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Derivation and Use of Radionuclide Screening Action Levels, Revision 2

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Acronyms

ALARA	as low as reasonably achievable
AOC	area of concern
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CZ	contaminated zone
DCF	dose conversion factor
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EFH	Exposure Factors Handbook
FGR	Federal Guidance Report
ICRP	International Commission on Radiation Protection
LANL	Los Alamos National Laboratory
MDA	material disposal area
NMED	New Mexico Environment Department
NRC	Nuclear Regulatory Commission
PA/CA	Performance Assessment/Composite Analysis
RCRA	Resource Conservation and Recovery Act
RESRAD	residual radioactivity computer code
RME	reasonable maximum exposure
RPF	Records Processing Facility
SAL	screening action level
SSL	soil screening level
SWMU	solid waste management unit

1.0 INTRODUCTION

This report documents the calculation of screening action levels (SALs) for radionuclides in soil at Los Alamos National Laboratory (LANL or the Laboratory). The SALs are used in the human health screening assessment as part of the Laboratory's corrective action process. The SAL calculations are performed for four exposure scenarios: residential, commercial/industrial, construction worker, and recreational. Among these scenarios, SALs related to residential land use correspond to the soil guidelines for unrestricted release of property described in U.S. Department of Energy (DOE) Order 458.1, "Radiation Protection of the Public and the Environment." Exposure to radionuclides in soil under these scenarios is assessed for exposure routes, including incidental ingestion of soil; inhalation of soil particulates; ingestion of homegrown produce (residential only); and external irradiation from soil. Inhalation and dermal absorption of tritiated water vapor in air are also assessed. Radionuclide SALs for each exposure scenario, with supporting information on the dominant exposure route(s) for each scenario and radionuclide, are provided in Appendix A.

The residual radioactivity (RESRAD) computer code, developed by Argonne National Laboratory for DOE, is used to calculate the radionuclide SALs presented in this guidance. The RESRAD code has been continually revised and improved since it was issued in 1989. RESRAD incorporates the dose assessment methodology described in DOE Order 458.1 and is cited in this order as an example of a dose assessment model that meets DOE quality assurance requirements for developing authorized limits to release real property. The most recent user's manual describing the use of the RESRAD code was published in July 2001 (Yu et al. 2001, 076874). The RESRAD code and associated documentation are available online at http://web.ead.anl.gov/resrad/home2/index.cfm. A description of the quality assurance program for verification, benchmarking, and validation of RESRAD is described in Yu et al. (2001, 076874).

The radiation dose that is the basis of the soil guidelines calculated using RESRAD is the total effective dose, which is defined in DOE Order 458.1 as the sum of the effective dose for external irradiation and the committed effective dose for internal irradiation. The effective dose is the weighted sum of the equivalent doses to specified organs and tissues, where the weighting factors correspond to the relative likelihood of detrimental effects to a given organ or tissue following whole body irradiation (ICRP 1977, 068750). The committed effective dose for internal irradiation is the weighted sum of the equivalent doses deposited in the body in a 50-yr period (for an adult) or a 70-yr period (for a child) following the intake of a radionuclide (ICRP 1996, 223038).

The dose conversion factors (DCFs) used in the SAL calculations for ingestion, inhalation, and external irradiation, including DCFs of short-lived progeny (e.g., radioactive decay products) of the primary radionuclides, are contained within the RESRAD code. The International Commission on Radiation Protection (ICRP) has developed age-dependent ingestion and inhalation committed effective dose coefficients (also known as DCFs) for members of the public of ages 3 mo and 1 yr, 5 yr, 10 yr, and 15 yr as well as adults. These dose coefficients employ the internal dosimetry methodology described in ICRP Publication 60 (ICRP 1991, 223037) and are summarized in ICRP Publication 72 (ICRP 1996, 223038). For the residential and recreational SALs, the DCFs for a child of the scenario-specific age range were calculated by linear interpolation of the ICRP 72 DCFs for the 3 mo, 1 yr, and 5 yr old. The external DCFs used in the SAL calculations originate with Federal Guidance Report (FGR) 12 (EPA 1993, 062798).

2.0 OBJECTIVES

The primary purpose of this guidance is to document the technical bases and assumptions for calculating radionuclide SALs in soil. Soil may include hillside colluvium and alluvial sediment as well as mesa-top soil, fill, and tuff. The radionuclide SALs described in this guidance are applicable to individual sites, including solid waste management units (SWMUs), areas of concern (AOCs), and consolidated units as well as aggregate areas, watershed aggregates, and watersheds. The list of radionuclides for which SALs are calculated is based upon the radionuclides historically used and/or produced by Laboratory operations and typically detected at one or more sites.

Radionuclide SALs are used as an initial screening tool to determine whether radionuclide concentrations could be associated with dose rates that are greater than target limits under current and reasonably foreseeable future land-use conditions. The primary audience for this document consists of risk assessors and other qualified program participants who use SALs to conduct screening assessments. Sufficient information is provided in this document to enable independent review of the program's methodology for calculating SALs. The methodology for applying SALs in the screening assessments is provided in Laboratory guidance (LANL 2011, 111726).

The RESRAD SAL calculations are reviewed annually (at the start of each new fiscal year [October]) to determine whether the values need to be updated. Because minor revisions may be made to RESRAD one or more times within a year, radionuclide SALs are revised only if a later version of the RESRAD code results in changes in one or more SAL values. This revision to the SALs is driven by the need to implement DOE Order 458.1 requirements and to include age-specific child DCFs in the SAL calculations. The program starts using the revised radionuclide SALs (if any) at the beginning of a fiscal year; new values are not retroactive.

3.0 POTENTIALLY APPLICABLE ORDERS, REGULATIONS, AND GUIDANCE

The Organization Act of 1977 authorizes DOE to protect the public from radiation and radioactive materials that result from research, development, and production activities at DOE facilities. DOE has published health and safety orders of which DOE Order 458.1, "Radiation Protection of the Public and the Environment," is most pertinent to developing and applying cleanup guidelines. DOE Order 458.1 requires the reduction of all DOE-source radiation doses to a level as low as reasonably achievable (ALARA) below the primary dose limit of 100 mrem/yr above background.

DOE approves limits developed by its project offices, authorizing approval on a case-by-case basis and in accordance with the primary dose limit and ALARA. Where achievement of an authorized limit is impractical or inappropriate, DOE may approve a supplemental limit that also complies with the primary dose limit of 100 mrem/yr above background.

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) authorizes the U.S. Environmental Protection Agency (EPA) to regulate hazardous substances, including radionuclides, released into the environment. EPA policy under CERCLA is to assess radionuclide health effects based on potential cancer risk, as described by EPA (Luftig 1997, 058693; EPA 1999, 221652). However, because the Laboratory implements corrective actions for hazardous constituent releases under the Resource Conservation and Recovery Act (RCRA) rather than CERCLA, CERCLA guidance is not directly applicable. Unlike CERCLA, RCRA does not regulate radionuclides and there is no equivalent EPA RCRA guidance. The Atomic Energy Act of 1954 authorizes the U.S. Nuclear Regulatory Commission (NRC) to regulate commercial, research, and medical uses of nuclear materials as well as their transport, storage, and disposal. One such NRC regulation is Title 10 of the Code of Federal Regulations, Part 20 (10 CFR 20), "Standards for Protection against Radiation." In Subpart E of 10 CFR 20, "Radiological Criteria for License Termination," NRC proposed an annual dose limit of 25 mrem/yr above background for the average member of a critical group for restricted or unrestricted use of a site.

4.0 SELECTION OF TARGET DOSE LIMIT

DOE Order 458.1 authorizes a site-specific modeled radiation dose up to 25 mrem/yr for cleanup guidelines and the release of real property. A 25-mrem/yr target dose limit is well below the basic dose limit of 100 mrem/yr above background established in DOE Order 458.1. Based on this guidance, any dose equal to or less than 25 mrem/yr (with ALARA addressed) is acceptable in determining that no further action is warranted at a site and/or allowing the release of real property. The Laboratory, therefore, proposes to use the 25 mrem/yr dose limit as the ultimate basis for site decisions, including remediation and land transfer. The radionuclide SALs presented in this guidance are calculated using RESRAD Version 6.5 (printouts are provided in Appendix A on CD).

The Laboratory's ALARA program description states that quantitative ALARA evaluations are not necessary for Laboratory activities that have a potential for annual public exposure less than a 3-mrem total effective dose equivalent individual dose ("Los Alamos National Laboratory Environmental ALARA Program," PD410, p. 7, effective November 8, 2008). For sites where public access is or will be available and the radiological dose is above 3 mrem/yr and equal to or below 25 mrem/yr, a quantitative ALARA analyses is conducted. If the analyses indicate that the dose is ALARA, no additional removal is necessary, the investigation and remediation of the site are complete, and the property can be transferred as is, if appropriate. If the analysis determines the dose is not ALARA, additional remediation is warranted to lower the dose further or an alternative scenario may be used to restrict activity and land use for that property, if transferred.

