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

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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	MCL (30 µg/L) [1]	0.4 (L/kg) [2]	0.018 mg/kg	0.36 mg/kg
Radium	MCL (5 pCi/L) [1]	3 (L/kg) [2]	0.016 pCi/g	0.32 pCi/g
Thorium-228	Risk-based (0.11 pCi/L)	20 (L/kg) [3]	0.0023 pCi/g	0.045 pCi/g
Thorium-230	Risk-based (0.042 pCi/L)	20 (L/kg) [3]	0.00084 pCi/g	0.017 pCi/g
Thorium-232	Risk-based (0.14 pCi/L)	20 (L/kg) [3]	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] http://www.epa.gov/safewater/contaminants/index.html
[2] USEPA 1996b; Oak Ridge National Laboratory (ORNL) Risk Assessment Information System (RAIS) (http://rais.ornl.gov/cgi-bin/tox/TOX_select?select=rad)
[3] 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 (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:

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

Where:

A	=	Activity in exposure area soil (pCi/g)
TR	=	target cancer risk
PEF	=	Particulate emission factor (m^3/kg)
CF	=	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:

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

Where:

A	=	Activity in exposure area soil (pCi/g)
TR	=	Target cancer risk
$ET_{c,in}$	=	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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