las Vegas, NV 89119.

NDEP. 2009c. *Significance Levels for The Gilbert Toolbox of Background Comparison Tests, BMI Plant Sites and Common Areas Projects, Henderson, Nevada*, prepared by Neptune and Company Inc, 8550 W. 14th Avenue, Lakewood, CO for the Nevada Division of Environmental Protection, Bureau of Corrective Actions, Special Projects Branch, 2030 East Flamingo Rd, Suite 230, Las Vegas, NV 89119. July

NDEP. 2009d. *Technical Guidance for the Calculation of Asbestos-Related Risk in Soils for the Basic Management Incorporated (BMI) Complex and Common Areas*, prepared by Neptune and Company Inc, 8550 W. 14th Avenue, Lakewood, CO for the Nevada Division of Environmental Protection, Bureau of Corrective Actions, Special Projects Branch, 2030 East Flamingo Rd, Suite 230, Las Vegas, NV 89119.

NDEP. 2010. *Soil to Groundwater Leaching Guidance*, January 16.

Northgate Environmental Management, Inc. 2010. Justification for Using an Adjustment Factor for Dioxins in Soil. Memorandum. February 2.

Northgate Environmental Management, Inc. 2010. Protocol: Bioaccessibility Method for Dioxin/Furans in Soil. Memorandum. February 11.

Oak Ridge National Laboratory (ORNL). 1993. Toxicity Summary for Pyrene. Chemical Hazard Evaluation Group, Biomedical and Environmental Information Analysis section, Health Sciences Research Division, Oak Ridge, TN, August.

Paustenbach, D.J., Fehling, K, Scott, P., Harris, M., and B.D Kerger. 2006. Identifying soil cleanup criteria for dioxins in urban residential soils: how have 20 years of research and risk assessment experience affected the analysis? Journal of Toxicology and Environmental Health, Part B, 9:87–145.

Roberts *et al*. 2001. Measurement of Arsenic Bioavailability in Soil Using a Primate Model. Toxicological Sciences, 67, 2: 303-310.

Ruby, M.V., R. Schoof, W. Brattin, M. Goldale, G. Post, M. Harnios, D. E. Mosby, S. W. Casteel, W. Berti, M. Carpenter, D. Edwards, D. Cragin, and W. Chappell. 1999. Advances in evaluating the oral bioavailability of inorganics in soil for use in human health risk assessment. Environ. Sci. Technol. 33(21):3697-3705.

Ruby, M.V., Fehling K.A, Paustenbach D.H, Drinkwater K. and Storck M. 2002. Oral bioaccessibiliyt of dioxins/furans at low concentrations (50-350 ppt toxicity equivalent) in soil. Environ Sci Technol 36:4905-4911.

USEPA. 1989. Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual (Part A). Interim Final. Office of Emergency and Remedial Response, Washington, D.C. USEPA/540/1-89/002. December.

USEPA. 1991a. Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions. Memorandum from D.R. Clay, Assistant Administrator, USEPA. OSWER Directive 9355.0-30, April.

USEPA. 1991b. Risk Assessment Guidance for Superfund: Volume I – Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Goals). Office of Emergency and Remedial Response. December.
http://www.epa.gov/oswer/riskassessment/ragsb/index.htm

USEPA. 1992a. Guidelines for Exposure Assessment. Federal Register, 57(104):22888-22938. May 29.

USEPA. 1992b. Guidance for Data Usability in Risk Assessment. Part A. Office of Emergency and Remedial Response, Washington D.C. Publication 9285.7-09A. PB92-963356. April.

USEPA. 1992c. Guidance for Data Usability in Risk Assessment. Part B. Office of Emergency and Remedial Response, Washington D.C. Publication 9285.7-09B. PB92-963362. May.

USEPA. 1993. Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons. Office of Research and Development, Washington, DC. EPA/600/R-93/089. July.

USEPA, 1995. Guidance for Risk Characterization. Science Policy Council. February. http://64.2.134.196/committees/aqph/rcpolicy.pdf

USEPA. 1996a. Soil Screening Guidance: Technical Background Document. Office of Emergency and Remedial Response, Washington, DC. USEPA/540/R-96/018. April.

USEPA, 1996b. Recommendations of the Technical Review Workgroup for Lead for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil. USEPA Technical Workgroup for Lead. December.
http://www.epa.gov/superfund/lead/products/adultpb.pdf

USEPA. 1997. Exposure Factors Handbook. Office of Research and Development, Washington DC. USEPA/600/P-95/002Fa-c. August.