5.0 EXPOSURE SCENARIOS AND ROUTES OF EXPOSURE

Four exposure scenarios have been identified for current and reasonably foreseeable future land use at the Laboratory: residential, commercial/industrial, construction worker, and recreational. These scenarios and their application are described in Laboratory guidance (LANL 2007, 099829). The residential scenario typically is most appropriate for townsite properties and is associated with both child and adult receptors. The construction worker scenario is a limited–time frame scenario that addresses the unique exposure conditions that may exist during construction activities. The commercial/industrial scenario typically is most appropriate for areas subject to continued Laboratory use and for locations where commercial businesses exist or where such development is foreseen. The recreational scenario is most appropriate for buffer areas or areas where development is constrained by topography, such as the slopes of canyons. The recreational scenario for an adult receptor is also described as a "trail user" scenario, and that for a child is described as an "extended backyard scenario," which assumes an older child playing in an undeveloped area near a residence or walking in any accessible canyon area (LANL 2007, 099829; LANL 2012, 221588). Because residential and recreational scenarios have both child and adult receptors, the four exposure scenarios equate to six exposure models.

The SALs described in this document were developed primarily for application to surface and near-surface soil. Below depths at which construction activities reasonably may be expected to occur (approximately 10 ft), and in solid environmental media (e.g., tuff), SALs are applied at the discretion of the risk assessor. In all cases, the conceptual site model should be used to compare the scenario-specific assumptions underlying the SALs and the conditions at a specific site to verify the SALs are applicable at that site.

Soil guideline values (i.e., SALs) are calculated in RESRAD as the sum of the products of several "pathway factors." A pathway factor is a model of the connections between environmental compartments (e.g., air, plants, and soil) within and among which radionuclides can be transported. A complete exposure pathway model is the product of a group of pathway factors. For example, the inhalation pathway contains the air/soil concentration ratio; the area, cover, depth, and occupancy factors; and annual intake of air. The individual exposure pathways, such as plant ingestion and external irradiation, can be activated independently in RESRAD to create a site-specific land-use scenario. User-defined and default values for the various pathways factors, and the results of RESRAD dose and soil guideline calculations, are available as RESRAD output in several reports and graphics. Summary reports generated by RESRAD that document input values and model outputs for the SAL calculations are provided in Appendix A (on CD). The 25-mrem/yr-based SALs are presented for each scenario in Table 5.0-1. Radionuclide SALs for each scenario, with supporting information on the dominant exposure route(s) for each scenario and radionuclide, are provided in Appendix B (Tables B-1 and B-2).

The exposure pathways used to calculate radionuclide SALs across all exposure scenarios are incidental soil ingestion, inhalation of soil particulates, and external irradiation from soil. All scenarios also include a unique exposure model for tritium (as water vapor), which includes both inhalation of tritiated water vapor and absorption of tritiated water vapor through the skin. Ingestion of garden produce (i.e., fruits and vegetables) is an exposure pathway that is commonly evaluated in radionuclide dose assessments but generally is excluded in screening-level chemical risk assessment calculations (i.e., produce ingestion is not addressed in the soil screening levels [SSLs] published by New Mexico Environment Department [NMED]). In keeping with common practice and because certain radionuclides (particularly strontium-90) known to occur at some sites are particularly susceptible to plant uptake, ingestion of garden produce is included in the residential scenario. Internal exposure related to dermal absorption of radionuclides (excepting tritiated water vapor) is assumed to be negligible, consistent with EPA guidance (EPA 1989, 008021). There are no SALs calculated for radon gas (radon-220 and radon-222) because DOE guidelines (DOE Order 458.1) set forth soil standards for the radium and thorium parents of radon-220 and radon-222. A summary of exposure routes employed in each exposure scenario is provided in Table 5.0-2.

The primary sources of exposure parameter values used in the SAL calculations are NMED's risk assessment guidance for investigations and remediation (NMED 2012, 219971) and EPA's Exposure Factors Handbook (EFH) (EPA 2011, 208374). The selected parameter values are intended to provide estimates of "reasonable maximum exposure" for each exposure scenario (EPA 1991, 056140). Selection of exposure parameter values and the scenario-specific assumptions constraining potential exposure conditions are described in section 6.0.

Table 5.0-1
Radionuclide SALs Based on 25 mrem/yr Using RESRAD Version 6.5

Radionuclide	Residential SAL (pCi/g)	Industrial SAL (pCi/g)	Construction Worker SAL (pCi/g)	Recreational SAL (pCi/g)	Time at Which SAL Applies[a] (yr)
Americium-241	82	990	140	1500	0.0
Cesium-134	2.5	16	13	150	0.0
Cesium-137+D[b]	4.7	39	31	340	0.0
Cobalt-60	11	8.5	6.8	76	0.0
Iodine-129	97	2100	680	2000	0.0
Plutonium-238	84	1300	130	1400	0.0
Plutonium-239[c]	79	1200	120	1300	0.0
Sodium-22	3.2	11	8.6	97	0.0
Strontium-90+D	15	3500	1600	5300	0.0
Technetium-99	21	320,000	100,000	220,000	0.0
Thorium-228+D	4.1	15	12	120	0.0

Table 5.0-1 (continued)

Radionuclide	Residential SAL (pCi/g)	Industrial SAL (pCi/g)	Construction Worker SAL (pCi/g)	Recreational SAL (pCi/g)	Time at Which SAL Applies[a] (yr)
Thorium-230[d]	5	5	5	5[e]	n/a[f]
Thorium-232[d]	5	5	5	5[e]	n/a
Tritium	850	200,000	62,000	710,000[g]	0.0
Uranium-234	270	3000	770	3900	1000
Uranium-235+D	39	150	100	940	1000
Uranium-238+D	150	750	410	2900	1000

[a] Modeling period is 1000 yr. Soil criteria at other times within the modeling period are higher.

[b] Includes contribution to dose of radionuclide progeny.

[c] Plutonium-239 and plutonium-240 are typically unresolved in laboratory analysis. SALs for the two isotopes are identical.

[d] The SAL is the generic soil guideline for release of property published in Chapter 4 ("Residual Radioactive Material") of DOE Order 458.1. For the concentration averaged over the first 15 cm of soil below the surface, 5 pCi/g applies; for subsequent 15-cm-thick layers, the generic soil guideline is 15 pCi/g. If both thorium-230 and radium-226 or both thorium-232 and radium-228 are present and not in secular equilibrium, or if other mixtures of radon-generating radionuclides occur, DOE Order 458.1 presents guidance for establishing soil criteria.

[e] The value of 5 pCi/g is protective of all possible recreational activities, including situations where enclosed structures may exist on the site to capture radon gas. In topographically constrained areas where structures are not feasible, such as hillsides or drainages, dose-based SALs may be employed as follows:
- Thorium-230: 110 pCi/g
- Thorium-232: 38 pCi/g

[f] n/a = Not applicable.

[g] The value used is for the adult (child value is 3.8E+06 pCi/g).

Table 5.0-2
Scenario-Specific Exposure Routes

Exposure Routes	Residential (child/adult)	Commercial/ Industrial (adult)	Construction Worker (adult)	Recreational (child/adult)
Incidental soil ingestion	X	X	X	X
Inhalation of soil particulates	X	X	X	X
External irradiation from soil	X	X	X	X
Tritium—inhalation and dermal absorption of tritiated water vapor	X	X	X	X
Ingestion of garden produce	X	—*	—	—

* — = Not applicable.

6.0 RESRAD INPUT PARAMETER VALUES AND ASSUMPTIONS

Only a subset of RESRAD input parameters are varied to differentiate the exposure scenarios described in section 5.0. These include variable parameters related to the nature and intensity of human exposure at the contaminated site and the age-specific DCFs. The variable exposure parameters for each scenario are also directly related to many of the exposure values employed by NMED in calculating SSLs for hazardous chemicals (NMED 2012, 219971). The RESRAD input parameters describing the physical dimensions and hydrologic setting of the site are generally held constant across the exposure scenarios because these are independent of human activities.

RESRAD input parameters that are varied across exposure scenarios are discussed in section 6.1. Parameter values that remain unchanged across all scenarios are discussed in section 6.2.

6.1 Input Values and Assumptions for Variable RESRAD Parameters

The RESRAD input parameters that are varied among the exposure scenarios are inhalation rate, ambient-air dust concentration, outdoor-time fraction at the site, indoor-time fraction at the site, and soil-ingestion rate. RESRAD is an integrated site-assessment model that incorporates many links between those components of the model describing human exposure and those governing the physical transport of radionuclides over time. To maintain consistency in exposure assumptions between the radionuclide SALs and chemical SSLs used in the screening assessments, the NMED daily soil ingestion rate parameter value was modified for application in RESRAD to assign 100% of the intake to time spent on-site.

