USER'S GUIDE AND BACKGROUND TECHNICAL DOCUMENT FOR THE NEVADA DIVISION OF ENVIRONMENTAL PROTECTION (NDEP) BASIC COMPARISON LEVELS (BCLs) FOR HUMAN HEALTH FOR THE BMI COMPLEX AND COMMON AREAS

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December 2008

Revision 8 – May 2012

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DISCLAIMER

The Nevada Division of Environmental Protection (NDEP) Basic Comparison Levels (BCLs) address common human health exposure pathways. They consider neither all potential human health exposure pathways nor do they address ecological concerns. The comparison of site characterization data against these risk-based media concentrations provides for an initial screening evaluation to assist users in risk assessment components such as the evaluation of data usability, determination of extent of contamination, identification of chemicals of potential concern, and identification of preliminary remediation goals. The values are derived using equations from U.S. Environmental Protection Agency (USEPA) guidance, USEPA toxicity criteria, and USEPA exposure factors. NDEP officials may decide to follow the guidance provided herein or act at variance with the guidance, based on analysis of site-specific circumstances or availability of new or more relevant data or regulatory policies. NDEP also reserves the right to change this guidance at any time without public notice. Every effort has been made to ensure accuracy in these tables; however, if an error is found, please send an e-mail to Shannon Harbour at sharbour@ndep.nv.gov.

These BCLs are designed for use at the BMI Complex and Common Areas in Henderson, Nevada. The applicability of the BCLs should be verified prior to use at any other site.

The guidance set out in this document is not final NDEP action. It is neither intended to nor can it be relied upon, to create any rights enforceable by a party in litigation with the state of Nevada.

1.0 BACKGROUND ON NDEP BASIC COMPARISON LEVELS (BCLs)

The Internet version of the Nevada Division of Environmental Protection (NDEP) Basic Comparison Levels (BCLs) can be found at the worldwide web address http://ndep.nv.gov/bmi/technical.htm. The printable version is referred to herein as the "BCL Table" and the "BCL Calculations Table" and "Leaching BCLs" spreadsheets are also included in the Excel® file and provide the input parameters and pathway-specific BCLs.

Users are advised to employ these BCLs only after fully understanding this guidance. The BCL Table was not generated to represent action levels or final cleanup levels but rather as a technical screening tool to assist users in risk assessment components such as the evaluation of data usability, determination of extent of contamination, identifying chemicals of potential concern, and identifying preliminary remediation goals. The BCL Table contains current human health toxicity values that are combined with standard exposure factors to estimate contaminant concentrations in environmental media [air, soil (on a dry-weight basis), and water] that are considered by NDEP to be protective of human exposures (including sensitive sub-groups) over a lifetime. Human health BCLs have also been computed for eight radionuclides. Finally, leaching-based BCLs are provided for both chemicals and the eight radionuclides. Exceedance of a BCL does not automatically designate the site as needing a response action. However, exceeding a BCL may suggest that further evaluation of the potential risks posed by site contaminants is appropriate. Further evaluation might include additional sampling, consideration of ambient levels in the environment, and/or a site-specific risk assessment.

For each chemical, BCLs are back-calculated from a target risk level for carcinogens and a target hazard level for non-carcinogens. For the inhalation and direct contact pathways, target risk levels for soil exposures are set at a one-in-a-million (1×10^{-6}) incremental lifetime cancer risk for each chemical for the cancer endpoint and a hazard quotient (HQ) of one (1) for the non-cancer endpoint. Leaching-based BCLs (LBCLs) for the migration-to-groundwater pathway are back-calculated from the following groundwater concentration limits (in order of preference): non-zero maximum contaminant level goals (MCLGs), maximum contaminant levels (MCLs), or health-based limits (based on a cancer risk of 1×10^{-6} or an HQ of 1), with the exception of the compounds discussed in Section 3.8. For residential tap water, USEPA MCLs (USEPA, 2009a) are employed as the BCL. For chemicals lacking an MCL, BCLs are back-calculated using a target cancer risk of 1×10^{-6} for the cancer endpoint and a target hazard index of 1 for the non-cancer endpoint.

BCLs are intended to provide health protection without a full understanding of the specific exposure conditions at the site under study. BCLs are applicable when the exposure factors based on site-specific considerations are likely to be no more conservative than the default exposure assumptions used in the BCL Table. BCLs are media contaminant concentrations below which no further action or study at a site is generally warranted, provided that specified application conditions associated with the BCLs are met. In general, if adequate site data collection shows that the measured maximum or 95% upper confidence level (UCL) (where appropriate[1]) concentration of a particular contaminant is below the relevant BCL (see Section

[1] If a 95% UCL is used, it must be specific to an exposure area.

3.7 for addressing multiple chemicals), then further action at a site may not be warranted. If the maximum or the 95% UCL concentration for relevant media is above the BCL, further study, though not necessarily a cleanup action, is warranted. When considering BCLs as initial cleanup goals, it is recommended that the residential BCL be used, unless agreement has been reached with NDEP officials that a non-residential land use assumption can be justified.

The responsibility for using the BCL Table, and for determining its relevance to site-specific circumstances, lies with the entity recommending the values to be used and the user of the BCL Table. Before using the BCLs at a particular site, the user should determine whether the exposure pathways and exposure scenarios at the site are fully accounted for in the BCL calculations. NDEP BCLs address direct contact exposure pathways for human health (i.e., ingestion, dermal contact, and inhalation) for which generally accepted methods, models, and assumptions have been developed for specific land uses, as well as the protection of groundwater (leaching) pathway. The BCLs do not consider other human exposure pathways or impact to ecological receptors [see Conceptual Site Model (CSM) Section 1.1]. The BCL Table contains guidance on soil chemical impacts to groundwater by identifying chemical-specific dilution-attenuation factors (DAF), that are multiplied by relevant soil concentrations to obtain the LBCL.

The BCLs will be updated over time, as appropriate (once a year at a minimum), to reflect evolving USEPA guidance, changes in toxicological data, and derivation of toxicological surrogates (as applicable) for BMI Complex and Common Areas compounds of interest. There are a number of exotic chemicals associated with the BMI Complex and Common Areas and the need for surrogate derivation will be identified on a case-by-case basis and surrogates will be derived where warranted. BCL updates and special considerations identified by NDEP and users will be posted in Appendix A of the User's Guide, and will be integrated into the BCL Table as needed. Therefore, users are urged to check this appendix for any changes relevant to their site-specific/media-specific chemicals.

1.1 Conceptual Site Model

Developing a CSM is a critical step in properly implementing the soil screening process at a site. The CSM is a comprehensive representation of the site that documents current site conditions. It characterizes the distribution of contaminant concentrations across the site in three dimensions and identifies all potential exposure pathways, migration routes, and potential receptors. The CSM is initially developed from existing site data. Where relevant, these site data should include input from stakeholders about their site knowledge, concerns, and interests, and should be revised continually as new site investigations produce updated or more accurate information. The final CSM represents links among contaminant sources, release mechanisms, exposure pathways, and routes and receptors based on historical information and site data. It summarizes the understanding of the contamination problem.

As an initial check, the CSM should answer the following questions:

- Are there potential ecological concerns?
- Is there potential for land use other than those covered by the BCLs (i.e., residential and commercial/industrial)?

- Are there other likely human exposure pathways that were not considered in development of the BCLs (e.g., impacts on areas used for gardens, farming, fishing, or raising beef, dairy, or other livestock)?
- Are there unusual site conditions (e.g., large areas of contamination, high fugitive dust levels, or wetland or floodplain issues)?
- Is there a probable source of vapor emissions from volatile soil or groundwater contaminants that may affect indoor air?
- Is there potential for a short-term construction scenario to result in higher risks than those associated with the long-term scenarios assumed for the BCLs?

If the answer to any of the questions is yes, then the BCLs may not be fully applicable to a site.

1.2 Application of the Basic Comparison Levels Table

The decision to use the BCLs at a site will be driven by the potential benefits of having generic risk-based concentrations in the absence of site-specific risk assessments. Additional potential uses include:

- Supporting quality assurance programs and data usability evaluations;
- Limiting the number of chemicals of potential concern (COPCs) evaluated in risk assessments;
- Screening sites to determine the need for further evaluation;
- Prioritizing multiple "hot spots" within a facility or exposure realm; and
- Focusing future risk assessment efforts.

In general, BCL concentrations provided in the Table are risk-based. However, for soil there are two important exceptions: (1) when the risk-based BCL for a volatile organic compound (VOC) exceeds its soil saturation limit, the BCL is based on the soil saturation limit ("sat"), and (2) when the risk-based BCL for relatively less toxic non-VOCs exceeds 10^{+5} mg/kg (max), then the max is used as the basis for the BCL. It is important to note that the BCLs for inhalation are for outdoor air and are not applicable to indoor air. The pathways addressed by the BCLs and those not addressed are summarized below.

Environmental Media	Pathways Addressed by BCLs		Pathways Not Addressed by BCLs	
	Residential	**Industrial/Commercial**	**Residential**	**Industrial/Commercial**
Soil	• Ingestion • Inhalation of particulates • Inhalation of VOCs • Dermal contact	• Ingestion • Inhalation of particulates • Inhalation of VOCs • Dermal contact	• Intrusion of VOCs into indoor air • Groundwater contact from soil-leached chemicals • Ingestion of livestock or produce	• Intrusion of VOCs into indoor air • Groundwater contact from soil-leached chemicals • Particulate emission during construction/ excavations activities
Groundwater	• Ingestion from drinking • Inhalation of VOCs	• None	• Dermal absorption while bathing • Intrusion of VOCs into indoor air	• Ingestion from drinking • Inhalation of VOCs • Dermal absorption • Intrusion of VOCs into indoor air

1.3 Potential Issues and Misapplication of BCLs

As discussed previously, the BCLs should be used only when the conditions at the site being screened are similar to those under which the BCLs were derived for use. Special care should be exercised to prevent misuse of the BCLs and to protect human health. Specifically, the following should be avoided:

- Applying BCLs to a site without adequately developing a conceptual site model that identifies relevant exposure pathways and exposure scenarios.
- Not considering background concentrations when choosing BCLs.
- Use of BCLs as cleanup levels without considering other relevant criteria.
- Use of BCLs as cleanup levels without verifying applicability with a qualified risk assessor.
- Use of outdated BCLs that have been superseded by more recent publications.
- Not considering the effects of the presence of multiple chemicals.

2.0 NDEP BASIC COMPARISON LEVELS (BCLs)

The BCL Table was generated using equations incorporated into a calculation spreadsheet, except for the column "DAF" [the dilution-attenuation factor for use in calculating LBCLs]. Table 1 provides the Standard Default Exposure Factors used to calculate BCLs. Toxicity values, as well as physical and chemical parameters, are input into the spreadsheet. There are seven primary sections of the BCL Table: 1) toxicity values, 2) physical/chemical input parameters, 3) BCLs for residential land use scenarios, 4) BCLs for industrial/commercial land use scenarios (indoor and outdoor workers), 5) BCLs for ambient air, 6) BCLs for residential tap water, and 7) LBCLs for protection of groundwater. The "printable" version of the BCL Table contains only the toxicity values, volatile organic compound (VOC) designation, skin absorption value, and final comparison levels (http://ndep.nv.gov/bmi/technical.htm) while the "BCLs Calculation

Table" provides the actual spreadsheet used to derive the BCLs. The default values and equations used in developing the Table are discussed below.

2.1 Toxicity Values

Cancer and noncancer toxicity values were obtained from USEPA's Integrated Risk Information System (IRIS) on-line database (USEPA, 2010), EPA's Provisional Peer-Reviewed Toxicity Values Database (PPRTV) (USEPA, 2008), USEPA's National Center for Environmental Assessment (NCEA), USEPA's Health Effects Assessment Summary Table (HEAST) (USEPA, 1997a), and other sources. The OSWER Directive 9285.7-53 (dated December 5, 2003) (USEPA, 2003a) designates the following hierarchy for toxicity criteria: IRIS (indicated by "I" in the table) and "other sources". For the BCLs, these other sources included (in order of preference) (1) PPRTV ("P") and (2) NCEA ("N"), (3) HEAST ("H"), (4) surrogate value (S), and (5) other documents ("o") (e.g., California EPA toxicity criteria). California EPA toxicity criteria were used on a case-by-case basis and are designated with a "CA" in the BCL Table. Finally, it should be noted that the USEPA has withdrawn toxicity values for certain chemicals. These are designated with an "x" in the BCL Table and should be discussed in the uncertainty section if used in a risk assessment.

HEAST has not been updated since the last version was released in 1997 (USEPA, 1997a). HEAST values that have been externally peer reviewed are now in the PPRTV database and are noted by the letter "P" in the key column of the BCL Table next to the toxicity value. The PPRTV values currently represent the second tier of human health toxicity values for the USEPA Superfund and hazardous waste programs.

The USEPA Superfund Program has updated its inhalation risk methodology (Risk Assessment Guidance for Superfund (RAGS), Part F", USEPA, 2009b) to be consistent with USEPA's *Inhalation Dosimetry Methodology*[2], which represents USEPA's current approach for inhalation dosimetry and derivation of inhalation toxicity criteria. RAGS Part F currently recommends that when estimating risk via inhalation, risk assessors should use the concentration of the chemical in air as the exposure metric (e.g., mg/m^3), rather than inhalation intake of a contaminant in air based on IR [intake rate] and BW [body weight] (e.g., mg/kg-day) (as described in USEPA 1989a). The full details of this approach are provided in RAGS, Part F (USEPA, 2009b). Consistent with that guidance, cancer-based BCLs for the inhalation pathway were calculated using the inhalation unit risk (IUR[3]) rather than the inhalation slope factor (SFi[4]) (USEPA, 2009b). Based on the same rationale, USEPA also currently recommends that non-cancer hazard

[2] http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=71993

[3] The IUR is defined by USEPA as the upper-bound excess lifetime cancer risk estimated to results from continuous exposure to an agent at a concentration of 1 $\mu g/m^3$ in air (USEPA, 2009b).

[4] The SF_i is defined by USEPA as the plausible upper-bound estimate of the probability of an increased cancer risk per unit intake of a chemical over a lifetime via inhalation, expressed in units of risk per mg of substance per kg body weight per day: $(mg/kg\text{-}day)^{-1}$ (USEPA, 1989a).

quotients should be calculated using the reference concentration (RfC[5]) rather than the inhalation reference dose (RfD_i[6]) (USEPA, 2009b). Accordingly, the non-cancer-based BCLs for the inhalation pathway were calculated using the chemical-specific RfC.

Several chemicals in the table did not have toxicity criteria from any of the USEPA hierarchy of sources used in this guidance (USEPA, 2003a). Therefore, other sources were used as the basis for the toxicity criteria for these chemicals. Table B-1 provides a listing of these chemicals and the source of the toxicity values used to calculate the BCLs.

In addition, due to the vast number of specialized compounds and analytical issues associated with the BMI Complex and Common Areas, toxicological surrogates have been derived for several compounds. The toxicity criteria for the surrogates are entered into the BCL Table for the applicable chemical lacking criteria. The derivations for the toxicological surrogates are summarized in Appendix B.