USEPA, 1998. Approach for Addressing Dioxin in Soil at CERCLA and RCRA Sites. OSWER Directive 9200.4-26, April 13. http://www.epa.gov/superfund/resources/remedy/pdf/92-00426-s.pdf

USEPA. 2000a. Soil Screening Guidance for Radionuclides. Office of Radiation and Indoor Air, Washington, DC. USEPA/540-R-00-007 and USEPA/540-R-00-006.

USEPA. 2000b. Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds. Part II: Health Assessment for 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) and Related Compounds. National Center for Environmental Assessment, Washington, DC. EPA/600/P-00/001Ae. May.

USEPA. 2001a. Risk Assessment Guidance for Superfund: Volume 3—Part A, Process for Conducting Probabilistic Risk Assessment. Draft. Office of Solid Waste and Emergency Response, Washington, DC.

USEPA. 2001b. Inorganic Arsenic – Report of the Hazard Identification Assessment Review Committee. Memorandum, From: J. Chen, S. Malish, T. McMathon, Risk Assessment and Science Support Branch; to: N. Cook, Chief, Risk Assessment and Science Support Branch. August 21.

USEPA. 2001c. Risk Assessment Guidance for Superfund: Volume I Human Health Evaluation Manual—Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments. Office of Emergency and Remedial Response, Washington, DC. Publication 9285.7-47. December.

USEPA. 2002a. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. Office of Solid Waste and Emergency Response, Washington, DC. OSWER 9355.4-24. December.

USEPA. 2002b. Memorandum on Role of Background in the CERCLA Cleanup Program, from USEPA Office of Emergency and Remedial Response Director Michael B. Cook to Superfund National Policy Managers and all Regions, dated 1 May. OSWER 9285.6-07P.

USEPA. 2002c. Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites. Office of Emergency and Remedial Response, Washington, DC. EPA 540-R-01-003. September.

USEPA. 2002d. Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites. Office of Emergency and Remedial Response, Washington, DC. OSWER 9285.6-10. December.

USEPA. 2003a. Technical Support Document for a Protocol to Assess Asbestos-Related risk. Final Draft. Office of Emergency and Remedial Response, Washington, DC. EPA #9345.4-06.October

USEPA. 2003b. Memorandum on Human Health Toxicity Values in Superfund Risk Assessments, from Michael B. Cook, Director, Office of Superfund Remediation and Technology Innovation to Superfund Remediation Policy Managers, Regions 1 - 10, dated 5 December. OSWER Directive 9285.7-53.

USEPA. 2003c. Technical Support Document for a Protocol to Assess Asbestos-Related Risk. Final Draft. October.

USEPA. 2004a. Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Final. Office of Emergency and Remedial Response, Washington, DC. EPA/540/R/99/005. July.

USEPA. 2004b. User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings. Prepared by Environmental Quality Management, Inc. for the U.S. Environmental Protection Agency (Office of Emergency and Remedial Response, Washington, D.C.). February 22nd.

USEPA. 2004c. Memorandum on Clarifying Cleanup Goals and Identification of New Assessment Tools for Evaluating Asbestos at Superfund Cleanups, from Michael B. Cook, Director, Office of Superfund Remediation and Technology Innovation to Superfund Remediation Policy Managers, Regions 1 - 10, dated 10 August. OSWER Directive 9345.4-05.

USEPA. 2004d. Users Guide and Background Technical document for USEPA Preliminary Remediation Goals (PRGs), Region 9. Website: http://www.epa.gov/region09/superfund/prg/files/04usersguide.pdf

USEPA. 2007. Preliminary Remediation Goals for Radionuclides. USEPA on-line database: http://epa-prgs.ornl.gov/radionuclides/.

USEPA. 2009a. Integrated Risk Information System. USEPA on-line database: http://www.epa.gov/iris/index.html.

USEPA. 2009b. Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment) Final. EPA-540-R-070-002. January.

Van Den Berg, M., Birnbaum, L., Denison, M., De Vito, M., et al. 2006. The 2005 World Health Organization Reevaluation of Human and Mammalian Toxic Equivalencey Factors for Dioxins and Dioxin-like Compounds. Toxicol. Sciences 92(2) 223-241.

Wittsieppe J., Erlenkamper B., Weige P. et al. 2007. Bioavailability of PCDD/F from contaminated soil in young Goettingen minipigs. Chemosphere 67 (9): S355-364.