6.1.1 Residential Scenario Variable Exposure Parameters

Residential exposure pertains to both adults and children. Therefore, separate calculations were conducted for each of these potential receptors. Radionuclide SALs (Appendix B) are defined based on the receptor with the highest potential dose; this is generally the child receptor. The residential exposure parameter values and their derivation (described in the table notes) are presented in Table 6.1-1. A detailed discussion of the technical basis for the updated residential SALs and a comparison with previous residential SALs is presented in Appendix C. The input exposure parameters used in the calculations are those obtained from the EFH (EPA 2011, 208374) as well as from NMED guidance (NMED 2012, 219971). These values represent a reasonable maximum exposure (RME) for a young child or an adult. The site parameters are a combination of RESRAD default values and local values, defined to effectively create static conditions in the contaminated zone with respect to radionuclide concentrations and thereby maximize dose (Appendix A).

Fruit and vegetable ingestion rate data are described in the EFH (EPA 2011, 208374) in various formats. Per capita ingestion rates of fruits and vegetables are provided for many different age groups in Chapter 9 of the handbook (EPA 2011, 208374), although the relative quantity of produce from home gardens is not specified. Alternatively, ingestion rates of home-produced fruits and vegetables are provided in Chapter 13 (EPA 2011, 208374). Rather than speculate on the fraction of home-produced foods originating from a home garden, the ingestion rate data from Chapter 13 (EPA 2011, 208374) were used to quantify intake for both adults and children via home-grown produce.

The home-grown plant ingestion rates for a child and adult (14 kg/yr and 22.1 kg/yr, respectively) apply to that portion of the population that has a home garden. The plant ingestion rate for the child is the age-weighted body-weight normalized sum of mean per capita fruit and vegetable ingestion rates for populations that garden biased high to include an older child/pre-adult (0 to less than 21 yr) to provide an RME estimate (EPA 2011, 208374, Tables 13-1 and 8-10). The adult plant ingestion rate is the age-weighted body-weight normalized sum of mean per capita fruit and vegetable ingestion rates for populations that garden ages 21 to 65 yr (EPA 2011, 208374, Tables 13-1 and 8-1).

Table 6.1-1
Residential Scenario: Variable Exposure Parameters

Parameters	Residential, Child	Residential, Adult
Inhalation rate (m^3/yr)	4712[a]	7780[b]
Mass loading (g/m^3)	1.5×10^{-7}[c]	1.5×10^{-7}[c]
Outdoor time fraction	0.0926[d]	0.0934[e]
Indoor-time fraction	0.8656[f]	0.8648[g]
Soil ingestion (g/yr)	73[h]	36.5[i]

[a] Calculated as 12.9 m^3/d × 365.25 d/yr, where 12.9 m^3/d is the mean upper percentile daily inhalation rate of a child (EPA 2011, 208374, Table 6-1).

[b] Calculated as 21.3 m^3/d × 365.25 d/yr, where 21.3 m^3/d is the mean upper percentile daily inhalation rate of an adult from 21 to less than 61 yr old (EPA 2011, 208374, Table 6-1).

[c] Calculated as (1 / 6.6×10^9 m^3/kg) × 1000 g/kg, where 6.6×10^9 m^3/kg is the particulate emission factor (NMED 2012, 219971).

[d] Calculated as (2.32 h/d × 350 d/yr) / 8766 h/yr, where 2.32 h/d (139 min) is the largest amount of time spent outdoors for child age groups between 1 to less than 3 mo and 3 to less than 6 yr (EPA 2011, 208374, Table 16-1) and is comparable with the adult time spent outdoors at a residence.

[e] Calculated as (2.34 h/d × 350 d/yr) / 8766 h/yr, where 4.68 h/d is the average total time spent outdoors for adults age 18 to less than 65 yr in all environments (EPA 2011, 208374, Table 16-1); 50% of this value (2.34 h/d) was applied to time spent outdoors at a residence and is similar to mean time outdoors at a residence for this age group (EPA 2011, 208374, Table 16-22).

[f] Calculated as [(24 h/d–2.32 h/d) × 350 d/yr] / 8766 h/yr.

[g] Calculated as [(24 h/d–2.34 h/d) × 350 d/yr] / 8766 h/yr.

[h] The soil ingestion rate compensates for the time-based occupancy factor applied by RESRAD in calculating exposure from the soil ingestion pathway. Calculated as [0.2 g/d × 350 d/yr] / [indoor + outdoor time fractions], where 0.2 g/d is the upper percentile site-related daily child soil ingestion rate (NMED 2012, 219971; EPA 2011, 208374, Table 5-1).

[i] The soil ingestion rate compensates for the time-based occupancy factor applied by RESRAD in calculating exposure from the soil ingestion pathway. Calculated as [0.1 g/d × 350 d/yr] / [indoor + outdoor time fractions], where 0.1 g/d is the site-related daily adult soil ingestion rate (NMED 2012, 219971).

6.1.2 Commercial/Industrial Scenario Variable Exposure Parameters

The RESRAD input values for certain exposure parameters are consistent with the analogous parameter values used in the calculation of chemical SSLs for the industrial scenario (NMED 2012, 219971) as well as those obtained from the EFH (EPA 2011, 208374). These values and their derivation (described in table notes) are presented in Table 6.1-2.

Table 6.1-2
Commercial/Industrial Scenario: Variable Exposure Parameters

Parameters	Commercial/Industrial, Adult
Inhalation rate (m^3/yr)	7780[a]
Mass loading (g/m^3)	1.5×10^{-7}[b]
Outdoor time fraction	0.2053[c]
Indoor time fraction	0[d]
Soil ingestion (g/yr)	109.6[e]

[a] Calculated as [21.3 m^3/d × 365.25 d/yr], where 21.3 m^3/d is the upper percentile daily inhalation rate of an adult from 21 to less than 61 yr old (EPA 2011, 208374, Table 6-1).

[b] Calculated as (1 / 6.6 × 10^9 m^3/kg) x 1000 g/kg, where 6.6 × 10^9 m^3/kg is the particulate emission factor (NMED 2012, 219971).

[c] Calculated as (8 h/d × 225 d/yr) / 8766 h/yr, where 8 h/d is an estimate of the average length of the work day and 225 d/yr is the exposure frequency (NMED 2012, 219971).

[d] The commercial/industrial worker is defined as someone who “spends most of the work day conducting maintenance or manual labor activities outdoors” (NMED 2012, 219971, p. 13).

[e] The soil-ingestion rate compensates for the time-based occupancy factor applied by RESRAD in calculating exposure from the soil-ingestion pathway. Calculated as [0.1 g/d × 225 d/yr] / [indoor + outdoor time fractions], where 0.1 g/d is the site-related daily adult soil-ingestion rate (NMED 2012, 219971).

6.1.3 Construction Worker Scenario Variable Exposure Parameters

The RESRAD input values for certain exposure parameters are consistent with the analogous parameter values used in the calculation of chemical SSLs for the construction worker scenario (NMED 2012, 219971) as well as those obtained from the EFH (EPA 2011, 208374). These values and their derivation (described in the table notes) are presented in Table 6.1-3.

Table 6.1-3
Construction Worker Scenario: Variable Exposure Parameters

Parameters	Construction Worker, Adult
Inhalation rate (m^3/yr)	7780[a]
Mass loading (g/m^3)	0.0004[b]
Outdoor time fraction	0.2282[c]
Indoor time fraction	0
Soil ingestion (g/yr)	362[d]

[a] Calculated as [21.3 m^3/d × 365.25 d/yr], where 21.3 m^3/d is the upper percentile daily inhalation rate of an adult from 21 to less than 61 yr old (EPA 2011, 208374, Table 6-1).

[b] Calculated as (1 / 2.1 × 10^6 m^3/kg) × 1000 g/kg, where 2.1 × 10^6 m^3/kg is the particulate emission factor (NMED 2012, 219971).

[c] Calculated as (8 h/d × 250 d/yr) / 8766 h/yr, where 8 h/d is an estimate of the average length of the work day and 250 d/yr is the exposure frequency (NMED 2012, 219971).

[d] The soil-ingestion rate compensates for the time-based occupancy factor applied by RESRAD in calculating exposure from the soil ingestion pathway. Calculated as [0.33 g/d × 250 d/yr] / [indoor + outdoor time fractions], where 0.33 g/d is the site-related daily soil ingestion rate for a construction worker (NMED 2012, 219971).

6.1.4 Recreational Scenario Variable Exposure Parameters

A recreational exposure scenario is defined in the technical approach (LANL 2012, 221588) for both adults and children. The recreational scenario describes exposure for children (ages 6 to less than 12 yr) as an "extended backyard" setting, and for adults as a "trail use" (hiker) activity. Other recreational activities (e.g., camping or hunting) are not evaluated because these activities do not occur and are not allowed on Laboratory or DOE property. Separate calculations were conducted for each of the potential recreational receptors. Radionuclide SALs (Appendix B) are defined based on the receptor with the highest exposure intensity, generally the child receptor. Unlike the case for the previous exposure scenarios, NMED and EPA have not published SSLs for a recreational scenario. The recreational parameter values obtained from NMED guidance (NMED 2012, 219971) and the EFH (EPA 2011, 208374) and their derivation (described in the table notes) are presented in Table 6.1-4.