2.2 Soil-to-Air Volatilization Factors (VFs)

The physical/chemical data section of the BCL calculation spreadsheet provides the information used to calculate the volatilization factors (VFs) for VOCs. VOCs are defined as those chemicals that have a Henry's Law constant greater than 10^{-5} (atm-m^3/mol) and a molecular weight less than 200 g/mole (USEPA, 1991a). The soil-to-air VF defines the relationship between the concentration of the contaminant in soil and the flux of the volatilized contaminant to air (USEPA, 1996a). The emission terms used in the VFs are chemical specific and were calculated using chemical-specific physical/chemical data obtained from the following sources: the 1996 *Soil Screening Guidance* (USEPA, 1996a,b), the 1996 *Superfund Chemical Data Matrix* (USEPA, 1996c), and the 1988 *Superfund Exposure Assessment Manual* (USEPA, 1988). The VFs used to calculate the soil screening levels are presented in the physical/chemical data section of the spreadsheet, based on equation below, which is from the USEPA's Soil Screening Guidance (USEPA, 1996a).

$$VF_s \left(\frac{m^3}{kg}\right) = \left(\frac{Q}{C}\right) x \ \frac{(3.14 \times D_A \times T)^{1/2}}{(2\,\rho_b \times D_A)} \times 10^{-4} \left(\frac{m^2}{cm^2}\right)$$

Default values for the soil-to-air VF input parameters, listed below, are taken from USEPA, 1996a.

[5] The RfC (expressed in units of mg of substance/m^3 air) is an estimate of a daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime (USEPA, 2009b).

[6] The RfD_i (expressed in units of mg of substance per kg body weight per day [mg/kg-day]) is an estimate of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime (USEPA, 2009b).

Input Parameter	Definition (units)	Value
VF	Volatilization factor (m^3/kg)	Chemical specific
D_A	Apparent diffusivity (cm^2/s)	Chemical specific
Q/C	Inverse of the mean concentrate at the center of a 0.5-acre square source (g/m^2-s per kg/m^3)	68.81(default)
T	Exposure interval (seconds [s])	9.5×10^8 (30 years)
ρ_b	Dry soil bulk density(g/cm^3)	1.5
Θ_a	Air-filled soil porosity (L_{air}/L_{soil})	0.28 ($n - \Theta_w$)
N	Total soil porosity (L_{pore}/L_{soil})	0.43 or $1 - (\rho_b/\rho_s)$
Θ_w	Water-filled soil porosity (L_{water}/L_{soil})	0.15
ρ_s	Soil particle density (g/cm^3)	2.65
Di	Diffusivity in air (cm^2/s)	Chemical specific
H	Henry's Law constant	Chemical specific
H'	Dimensionless Henry's Law constant	Calculated from H by multiplying by 41 (USEPA, 1991a)
D_w	Diffusivity in water (cm^2/s)	Chemical specific
K_d	Soil/water partition coefficient (cm^3/g) = $K_{oc}f_{oc}$	Chemical specific
K_{oc}	Soil organic carbon/water partition coefficient (cm^3/g)	Chemical specific
f_{oc}	Fraction organic carbon in soil (g/g)	0.006 (0.6%)

2.3 Volatilization Factor for Residential Water

For residential water, a default upper-bound volatilization constant (VFw) of 0.5 L/m^3 is used that is based on all uses of household water (e.g., showering, laundering, and dish washing) (RAGS Part B; USEPA 1991a).

2.4 Soil Saturation Limits

The physical/chemical data section of the BCL calculation spreadsheet provides the information used to calculate the soil saturation limits. The soil saturation concentration limit, "sat", corresponds to the contaminant concentration in soil at which the absorptive limits of the soil particles, the solubility limits of the soil pore water, and saturation of soil-pore air have been reached. Above this concentration, the soil contaminant may be present in free phase (i.e., nonaqueous-phase liquids [NAPLs]) for contaminants that are liquid at ambient soil temperatures and in pure solid phases for compounds that are solid at ambient soil temperatures.

The equation below was used to calculate "sat" for each volatile contaminant. As an update to RAGS HHEM, Part B (USEPA 1991a), the equation takes into account the amount of contaminant that is in the vapor phase in soil, in addition to the amount dissolved in the soil's pore water and sorbed to soil particles. The VF is not applicable when free-phase contaminants are present. How these cases are handled depends on whether the contaminant is liquid or solid at ambient temperatures. Liquid contaminants for which screening levels exceed the "sat" concentration are set equal to "sat," whereas for solids (e.g., non-VOCs), BCLs are based on other appropriate pathways of concern at the site (e.g., ingestion and dermal contact).

$$Sat = \frac{S}{\rho_b}\left(K_d\,\rho_b + \Theta_W + H'\Theta_a\right)$$

Default values for the soil "sat" input parameters, listed below, and are taken from USEPA, 1996a.

Parameter	Definition (units)	Value
Sat	Soil saturation concentration (mg/kg)	Calculated
S	Solubility in water (mg/L-water)	Chemical specific
ρ_b	Dry soil bulk density (kg/L)	1.5
K_d	Soil-water partition coefficient (L/kg)	K_{oc} x f_{oc} (chemical specific)
K_{oc}	Soil organic carbon/water partition coefficient (L/kg)	Chemical specific
f_{oc}	Fraction organic carbon content of soil (g/g)	0.006 or site specific
Θ_w	Water-filled soil porosity (L_{water}/L_{soil})	0.15
Θ_a	Air-filled soil porosity (L_{air}/L_{soil})	0.28 or n – Θ_w
n	Total soil porosity (L_{pore}/L_{soil})	0.43 or 1 – (ρ_b/ ρ_s)
ρ_s	Soil particle density (g/cm^3)	2.65
H	Henry's Law constant (atm-m^3/mol)	Chemical specific
H'	Dimensionless Henry's Law constant (unitless)	Calculated from H by multiplying by 41 (USEPA, 1991a)

2.5 Particulate Emission Factor for Soils

To address the soil-to-air pathway for particulate emission, the BCL calculations incorporate a particulate emission factor (PEF) for nonvolatile contaminants (designated as "0" in the VOC column of the BCL Table). The PEF relates the contaminant concentration in soil to the concentration of respirable particles in the air due to fugitive dust emissions from soil. The generic PEF was derived using default values that correspond to a receptor-point airborne particulate concentration of approximately 0.76 µg/m^3 (USEPA, 1996a). The relationship is derived by Cowherd (1985) for a rapid assessment procedure applicable to a typical hazardous waste site where the surface contamination provides a relatively continuous and constant potential for emission over an extended period of time (e.g., years). This represents an annual average emission rate based on wind erosion. The PEF evaluates windborne emissions only and does not consider dust emissions from traffic, or other forms of mechanical disturbance that are typical of short-term construction scenarios, which are not addressed in the BCLs.

The USEPA methodology was followed to derive a PEF for Las Vegas (UESPA, 1996a). Specifically, all standard default parameters were used (e.g., PEF calculation parameters "A", "B", and "C" as obtained from USEPA, 1996a[7]) with the exception of air dispersion modeling constants for the climate zone of Las Vegas. The resulting PEF of 1.2×10^9 m^3/kg (USEPA, 1996a) was used to calculate BCLs.

2.6 Dermal Absorption Factors

Chemical-specific dermal absorption factors for contaminants in soil and dust based on USEPA (2004; RAGS Part E, *Supplemental Guidance for Dermal Risk Assessment*) are employed in the BCL derivations for arsenic, cadmium, chlordane, 2,4-D, DDT, lindane, PAHs, pentachlorophenol, polychlorinated biphenyls (PCBs), and polychlorinated dibenzo-p-dioxins and dibenzofurans (collectively referred to as "dioxins"). For other chemicals, a default dermal

[7] See Exhibits D-1, D-2 and D-4 of USEPA, 1996a.

absorption factor of 0.10 was applied for semi-volatile organic chemicals, in accordance with USEPA (2004). USEPA does not recommend absorption factors for volatile organic chemicals (VOCs) based on the rationale that VOCs are volatilized from the soil on skin and exposure is accounted for via inhalation routes. USEPA does not provide absorption factors for inorganics based on the dependence of absorption on the speciation of the compound and the fact that there are inadequate data in this regard.

2.7 Age-Adjustment Factors

Because contact rates may be different for children and adults, carcinogenic risks during the first 30 years of life were calculated using age-adjusted factors ("adj"). Use of age-adjusted factors is especially important for soil ingestion exposures, which are higher during childhood and decrease with age. For purposes of combining exposures across pathways, additional age-adjusted factors are used for dermal exposures. These factors approximate the integrated exposure from birth until age 30, combining contact rates, body weights, and exposure durations for two age groups small children and adults. Age-adjusted factors were obtained from USEPA RAGS Part B (USEPA, 1991a) or developed by analogy. Age-adjusted factors are not applicable to inhalation exposures based on USEPA RAGS Part F (USEPA, 2009b. The equations depicted below are for carcinogens.

(1) ingestion for soil ([mg × yr]/[kg × d]:

$$IFS_{adj} = \frac{ED_c \times IRS_c}{BW_c} + \frac{(ED_r - ED_C) \times IRS_a}{BW_a}$$

(2) skin contact ([mg × yr]/[kg × d]:

$$SFS_{adj} = \frac{ED_c \times \mathrm{AF} \times SA_c}{BW_c} + \frac{(ED_r - ED_c) \times AF \times SA_a}{BW_a}$$

(3) ingestion for water ([l × yr]/[kg × d])

$$IFW_{adj} = \frac{ED_c \times IRW_c}{BW_c} + \frac{(ED_r - ED_c) \times IRW_a}{BW_a}$$

The acronyms and their values are provided in Table 1. These values can also be found in the exposure default section of the BCL Calculations Table.

3.0 HUMAN HEALTH-BASED BCLs

A multi-pathway (integrated) soil BCL was calculated for each chemical for the noncancer and, where relevant, cancer endpoint. For contaminants that exhibit both carcinogenic and non-carcinogenic endpoints, the more stringent (i.e., lower) of the two BCLs is presented in the BCL Table. The integrated soil BCLs were generated from the pathway-specific BCLs for each exposure pathway (ingestion, inhalation, and dermal) which are listed separately in the BCL Calculations Table.

In addition to the multi-pathway soil BCL, tap water BCLs and ambient air BCLs were derived. Where available, the USEPA MCL was used as the basis for tap water BCLs. For chemicals not assigned an MCL, a risk-based tap water concentration was derived. Ambient air BCLs were derived in accordance with USEPA, 2009a.

Default exposure factors used to develop the BCL values were obtained primarily from the USEPA Exposure Factors Handbook (USEPA, 1997b) and the USEPA Supplemental Soil Screening Guidance (USEPA, 2002a). Table 1 lists all exposure factors used, their abbreviations used in the equations in this text, and the source. The equations for calculating the risk or hazard by exposure pathway, as well as for the combined soil pathway BCLs, are provided below.

3.1 Equations for Residential Land Use Scenario (Soil)

Ingestion of Carcinogenic Contaminants in Soil

Eq. 1

$$BCL \text{ mg/kg} = \frac{\text{TR} \times \text{AT} \times 365 \text{ days/year}}{SF_{\text{o}} \times 10^{-6} \text{ kg/mg} \times EF \times IFS_{adj}}$$

where:

TR	=	Target risk of 10^{-6}
AT	=	Averaging time (70 years)
SF_o	=	Oral cancer slope factor $(\text{mg/kg-day})^{-1}$
EF	=	Exposure frequency (350 days)
IFS_{adj}	=	Adjusted soil ingestion (mg-year)/(kg-day) = 114

Ingestion of Non-carcinogenic Contaminants

Eq. 2

$$BCL \text{ mg/kg} = \frac{\text{THQ} \times \text{BW} \times \text{AT} \times 365 \text{ days/year}}{\frac{1}{\text{RfD}_{\text{o}}} \times 10^{-6} \text{ kg/mg} \times EF \times ED \times IRS}$$

where:

THQ	=	Target hazard quotient of 1

BW	=	Body weight of child (15 kg)
AT	=	Averaging time for child (6 years)
RfD_o	=	Oral reference dose (mg/kg-day)
EF	=	Exposure frequency (350 days/year)
ED	=	Exposure duration of child (6 years)
IRS	=	Soil ingestion rate for child (200 mg/day)

Inhalation of Carcinogenic Contaminants

Eq. 3

$$BCL \text{ mg/kg} = \frac{\text{TR} \times \text{AT}}{IUR_{\text{i}} \times \text{EF} \times \text{ED} \times \text{ET} \times \text{CF} \times [(\frac{1}{\text{PEF}}) \text{ or } (\frac{1}{\text{VF}})]}$$

where:

TR	=	Target risk of 10^{-6}
AT	=	Averaging time (70 years x 365 days/year x 24 hours/day)
IUR_i	=	Inhalation unit risk (chemical-specific) $(\mu g/m^3)^{-1}$
EF	=	Exposure frequency (350 days/year)
ED	=	Exposure duration (30 years)
ET	=	Exposure time (24 hours/day)
CF	=	Conversion factor (1,000 µg/mg)
PEF	=	Particulate emission factor used for dusts (1.2×10^9 m^3/kg)
VF	=	Volatilization factor used for volatile organic chemicals (m^3/kg)

Inhalation of Non-carcinogenic Contaminants

Eq. 4

$$BCL \text{ mg/kg} = \frac{\text{THQ} \times \text{AT}}{\text{EF} \times \text{ED} \times \text{ET} \times \frac{1}{RfC_i} \times [(\frac{1}{\text{PEF}}) \text{ or } (\frac{1}{\text{VF}})]}$$

where:

THQ	=	Target hazard quotient of 1
AT	=	Averaging time for child (6 years x 365 days/year x 24 hours/day)
EF	=	Exposure frequency (350 days/year)
ED	=	Exposure duration for child (6 years)
ET	=	Exposure time (24 hours/day)
RfC_i	=	Inhalation reference concentration in (chemical specific) (mg/m^3)
PEF	=	Particulate emission factor used for dusts (1.2×10^9 m^3/kg)
VF	=	Volatilization factor used for volatile organic chemicals (m^3/kg)

Skin Contact of Carcinogenic Contaminants

Eq. 5

$$BCL \text{ mg/kg} = \frac{\text{TR} \times \text{AT} \times 365 \text{ days/year}}{SF_{\text{o}} \times \text{EF} \times SFS_{\text{adj}} \times \text{ABS} \times 10^{-6} \text{ kg/mg}}$$

where:

TR	=	Target risk of 10^{-6}
AT	=	Averaging time (70 years)
SF_o	=	Oral cancer slope factor (chemical specific) $(\text{mg/kg-day})^{-1}$
EF	=	Exposure frequency (350 days/year)
SFS_{adj}	=	Skin contact factor for soils (361 mg-year/kg-day)
ABS	=	Skin absorption (chemical specific)

Skin Contact of Non-carcinogenic Contaminants

Eq. 6

$$BCL \text{ mg/kg} = \frac{\text{THQ} \times \text{BW} \times \text{AT} \times 365 \text{ day/year}}{\text{EF} \times \text{ED} \times \frac{1}{\text{RfD}_{\text{o}}} \times 10^{-6} \text{ kg/mg} \times \text{SA} \times \text{AF} \times \text{ABS}}$$

where:

THQ	=	Target hazard quotient of 1
BW	=	Body weight of child (15 kg)
AT	=	Averaging time of child (6 years)
EF	=	Exposure frequency (350 days/year)
ED	=	Exposure duration of child (6 years)
RfD_o	=	Oral reference dose (chemical-specific) (mg/kg-day)
SA	=	Surface area of child (2800 cm^2/day)
AF	=	Adherence factor of child (0.2 mg/cm^2)
ABS	=	Skin absorption (chemical specific)

Soil BCL for Combined Exposure Pathways for Carcinogenic Contaminants for Residential Receptor

Eq. 7

$$BCL \text{ mg/kg} = \frac{1}{\frac{1}{\text{Eq. 1}} + \frac{1}{\text{Eq. 3}} + \frac{1}{\text{Eq. 5}}}$$

Soil BCL for Combined Exposure Pathways for Non-carcinogenic Contaminants for Residential Receptor-

Eq. 8

$$BCL \text{ mg/kg} = \frac{1}{\frac{1}{\text{Eq. 2}} + \frac{1}{\text{Eq. 4}} + \frac{1}{\text{Eq. 6}}}$$

Equation 4 for uses the PEF approach for solids and the VF approach for volatile compounds.