Table 6.1-4
Recreational Scenario: Variable Exposure Parameters

Parameters	Recreational, Child	Recreational, Adult
Inhalation rate (m^3/yr)	15250[a]	19460[b]
Mass loading (g/m^3)	1.5×10^{-7}[c]	1.5×10^{-7}[c]
Outdoor time fraction	0.0228[d]	0.0228[d]
Indoor time fraction	0	0
Soil ingestion (g/yr)	797[e]	244[f]

[a] Calculated as (0.029 m^3/min × 60 min/h × 24 h/d × 365.25 d/yr), where 0.029 m^3/min is the upper percentile child inhalation rate for moderate activity for 6 to less than 11 yr old (EPA 2011, 208374, Table 6-2).

[b] Calculated as (0.037 m^3/min × 60 min/h × 24 h/d × 365.25 d/yr), where 0.037 m^3/min is the age-weighted upper percentile adult inhalation rate for moderate activity (12 to 35 yr) (EPA 2011, 208374, Table 6-2).

[c] Calculated as (1 / 6.6×10^9 m^3/kg) × 1000 g/kg, where 6.6×10^9 m^3/kg is the particulate emission factor used for residential and industrial scenarios (NMED 2012, 219971).

[d] Calculated as (1 h/d × 200 d/yr) / 8766 h/yr, where 1 h/d is the exposure time for a recreational adult or child and 200 d/yr is the exposure frequency (LANL 2012, 221588).

[e] The soil ingestion rate is defined to compensate for the time-based occupancy factor applied by RESRAD in calculating exposure from the soil ingestion pathway. 100% of daily soil ingestion is protectively assumed to occur during outdoor activity. Calculated as [(0.2 g/d / 2.2 h/d) × 1 h/d × 200 d/yr)] / [indoor + outdoor time fractions], where 2.2 h/d is the mean time spent outdoors per d for a 6 to less than 11 yr old child (EPA 2011, 208374, Table 16-1), and where 0.2 g/d is the upper bound child soil ingestion rate (EPA 2011, 208374, Table 5-1; NMED 2012, 219971).

[f] Calculated as [(0.1 g/d / 3.6 h/d) × 1 h/d × 200 d/yr)] / [indoor + outdoor time fractions], where 3.6 h/d is the mean time spent outdoors per d for an adult (12 to 35 yr) (EPA 2011, 208374, Table 16-1) and where 0.1 g/d is the adult soil ingestion rate (NMED 2012, 219971).

The age range of the child applied as the receptor under the extended backyard premise is appropriate given that a child in the 6 to less than 12 yr age range could potentially walk or play in an unsupervised manner on a SWMU or AOC or in any part of a canyon that is accessible. A younger child is unlikely to do so, is more likely to be supervised by an adult, and would likely experience minimal hours of potential exposure because a younger child is more apt to be carried by an adult at least for part of the time because they don't have sufficient attention span or stamina to walk for any length of time. The 200 d/yr exposure frequency is equivalent to 4 d/wk for 50 wk/yr and is more frequent than a younger child will typically be exposed. It is therefore appropriate to conclude that the exposure frequency and the age range are representative of the reasonably maximum exposed child for this scenario.

The parameters used to define the exposure under the extended backyard scenario are protective of a younger child as well. For example, the soil ingestion rate (200 mg/d) is the upper percentile ingestion rate for a 3 to <6 yr old child according to EPA (EPA 2011, 208374, Table 5-1) and is the soil ingestion rate used by NMED (NMED 2012, 219971) and EPA (http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm) for calculating residential SSLs for a 0 to 6 yr old child. The central tendency soil ingestion rate for an older child/young adult (6 to less than 21 yr) is 100 mg/d according to EPA (EPA 2011, 208374, Table 5-1). The time spent outdoors (2.2 h/d) for a 6 to less than 11-yr-old child is the highest outdoor time for a child less than 12 yr old and nearly twice the time spent outdoors for a 2 to 3 yr old child (EPA 2011, 208374, Table 16-1). The 0.029 m^3/min inhalation rate is the upper percentile value for moderate activity for 6 to less than 11 yr old and is equal to or greater than the rates for younger children (EPA 2011, 208374, Table 6-2). As mentioned previously, the 200 d/yr exposure frequency is conservatively high and is more frequent than a younger child will typically be exposed. Therefore, the exposure parameters provide protection to a younger child (less than 6 yr old) under the recreational scenario.

6.1.5 Dose Conversion Factors

Previous SALs employed dose coefficients published in FGR 11 (EPA 1988, 050123), which are based on older uptake, metabolism, and internal dosimetry models. The FGR 11 dose coefficients also pertain only to adults. However, ICRP 72 DCFs, which are now available in RESRAD, have been developed for ages infant (3 mo), 1 yr, 5 yr, 10 yr, 15 yr, and adult (ICRP 1996, 223038). The age dependency of the DCFs is particularly significant for the residential and recreational scenarios, which include a child receptor. As a result, SALs for all scenarios have been recalculated using the ICRP 72 DCFs for a child or an adult; if both a child and adult receptor are applicable for a scenario, the lower of the two values calculated are used as the SALs. For the residential scenario, SALs that integrate radiation dose over a child exposure period (age 0 to less than 6 yr) were derived by using the ICRP 72 DCFs for ages infant (3 mo), 1 yr, and 5 yr interpolated over the 0 to less than 6 yr age range. For the recreational scenario, the extended backyard calculations, which apply to ages 6 to less than 12 yr, were performed using the ICRP 72 DCFs for ages 5 yr, 10 yr, and 15 yr interpolated over the 6 to less than 12 yr age range. Adult radiation dose uses the ICRP 72 dose coefficients for an adult (ICRP 1996, 223038) to calculate the SALs for the industrial and construction worker scenarios.

The external DCFs used in the dose calculations described in this report are identical to those used in the previous SALs. These DCFs are published in FGR 12 (EPA 1993, 062798). Both internal and external DCFs used in the SAL calculations for each exposure scenario are documented in the summary reports provided in Appendix A on CD.

6.2 Input Values and Assumptions for Unchanging RESRAD Parameters

Certain RESRAD input parameters defining physical site conditions and how these conditions may change over time are critical for calculating SALs applicable to the Laboratory. These parameters generally are subject to great site-specific variability and involve such things as the dimensions of the contaminated zone, local meteorological conditions, and the hydrogeology of the vadose and saturated zones. The transport of radionuclides over time within and among environmental media is affected by the values of these parameters. Hence, the length of the modeling period can influence the SALs, particularly for certain radionuclides associated with the ingrowth of radioactive progeny.

To calculate SALs that are protective across a variety of sites, two types of simplifying assumptions are made. First, RESRAD input parameters related to soil erosion and water infiltration are defined to effectively create static conditions in the contaminated zone with respect to radionuclide concentrations. Minimizing soil erosion and infiltration maximizes potential doses from exposures to surface soil. Second, the dimensions of the contaminated zone are set to values that reasonably capture the maximum size of an individual site. A summary of the values for key RESRAD input parameters that are constant across all exposure scenarios is provided in Table 6.2-1. Values for all RESRAD input parameters are provided in the summary reports included as Appendix A of this report.

Table 6.2-1
Unchanging RESRAD Input Parameters

RESRAD Data Field	Parameter	Units	Values	Rationale
Soil Concentrations	Distribution coefficients	cm^3/g	Default values	RESRAD default values
	Radiation dose limit	mrem/yr	25	DOE Order 458.1
Contaminated Zone (CZ)	Area of CZ	m^2	10,000	RESRAD default: protectively assumes an area is effectively infinite for ingestion and external irradiation exposure pathways
	Thickness of CZ	m	2	RESRAD default
Cover and CZ Hydrological Data	Cover depth	m	0	Assumes site is contaminated at ground surface
	Density of CZ	g/cm^3	1.5	RESRAD default
	CZ erosion rate	m/yr	0	Results in constant depth of contamination over time; protectively assumes contamination is not lost by erosion
	CZ Total porosity	unitless	0.48	Value for crushed tuff used in Material Disposal Area (MDA) G performance assessment/composite analysis (PA/CA) (Hollis et al. 1997, 063131, Appendix 2e)
	CZ Field capacity	unitless	0.2	RESRAD default
	CZ Hydraulic conductivity	m/yr	10	RESRAD default
	CZ "b" parameter	unitless	5.3	RESRAD default
	Humidity in air	g/m^3	5.55	Range is 2.4 (January) to 8.7 g/m^3 (July-August) over the year; 5.55 g/m^3 is range midpoint (Source: http://www.weather.lanl.gov/documentation.asp)
	Evapotranspiration coefficient	unitless	0.999	Maximum allowed value: results in effectively no water infiltration through CZ; assumption maximizes potential dose by soil exposure over time
	Wind speed	m/s	3	Annual average wind speed at Laboratory is 2.5 m/s (rounded to 3 to give an upper bound limit), with sustained winds over 4 m/s occurring 20% of the time between mid-March and early June (Source: http://www.weather.lanl.gov/documentation.asp)
	Precipitation	m/yr	0.29	Lower 5th percentile of annual precipitation (Source: http://www.weather.lanl.gov/documentation.asp); assumption maximizes potential dose by eliminating contaminant removal from soil.
	Irrigation	m/yr	0	Consistent with evapotranspiration coefficient of 0.999; assumption maximizes potential dose via soil exposure over time