3.2 Equations for the Indoor Commercial/Industrial Worker Scenario (Soil)

Ingestion of Carcinogenic Contaminants

Eq. 9

$$BCL \text{ mg/kg} = \frac{\text{TR} \times \text{BW} \times \text{AT} \times 365 \text{ days/year}}{SF_{\text{o}} \times 10^{-6} \text{ kg/mg} \times \text{EF} \times \text{ED} \times \text{IRS}}$$

where:

TR	=	Target risk of 10^{-6}
AT	=	Averaging time (70 years)
BW	=	Body weight of adult (70 kg)
SF_o	=	Oral cancer slope factor (chemical specific) $(\text{mg/kg-day})^{-1}$
EF	=	Exposure frequency (250 days/year)
ED	=	Exposure duration (25 years)
IRS	=	Soil ingestion rate for adult (50 mg/day)

Ingestion of Non-carcinogenic Contaminants

Eq. 10

$$BCL \text{ mg/kg} = \frac{\text{THQ} \times \text{BW} \times \text{AT} \times 365 \text{ days/year}}{\frac{1}{\text{RfD}_{\text{o}}} \times 10^{-6} \text{ kg/mg} \times \text{EF} \times \text{ED} \times \text{IRS}}$$

where:

THQ	=	Target hazard quotient of 1
BW	=	Body weight of adult (70 kg)
AT	=	Averaging time (25 years)
RfD_o	=	Oral reference dose (chemical specific) (mg/kg-day)
EF	=	Exposure frequency (250 days/year)

ED = Exposure duration (25 years)
IRS = Ingestion rate for soil (50 mg/day)

Inhalation of Carcinogenic Contaminants

Eq. 11

$$BCL \text{ mg/kg} = \frac{\text{TR} \times \text{AT}}{IUR_{\text{i}} \times \text{EF} \times \text{ED} \times \text{ET} \times \text{CF} \times [(\frac{1}{\text{PEF}}) \text{ or } (\frac{1}{\text{VF}})]}$$

where:

TR = Target risk of 10^{-6}
AT = Averaging time (70 years x 365 days/year x 24 hours/day)
IUR_i = Inhalation unit risk (chemical-specific) $(\mu g/m^3)^{-1}$
EF = Exposure frequency (250 days/year)
ED = Exposure duration (25 years)
ET = Exposure time (8 hours/day)
CF = Conversion Factor (1,000 µg/mg)
PEF = Particulate emission factor used for dusts (1.2×10^9 m^3/kg)
VF = Volatilization factor used for volatile organic chemicals (m^3/kg)

Inhalation of Non-carcinogenic Contaminants

Eq. 12

$$BCL \text{ mg/kg} = \frac{\text{THQ x AT}}{\text{EF} \times \text{ED} \times \text{ET} \times (\frac{1}{\text{RfC}_{\text{i}}}) \text{ x } [(\frac{1}{\text{PEF}}) \text{ or } (\frac{1}{\text{VF}})]}$$

where:

THQ = Target hazard quotient of 1
AT = Averaging time (25 years x 365 days/year x 24 hours/day)
EF = Exposure frequency (250 days/year)
ED = Exposure duration (25 years)
ET = Exposure time (8 hours/day)
RfC_i = Inhalation reference concentration in (chemical specific) (mg/m^3)
PEF = Particulate emission factor used for dusts (1.2×10^9 m^3/kg)
VF = Volatilization factor used for volatile organic chemicals (m^3/kg)

Dermal contact pathway is not quantitatively evaluated as per USEPA (2002a, 2004).

Soil BCL for Combined Exposure Pathways for Carcinogenic Contaminants for Indoor Commercial/Industrial Worker

Eq. 13

$$BCL \text{ mg/kg} = \frac{1}{\frac{1}{\text{Eq. 9}} + \frac{1}{\text{Eq. 11}}}$$

Soil BCL for Combined Exposure Pathways for Non-carcinogenic Contaminants for Indoor Commercial/Industrial Worker

Eq. 14

$$BCL \text{ mg/kg} = \frac{1}{\frac{1}{\text{Eq. 10}} + \frac{1}{\text{Eq. 12}}}$$

3.3 Equations for the Outdoor Commercial/Industrial Worker Scenario (Soil)

Ingestion of Carcinogenic Contaminants

Eq. 15

$$BCL \text{ mg/kg} = \frac{\text{TR} \times \text{BW} \times \text{AT} \times 365 \text{ days/year}}{SF_o \times 10^{-6} \text{ kg/mg} \times \text{EF} \times \text{ED} \times \text{IRS}}$$

where:

TR	=	Target risk of 10^{-6}
AT	=	Averaging time (70 years)
BW	=	Body weight of adult (70kg)
SF_o	=	Oral cancer slope factor (chemical-specific) $(\text{mg/kg-day})^{-1}$
EF	=	Exposure frequency (225 days/year)
ED	=	Exposure duration (25 years)
IRS	=	Soil ingestion rate for adult (100 mg/day)

Ingestion of Non-carcinogenic Contaminants

Eq. 16

$$BCL \text{ mg/kg} = \frac{\text{THQ} \times \text{BW} \times \text{AT} \times 365 \text{ days/year}}{\frac{1}{\text{RfD}_\text{o}} \times 10^{-6} \text{ kg/mg} \times \text{EF} \times \text{ED} \times \text{IRS}}$$

where:

THQ	=	Target hazard quotient of 1
BW	=	Body weight of adult (70 kg)
AT	=	Averaging time (25 years)
RfD_o	=	Oral reference dose (chemical-specific) (mg/kg-day)
EF	=	Exposure frequency (225 days/year)
ED	=	exposure duration (25 years)
IRS	=	Soil ingestion rate for adult (100 mg/day)

Inhalation of Carcinogenic Contaminants

Eq. 17

$$BCL \text{ mg/kg} = \frac{\text{TR} \times \text{AT}}{IUR_\text{i} \times \text{EF} \times \text{ED} \times \text{ET} \times \text{CF} \times [(\frac{1}{\text{PEF}}) \text{ or } (\frac{1}{\text{VF}})]}$$

where:

TR	=	Target risk of 10^{-6}
AT	=	Averaging time (70 years x 365 days/year x 24 hours/day)
IUR_i	=	Inhalation unit risk (chemical specific) $(\mu g/m^3)^{-1}$
EF	=	Exposure frequency (225 days/year)
ED	=	Exposure duration (25 years)
ET	=	Exposure time (8 hours/day)
CF	=	Conversion Factor (1,000 µg/mg)
PEF	=	Particulate emission factor used for dusts (1.2×10^9 m^3/kg)
VF	=	Volatilization factor used for volatile organic chemicals (m^3/kg)

Inhalation of Non-carcinogenic Contaminants

Eq.18

$$BCL \text{ mg/kg} = \frac{\text{THQ} \times \text{AT}}{\text{EF} \times \text{ED} \times \text{ET} \times (\frac{1}{\text{RfC}_i}) \times [(\frac{1}{\text{PEF}}) \text{ or } (\frac{1}{\text{VF}})]}$$

where:

THQ	=	Target hazard quotient of 1
AT	=	Averaging time (25 years x 365 days/year x 24 hours/day)
EF	=	Exposure frequency (225 days/year)
ED	=	Exposure duration (25 years)
ET	=	Exposure time (8 hours/day)
RfC_i	=	Inhalation reference concentration in (chemical specific) (mg/m^3)
PEF	=	Particulate emission factor used for dusts ($1.2\times10^9 m^3/kg$)
VF	=	Volatilization factor used for volatile organic chemicals (m^3/kg)

Skin Contact with Carcinogenic Contaminants

Eq. 19

$$BCL \text{ mg/kg} = \frac{\text{TR} \times \text{BW} \times \text{AT} \times 365 \text{ days/year}}{\text{EF} \times \text{ED} \times SF_o \times 10^{-6} \text{ kg/mg} \times \text{SA} \times \text{AF} \times \text{ABS}}$$

where:

TR	=	Target risk of 10^{-6}
BW	=	Body weight of adult (70 kg)
AT	=	Averaging time of worker (25 years)
EF	=	Exposure frequency (225 days/year)
ED	=	Exposure duration of worker (25 years)
SF_o	=	Oral cancer slope factor (chemical specific) $(mg/kg\text{-}day)^{-1}$
SA	=	Surface area exposed for adult (3300 cm^2/day)
AF	=	Adherence factor (0.2 mg/cm^2)
ABS	=	Skin absorption (chemical specific)

Skin Contact with Non-carcinogenic Contaminants

Eq. 20

$$BCL \text{ mg/kg} = \frac{\text{THQ} \times \text{BW} \times \text{AT} \times 365 \text{ days/year}}{\text{EF} \times \text{ED} \times \frac{1}{\text{RfD}_o} \times 10^{-6} \text{ kg/mg} \times \text{SA} \times \text{AF} \times \text{ABS}}$$

where:

THQ	=	Target hazard quotient of 1

BW	=	Body weight of adult (70 kg)
AT	=	Averaging time of outdoor worker (25 years)
EF	=	Exposure frequency (225 days/year)
ED	=	Exposure duration of worker (25 years)
RfD_o	=	Oral reference dose (chemical specific) (mg/kg-day)
SA	=	Surface area exposed for adult (3300 cm^2/day)
AF	=	Adherence factor (0.2 mg/cm^2)
ABS	=	Skin absorption (chemical-specific)

Soil BCL for Combined Exposure Pathways for Carcinogenic Contaminants for Outdoor Commercial/Industrial Worker

Eq. 21

$$BCL \text{ mg/kg} = \frac{1}{\frac{1}{Eq.15} + \frac{1}{Eq.17} + \frac{1}{Eq.19}}$$

Soil BCL for Combined Exposure Pathways for Non-carcinogenic Contaminants for Outdoor Commercial/Industrial Worker

Eq.22

$$BCL \text{ mg/kg} = \frac{1}{\frac{1}{Eq.16} + \frac{1}{Eq.18} + \frac{1}{Eq.20}}$$

3.4 Equations for Ambient Air

Inhalation of Carcinogenic Contaminants

Eq. 23

$$BCL\ (\mu g/m^3) = \frac{\text{TR} \times \text{AT}}{\text{ET} \times \text{EF} \times \text{ED} \times IUR_i}$$

where:

TR	=	Target risk of 10^{-6}
AT	=	Averaging time (25 years x 365 days/year x 24 hours/day)
ET	=	Exposure time (24 hours/day)
EF	=	Exposure frequency (350 days/year)
ED	=	Exposure duration of adult resident (30 years)
IUR_i	=	Inhalation unit risk (chemical specific) $(\mu g/m^3)^{-1}$

Inhalation of Non-carcinogenic Contaminants

Eq.24

$$BCL\ (\mu g/m^3) = \frac{THQ \times AT \times 1{,}000\ \mu g/mg}{ET \times EF \times ED \times \frac{1}{RfC_i}}$$

where:

THQ	=	Target hazard quotient of 1
AT	=	Averaging time (6 years x 365 days/year x 24 hours/day)
ET	=	Exposure time (24 hours/day)
EF	=	Exposure frequency (350 days/year)
ED	=	Exposure duration (6 years)
RfC_i	=	Inhalation reference concentration (chemical-specific) (mg/m^3).

3.5 Equations for Residential Tap Water

Ingestion and Inhalation of Carcinogenic Contaminants

Eq. 25

$$BCL\ (\mu g/l) = \frac{TR \times AT \times 365\ days/year}{EF \times [(IFW_{adj} \times SF_o \times 0.001\ mg/\mu g) + (ED \times VF \times IUR_i)^*]}$$

where:

TR	=	Target risk of 10^{-6}
AT	=	Averaging time (70 years)
EF	=	Exposure frequency (350 days/year)
ED	=	Exposure duration (30 years)
IFW_{adj}	=	Ingestion factor for water (1.1 L-year/kg-day)
SF_o	=	Oral cancer slope factor (chemical specific) $(mg/kg\text{-}day)^{-1}$
VF	=	Volatilization factor for water (0.5 L/m^3)
IUR_i	=	Inhalation unit risk (chemical specific) $(\mu g/m^3)^{-1}$

* Inhalation component of the equation is calculated only for volatile organic chemicals.

Ingestion and Inhalation of Non-carcinogenic Contaminants

Eq. 26

$$BCL\ \mu g/L = \frac{THQ \times BW \times AT \times 365\ days/year \times 1{,}000\ \mu g/mg}{EF \times ED\ [(\frac{IRW}{RfD_o}) + (VF \times \frac{1}{RfC_i})^*]}$$

where:

THQ	=	Target hazard quotient of 1
BW	=	Body weight of adult (70 kg)
AT	=	Averaging time of resident (30 years)
EF	=	Exposure frequency (350 days/year)
ED	=	Exposure duration (30 years)
IRW	=	Drinking water ingestion (2 L/day)
RfD_o	=	Oral reference dose (chemical specific) (mg/kg-day)
VF	=	Volatilization factor for water (0.5 L/m^3)
RfC_i	=	Inhalation reference concentration (chemical specific) (mg/m^3)

*Inhalation part of equation only calculated for volatile organic chemicals

Table 1 provides the Standard Default Exposure Factors used in the preceding equations.

3.6 Development of Final Human Health Soil BCLs

Several values are compared in order to develop the final soil BCL. These include the comparison of the health-based BCL to a maximum soil concentration of 100,000 mg/kg for the less toxic chemicals, and to the soil saturation limit, the lower of which is used as the final BCL. These equations are listed below.

Residential Soil BCL

If the contaminant is a solid, the following applies:

Eq. 27a BCL (mg/kg) = Minimum value from Eq. 7, Eq. 8*, or 100,000 mg/kg

*Equation 8 uses the Eq. 4 option.

If the contaminant is not a solid, then the following applies:

Eq. 27b BCL (mg/kg) = Minimum value from saturation, Eq. 7, Eq. 8*, or 100,000 mg/kg

*Equation 8 uses the Eq. 4 option.

Commercial/Industrial Soil BCL

If the contaminant is a solid, the following applies:

Eq. 28a BCL (mg/kg) = Minimum value from Eq. 13, Eq. 14, or 100,000 mg/kg

If the contaminant is not a solid, the following applies:

Eq. 28b BCL (mg/kg) = Minimum value from saturation, Eq. 13, Eq. 14, or 100,000 mg/kg

Commercial/Industrial BCL

If the contaminant is a solid, the following applies:

Eq. 29a BCL (mg/kg) = Minimum value from Eq. 21, Eq. 22, or 100,000 mg/kg

If the contaminant is not a solid, the following applies:

Eq. 29b BCL (mg/kg) = Minimum value from saturation, Eq. 21, Eq. 22, or 100,000 mg/kg

Ambient Air BCL

Eq. 30 BCL ($\mu g/m^3$) = Minimum value from Eq. 23 or Eq. 24

Residential Water BCL

Eq. 31 BCL ($\mu g/L$) = MCL. If an MCL is not assigned, then the minimum value from Eq. 25 or Eq. 26 is used.

3.7 Screening with Multiple Contaminants

A suggested stepwise approach for BCL-screening of sites with multiple pollutants (for each environmental medium of interest) is as follows:

- Compile existing site data.
- Use the CSM to identify all known and potential site contaminants in the BCL Table. Record the BCL concentrations for various media and note whether the chemical has been assigned cancer (indicated by "ca") and/or non-cancer (indicated by "nc") toxicological criteria. Segregate cancer BCLs from non-cancer BCLs and exclude (but do not eliminate) non-risk based BCLs ("sat" or "max").

- For cancer risk estimates, divide the site exposure point concentration (maximum or 95% UCL) by the BCL concentration designated for cancer evaluation ("ca"). Multiply this ratio by 10^{-6} to estimate chemical-specific risk for a reasonable maximum exposure (RME). For multiple pollutants, add this risk estimate for each chemical as follows:

$$Risk = \left[\left(\frac{Conc_x}{BCL_x}\right) + \left(\frac{Conc_y}{BCL_y}\right) + \ldots + \left(\frac{Conc_z}{BCL_z}\right)\right] \times 10^{-6}$$

- For non-cancer hazard estimates, divide the site exposure point concentration term by the respective non-cancer BCL (designated as "nc") and sum the ratios for multiple contaminants. The cumulative ratio represents a screening non-cancer hazard index (HI). A screening hazard index of 1 or less is considered "safe". A ratio greater than 1 suggests the need for further evaluation (see USEPA, 1989a, page 8-14 for segregation of hazard indices by effect and mechanism of action). [Note that carcinogens may also have an associated non-cancer BCL that is not listed in the BCL Table. To obtain these values, the user should view or download the BCL Calculations Tables at the BCL website and display the appropriate sections.]

$$Hazard\ Index = \left[\left(\frac{Conc_x}{BCL_x}\right) + \left(\frac{Conc_y}{BCL_y}\right) + \ldots + \left(\frac{Conc_z}{BCL_z}\right)\right]$$

For initial screening of data when multiple chemicals have been released, a simplified conservative approach of employing one-tenth of the BCL can be applied.

3.8 BCLs for Chemicals with Special Considerations

Most of the BCLs are derived using the equations provided in Sections 3.1 through 3.5. However, there are some chemicals for which the additional information is required. These special cases are discussed below

Asbestos

Technical Guidance for the Calculation of Asbestos-Related Risk in Soils for the Basic Management Incorporated (BMI) Complex and Common Areas (NDEP, 2009a) (http://ndep.nv.gov/bmi/docs/090424_asbestos_guidance_apr09.pdf) provides a guidance framework for characterizing asbestos-related risks (ARR) in soils. This NDEP guidance document provides methodological direction to evaluate soil disturbing activities in areas with known or suspected presence of asbestos contaminated soils and is based on the 2003 draft protocol for assessing ARR prepared for USEPA's Office of Solid Waste and Emergency Response (OSWER) (Berman and Crump, 2003, Berman 2003a; 2003b; 2005). This guidance document is also accompanied by a spreadsheet that can be used as a template for estimating ARR. At present, the inhalation cancer potency factor for asbestos fibers provided by USEPA in the Integrated Risk Information System (IRIS) electronic database[8] is based on dose-response

[8] A database of non-cancer and cancer health effects information maintained by USEPA's National Center for Environmental Assessment (NCEA), used to support risk assessment activities under Superfund and other USEPA programs.

information summarized in USEPA (1986). The NDEP has chosen to utilize the more recent methodology for assessing ARR proposed in Berman and Crump (2003) and fully described in the guidance document.

Cadmium

Because IRIS provides different oral RfDs for cadmium in water and in foods, the BCL for cadmium in water is based on the oral RfD for water, and the BCL for soil ingestion is based on the RfD for food.

4,4-Dichlorobenzil

In the absence of 4,4-dichlorobenzil toxicity criteria from standard hierarchy of sources, NDEP has provided interim guidance on this chemical (NDEP, 2009b). This guidance may be found at http://ndep.nv.gov/bmi/docs/090115_dichlorobenzil.pdf and provides an interim RfD for dichlorobenzil of 3.0×10^{-4} mg/kg-d.

Hexachlorocyclohexane (HCH)

The NDEP has adopted a threshold dose value for alpha-, beta-, and gamma-HCH for use in quantifying potential human health risks at the BMI Complex (Integral 2011a, b, and c). The criteria documents supporting this decision are provided on the NDEP BMI Complex website (http://ndep.nv.gov/bmi/technical.htm). These toxicity values have been incorporated into the BCLs for these compounds.

Essential Nutrients; Specifically Calcium, Potassium, and Sodium

Calcium, potassium, and sodium are essentially nutrients and are on the Generally Recognized As Safe (GRAS) list of the Food and Drug Administration (FDA, 2011).

> "GRAS exemptions are granted for substances that are generally recognized, among experts qualified by scientific training and experience to evaluate their safety, as having been adequately shown through scientific procedures …to be safe under the conditions of their intended use." FDA, 2011
>
> "There is no evidence in the available information on [substance] that demonstrates, or suggests reasonable grounds to suspect, a hazard to the public when they are used at levels that are now current or might reasonably be expected in the future." FDA, 2011

Therefore, these three elements do not need to be included in a risk assessment for potential human health impacts unless they are present in a compound that is a regulated chemical agent and/or in compounds present at concentrations that may create a health hazard through physical/chemical properties (e.g., extremely low or high pH having caustic potential).

Lead

The residential soil value for lead is based on the Integrated Exposure Uptake Biokinetic (IEUBK) Model for lead in children developed using default parameters (USEPA, 1994). More information on this model and other lead risk assessment guidance can be found at

http://www.epa.gov/superfund/health/contaminants/lead/index.htm. The industrial BCL is based on equations developed by the technical review group (adult lead model), as described below.

The Adult Lead Model (ALM) is a tool for assessing risks associated with **non-residential** adult exposures to lead in soil. The ALM focuses on estimating fetal blood lead concentrations in pregnant women exposed to lead-containing soils in a commercial/industrial setting. It is the product of extensive evaluations by the Technical Review Workgroup for Lead (TRW). In December 1996, the TRW released the document *Recommendations of the Technical Review Workgroup for Lead for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil* (*TRWR*; USEPA, 1996d), which describes the equations and default parameters that can be used with the ALM.

Magnesium

Magnesium does not have a toxicity criterion, thus an oral RfD was derived using the National Institute of Health (NIH) Recommended Daily Allowance data. An age-adjusted oral RfD was derived using the age-specific RDAs provided by NIH (http://ods.od.nih.gov/factsheets/magnesium.asp). The soil BCLs were derived as described in Section 3.0 using the derived oral RfD. The tap water BCL was calculated using the oral RfD and the methods described in Section 3.5 and was subsequently used in the derivation of a LBCL for magnesium.

Manganese

The IRIS RfD (0.14 mg/kg-day) includes manganese from all sources, including the diet. The IRIS assessment on manganese recommends that the dietary contribution from the normal U.S. diet (an upper limit of 5 mg/day) be subtracted when evaluating non-food (e.g., drinking water or soil) exposures to manganese, leading to an RfD of 0.071 mg/kg-day for non-food items. The explanatory text in IRIS further recommends using a modifying factor of 3 when calculating risks associated with non-food sources, due to a number of uncertainties that are discussed in the IRIS file for manganese, leading to an RfD of 0.024 mg/kg-day. This modified RfD is applied in the derivation of manganese BCLs for soil and water.

Methyl Iodide

The USEPA has determined a human equivalent concentration (HEC)-based on a NOAEL for methyl iodide of 0.89 ppm (5.2 mg/m^3). The toxic endpoint is based on an increased incidence of salivary gland squamous cell metaplasia (USEPA, 2006). USEPA applied a total uncertainty factor of 30 to account for interspecies extrapolation (UF = 3) and intraspecies extrapolation (UF = 10), resulting in an RfC of 0.17 mg/m^3.

Perchlorate

The residential drinking water BCL for perchlorate is based upon the provisional Nevada Action Level of 18 ppb.

Polychlorinated Dibenzo-p-dioxins, Dibenzofurans, and Some Polychlorinated Biphenyls

The USEPA OSWER Directive 9200.4-26 (USEPA, 1989b) identified a preliminary soil remediation goal of 1 part per billion (ppb) for total dioxin toxicity equivalents (TEQ) at Superfund sites for assumed residential land use, and 5 to 20 ppb TEQ for industrial or

commercial land uses. Since this OSWER Directive was issued in 1998, the USEPA issued two sets of documents (USEPA 2000, 2003b) describing their reassessment of the underlying scientific issues pertaining to the risk assessment of dioxins. These documents support some modification to the 1998 preliminary remediation goals. The reassessment proposed that the toxicity criteria for assessing both carcinogenic and non-carcinogenic effects of dioxins should be adjusted to reflect a more conservative judgment based on recent toxicological studies and concerns that background doses and body burdens in humans do not provide an adequate margin of safety. To date, however, no new USEPA guidance regarding soil screening levels for dioxins has been issued, despite the extensive analyses presented in the dioxin reassessment documents.

One of the key premises of the dioxin reassessment documents was the recent publication of dioxin cancer potency estimates that were based on epidemiological studies. The current dioxin cancer potency estimate of 1.56×10^5 per $(mg/kg\text{-}day)^{-1}$ based on a rat bioassay (Kociba et al., 1978) was suggested to be considerably lower than potency estimates suggested by the epidemiology studies of Becher et al. [1998; 2.2×10^6 $(mg/kg\text{-}day)^{-1}$], Steenland et al. [2001; 1.5×10^6 per $(mg/kg\text{-}day)^{-1}$] and a meta-analysis by USEPA [2003b; 1.1×10^6 (per $mg/kg\text{-}day)^{-1}$]. USEPA (2000, 2003b) also suggested that alternative dose-response modeling of the rat cancer bioassays could support dioxin potency factors in the same range, e.g., 1.1 to 1.4×10^6 per $(mg/kg\text{-}day)^{-1}$. On the other hand, a recent National Toxicology Program rat study (NTP, 2004) reported much lower tumor rates in the same rat strain tested by Kociba et al. (1978). Crouch et al. (2005) estimated this new study would yield a dioxin cancer potency of approximately 1.6×10^4 per $(mg/kg\text{-}day)^{-1}$. The technical issues surrounding this range of cancer potency estimates have been reviewed by Paustenbach et al. (2006).

In view of the current uncertainties about the most appropriate regulatory risk assessment approach for dioxins, NDEP utilized the 1998 OSWER Directive with a modification to address recently identified uncertainties regarding cancer potency in humans. There is approximately one order of magnitude (10-fold) difference between the current USEPA cancer potency factor (which was used to derive the OSWER Directive soil goal of 5 to 20 ppb for industrial/commercial sites) and the midpoint of the epidemiology-based cancer potency estimates discussed above. Applying a 10-fold uncertainty factor to the 5 to 20 ppb soil screening range results in a range of 0.5 to 2 ppb for consideration for a NDEP soil screening level for industrial/commercial land use. Based on this range, a single value of 1 ppb TEQ was selected as an appropriate BCL for industrial/commercial sites. For residential sites, NDEP has adopted the ATSDR soil "screening level" of 50 ppt (0.00005 mg/kg) for residential sites (ATSDR, 2008).

Polycyclic Aromatic Hydrocarbons (PAHs)

USEPA has developed a potency factors approach for calculating the potential health risks from PAHs with the characteristic "Bay-K region," a structural distinction that defers carcinogenic properties to benzo-a-pyrene (BaP) and the other carcinogenic PAHs (USEPA, 1993). BaP is the best characterized and most potent of the carcinogenic PAH compounds, and hence, the slope factors for BaP are used in conjunction with the potency factor approach to calculate a BaP equivalent (BaPEq) concentration. Accordingly, each of the carcinogenic PAHs must be multiplied by its associated potency factor to calculate the BaPEq. For each site sample, the summed BaPEq concentration is compared to the BCL for BaP. The TEFs are as follows:

benzo(a)pyrene (1.0), benzo(a)anthracene (0.1), benzo(b)fluoranthene (0.1), benzo(k)fluoranthene (0.01), chrysene (0.001), dibenz(a,h)anthracene (1.0), and indeno(1,2,3,-cd)pyrene (0.1) (USEPA, 1993). If one of these seven PAHs is detected at a site, then all seven should be addressed for BaPEqs. One half the detection limit in BaPEqs should be used for all non-detect results.

Thallium

IRIS has many values for the different salts of thallium. However, analytical data packages typically report only total thallium. Therefore, a BCL based on total thallium was derived for practical purposes by adjusting the thallium sulfate RfD by the molecular weight of thallium to derive a thallium-only RfD of 6.6×10^{-5} mg/kg-day.

Total Petroleum Hydrocarbons

Petroleum hydrocarbon mixtures in soils, such as gasoline, kerosene, diesel, or waste oils, are relatively common, and some groups have attempted to develop non-cancer toxicity criteria based on selected petroleum fractions such as gasoline- or diesel-range hydrocarbons. At present, NDEP does not recommend using these petroleum fraction toxicity criteria. Instead, the indicator chemicals for common petroleum hydrocarbon mixtures should be evaluated, including benzene, toluene, ethylbenzene, and total xylenes (BTEX); MTBE (and other oxygenates and/or additives, where relevant); and PAHs. Demonstrating compliance with respect to these indicator compounds will be assumed to also minimize any risks attributable to other petroleum-fraction components in soils.