Table 6.2-1 (continued)

RESRAD Data Field	Parameter	Units	Values	Rationale
Cover and CZ Hydrological Data (continued)	Runoff coefficient	unitless	0.9	High value minimizes water infiltration; consistent with evapotranspiration coefficient of 0.999; assumption maximizes potential dose via soil exposure over time
	Watershed area for nearby stream or pond	m^2	$1 \times 10^{+6}$	RESRAD default
	Accuracy for water/soil computations	unitless	0.001	RESRAD default
Saturated Zone Hydrologic Data	Values of all parameters set to RESRAD defaults: the drinking water exposure pathway is inactive and use of irrigation water is not specified.			
Uncontaminated Unsaturated Zone Data	Number of unsaturated strata below CZ	unitless	1	Simplified hydrology—effectively no water infiltration
	Thickness of unsaturated strata	m	300	Approximate thickness of vadose zone at Pajarito Plateau (Hollis et al. 1997, 063131)
	Soil density	g/cm^3	1.5	RESRAD default
	Total porosity	unitless	0.48	Value for crushed tuff used in MDA G PA/CA (Hollis et al. 1997, 063131, Appendix 2e)
	Effective porosity	unitless	0.40	Calculated as total porosity minus water content of approximately 0.08 (Hollis et al. 1997, 063131, Appendix 2e)
	Field capacity	unitless	0.2	RESRAD default
	Hydraulic conductivity	m/yr	10	RESRAD default
	Soil-specific “b” parameter	unitless	5.3	RESRAD default
Occupancy	Exposure duration	yr	6 or 30	Young child exposure (6 yr) or RESRAD default (30 yr) for an adult
	Indoor dust filtration factor	unitless	1	Protectively assumes indoor dust radionuclide concentrations equal to ambient soil concentrations; equivalent assumption implicit in NMED SSL calculations
	External gamma shielding factor	unitless	0.7	RESRAD default (conservative for low to moderate energy gamma emitters)
	Shape factor	unitless	1	Assumes a circular CZ
Ingestion Pathway: Dietary Data	Leafy vegetable consumption	kg/yr	0	Assumes home production of leafy vegetables is negligible
	Irrigation water contaminated fraction	unitless	0	No contribution to plant contamination from irrigation water is assumed
	Plant food contaminated fraction	unitless	1	Produce ingestion rates specified as home-grown exclusively

Table 6.2-1 (continued)

RESRAD Data Field	Parameter	Units	Values	Rationale
	Mass loading for foliar deposition	g/m^3	0.001	RESRAD default
Ingestion Pathway: Nondietary Data	Depth of soil mixing layer	m	0.15	RESRAD default: contaminated zone depth set at 2 m with no dilution resulting from mixing
	Depth of roots	m	0.9	RESRAD default: protectively assumes all roots are contained within the depth of contaminated soil
	Plant factors	unitless kg/m yr	Default values	RESRAD default
Storage Times	Fruits, nonleafy vegetables, and grain	d	1	Protectively assumes that homegrown garden produce is eaten soon after harvesting

The size of the contaminated area may affect exposure by incidental soil ingestion, inhalation of particulates, and external gamma irradiation. The RESRAD default contaminated zone area of 10,000 m^2 results in an effectively infinite area for the incidental soil ingestion and external gamma irradiation exposure routes. However, the area factor atmospheric mixing model used in RESRAD for inhalation exposure produces an area factor of approximately 10% to 15% with an area of 10,000 m^2 (2.5 acres), a Laboratory-specific wind speed of 3 m/s, and a set particle diameter of 1 µm (Chang et al. 1998, 068749). Because only 10% to 15% of the suspended dust at the theoretical site used in the SAL calculations originates on the site, inhalation exposure concentrations are only 10% to 15% of the corresponding site soil concentration. In practice, increasing the defined site area within reasonable bounds would influence the area factor only slightly. For example, a 250-acre site would still have an area factor of less than 20% with a wind speed of 3 m/sec.

The evapotranspiration coefficient for calculating SALs has been set at the RESRAD limit of 0.999, effectively eliminating leaching of radionuclides from the contaminated zone by water, thereby maximizing the retention of radionuclides in surface soil over time. Because the value used for the evapotranspiration coefficient results in no infiltration, RESRAD vadose and saturated zone hydrogeologic parameters have little influence on the calculated SAL. A value of 0.999 is unrealistic for any individual site (i.e., plant growth would be impossible) but has the utility of simplicity and conservatism for these calculations. A local precipitation rate value is used in the calculations because this parameter influences the SAL for tritium. Additionally, the soil-erosion rate has been set at zero for the SAL calculations. The combination of no water infiltration and no erosion creates a static contaminated zone, which, in turn, results in maximum on-site dose over time. Under the static site conditions achieved in the calculation of SALs (i.e., the contaminated zone is not depleted by erosion or infiltration of water), progeny continue to ingrow in soil at a rate proportional to the half-life of these nuclides.

SALs are calculated within a 1000-yr time frame. One thousand years was selected as the time limit for dose calculations based on DOE requirements for performance assessment of low-level waste sites in DOE Order 435.1. For most radionuclides, maximum exposure (dose) occurs at the beginning of this 1000-yr time interval, but the uranium isotopes for which SALs are calculated (uranium-234, uranium-235, and uranium-238) contribute their maximum dose at the end of the modeling period because of the slow ingrowth of radioactive progeny.

Although the contaminated zone is modeled as static with respect to loss of radionuclides through erosion and leaching, RESRAD accounts for tritium diffusing as water vapor from contaminated soil (lost to the atmosphere). As a result, the modeled tritium dose declines rapidly over time. Tritium diffusion from soil as water vapor (resulting in dose by inhalation and dermal absorption) is greatly affected by the absolute humidity of the air above the contaminated zone (a local value for absolute humidity is used in SAL calculations).

7.0 APPLICATION OF SALs

To determine whether SALs are applicable to a particular site, it is necessary to determine if the assumptions underlying their calculation are consistent with the conceptual site model. The conceptual site model includes what is known or assumed about the spatial distribution of radionuclides in soil, the potential for radionuclide migration over time, and the characteristics of the applicable receptor population. If potentially important site-specific transport or exposure pathways are not included in the derivation of the SALs, a comparison of site data to SALs may be inappropriate. If such a screening is determined to be inappropriate for a site, a site-specific dose assessment should be conducted.

Radionuclide migration from a contaminated site may occur by dissolution in surface or groundwater, erosion of soil, resuspension as airborne particulate, through biotic uptake, and/or volatilization as a vapor. Radionuclide migration to an off-site location is not incorporated in the SALs, and RESRAD does not directly support such evaluations. Although potential off-site radionuclide concentrations generally should be lower than those observed on the site, modeling remote concentrations over time may be important because of (1) public concerns, (2) different routes and/or intensities of exposure than are considered for on-site receptors, and (3) regulatory requirements to assess off-site impacts. An example of a potentially significant off-site impact is strontium-90 uptake by plants rooted in contaminated soil and the subsequent redistribution in leaf litter or in fine particulates if the plant or plant material burns. Appendix K of Yu et al. (2001, 076874) provides guidance for evaluating off-site migration using RESRAD output. The RESRAD-Offsite computer code distributed by Argonne National Laboratory may also be used for evaluating doses to remote receptors.

Radionuclide SALs are calculated for individual radionuclides such that a receptor will not receive a dose greater than 25 mrem/yr when the contaminated zone contains a uniform radionuclide concentration equal to the SAL. When two or more radionuclides have been released, however, it is necessary to determine whether their cumulative impact may result in a total annual dose greater than the target dose limit. If no SAL is exceeded, the soil concentration of each radionuclide is divided by the SAL for that radionuclide to produce a ratio. These ratios are then summed. If the sum exceeds unity, the dose for a receptor exceeds 25 mrem/yr, although all radionuclides are present at concentrations below their individual SALs.

8.0 SUMMARY

In summary, SALs are applicable for screening contaminated media at most sites and are protectively biased within the bounds of the assumptions used in the calculations. The user must verify these bounds are appropriate for a screening assessment at a specific site. The applicability of the SALs for site screening can be established by comparing the underlying SAL assumptions, described in this document, with site-specific conditions.

9.0 REFERENCES

The following list includes all documents cited in this report. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

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Appendix A

Scenario-Specific RESRAD Summary Reports for Screening Action Levels (on CD included with this document)

The following 25-mrem/yr RESRAD reports present the basis used for developing screening action levels (SALs) for each scenario.

- Residential 25 mrem/yr, child
- Residential 25 mrem/yr, adult
- Commercial/industrial 25 mrem/yr, adult
- Construction worker 25 mrem/yr, adult
- Recreational 25 mrem/yr, child, includes radium and thorium isotopes dose-based SALs (see table note e in Tables 5.0-1 and B-1)
- Recreational 25 mrem/yr, adult, includes radium and thorium isotopes dose-based SALs

The following 15-mrem/yr RESRAD reports are for possible use in as low as reasonably achievable (ALARA) reviews.