Vinyl Chloride

IRIS (USEPA, 2009b) presents two cancer slope factors for vinyl chloride—one for adult exposures and a second, more protective, slope factor to account for the unique susceptibility identified in young animals that suggests a greater susceptibility to vinyl chloride carcinogenicity in young children. The more conservative factor for children is applied for the BCL corresponding to residential vinyl chloride exposure scenarios, and includes an assumption of lifetime (70 years) exposure for residential receptors as an added conservative measure based on USEPA Region 9 recommendations. The adult exposure cancer slope factor is used as the basis for the commercial/industrial BCL.

Chemicals for Which the BCL is Based on a Toxicological Surrogate

Soil BCLs for the following chemicals that are based on a toxicological surrogate approach include:

- Acenaphthalene
- Benzo[g,h,i]perylene
- Phenanthrene
- Diethyl phosphorodithioate(DEPT)
- Dimethyl phosphorodithioate (DMPT)
- m-Phthalic acid
- o-Phthalic acid
- p-Chlorobenzene sulfonic acid (pCBSA)
- Benzene sulfonic acid (BSA)

Documentation of the basis of the surrogate selection for each of these chemicals is provided in Appendix B.

In addition to the surrogate toxicity values discussed above, several VOCs in the BCL tables had oral toxicity values but were lacking inhalation (RfC) values. In the absence of toxicity values from the usual hierarchy of sources, surrogate values were derived based upon structure activity relationships and similar target organs (when possible). These chemicals along with their surrogate RfCs and the source chemical for the surrogate values are provided in Table B-2.

4.0 LEACHING-BASED BCLS (LBCLS)

Leaching-based soil screening levels (LBCLs) (on a dry-weight basis) are provided to evaluate the migration to groundwater pathway. Migration of contaminants from soil to groundwater is evaluated as a two-stage process: (1) release of contaminant in soil leachate into groundwater, and (2) dilution of the contaminant upon mixing in groundwater. The LBCL methodology considers both of these transport mechanisms. The USEPA has previously derived soil to groundwater screening levels for several constituents in their *Soil Screening Guidance* (USEPA, 1996a). These values are presented in the BCL Table and the reader is advised to refer to the original USEPA guidance document for their derivation.

Additional LBCLs were derived in accordance with USEPA methodology (1996a) for 15inorganic constituents that have not been derived by the USEPA (1996a) but are included as Site-Related Chemicals (SRCs) at the BMI Complex and Common Areas site, which are:

- Aluminum
- Boron
- Cobalt
- Copper
- Iron
- Lithium
- Magnesium
- Manganese
- Mercury
- Molybdenum
- Nitrate
- Perchlorate
- Titanium
- Tungsten
- Uranium

Also, LBCLs were derived in accordance with USEPA methodology (1996a) for α - hexachlorocyclohexane and β - hexachlorocyclohexane for which the noncancer RfD were updated. Other than the RfD used to estimate the risk-based groundwater concentration for these two chemicals, the same parameters used in USEPA (1996a) were used to develop their LBCLs.

LBCLs were calculated for the 15 inorganic constituents based upon the assumption that the constituent is in equilibrium with the concentration in the adsorbed (soil matrix) phase, the soils are near neutral pH (~6.8), and application of a simple water-balance equation that calculates a dilution factor to account for dilution of soil leachate in an aquifer (USEPA, 1996a). The dilution factor is expressed as the ratio of leachate concentration to the concentration in groundwater at the receptor point. Accordingly, USEPA refers to this factor as a dilution attenuation factor (DAF). It should be noted that if the soils of interest are not near the specified pH used to develop the LBCLs of 6.8, then the LBCLs may not be used for screening purposes.

The chemical-specific LBCL is back-calculated from a risk-based groundwater concentration (RBCG) (e.g., non-zero MCLGs, MCLs, or other risk-based screening level). As a first step, the RBCG is derived based on the assumptions of a 70-kilogram body weight and ingestion of two liters of water per day. For carcinogens, a target risk of 10^{-6} was employed; for non-carcinogens, a hazard quotient of 1 was employed. As a second step, the RBGC is multiplied by a dilution factor to obtain a target leachate concentration.

Dilution-attenuation processes are physical, chemical, and biological processes that tend to reduce the eventual contaminant concentration at the receptor point and are expressed by a DAF (USEPA, 1996a). When calculating a LBCL value, a DAF is used to back-calculate the target soil leachate concentration from a risk-based groundwater concentration (*e.g.*, maximum contaminant level [MCL] or tap water BCL as presented in the BCL Table). For example, if the RBGC is 0.05 milligrams per liter (mg/L) and the DAF is 10, the target leachate concentration would be 0.5 mg/L. Expressed mathematically:

Eq. A

$$C_L = DAF \times RBGC$$

Where

C_L	=	target leachate concentration (mg/L_W)
DAF	=	dilution-attenuation factor (unitless)
RBGC	=	risk-based groundwater concentration (*e.g.*, maximum contaminant level [MCL] or tap water BCL) (mg/L_w)

The target leachate concentration C_L is related to the concentration sorbed on the soil matrix C_S by the soil-water partition coefficient K_d. Assuming equilibrium between the aqueous phase[9] and adsorbed (soil matrix) phase in the unsaturated zone and that adsorption is linear with respect to concentration:

Eq. B

$$K_d = \frac{C_S}{C_L}$$

where:

[9] The calculation of LBCLs assumes that non-aqueous phase liquids (NAPLs) are not present.

K_d	=	soil-water partition coefficient (mg/kg_S per mg/L_W or L_W/kg)
C_S	=	concentration sorbed on soil matrix (mg/kg)
C_L	=	target leachate concentration (mg/L_W).

To develop the LBCLs the sorbed concentration C_S needs to be related to the total concentration measured in a soil sample. Equation 22 of USEPA 1996a relates C_S, using the above relationship between C_S and C_L, to the total concentration measured in soil (C_T) on a dry weight basis as follows:

Eq. C

$$C_T = C_L \left(K_d + \frac{\theta_W}{\rho_b} + \frac{\theta_A H'}{\rho_b} \right)$$

where:

C_T	=	total concentration (on a dry weight basis) based on mass of analyte in soil air, soil moisture, and soil matrix (mg/kg_T)
C_L	=	target leachate concentration (mg/L_W).
K_d	=	soil-water partition coefficient (mg/kg_S per mg/L_W or L_W/kg_S)
θ_W	=	moisture content ($cm^3{}_W/cm^3{}_T$)
ρ_b	=	dry bulk density ($g_S/cm^3{}_T$)
θ_A	=	air-filled porosity ($cm^3{}_A/cm^3{}_T$)
H'	=	dimensionless Henry's law constant (unitless)

Substituting Eqn. A into Eqn. C gives:

Eq. D

$$C_T = (DAF \times RBGC) \times \left(K_d + \frac{\theta_W}{\rho_b} + \frac{\theta_A H'}{\rho_b} \right)$$

when expressed in this manner, C_T is equal to LBCL:

Eq. E

$$LBCL = (DAF \times RBGC) \times \left(K_d + \frac{\theta_W}{\rho_b} + \frac{\theta_A H'}{\rho_b} \right)$$

Consistent with USEPA 1996a (page 37) mercury is the only volatile inorganic constituent for which an LBCL was derived; the remaining inorganic constituents are assumed to be non-volatile (*i.e.*, H' is assumed to be zero).

Also consistent with USEPA 1996a, LBCL values are presented in this guidance for DAF values of 1 and 20. The LBCLs were developed using a DAF of 20 to account for natural processes that reduce chemical concentrations in the subsurface soil and groundwater. Also included are LBCLs that assume no dilution or attenuation between the source and the receptor (i.e., a DAF of 1). These values can be used at sites where little or no dilution or attenuation of soil leachate

concentrations is expected at a site (e.g., sites with shallow water tables, fractured media, karst topography, or source size greater than 30 acres).

The LBCL values (for DAF = 1 and 20) calculated using Equation E, along with the sources of the various parameter values, are listed in Appendix D Table D-1.

Further NDEP guidance on leaching from soil to groundwater is provided in the following documents:

http://ndep.nv.gov/bmi/docs/cover_let-%20leach_guidance.pdf
http://ndep.nv.gov/bmi/docs/100116%20leaching_guidance.pdf

5.0 BCLS FOR RADIONUCLIDES

Radionuclide health effects are based on the deposition of energy in body tissues resulting from radioactive decay. Soil BCLs were calculated for direct exposure pathways related to an individual exposed to site soils, and also for protection of groundwater from leaching of soil radionuclides over time. For each radionuclide, soil BCLs related to direct exposure (ingestion, inhalation, and external irradiation) are back-calculated from a target risk level of one-in-a-million (1×10^{-6}) incremental lifetime cancer risk. BCLs for the migration-to-groundwater pathway are back-calculated from the following groundwater activity limits (in order of preference): non-zero maximum contaminant level goals (MCLGs), maximum contaminant levels (MCLs), or risk-based limits based on a cancer risk of 1×10^{-6}.

Radionuclide BCLs are calculated for a limited number of radionuclides for which soil samples are routinely analyzed at the BMI Complex and Common Areas. These radionuclides include isotopic uranium (uranium-234, uranium-235, uranium-238), isotopic radium (radium-226 and radium-228), and isotopic thorium (thorium-228, thorium-230, and thorium-232). The BCLs for these eight radionuclides and the basis of their derivation are presented in Appendix E.

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Appendix A

Annotation of Updates to the BCL Table

February 2009

1. Corrections to Equations 1 and 4 under Section 2.7.
2. Addition of an Indoor Commercial/Industrial Worker screening values to the BCL Table.
3. Addition of BCLs for lithium, titanium, tungsten, and uranium.
4. Correlation of the "a" footnote in the BCL table to lead.
5. Update to the PEF to reflect the Las Vegas meteorological zone per USEPA (1996a) guidance.
6. Update to the iron oral reference dose from 0.003 to 0.7 mg/kg-day.
7. Removal of the cancer classification for 1,2-dibromoethane from the BCL table.
8. Oral SF for dicofol added to BCL table.
9. Inhalation RfD updated for ethylene glycol.
10. Inhalation RfD for tetrachloroethylene removed from BCL table.
11. Appendix C and Table C-1 added to present source of "other" toxicity criteria.

June 2009

1. Citations corrected in Table 1.
2. Text edits and reformatting of Guidance Document.
3. BCL for magnesium added to table.
4. Radionuclide BCLs added as Appendix D.
5. Leaching based BCLs (LBCLs) added for Aluminum, Boron, Cobalt, Copper, Iron, Magnesium, Manganese, Mercury, Molybdenum, Titanium, Tungsten, and Uranium.
6. Asbestos BCL added.
7. Inhalation pathways revised consistent with USEPA RAGS Part F guidance.
8. Toxicity criteria updated with latest values from IRIS.
9. MCLs used as residential tap water BCLs when available.
10. Dioxin/Furan TEQ BCLs updated.

November 2009

1. Technical HCH removed from table.
2. Soil pH for LBCLs stated.
3. Links in the calculation spreadsheet were corrected for the IURs and their associated citations. It is believed that this error occurred during the June 2009 update. This error is not believed to have materially impacted the resulting BCLs and is noted here for completeness.
4. Uranium LBCL removed from Appendix E; the main BCL table provides an LBCL for this constituent.

August, 2010

1. Email contact for questions or errors updated.
2. Typographical errors corrected.
3. BCL Spreadsheet updated to reflect correct BCLs for dioxin TEQs.
4. Removed route-to-route extrapolations for inhalation toxicity criteria including Table B-1.
5. Clarification that air BCLs are for outdoor air only. Indoor air is not addressed by BCLs.
6. PAH BaPEqs methodology clarified to direct user to include all seven carcinogenic PAHs if one or more are detected in site media.
7. 2-Hexanone added to BCL spreadsheets.
8. Updated BCLs with additions of surrogate-based inhalation toxicity values as provided in Table B-2.
9. Corrected the tapwater BCLs to reflect MCLs when available.
10. Updated Industrial/Commercial worker BCLs for 8 of 24 hours (as appropriate).

January, 2011

1. Minor typographical errors corrected for various entries.
2. Toxicity criteria values updated.
3. For 2,3,7,8-TCDD (1746-01-6), there were two entries in the BCL table and BCL calculation sheet for this chemical, one labeled "Dioxin (2,3,7,8-TCDD)" and another labeled "2,3,7,8-TCDD (Dioxin)." The entry labeled "Dioxin (2,3,7,8-TCDD)" was deleted from the BCL table and the BCL calculations.
4. For octahydro-1357-tetranitro-1357-tetrazocine (HMX) (2691-41-0), there were two entries in the BCL table and BCL calculation sheet for this chemical, one labeled "HMX" and another labeled "octahydro-1357-tetranitro-1357-tetrazocine (HMX)." The entry labeled "HMX" was deleted from the BCL table and the BCL calculations.
5. Four chemicals were added to the BCL tables and BCL calculation tables: 1,2-dichlorotetrafluorethane (1717-00-6), ethanol (64-17-5), n-heptane (142-82-5), and n-octane (111-65-9). All four are VOCs and surrogate RfC values were used.

January, 2012

1. NDEP approved HCH reference doses included in the BCL tables.
2. Equations C, D, and E were edited for minor corrections in Section 4.0.
3. Toxicity criteria values updated.
4. Tap water BCLs for VOCs were corrected for a calculation error.

May, 2012

1. Leaching LBCL added for lithium, nitrate, and perchlorates.

Appendix B

Documentation for Toxicological Surrogates

TABLE B-1 TOXICOLOGICAL SURROGATES APPLIED FOR BCLS

Chemical	CAS #	Surrogate	Surrogate CAS Number	Oral RfD (mg/kg-day)
Acenaphthalene	208-96-8	pyrene	129-00-0	3.0×10^{-2} (IRIS)
Benzo[g,h,i]perylene	191-24-2	pyrene	129-00-0	3.0×10^{-2} (IRIS)
Phenanthrene	85-01-8	pyrene	129-00-0	3.0×10^{-2} (IRIS)
Diethyl phosphorodithioate (DEPT)	298-06-6	diisopropyl methylphosphonate (DIMP)	1445-75-6	8.0×10^{-2} (Integral, 2006; NDEP, 2007)
Dimethyl phosphorodithioate (DMPT)	756-80-9	isopropyl methylphosphonate (IMPA)	1832-54-8	1.0×10^{-1} (Integral, 2006; NDEP, 2007)
m-Phthalic acid	121-91-5	phthalic anhydride	85-44-9	2.0×10^{0} (IRIS)
o-Phthalic acid	88-99-3	phthalic anhydride	85-44-9	2.0×10^{0} (IRIS)
p-Chlorobenzene sulfonic acid (pCBSA)	98-66-8	NA (RfD based on pCBSA study)	NA	1.0×10^{0} (derived by Integral, 2007)
Benzene sulfonic acid (BSA)	98-11-3	p-toluenesulfonic acid (pTSA)	104-15-4	5.0×10^{-1} (derived by Integral, 2007)

Integral Consulting, Inc., 2006. Development of Human Health Toxicological Criteria for DMPT and DEPT, October 31. http://ndep.nv.gov/bmi/docs/061031%20surrogate_toxicity_report_20061031_final_integral.pdf

Integral Consulting, Inc., 2007. Toxicological Profiles for Three Organic Acids, November 16, 2007 (p. 3-3). http://ndep.nv.gov/bmi/docs/071116-organicacidprofiles.pdf

TABLE B-1 TOXICOLOGICAL SURROGATES APPLIED FOR BCLS

NDEP, 2007. NDEP concurrence regarding the derivation of toxicological surrogates for DEPT and DMPT, February 12. http://ndep.nv.gov/bmi/docs/070212_dmpt_dept.pdf

Note: all surrogate derivations can be found at http://ndep.nv.gov/bmi/technical.htm under “Toxicology”.