- Residential 15 mrem/yr, child
- Residential 15 mrem/yr, adult
- Commercial/industrial 15 mrem/yr, adult
- Construction worker 15 mrem/yr, adult
- Recreational 15 mrem/yr, child, includes radium and thorium isotopes dose-based SALs (see table note e in Tables 5.0-1 and B-1)
- Recreational 15 mrem/yr, adult, includes radium and thorium isotopes dose-based SALs

Appendix B

Radionuclide Screening Action Levels

Radionuclide screening action levels (SALs) according to the methods described in this guidance are shown in Table B-1. The exposure pathway(s) contributing most to the SALs are presented in Table B-2. Residential SALs were calculated for both adult and child receptors where these receptors were differentiated based on exposure parameters such as the daily rates of incidental soil ingestion and inhalation. For all radionuclides, the residential SAL for the child was lower than or equal to that for an adult. Therefore, the residential SAL from the RESRAD results for the child receptor is shown. For the child, the SAL is weighted across an age range of 0 to less than 6 yr because that is the age range used in calculating chemical SSLs for a child.

Both child and adult receptors were also evaluated for the recreational scenario. The child recreational scenario is based on an “extended backyard” in which a child is playing in an undeveloped area near a residence. The adult receptor is described as a “trail user,” walking or hiking through the site in question. With one exception, recreational SAL values for children are also equal to or lower than those for adults. The exception is tritium, where the higher inhalation rate for an adult results in a higher tritium dose than is the case for a young child.

The adult receptor was evaluated for the industrial and construction worker scenarios.

Table B-1
Radionuclide Screening Action Levels Using RESRAD Version 6.5

Radionuclide	Residential SAL (pCi/g)		Industrial SAL (pCi/g)		Construction Worker SAL (pCi/g)		Recreational SAL (pCi/g)		Time at Which SAL Applies[a] (yr)
	15 mrem/yr	25 mrem/yr	15 mrem/yr	25 mrem/yr	15 mrem/yr	25 mrem/yr	15 mrem/yr	25 mrem/yr	
Americium-241	49	82	590	990	85	140	890	1500	0.0
Cesium-134	2.8	2.5	9.7	16	7.7	13	87	150	0.0
Cesium-137+D[b]	6.7	4.7	23	39	18	31	210	340	0.0
Cobalt-60	1.5	11	5.1	8.5	4.1	6.8	46	76	0.0
Iodine-129	58	97	1300	2100	410	680	1200	2000	0.0
Plutonium-238	50	84	780	1300	79	130	850	1400	0.0
Plutonium-239[c]	48	79	720	1200	72	120	770	1300	0.0
Sodium-22	1.9	3.2	6.5	11	5.2	8.6	58	97	0.0
Strontium-90+D	9	15	2100	3500	980	1600	3200	5300	0.0
Technetium-99	13	21	190,000	320,000	62,000	100,000	130,000	220,000	0.0
Thorium-228+D	2.5	4.1	9	15	7	12	71	120	0.0
Thorium-230[d]	5	5	5	5	5	5	5[e]	5[e]	n/a[f]
Thorium-232[d]	5	5	5	5	5	5	5[e]	5[e]	n/a
Tritium	510	850	120,000	200,000	37,000	62,000	430,000[g]	710,000[g]	0.0
Uranium-234	160	270	1800	3000	460	770	2300	3900	1000
Uranium-235+D	23	39	91	150	61	100	570	940	1000
Uranium-238+D	92	150	450	750	250	410	1700	2900	1000

Note: See RESRAD reports on CD in Appendix A for details of calculations.

[a] Modeling period is 1000 yr. Soil criteria at other times within the modeling period are higher.

[b] Includes contribution to dose of radionuclide progeny.

[c] Plutonium-239 and plutonium-240 are typically unresolved in laboratory analysis. SALs for the two isotopes are identical.

[d] The SAL is the generic soil guideline for release of property published in Chapter 4 ("Residual Radioactive Material") of U.S. Department of Energy (DOE) Order 458.1. For the concentration averaged over the first 15 cm of soil below the surface, 5 pCi/g applies; for subsequent 15-cm-thick layers, the generic soil guideline is 15 pCi/g. If both thorium-230 and radium-226 or both thorium-232 and radium-228 are present and not in secular equilibrium, or if other mixtures of radon-generating radionuclides occur, DOE Order 458.1 presents guidance for establishing soil criteria.

[e] The value of 5 pCi/g is protective of all possible recreational activities, including situations where enclosed structures may exist on the site to capture radon gas. In topographically constrained areas where structures are not feasible, such as hillsides or drainages, dose-based SALs may be employed as follows:

- Radium-226: 27 pCi/g at 15 mrem/yr; 44 at 25 mrem/yr
- Radium-228: 36 pCi/g at 15 mrem/yr; 59 at 25 mrem/yr
- Thorium-230: 68 pCi/g at 15 mrem/yr; 110 at 25 mrem/yr
- Thorium-232: 23 pCi/g at 15 mrem/yr; 38 at 25 mrem/yr

[f] n/a = Not applicable.

[g] The value used is for the adult (child values are 2.3E+06 pCi/g and 3.8E+06 pCi/g, respectively).

Table B-2
Primary Exposure Routes Contributing to SALs

Analyte Code	Radionuclide	Exposure Scenarios			
		Residential	Commercial/ Industrial	Construction Worker	Recreational
AM-241	Americium-241	Soil Ingestion: 75% Plant Ingestion: 15% External: 10%	Soil Ingestion: 66% External: 34%	Inhalation: 59% Soil Ingestion: 35% External: 6%	Soil Ingestion: 94% External: 6%
CS-134	Cesium-134	External: 99%	External: 100%	External: 100%	External: 100%
CS-137	Cesium-137+D	External: 99%	External: 100%	External: 100%	External: 100%
CO-60	Cobalt-60	External: 99%	External: 100%	External: 100%	External: 100%
H-3[a]	Tritium	Plant Ingestion: 100%	Inhalation: 97%	Inhalation: 97%	Inhalation: 98%
I-129	Iodine-129	Plant Ingestion: 77% Soil Ingestion: 19%	Soil Ingestion: 78% External: 22%	Soil Ingestion: 91% External: 9%	Soil Ingestion: 98%
NA-22	Sodium-22	External: 100%	External: 100%	External: 100%	External: 100%
PU-238	Plutonium-238	Soil Ingestion: 83% Plant Ingestion: 17%	Soil Ingestion: 100%	Inhalation: 63% Soil Ingestion: 37%	Soil Ingestion: 100%
PU-239	Plutonium-239	Soil Ingestion: 83% Plant Ingestion: 17%	Soil Ingestion: 100%	Inhalation: 63% Soil Ingestion: 37%	Soil Ingestion: 100%
SR-90	Strontium-90+D	Plant Ingestion: 97%	External: 65% Soil Ingestion: 35%	Soil Ingestion: 60% External: 38%	Soil Ingestion: 89% External: 11%
TC-99	Technetium-99	Plant Ingestion: 100%	Soil Ingestion: 68% External: 32%	Soil Ingestion: 81% External: 13% Inhalation: 6%	Soil Ingestion: 98%
TH-228	Thorium-228+D	External: 99%	External: 99%	External: 96%	External: 87% Soil Ingestion: 13%
TH-230	Thorium-230	n/a[b]	n/a	n/a	n/a
TH-232	Thorium-232	n/a	n/a	n/a	n/a
U-234[c]	Uranium-234	Soil Ingestion: 50% Plant Ingestion: 36% External: 14%	Soil Ingestion: 55% External: 45%	Soil Ingestion: 51% Inhalation: 35% External: 14%	Soil Ingestion: 94% External: 6%
U-235[c]	Uranium-235+D	External: 82% Soil Ingestion: 11% Plant Ingestion: 7%	External: 96%	External: 79% Soil Ingestion: 11% Inhalation: 10%	External: 66% Soil Ingestion: 34%
U-238[c]	Uranium-238+D	External: 61% Soil Ingestion 26% Plant Ingestion: 13%	External: 88% Soil Ingestion: 12%	External: 61% Soil Ingestion: 24% Inhalation: 15%	Soil Ingestion: 63% External: 37%

Note: Exposure routes shown, in order of importance, are those whose sum first contributes 95% or more to the SAL.

[a] The inhalation pathway incorporates intake of tritium through dermal absorption at 50% of the inhalation rate of water vapor (Yu et al. 2001, 076874, Section L.2.4).

[b] n/a = Not applicable. The SAL pertains to protection against radon gas based on generic soil guidelines published in DOE Order 458.1.

[c] The percent contribution of individual exposure routes to the SAL pertains to the combination of parent and long-lived progeny present at 1000 yr.