Table B-2.
Surrogate Inhalation Toxicity Criteria for Volatile Organic Compounds
NDEP Basic Comparison Levels

Chemical Constituents	CAS	Why On List?	Chemical Surrogate	Surrogate CAS	Surrogate RfC (mg/m^3)	Surrogate Criterion Source
Acetophenone	98-86-2	BCLs	Isopropylbenzene (Cumene)	98-82-8	4.00E-01	USEPA, 2010a
Benzaldehyde	100-52-7	BCLs	Isopropylbenzene (Cumene)	98-82-8	4.00E-01	USEPA, 2010a
Bromodichloromethane	75-27-4	BCLs	Dichloromethane	75-09-2	1.00E+00	ATSDR, 2010
n-Butylbenzene	104-51-8	BCLs	Isopropylbenzene (Cumene)	98-82-8	4.00E-01	USEPA, 2010a
sec-Butylbenzene	135-98-8	BCLs	Isopropylbenzene (Cumene)	98-82-8	4.00E-01	USEPA, 2010a
tert-Butylbenzene	98-06-6	BCLs	Isopropylbenzene (Cumene)	98-82-8	4.00E-01	USEPA, 2010a
1-Chlorobutane	109-69-3	BCLs	Ethyl chloride	75-00-3	1.00E+01	USEPA, 2010a
beta-Chloronaphthalene	91-58-7	BCLs	beta-Chloronaphthalene	91-58-7	1.00E-03	RIVM (TERA 2010)
2-Chlorophenol	95-57-8	BCLs	Chlorobenzene	108-90-7	5.00E-02	PPRTV (USEPA, 2010b)
o-Chlorotoluene	95-49-8	BCLs	Chlorobenzene	108-90-7	5.00E-02	PPRTV (USEPA, 2010b)
1,2-Dichloroethylene (cis)	156-59-2	BCLs	trans-1,2-Dichloroethylene	156-60-5	6.00E-02	PPRTV (USEPA, 2010b)
1,3-Dichloropropane	142-28-9	BCLs	1,2-Dichloropropane	78-87-5	4.00E-03	USEPA, 2010a
N-N-Dimethylaniline	121-69-7	BCLs	Aniline	62-53-3	1.00E-03	USEPA, 2010a
Ethyl acetate	141-78-6	BCLs	Methyl methacrylate	80-62-6	7.00E-01	USEPA, 2010a
Ethyl ether	60-29-7	BCLs	Methyl tert-Butyl Ether (MTBE)	1634-04-4	3.00E+00	USEPA, 2010a
Ethyl methacrylate	97-63-2	BCLs	Methyl methacrylate	80-62-6	7.00E-01	USEPA, 2010a
Furan	110-00-9	BCLs	Tetrahydrofuran	109-99-9	3.50E-02	RIVM (TERA 2010)
Isobutanol	78-83-1	BCLs	sec-Butyl Alcohol	78-92-2	3.00E+01	PPRTV (USEPA, 2010b)
Methyl acetate	79-20-9	BCLs	Methyl methacrylate	80-62-6	7.00E-01	USEPA, 2010a
Methyl acrylate	96-33-3	BCLs	Methyl methacrylate	80-62-6	7.00E-01	USEPA, 2010a
Methylene bromide	74-95-3	BCLs	Methylene bromide	74-95-3	4.00E-03	USEPA, 2010a
Methyl styrene (alpha)	98-83-9	BCLs	Styrene	100-42-5	1.00E+00	USEPA, 2010a
Polynuclear Aromatic Hydrocarbons	--	--	--	--	--	--
Acenaphthene	83-32-9	BCLs	Naphthalene	91-20-3	3.00E-03	USEPA, 2010a
Acenaphthylene	208-96-8	BCLs	Naphthalene	91-20-3	3.00E-03	USEPA, 2010a
Anthracene	120-12-7	BCLs	Naphthalene	91-20-3	3.00E-03	USEPA, 2010a
Fluorene	86-73-7	BCLs	Naphthalene	91-20-3	3.00E-03	USEPA, 2010a
Phenanthrene	85-01-8	BCLs	Naphthalene	91-20-3	3.00E-03	USEPA, 2010a
Pyrene	129-00-0	BCLs	Naphthalene	91-20-3	3.00E-03	USEPA, 2010a
n-Propylbenzene	103-65-1	BCLs	Isopropylbenzene (Cumene)	98-82-8	4.00E-01	USEPA, 2010a
Pyridine	110-86-1	BCLs	Trichloracetic acid	76-03-9	1.20E-01	TERA 2010
1,1,2-Trichloropropane	598-77-6	BCLs	1,2,3-Trichloropropane	96-18-4	3.00E-04	USEPA, 2010a
1,3-Dichlorobenzene	541-73-1	TO-15	1,2-Dichlorobenzene	95-50-1	2.00E-01	HEAST
4-Isopropyltoluene	99-87-6	TO-15	Isopropylbenzene (Cumene)	98-82-8	4.00E-01	USEPA, 2010a
Methyl Iodide	74-88-4	TO-15	USEPA HEC	74-88-4	1.70E-01	USEPA, 2006
1,3,5-Trimethyl Benzene	108-67-8	TO-15	1,2,4-Trimethylbenzene	95-63-6	7.00E-03	PPRTV (USEPA, 2010b)
para-Ethyltoluene	622-96-8	TO-15	Isopropylbenzene (Cumene)	98-82-8	4.00E-01	USEPA, 2010a
Isobutylbenzene	538-93-2	TO-15	Isopropylbenzene (Cumene)	98-82-8	4.00E-01	USEPA, 2010a
Isopropyl Alcohol	67-63-0	TO-15	sec-Butyl Alcohol	78-92-2	3.00E+01	PPRTV (USEPA, 2010b)
tert-Butyl Alcohol	75-65-0	TO-15	sec-Butyl Alcohol	78-92-2	3.00E+01	PPRTV (USEPA, 2010b)
1-Butanol	71-36-3	TO-15	sec-Butyl Alcohol	78-92-2	3.00E+01	PPRTV (USEPA, 2010b)
Propyl Alcohol	71-23-8	TO-15	sec-Butyl Alcohol	78-92-2	3.00E+01	PPRTV (USEPA, 2010b)

USEPA 2010a. Integrated Risk Information System. http://www.epa.gov/ncea/iris/index.html
USEPA 2010b. Regional Screening Table. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm
RIVM; National Institute of Public Health and the Environment, the Netherlands as compiled by TERA 2010. http://www.tera.org/ITER/index.html

Appendix C

Documentation of “Other” Toxicity Value

Table C-1 Source of "Other" Toxicity Values

Chemical	CAS #	Toxicity Value	Source
p-Chlorobenzene sulfonic acid	98-66-8	Oral RfD	Integral, 2007
Methyl terbutyl ether (MTBE)	1634-04-4	Oral and Inhalation SF	CalEPA, 2009
Tetrachloroethylene (PCE)	127-18-4	Oral and Inhalation SF	CalEPA, 2009
Titanium	N/A	Oral and Inhalation RfD	USEPA (Region 9), 2008 Kerger, 2008
Tungsten	N/A	RfD	Kerger, 2008

CalEPA, 2009. Toxicity Criteria Database, Office of Environmental Health Hazard Assessment. http://oehha.ca.gov/risk/ChemicalDB/index.asp

Integral Consulting, Inc., 2007. Toxicological Profiles for Three Organic Acids, November 16, 2007 (p.3-3). http://ndep.nv.gov/bmi/docs/071116-organicacidprofiles.pdf

Kerger, B.D., 2008. Toxicity Criteria for Titanium and Compounds, and for Tungsten and Compounds. December 19. (http://ndep.nv.gov/bmi/docs/ndeptechmemotitaniumtungsten.pdf)

USEPA Region 9, 2008. Risk Assessment Issue Paper for: derivation of interim oral and inhalation toxicity values for titanium (CAS No. 7440-32-6) and compounds, especially titanium dioxide (CAS No. 13463-67-7), but excluding titanium tetrachloride (CAS No. 7550-45-0_, titanium dichloride and organic complexes of titanium such as titanocenes. DRAFT document; 95-019/05-26-95).

Appendix D

Documentation for the Derivation of Leaching BCL

Table D-1. DRAFT Leaching Based Basic Comparison Levels (LBCLs)

Chemical	RBGC (mg/L_w)	K_d (L_w/kg_s)	θ_w (L_w/L_T)	ρ_b (kg_s/L_T)	θ_a (L_a/L_T)	K'_H (L_w/L_a)	DAF = 1	DAF = 20	MCL Notes	K_d Notes	K'_H Notes
Aluminum	0.05	1.5E+03	0.30	1.5	0.13	0.0E+00	**7.5E+01**	**1.5E+03**	a	Kd a	-
Boron	7.3	3.0E+00	0.30	1.5	0.13	0.0E+00	**2.3E+01**	**4.7E+02**	b	Kd a	-
Cobalt	0.011	4.5E+01	0.30	1.5	0.13	0.0E+00	**4.9E-01**	**9.9E+00**	b	Kd a	-
Copper	1.3	3.5E+01	0.30	1.5	0.13	0.0E+00	**4.6E+01**	**9.2E+02**	c	Kd a	-
Iron	0.3	2.5E+01	0.30	1.5	0.13	0.0E+00	**7.6E+00**	**1.5E+02**	c	Kd a	-
HCH (alpha) noncancer	0.011	2.5E+00	0.30	1.5	0.13	4.4E-04	**2.9E-02**	**5.8E-01**	b	Kd c	KH a
HCH (beta) noncancer	0.0022	2.5E+00	0.30	1.5	0.13	3.1E-05	**6.0E-03**	**1.2E-01**	b	Kd c	KH a
Lithium	0.073	3.0E+02	0.30	1.5	0.13	0.0E+00	**2.2E+01**	**4.4E+02**	b	Kd a	-
Magnesium	206.955	4.5E+00	0.30	1.5	0.13	0.0E+00	**9.7E+02**	**1.9E+04**	b	Kd a	-
Manganese	0.02	6.5E+01	0.30	1.5	0.13	0.0E+00	**1.3E+00**	**2.6E+01**	c	Kd a	-
Mercury	0.0020	5.2E+01	0.30	1.5	0.13	4.7E-01	**1.0E-01**	**2.1E+00**	d	Kd b	KH b
Molybdenum	0.183	2.0E+01	0.30	1.5	0.13	0.0E+00	**3.7E+00**	**7.4E+01**	b	Kd a	-
Nitrate	10	5.0E-01	0.30	1.5	0.13	0.0E+00	**7.0E+00**	**1.4E+02**	d	Kd d	-
Perchlorate	0.026	8.3E-01	0.30	1.5	0.13	0.0E+00	**2.6E-02**	**5.3E-01**	b	Kd e	-
Silver	0.10	8.3E+00	0.30	1.5	0.13	0.0E+00	**8.5E-01**	**1.7E+01**	c	Kd b	-
Titanium	146	1.0E+03	0.30	1.5	0.13	0.0E+00	**1.5E+05**	**2.9E+06**	b	Kd a	-
Tungsten	0.27	1.5E+02	0.30	1.5	0.13	0.0E+00	**4.1E+01**	**8.2E+02**	b	Kd a	-
Uranium	0.03	4.5E+02	0.30	1.5	0.13	0.0E+00	**1.4E+01**	**2.7E+02**	d	Kd a	-

SYMBOLS

K_d (L_W/kg_S) = soil-water partition coefficient
q_w (L_W/L_T) = moisture content (value from USEPA, 1996; page 36)
r_b (kg_S/L_T) = dry bulk density (default value from USEPA, 1996; page 36)
q_a (L_A/L_T) = air-filled porosity (default value from USEPA, 1996; page 36)
K'_H (L_W/L_A) = dimensionless Henry's constant
DAF ($C_{leachate}$/MCL) = dilution-attenuation factor
LBCL = Leaching-based comparison level
RBCL = Risk-based groundwater concentrations

UNITS

mg = milligrams
L_W = liters of water
L_A = liters of air
L_T = liters of total bulk soil (soil air, soil water, and soil)

Notes

Hierarchy of values used for RBGCs as follows: 1) Primary Federal (USEPA) MCL, 2) Secondary USEPA MCL, 3) USEPA tap water PRG (USEPA, 2004), and 4) NDEP tap water basic comparison levels (NDEP, 2009 BCLs).
All MCLs from http://www.epa.gov/safewater/consumer/pdf/mcl.pdf and are primary MCLs unless otherwise noted.
a - Minimum of range given for secondary MCL for aluminum (0.05 to 0.2 mg/L_W).
b - NDEP, 2009 tap water basic comparison level (BCL).
c - Secondary MCL.
d - Primary MCL.

Kd a - Value from Figure 2.31 of Baes et al., 1984.
Kd b - Value from Table 46 of USEPA, 1996 (at default pH value of 6.8 [page 40 of USEPA, 1996]).
Kd c - Value is Koc from Appendix C, Table C-3 of the USEPA (1996) Soil Screening Guidance multiplied by the default fraction of organic carbon in soil of 0.002.
Kd d - Value is from Serne (2007).
Kd e - Value is from Clausen et al. (2007).
KH a - Value is from Appendix C, Table C-3 of the USEPA (1996) Soil Screening Guidance.
KH b - Value is for elemental mercury as listed in USEPA PRG chemical-specific parameters table (http://www.epa.gov/region09/superfund/prg/pdf/params_sl_table_bwrun_12SEP2008.pdf).

Appendix E

Radionuclide BCL Guidance

Appendix E

USER'S GUIDE FOR NEVADA DIVISION OF ENVIRONMENTAL PROTECTION RADIONUCLIDE BASIC COMPARISON LEVELS (BCLs) FOR SOILS AT THE BMI COMPLEX AND COMMON AREAS

April 2009

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1.0 BACKGROUND

This guidance, which describes radionuclide basic comparison levels (BCLs) for soils at the BMI Complex and Common Areas, is a supplement to an existing User's Guide and Background Technical Document for chemical BCLs (NDEP, 2009). The objective of both the chemical and radionuclide BCLs is to assist users in conducting aspects of human health risk assessment such as the evaluation of data usability, determination of extent of contamination, identifying chemicals of potential concern, and identifying preliminary remediation goals. The radionuclide BCLs tabulated in this guidance are considered by NDEP to be protective of most reasonably-anticipated human exposures. It is important to note that unlike non-radiological chemical agents for which quantities are based upon concentrations in an environmental medium, quantities of radionuclide BCLs are expressed as a given "activity" [i.e. picoCuries (pCi)] in an environmental medium.