REFERENCE

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

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Appendix C

Technical Basis for Residential Screening Action Level Updates

Authorization Request for Levels of Residual Radionuclides in Soil Based on a Residential Exposure Scenario, Revision 1

August 2012

LA-UR-12-24141

AUTHORIZATION REQUEST

Los Alamos National Laboratory is requesting authorization to use revised screening action levels (SALs) for residual radioactive materials in soils under the residential exposure scenario. The proposed values, once authorized, could then be used for evaluating land transfers under the requirements of U.S. Department of Energy (DOE) Order 458.1 for real property release. Previously used SALs were based on the adult dose conversion factors (DCFs) from Federal Guidance Report 11. This revision updates the effective dose limit for public exposure to 25 mrem/yr, as stipulated in DOE Order 458.1, and uses DCFs and exposure factors for child receptors. In compliance with DOE Order 458.1, the dose assessment model RESRAD was used to establish the proposed SALs. Model parameters were selected to be site specific and protective of the potentially exposed individuals. This document provides the technical basis for the revised residential SALs and compares them with previous residential SALs.

1.0 BACKGROUND

Los Alamos National Laboratory (LANL or the Laboratory) calculates screening action levels (SALs) for radionuclides in soil using the U.S. Department of Energy (DOE) residual radioactive (RESRAD) material computer code, which is a model for assessing radiation dose from soil containing residual radioactive material (Yu et al. 2001). The SALs are used to estimate the potential dose to a receptor under various exposure conditions and scenarios as well as to guide site remediation and land transfer decisions. The SALs are calculated for four exposure scenarios: residential, recreational, industrial, and construction worker. The residential and recreational scenarios use the lower of the SALs calculated for a child and an adult receptor; the lower SAL for these scenarios typically pertains to the child receptor. Industrial and construction worker SALs employ an adult as the receptor to estimate dose. The residential SALs are the only values that allow the unrestricted or free release of real property and are the subject of this authorization request.

Over the history of the corrective action programs at the Laboratory, radionuclides have been addressed with respect to dose rather than cancer risk and have been evaluated based on a 15 mrem/yr radiation dose limit. In 2000, DOE Albuquerque Operations Office issued a memorandum describing a process for releasing real property based on 15 mrem/yr (Soden 2000), which was the limit upon which the SALs were based.

DOE Order 458.1, Radiation Protection of the Public and the Environment, stipulates a dose limit up to 25 mrem/yr to the public as the release limit for real property. This Order supersedes DOE Order 5400.5 and the prior guidance from local DOE offices. The Laboratory proposes to use the 25 mrem/yr dose limit as the ultimate basis for site and land transfer decisions. In addition to the application of the 25 mrem/yr dose limit, the as low as reasonably achievable (ALARA) process will be used to ensure that doses to members of the public and releases to the environment are minimized and determine if further site cleanup is needed (LANL 2009a).

1.1 RESRAD Dose Assessment Model and Residential Exposure Scenario

RESRAD is an integrated site-assessment model that incorporates many links between those components of the model describing human exposure and those governing the physical transport of radionuclides over time. RESRAD is cited in DOE Order 458.1 as an acceptable model for dose assessment [Attachment 1, paragraph 2.k.(6)(b)2]. The selection of parameter values used in the RESRAD model is important to ensure protective inputs are used to represent a reasonable maximum exposure (RME) condition at any site evaluated. The parameters used in the pathway analysis for this dose assessment are provided in Table 1. Values were selected to represent upper-bound estimates of exposure to the sensitive population (i.e., the child receptor) to ensure protective SALs. This analysis focuses on the residential scenario, which includes a family with children that has a home on the site. The family gardens and eats the home-grown produce as a supplement to produce purchased from outside locations. Drinking water is not an exposure pathway because drinking water in Los Alamos is obtained from an uncontaminated municipal well. All meat and other foodstuffs are assumed to be obtained from outside sources and are uncontaminated. Thus, the main exposure pathways are inhalation of local dust, ingestion of home-grown produce, soil ingestion, and direct-penetrating radiation.

1.2 Updated Dose Conversion Factors

RESRAD provides adult dose conversion factors (DCFs) for internal exposure (ingestion and inhalation) from Federal Guidance Report (FGR) 11 (EPA 1988), consistent with direction in DOE Order 5400.5, which specifies use of these DCFs for compliance with its standards and requirements. However, DOE Order 458.1 no longer defines a specific reference for DCFs. In Version 6.4 (December 2007), the RESRAD code added age-dependent committed effective dose coefficients (aka DCFs) published by the International Commission on Radiation Protection (ICRP) for members of the public for internal exposure from intake of radioisotopes via ingestion and inhalation. These dose coefficients are described in ICRP Publications 56, 67, 68, 69, and 71 and are compiled in ICRP Publication 72 (ICRP 1996). The ICRP 72 DCFs employ age-specific dosimetry models for children of five different ages ranging from 3 mo to 15 yr as well as for an adult. For the SAL calculations in this assessment, the DCFs for a representative child were calculated by linear interpolation of the ICRP 72 DCFs for children aged 0 to <6 yr (including DCFs for children 3 mo, 1 yr, and 5 yr old) (ICRP 1996). The availability of age-dependent DCFs is relevant to the residential scenario, which uses a child as the target receptor for SAL calculations. Because the ICRP 72 DCFs for children are higher than the DCFs for adults currently used from FGR 11 (EPA 1988), it is appropriate to employ these values in the SAL calculations.

1.3 Updated Exposure Factors for the Residential Receptors

In addition to the DCFs, the exposure parameter values, such as inhalation and ingestion rates, differ between adults and children and affect the radionuclide SALs generated by RESRAD. The exposure parameters used to calculate the residential SALs currently used by the Laboratory reflect the values provided in New Mexico Environment Department (NMED) guidance (NMED 2009; NMED 2012) and the EPA regional screening tables, available at http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm. Since residential radionuclide SALs were last calculated (LANL 2009b), the EPA has released a new Exposure Factors Handbook (EFH) (EPA 2011). The new EFH includes age-specific exposure parameters that are updated from what NMED and EPA currently provide for calculating chemical soil screening levels (SSLs). In this latest calculation, the residential radionuclide SALs were calculated for the child and adult using ICRP 72 DCFs and age-specific exposure parameters from the new EFH (EPA 2011). The SALs for the residential scenario are evaluated because this scenario is the most protective and commonly used of the four exposure scenarios and is represented by a young child receptor.

The exposure parameters are generally upper-bound values used to depict the RME for a site. The exposure factors from the 2011 EFH are similar to historically used parameters but are updated based either on more recent data or more recent analysis of the historical data. The exposure factors used to calculate child and adult residential SALs are presented in Table 2. Table 1 presents a comparison between RESRAD default exposure parameters and the values used. The inhalation rates of (12.9 m^3/d and 21.3 m^3/d for the child and adult, respectively) are the mean age-weighted 95th percentile long-term inhalation rates for a child aged 0 to <6 yr and an adult aged 21 to <61 yr (EPA 2011, Table 6-1). Soil ingestion rates (200 mg/d and 100 mg/d, respectively, for a child and an adult) are the upper percentile rate for a child aged 3 to <6 yr and a mean soil ingestion rate for ages 6 to <21 yr, which is 2 times the adult mean soil ingestion rate and equals the adult value NMED uses (NMED 2012) and the EPA regional screening tables at http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm (this value provides an upper-bound estimate of adult soil ingestion) (EPA 2011, Table 5-1). The home-grown plant ingestion rates (14 kg/yr and 22.1 kg/yr, respectively, for the child and the adult) represent the population that has a home garden. The plant ingestion rate for the child is the age-weighted body-weight normalized sum of mean per capita fruit and vegetable ingestion rates for populations that garden and is biased high to an older child/pre-adult (0 to <21 yr) to provide an upper-bound estimate (EPA 2011, Tables 13-1 and 8-10). The adult plant-ingestion rate is the age-weighted body-weight normalized sum of mean per capita fruit and vegetable ingestion rates for populations that garden for ages 25 to 61 yr (EPA 2011, Tables 13-1 and 8-1). The fraction of time outdoors represents the largest mean total time spent outdoors for a child ages 1 to <3 mo and 3 to <6 yr and is assumed to occur entirely at the residence (EPA 2011, Table 16-1).

The largest mean time spent outdoors was used to obtain an upper-bound estimate for the child. The adult (ages 18 to <65) uses 50% of the average total time spent outdoors in all environments (EPA 2011, Table 16-1) to represent the time spent outdoors at a residence and is similar to the mean time outdoors at a residence for this age group (EPA 2011, Table 16-22).

1.4 Site Parameters

For site conditions, a combination of site-specific parameters and RESRAD default parameters are used. Certain RESRAD input parameters are critical for defining physical site conditions and determining how these conditions may change over time. These parameters generally are subject to site-specific variability and involve such variables as the dimensions of the contaminated zone, local meteorological conditions, and the hydrogeology of the vadose and saturated zones. The transport of radionuclides over time within and among environmental media is affected by these parameter values. Hence, the length of the modeling period can influence the SALs, particularly for certain radionuclides associated with the ingrowth of radioactive progeny.