A radionuclide activity measured above the relevant BCL does not automatically designate the site as needing a response action. However, exceeding a BCL may suggest that further evaluation of the potential risks posed by site contaminants is appropriate. Such evaluation might include additional sampling, consideration of ambient levels in the environment, or a reassessment of the screening-level assumptions used in the calculation of the BCLs.

The adverse health effects of radionuclides are based on the deposition of energy in body tissues resulting from radioactive decay. Radionuclides decay by a number of different processes. All types of radiation may cause cellular damage by internal exposure (such as after ingestion or inhalation), and some types of radiation may also contribute to external exposure (from outside of the body). At exposure levels related to environmental contamination, the major kinds of adverse health effects caused by radionuclide exposure are cancer, cell mutation, and birth defects. However, cancer risk is considered the limiting effect of radionuclides, meaning that USEPA considers risk-based decisions using the cancer risk endpoint to be protective of noncancer effects (USEPA, 1989). Therefore, cancer risk is used as the basis for assessing human health risks at sites with radionuclide contamination.

Soil BCLs are calculated for direct exposure pathways related to an individual exposed to site soils, and also for protection of groundwater from leaching of soil radionuclides over time. For each radionuclide, soil BCLs related to direct exposure (ingestion, inhalation, and external irradiation) are back-calculated from target risk levels of one-in-a-million (1×10^{-6}) incremental lifetime cancer risk. BCLs for the migration-to-groundwater pathway are back-calculated from the following groundwater limits (in order of preference): non-zero maximum contaminant level goals (MCLGs), maximum contaminant levels (MCLs), or health-based limits based on a cancer risk of 1×10^{-6}.

BCLs are intended to provide protection of human health without detailed knowledge of site-specific exposure conditions. Direct-contact BCLs are applicable when the anticipated exposure at a site is consistent with, or less intensive than the default exposure assumptions used in calculating the BCLs. When considering BCLs as initial cleanup goals, it is recommended that the residential BCL be used, unless agreement has been reached with NDEP officials that a non-

residential land use assumption can be justified. The responsibility for applying BCLs for site-specific remedial decisions lies with the entity recommending the values and with the risk manager. Before using the BCLs at a particular site, users should consider whether the land use scenarios and associated potential exposure pathways for the site are fully accounted for in the BCL calculations. For example, NDEP BCLs do not consider impact to ecological receptors or agricultural uses of a site.

Radionuclide BCLs are calculated for a limited number of radionuclides for which soil and groundwater samples are routinely analyzed at the BMI Complex and Common Areas. These radionuclides include isotopic uranium (uranium-234, uranium-235, uranium-238), isotopic radium (radium-226 and radium-228), and isotopic thorium (thorium-228, thorium-230, and thorium-232).

1.1 Conceptual Site Model

The utility of a conceptual site model (CSM) for appropriately implementing soil screening is reviewed in NDEP (2009) and described in detail in various USEPA guidance documents, such as *Soil Screening Guidance: User's Guide* (USEPA, 1996a), *Soil Screening Guidance for Radionuclides: User's Guide* (USEPA, 2000a), and *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* (USEPA, 2002a).

Questions suggested in NDEP (2009) as an initial check for determining the suitability of BCLs relative to the site-specific CSM include:

- Are there potential ecological concerns?
- Is there potential for land use other than those covered by the BCLs (i.e., residential and commercial/industrial)?
- Are there other likely human exposure pathways that were not considered in development of the BCLs (e.g., impacts on areas used for gardens, farming, fishing, or raising beef, dairy, or other livestock)?
- Are there unusual site conditions (e.g., large areas of contamination, high fugitive dust levels, or wetland or floodplain issues)?
- Is there a probable source of vapor emissions from volatile soil or groundwater contaminants that may affect indoor air?
- Is there potential for a short-term construction scenario to result in higher risks than those associated with the long-term scenarios assumed for the BCLs?

If the answer to any of these questions is yes, then the BCLs may not be applicable to a site.

The exposure pathways encompassed in the calculation of the radionuclide BCLs are summarized below. Consistent with USEPA guidance (USEPA, 1989; Section 10.5.5), radiation risk via dermal absorption is not quantified as it is likely to be negligible compared with other pathways of radiation exposure.

Environmental Media	Pathways Addressed by Radionuclide BCLs		Pathways Not Addressed by Radionuclide BCLs	
	Residential	**Industrial/Commercial**	**Residential**	**Industrial/Commercial**
Soil	• incidental ingestion • particulate inhalation • external irradiation	• incidental ingestion • particulate inhalation • external irradiation	• inhalation of radon gas • ingestion of foods raised on-site	• inhalation of radon gas • particulate emissions during construction activities
Soil (Groundwater Protection)	• drinking water ingestion	• not applicable	• inhalation of radon gas	• not applicable

2.0 INPUTS FOR CALCULATING RADIONUCLIDE BCLS

The inputs to the calculation of radionuclide BCLs may be organized in three categories; 1) toxicity criteria, 2) behavioral and receptor variables, 3) inputs to transport models used to relate radionuclide activities in soil to other exposure media, and 4) a target risk threshold. The toxicity criteria pertain to individual radionuclides, whereas the behavioral and receptor variables are related to particular land use scenarios and receptors. Transport models are used in the derivation of radionuclide BCLs to estimate airborne particulate activities in ambient air and to screen for possible impacts due to leaching of soil radionuclides to groundwater.

2.1 Toxicity Criteria

The toxicity criterion used to evaluate chemical and radionuclide carcinogenic health effects is the cancer slope factor (SF). A SF is a quantitative relationship between the dose of an agent and a carcinogenic response. For chemical carcinogens, the SF is usually representative of a plausible *upper-bound* estimate of the lifetime probability of developing cancer (USEPA, 1989). The radionuclide SF, however, reflects an *average* estimate of the lifetime risk of cancer (USEPA, 1999). The units of a radionuclide SF are expressed as cancer risk per annual intake of radionuclide activity, with units of risk per activity $(pCi)^{-1}$. For external irradiation, radionuclide SFs define the relationship between annual cancer risk and the radionuclide activity in the source medium (risk/year per pCi/g).

Radionuclide SFs published by USEPA (1999) are used in the calculation of the BCLs. These SFs were derived using age- and gender-specific values for intake and radionuclide dosimetry. The SFs pertain to the general U.S. population and are, therefore, applicable for use in estimating cancer risks for a general population comprised of adults and children. Radionuclide SFs used in the radionuclide BCL calculations are described in Section 3.0.

2.2 Behavioral and Receptor Variables

Behavioral and receptor parameter values used in the calculation of radionuclide BCLs are largely identical to those used to derive chemical BCLs in NDEP (2009). NDEP (2009) notes, "…exposure factors used to develop the BCL values were obtained primarily from the USEPA Exposure Factors Handbook and the USEPA Supplemental Soil Screening Guidance." These parameters include contact rates with environmental media (daily soil ingestion, water ingestion, and inhalation rates), temporal parameters (exposure frequency and duration), body weights, etc. Behavioral and receptor parameter values used in the radionuclide BCL calculations are described in Section 3.0.

2.3 Transport Model Equations and Parameters

The particulate emission factor (PEF) model described in Section 2.6 of NDEP (2009) is an USEPA screening model for estimating the concentration of respirable particles in air. The PEF model combines an atmospheric dispersion term with a particulate emission model related to wind erosion. As described in NDEP (2009), the PEF model was used with default parameter values for all inputs with the exception of the air dispersion term, which was calculated using model constants pertaining to the Las Vegas climatic zone (USEPA, 1996b). The results of the PEF model calculation are expressed as the volume of air associated with a unit mass of suspended particles. A PEF value of 1.2×10^9 m^3/kg is given in NDEP (2009), corresponding to a 1-acre site. The PEF equation and associated parameter values are provided in NDEP (2009).

Radionuclide BCLs were also calculated that are protective of impacts to groundwater that may be used as a drinking water source. The methodology for these leaching-based BCLs (LBCLs) is described in Section 3.6.2 of NDEP (2009). Unlike the PEF model, which is independent of individual analytes, the soil leaching model is dependent on the physical characteristics of each chemical element or compound. For radionuclides, the equation used to calculate soil activity levels protective of groundwater is provided in USEPA (1996b; equations 22 and 24) and USEPA (2002; equations 19 and 20). The equation with units for radionuclides is:

$$BCL = A_w \times DAF \times \left(K_d + \left[\frac{\Theta_W}{\rho_b}\right]\right) \times CF$$

Where,

BCL	=	Basic comparison level for groundwater protection (pCi/g)
A_w	=	Target groundwater activity[1] (pCi/L)
DAF	=	Dilution attenuation factor (unitless)
K_d	=	Soil-water partition coefficient (chemical-specific) (L/kg)
Θ_w	=	Water-filled soil porosity (L_{water}/L_{soil})
ρ_b	=	Dry bulk soil density (kg/L)
CF	=	Conversion factor (0.001 kg/g)

[1] The target groundwater activity is the MCL for uranium and radium isotopes and the risk based activity for thorium isotopes (see Table E-1).

The dilution attenuation factor (DAF) relates the vadose zone soil pore water activity to the groundwater target activity (A_w). The remaining terms in the model relate the bulk soil activity of a radionuclide to its activity in pore water. Input parameter values for calculating groundwater-protective activities of radionuclides in soil, and the resulting radionuclide specific BCLs, are shown in Table E-1.

As described in NDEP (2009; Section 1.0), BCLs for the migration-to-groundwater pathway will prioritize groundwater limits as follows: 1) non-zero maximum contaminant level goals (MCLGs), 2) maximum contaminant levels (MCLs), and 3) health-based limits (based on a cancer risk of 1×10^{-6}). The radium MCL is based upon the sum of radium-226 and radium-228. In this instance, a user simply sums the measured soil activity (in pCi/g) and compares that value to the LBCL for radium shown in Table E-1.

Thorium has not been assigned an MCL. Accordingly, the health-based groundwater BCL is used. All three thorium isotopes decay by alpha emission. If BCLs are exceeded for thorium isotopes, it is recommended that groundwater sampling for gross alpha levels in groundwater (minus uranium and radon) be conducted according to USEPA methods in order to compare alpha levels to the gross alpha MCL value of 15 pCi/L. Only if the gross alpha MCL is exceeded would additional investigation to identify specific alpha-emitters be considered.

Table E-1. Parameter Values and Basic Comparison Levels for Groundwater Protection.

Radionuclide-Specific Parameters and Groundwater Protection BCLs				
Element / Isotope	**Target Water Activity**	**K_d**	**Groundwater Protection BCL DAF = 1**	**Groundwater Protection BCL DAF = 20**
Uranium[1]	---	---	---	---
Radium	MCL (5 pCi/L) [2]	3 (L/kg) [3]	0.016 pCi/g	0.32 pCi/g
Thorium-228	Risk-based (0.11 pCi/L)	20 (L/kg) [4]	0.0023 pCi/g	0.045 pCi/g
Thorium-230	Risk-based (0.042 pCi/L)	20 (L/kg) [4]	0.00084 pCi/g	0.017 pCi/g
Thorium-232	Risk-based (0.14 pCi/L)	20 (L/kg) [4]	0.0029 pCi/g	0.058 pCi/g
Common Parameters				
Abbreviation	**Definition**	**Value**	**Reference**	
DAF	Dilution attenuation factor	1 or 20	USEPA 1996b	USEPA 2000b
θ_w	Water-filled soil porosity	0.3	USEPA 1996b	USEPA 2000b
ρ_b	Dry bulk soil density (kg/L)	1.5	USEPA 1996b	USEPA 2000b
Additional Parameters				
Isotope	**Radioactive Half Life ($T_{1/2}$)**		**Reference**	
Uranium-234	2.45×10^5 (year)		ORNL RAIS	2009
Uranium-235	7.04×10^8 (year)		ORNL RAIS	2009
Uranium-238	4.47×10^9 (year)		ORNL RAIS	2009

[1] Please refer to the main BCL table for the LBCL for this constituent.
[2] http://www.epa.gov/safewater/contaminants/index.html
[3] USEPA 1996b; Oak Ridge National Laboratory (ORNL) Risk Assessment Information System (RAIS): http://rais.ornl.gov/cgi-bin/tox/TOX_select?select=rad
[4] ORNL RAIS (http://rais.ornl.gov/cgi-bin/tox/TOX_select?select=rad)

2.4 Cancer Risk Threshold

Cancer risk is evaluated as the incremental probability that an individual will develop cancer during their lifetime. This cancer risk is the product of the average daily dose (i.e., radionuclide intake or external irradiation) and a cancer SF. The acceptability of any calculated incremental cancer risk is generally evaluated relative to the target risk range of 10^{-6} to 10^{-4} described in the National Contingency Plan (USEPA 1993).

As the BCLs are to be used as conservative screening values, the *de minimis* cancer risk threshold of 10^{-6} is used to calculate BCLs for individual radionuclides in soil and tap water (USEPA 1993).

3.0 RADIONUCLIDE BCL CALCULATIONS

Intake for radiation cancer risk is calculated in a somewhat different manner than for chemical agents. As described in Chapter 10 of USEPA (1989), the general intake equation for radiation dose is analogous to that for chemical exposures, except that averaging time and body weight are omitted. These terms are effectively incorporated within the radionuclide cancer slope factors. Instead of chemical mass, radionuclide activity (e.g., pCi) is used to quantify the amount of a radionuclide in an environmental medium.

With the exception of the radionuclide SFs, the exposure parameter values used for calculating radionuclide BCLs are mostly identical to those defined for chemical BCLs in NDEP (2009). Behavioral and receptor exposure parameter values for the radionuclide BCLs are listed in Table E-2. Parameter names are defined in the pathway-specific equations provided below. Cancer SFs are provided in Table E-3. Radionuclide BCLs for soil are shown in Table E-4. Radionuclide BCLs that relate to protection of groundwater are discussed in Section 2.3.

The general equation for radiation cancer risk that serves as the basis for pathway-specific equations is:

$$Radionuclide\ Risk = A \times CR \times EF \times ED \times SF$$

Where:

A = Activity at exposure point (e.g., pCi/g soil, pCi/L water)

CR = Contact rate with the environmental medium (e.g., mg soil per day; L water ingestion per day)

EF = Exposure frequency (days/year)

ED = Exposure duration (year)

SF = Cancer slope factor (risk/pCi).

CF = Conversion factor (0.001 g/mg)

To calculate radionuclide BCLs, the cancer risk equation is rearranged to solve for A, based on a predetermined cancer risk threshold (e.g., 10^{-6}).

3.1 Residential Scenario BCL Equations

For residential scenario BCLs, the contribution to lifetime exposure of both children and adults is addressed.

Soil Ingestion. The pathway-specific residential scenario equation for A for soil ingestion is:

$$A = TR \times \frac{CF}{\{[(IRS_c \times EF_c \times ED_c) + (IRS_a \times EF_a \times ED_a)] \times B \times SF_o\}}$$

Where:

A	=	Activity in exposure area soil (pCi/g)
TR	=	Target cancer risk
CF	=	Conversion factor (1,000 mg/g)
IRS_c,	=	Child daily soil ingestion rate (mg of soil/day)
EF_c	=	Child exposure frequency (days/year)
ED_c	=	Child exposure duration (year)
IRS_a	=	Adult daily soil ingestion rate (mg of soil/day)
EF_a	=	Adult exposure frequency (days/year)
ED_a	=	Adult exposure duration (year)
B	=	Bioavailability
SF_o	=	Oral cancer slope factor of (risk/pCi).

Inhalation of Particulates. The pathway-specific residential scenario equation for A for the inhalation of particulates is:

$$A = \frac{TR \; x \; PEF \; x \; CF}{\{[(IRA_c \times EF_c \times ED_c) + (IRA_a \times ET_a \times EF_a \times ED_a)] \; x \; SF_i\}}$$

Where:

A	=	Activity in exposure area soil (pCi/g)
TR	=	target cancer risk
PEF	=	Particulate emission factor (m^3/kg)
CF	=	Units conversion factor (0.001 kg/g)
IRA_c	=	Child inhalation rate (m^3/day)
EF_c	=	Child exposure frequency (days/year)
ED_c	=	Child exposure duration (year)
IRA_a	=	Adult inhalation rate (m^3/hr)
ET_a	=	Adult exposure time on-site (hr/day)
EF_a	=	Adult exposure frequency (days/year)
ED_a	=	Adult exposure duration (year)
SF_i	=	Inhalation cancer slope factor (risk/pCi).

External Irradiation. For external irradiation from soil, contact is a function of daily exposure time, and the pathway-specific residential scenario equation for A is:

$$A = \frac{TR}{\left\{\left[\left(\left(ET_{c,in}\ x\ GSF\right) + ET_{c,out}\right) \times EF_c \times ED_c\right] + \left[\left(\left(ET_{a,in} \times GSF\right) + ET_{a,out}\right) \times EF_a \times ED_a\right] \times CF \times SF_{ext}\right\}}$$

Where:

A	=	Activity in exposure area soil (pCi/g)
TR	=	Target cancer risk
$ET_{c,in}$	=	Child indoor exposure time on-site (hr/day)
$ET_{c,out}$	=	Child outdoor exposure time on-site (hr/day)
EF_c	=	Child exposure frequency (days/year)
ED_c	=	Child exposure duration (year)
$ET_{a,in}$	=	Adult indoor exposure time on-site (hr/day)
$ET_{a,out}$	=	Adult outdoor exposure time on-site (hr/day)
EF_a	=	Adult exposure frequency (days/year)
ED_a	=	Adult exposure duration (year)
GSF	=	Gamma shielding factor for indoor exposure
CF	=	Conversion factor (0.000114 yr/hr)
SF_{ext}	=	Cancer slope factor for external exposure (risk /yr per pCi/g).

Tap Water Ingestion. The drinking water equation pertains to the calculation of risk-based drinking water radionuclide activities, which may be used as an input for calculating soil BCLs that are protective of groundwater uses (see Section 2.3). The pathway-specific equation for A for drinking water ingestion is:

$$A = \frac{TR}{\{[(IRW_c \times EF_c \times ED_c) + (IRW_a \times EF \times ED_a)] \times SF_o\}}$$

Where:

A	=	Activity in drinking water (pCi/L)
IRW_c	=	Child daily water ingestion rate (L of water/day)
EF_c	=	Child exposure frequency (days/year)
ED_c	=	Child exposure duration (year)
IRW_a	=	Adult daily water ingestion rate (L of water/day)
EF_a	=	Adult exposure frequency (days/year)
ED_a	=	Adult exposure duration (year)
SF_o	=	Oral cancer slope factor for ingestion exposure (risk/pCi).

3.2 Industrial / Commercial Scenario BCL Equations

Adults are the only receptors exposed in the industrial/commercial scenario.

Soil Ingestion. The pathway-specific industrial/commercial scenario equation for A for soil ingestion is:

$$A = \frac{TR \times CF}{(IRS_a \times EF \times ED_a \times B \times SF_o)}$$

Where:

A	=	Activity in exposure area soil (pCi/g)
TR	=	Target cancer risk
CF	=	Conversion factor (1,000 mg/g)
IRS_a	=	Adult daily soil ingestion rate (mg of soil/day)
EF_a	=	Adult exposure frequency (days/year)
ED_a	=	Adult exposure duration (year)
B	=	Bioavailability
SF_o	=	Oral cancer slope factor for ingestion exposure (risk/pCi).

Inhalation of Particulates. The pathway-specific industrial/commercial scenario equation for C_i for the inhalation of particulates is:

$$A = \frac{TR \times PEF \times CF}{(IRA_a \times ET_a \times EF_a \times ED_a \times SF_i)}$$

Where:

A	=	Activity in exposure area soil (pCi/g)
TR	=	Target cancer risk
PEF	=	particulate emission factor (m^3/kg)
CF	=	Conversion factor (0.001 kg/g)
IRA_a	=	Adult inhalation rate (m^3/hr)
ET_a	=	Adult exposure time on-site (hr/day)
EF_a	=	Adult exposure frequency (days/year)
ED_a	=	Adult exposure duration (year)
SF_i	=	Cancer slope factor for inhalation exposure (risk/pCi).

External Irradiation. For external irradiation from soil, contact is a function of daily exposure time, and the pathway-specific industrial/commercial scenario equation for A is:

$$A = \frac{TR}{\{[(ET_{a,in} \times GSF) + ET_{a,out}] \times EF_a \times ED_a \times CF \times SF_{ext}\}}$$

Where:

A	=	Activity in exposure area soil (pCi/g)
TR	=	Target cancer risk
$ET_{a,in}$	=	Adult indoor exposure time on-site (hr/day)
$ET_{a,out}$	=	Adult outdoor exposure time on-site (hr/day)
EF_a	=	Adult exposure frequency (days/year)
ED_a	=	Adult exposure duration (year)
GSF	=	Gamma shielding factor for indoor exposure
CF	=	Conversion factor (0.000114 yr/hr)
SF_{ext}	=	Cancer slope factor for external exposure (risk /yr per pCi/g).

3.3 Summation of Pathway-Specific BCLs

The soil BCLs are calculated for each of three exposure pathways; soil ingestion, inhalation of particulates, and external irradiation. These exposure pathways must be integrated to compute a final BCL. Normally, cancer risks are summed for multiple pathways of exposure. In the case of soil BCLs, cancer risk is inversely proportional to the activity of the radionuclide in soil.. A lower BCL indicates a more potent carcinogen. Similarly, a BCL based on one exposure pathway must necessarily decrease as additional pathways of exposure are added. Soil BCLs across all exposure pathways are computed as follows:

$$BCL = \left(\left(\frac{1}{BCL_{soil\ ing}}\right) + \left(\frac{1}{BCL_{part\ inh}}\right) + \left(\frac{1}{BCL_{external}}\right)\right)^{-1}$$

Table E-2. Behavioral and Receptor Parameter Values.

Parameter	Parameter Definition	Units	Value	Reference
TR	Target cancer risk	unitless	1×10^{-6}	NDEP 2009
$IRS_{,c}$	Child soil ingestion rate	mg/day	200	NDEP 2009 (USEPA 1997b)
IRS_a (resident and outdoor worker)	Adult resident and outdoor worker soil ingestion rate	mg/day	100	NDEP 2009 (USEPA 2002a)
$IR_{s,adult}$ (indoor worker)	Adult indoor worker soil ingestion rate	mg/day	50	NDEP 2009 (USEPA 1997b)
B	Bioavailability	unitless	1	screening assumption; 100% bioavailability
IRA_c	Child inhalation rate	m^3/day	10	NDEP 2009 (USEPA 2002c)
IRA_a (residential)	Adult resident inhalation rate	m^3/hr	0.83	NDEP 2009 (USEPA 2002a)
IRA_a (worker)	Adult worker inhalation rate	m^3/hr	2.5	NDEP 2009 (USEPA 1991; equivalent to 20 m^3/ workday)
PEF	Particulate emission factor	m^3 /kg	1.2×10^9	NDEP 2009
IRW_c	Child water ingestion rate	L/day	1	NDEP 2009 (USEPA 2002c; 95th percentile)
IRW_a	Adult water ingestion rate	L/day	2	NDEP 2009 (USEPA 2002a)
EF_c	Child exposure frequency	day/yr	350	NDEP 2009 (USEPA 2002a)
EF_a (resident)	Adult resident exposure frequency	day/yr	350	NDEP 2009 (USEPA 2002a)
EF_c (resident)	Child resident exposure frequency	day/yr	350	NDEP 2009 (USEPA 2002a)
EF_a (outdoor worker)	Adult outdoor worker exposure frequency	day/yr	225	NDEP 2009 (USEPA 2002a)
EF_a (indoor worker)	Adult indoor worker exposure frequency	day/yr	250	NDEP 2009 (USEPA 2002a)
ED_c	Child exposure duration	yr	6	NDEP 2009 (USEPA 1991)
ED_a (resident)	Adult resident exposure duration	yr	24	NDEP 2009 (USEPA 1997b)
ED_a (workers)	Adult worker exposure duration	yr	25	NDEP 2009 (USEPA 2002a)
$ET_{c,out}$	Child outdoor exposure time	hr/day	3	USEPA 1997c; Table 15-120. 75th percentile time spent home in the yard; child age 1-6 years.
$ET_{c,in}$	Child indoor exposure time	hr/day	21	24 hr/day - $ET_{child,out}$
$ET_{a,out}$ (resident)	Adult resident outdoor exposure time	hr/day	3	USEPA 1997c; Table 15-120. 75th percentile of time spent home in the yard; adult age categories.
$ET_{a,in}$ (resident)	Adult resident indoor exposure time	hr/day	21	24 hr/day – $ET_{adult,out}$
$ET_{a,out}$ (indoor worker)	Adult indoor worker outdoor exposure time	hr/day	0	scenario definition is indoor exposure
$ET_{a,in}$ (indoor worker)	Adult indoor worker indoor exposure time	hr/day	8	an 8-hour average work day is assumed
$ET_{a,out}$ (outdoor worker)	Adult outdoor worker outdoor exposure time	hr/day	8	an 8-hour average work day is assumed
$ET_{a,in}$ (outdoor worker)	Adult outdoor worker indoor exposure time	hr/day	0	scenario definition is outdoor exposure
GSF	Indoor exposure gamma shielding factor	unitless	0.4	USEPA, 2000a

References in parentheses indicate a primary reference. These are included when a parameter value obtained from the chemical BCL guidance (NDEP 2009) is directly cited from that reference.

Table E-3. Radionuclide Cancer Slope Factor Values.

Radionuclide	Soil Ingestion	Water Ingestion	Inhalation	External
	risk/pCi	risk/pCi	risk/pCi	risk/yr per pCi/g
radium-226	7.30E-10	3.86E-10	1.16E-08	8.49E-06
radium-228	2.29E-09	1.04E-09	5.23E-09	4.53E-06
thorium-228	8.09E-10	3.00E-10	1.43E-07	7.76E-06
thorium-230	2.02E-10	9.10E-11	2.58E-08	8.19E-10
thorium-232	2.31E-10	1.01E-10	4.33E-08	3.42E-10
uranium-234	1.58E-10	7.07E-11	1.14E-08	2.52E-10
uranium-235	1.63E-10	7.18E-11	1.01E-08	5.43E-07
uranium-238	2.10E-10	8.71E-11	9.35E-09	1.14E-07

SF values obtained from USEPA's Health Effects Assessment Summary Tables (HEAST), Office of Radiation and Indoor Air, on-line at http://www.epa.gov/radiation/heast/.

Table E-4. Radionuclide Soil Basic Comparison Levels (pCi/g).

Radionuclide	Residential BCL	Indoor Worker BCL	Outdoor Worker BCL
radium-226	7.1E-03	5.1E-02	2.3E-02
radium-228	1.3E-02	9.1E-02	4.1E-02
thorium-228	7.8E-03	5.6E-02	2.5E-02
thorium-230	3.2E+00	1.5E+01	8.3E+00
thorium-232	2.8E+00	1.3E+01	7.4E+00
uranium-234	4.2E+00	2.0E+01	1.1E+01
uranium-235	1.1E-01	7.8E-01	3.5E-01
uranium-238	4.6E-01	3.1E+00	1.4E+00

4.0 APPLICATION OF RADIONUCLIDE BCLS

Radionuclide soil BCLs were calculated for eight radionuclides; isotopes of radium, thorium, and uranium. BCLs were developed for direct soil contact (including soil ingestion, inhalation of particulates, and external irradiation) and for protection of groundwater due to leaching of soil contamination with precipitation or irrigation. The groundwater protection soil BCLs are related to either risk-based groundwater radionuclide activities (isotopes of thorium) or regulatory drinking water standards (isotopes of radium and uranium). As described in Section 2.3, if groundwater protection BCLs for thorium isotopes are exceeded, groundwater sampling for gross alpha radiation levels could be conducted to determine if current groundwater activities of alpha-emitting radionuclides (including thorium isotopes) are above the USEPA drinking water standard.

Unlike the case with drinking water MCLs, there are no published regulatory standards for chemical and radionuclide contamination in soil. However, USEPA has published regulations under 40 CFR Part 192.12 pertaining to protective levels of radium isotopes in soil. These regulations were developed for sites where uranium ore had been processed, but they have also been used as "applicable or relevant and appropriate requirements" (ARAR) levels at Superfund sites with uranium, thorium, or radium contamination (USEPA, 2002b).

As described in Section 1.1, inhalation of radon gas within commercial or residential buildings is not addressed in the radionuclide BCLs. This exposure pathway could be a significant contributor to potential human health risks, particularly if activities of radium-226 are elevated in soils beneath a building. Risk management decisions related to radium-226 in soil should recognize that indoor radon inhalation is potentially of greater concern than exposure to radium-226 via soil ingestion, inhalation of particulates, and external irradiation.

A suggested stepwise approach for BCL-screening of sites with multiple radionuclides (for each environmental medium of interest) is as follows:

- Perform an extensive records search and compile existing data.
- Take the site exposure point activity and divide by the BCL. Multiply this ratio by 10^{-6} to estimate radionuclide-specific risk. For multiple radionuclides, add this risk estimate for each radionuclide as follows:

$$Risk = \left[\left(\frac{Activity_x}{BCL_x}\right) + \left(\frac{Activity_y}{BCL_y}\right) + \ldots + \left(\frac{Activity_z}{BCL_z}\right)\right] \times 10^{-6}$$

Alternatively, a simplified conservative approach of employing one-tenth of the BCL can be applied.

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