To calculate SALs that are protective across a variety of sites, two types of simplifying assumptions are made. First, RESRAD input parameters related to soil erosion and water infiltration are defined to effectively create static conditions in the contaminated zone with respect to radionuclide concentrations. Second, the dimensions of the contaminated zone are set to values that reasonably capture the maximum size of sites addressed.

The size of the contaminated area may affect exposure by incidental soil ingestion, inhalation of particulates, and external gamma irradiation. The RESRAD default contaminated zone area of 10,000 m^2 results in an effectively infinite area for the incidental soil ingestion and external gamma irradiation exposure routes. However, the area factor atmospheric mixing model used in RESRAD for inhalation exposure produces an area factor of approximately 10% to 15% with an area of 10,000 m^2 (2.5 acres), a Laboratory-specific wind speed of 3 m/s, and a set particle diameter of 1 µm (Chang and Wang 1998). Because only 10% to 15% of the suspended dust at the theoretical site used in the SAL calculations originates on the site, inhalation exposure concentrations are only 10% to 15% of the corresponding site soil concentration. In practice, increasing the defined site area within reasonable bounds would influence the area factor only slightly. For example, a 250-acre site would still have an area factor of less than 20% with a wind speed of 3 m/s.

The evapotranspiration coefficient for calculating SALs has been set at the RESRAD limit of 0.999, effectively eliminating leaching of radionuclides from the contaminated zone by water, thereby maximizing the retention of radionuclides in surface soil over time. Because the value used for the evapotranspiration coefficient results in no infiltration, RESRAD vadose and saturated zone hydrogeologic parameters have little influence on the calculated SAL. A value of 0.999 is unrealistic for any individual site (i.e., plant growth would be impossible) but has the utility of simplicity and conservatism for these calculations. This condition results in the most protective SAL because it reflects no loss over time. Additionally, the soil-erosion rate has been set at zero for the SAL calculations. The combination of no water infiltration and no erosion creates a static contaminated zone, which, in turn, results in maximum on-site dose over time. Under the static site conditions achieved in the calculation of SALs (i.e., the contaminated zone is not depleted by erosion or infiltration of water), progeny continue to ingrow in soil at a rate proportional to the half-life of these nuclides.

SALs are calculated within a 1000-yr time frame. The time limit of 1000 yr was selected for dose calculations based on DOE requirements for performance assessment of low-level waste sites in DOE Order 435.1. For most radionuclides, maximum exposure (dose) occurs at the beginning of this 1000-yr time interval, but the uranium isotopes for which SALs are calculated (uranium-234, uranium-235, and uranium-238) contribute their maximum dose at the end of the modeling period because of the slow ingrowth of radioactive progeny.

Although the contaminated zone is modeled as static with respect to loss of radionuclides through erosion and leaching, RESRAD accounts for tritium diffusing as water vapor from contaminated soil (lost to the atmosphere). As a result, the modeled tritium dose declines rapidly over time. Tritium diffusion from soil as water vapor (resulting in dose by inhalation and dermal absorption) is greatly affected by the absolute humidity of the air above the contaminated zone and the precipitation rate (local values for absolute humidity and precipitation rate are used in SAL calculations). The potential dose from tritium is inversely related to the annual precipitation rate. Because of the sensitivity of the tritium SAL to precipitation amounts, the local lower-bound value for precipitation used is the 5^{th} percentile of the annual precipitation rate in Los Alamos (0.29 m/yr), which is the most protective.

1.5 Sensitivity Analysis

Use of the RESRAD model requires the proper selection of parameter values for meaningful dose evaluation. In a number of cases, the parameter values are not sufficiently known for a specific site, or the variation of the values across the site is particularly large. It then becomes important to conduct a sensitivity analysis because the SAL for each individual radionuclide is more sensitive to some parameters than to others. It is particularly important to use credible upper- or lower-bound values for those parameters that are critical to determining reasonably conservative SALs, whenever possible. RESRAD has a built-in sensitivity analysis module and allows the selection of multipliers for establishing upper and lower boundaries of the parameter values around the selected value. This module was used to perform a sensitivity analysis on each input parameter in RESRAD to determine the sensitivity of the result to variations in parameter values. The degree of change in the dose conversion value output (i.e., mrem/pCi/g) between the selected value and the upper- or lower-bound value was used as the metric for selecting sensitive parameters. If the difference between these outputs was less than 10% for the parameter, the parameter was categorized as not sensitive. Conversely, if the difference was greater than 10%, the parameter was categorized as sensitive. The results of the sensitivity analysis can vary across radionuclides, so the primary Laboratory-generated radionuclides detected in on-site soil were evaluated. The radionuclides evaluated in the sensitivity analysis included americium-241, cesium-137, strontium-90, tritium, plutonium-239, and uranium-238, which collectively represent a wide variety of exposure pathways. The results of the sensitivity analyses were used to ensure that upper- or lower-bound estimates of sensitive parameters are protective for a child receptor.

2.0 RESULTS

2.1 ICRP 72 DCFs for a Representative Child

The composited ICRP 72-based DCFs for the representative child (ages 0 to <6 yr) for ingestion and inhalation calculated by linear interpolation and the ICRP 72 age dependent DCFs for a 3 mo, a 1 yr, and a 5 yr old are presented in Table 3. The results show the use of interpolated DCFs from ICRP 72 are protective of a child over a given exposure duration (6 yr) and include all of the ages for which individual ICRP 72 DCFs are provided for a young child without overestimating the dose based on a child of a specific age. The DCFs for a child ranging from 0 to <6 yr old were calculated and entered as a user-defined dose library in the RESRAD code (Version 6.5).

2.2 SALs for a Representative Child

Table 4 presents revised radionuclide SALs for the residential scenario for the child and the adult receptors. The child SALs are the same as or lower than the adult SALs for all radionuclides; thus, the child receptor is deemed the most sensitive receptor for this scenario. The residential SALs were calculated for a young child of different ages below the age of 6 yr; the 6-yr period reflects the age range for a child NMED uses in the default residential scenario (NMED 2009; NMED 2012) and EPA employs (http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm).

The use of interpolated DCFs from ICRP 72 and 2011 EFH exposure parameters are protective of a child over a given exposure duration (6 yr) and include all of the ages for which individual ICRP 72 DCFs are provided for a young child without overestimating the dose based on a specific-aged child. The most sensitive child is a 3 mo old and has the lowest SALs for some radionuclides based on the age-specific DCFs and 2011 EFH parameters. Table 5 presents the SALs calculated for a 3-mo-old child using the age-specific DCFs and 2011 EFH parameters with the 0 to <6 yr interpolated DCFs and 2011 EFH parameters. For nine radionuclides (americium-241, cobalt-60, cesium-134, cesium-137, sodium-22, plutonium-238, plutonium-239/240, thorium-228, and uranium-235), the SALs for the 3 mo old are 0.1 to 2 mrem/yr lower than SALs for the 0- to <6-yr-old child based on 15 mrem/yr and 0.2 to 4 mrem/yr lower based on 25 mrem/yr. The SALs for the other radionuclides (tritium, iodine-129, strontium-90, technetium-99, uranium-234, and uranium-238) for the 3 mo old are 18 to 17,000 mrem/yr higher than the 0- to <6-yr-old child SALs based on 15 mrem/yr and 30 to 28,000 mrem/yr higher based on 25 mrem/yr. A difference between the latter two sets of SALs is that no ingestion of home-grown produce was assumed for a 3 mo old based on information in Chapter 13 of the EFH (EPA 2011), while the SALs for the 0 to <6 yr old include ingestion of home-grown produce. Therefore, the SALs for radionuclides for the 3 mo old where a substantial component of dose is related to produce ingestion are higher than for the 0- to <6-yr-old child.

Based on this comparison, the SALs for the 0 to <6 yr old child are either similar to or are more protective than the residential SALs for the 3 mo old. By interpolating the DCFs over the age range of 0 to <6 yr old, the SALs represent a reasonable dosimetric mode and exposure to a young child (similar to the age range defined by NMED and EPA for a residential child receptor) without providing a specific age, which is comparable with looking at an adult where no specific age is represented (generally defined by ICRP 72 as older than 17 yr and by EPA as older than 21 yr). The scenario for the 0- to <6-yr-old child also includes the plant ingestion pathway, which causes the resulting SALs to be more inclusive and representative of a young child. These SALs are protective of the child receptor and do not substantially over- or underestimate the potential dose to the sensitive receptor per DOE Order 458.1.

2.3 Impact of Updating Exposure Factors on SALs

As Table 4 shows, the EFH exposure parameters (EPA 2011) resulted in generally higher SALs than the current SALs (LANL 2009b). For radionuclides where radiation dose is primarily related to external irradiation (cobalt-60, cesium-134, cesium-137, sodium-22, and thorium-228), little difference was observed in SALs calculated using the age-dependent internal DCFs and either set of exposure parameters. For the child SALs of the remaining radionuclides, the SALs calculated using the interpolated DCFs for the 0 to <6 yr old child and the 2011 EFH parameters are higher than current SALs. The primary inputs causing the higher SALs for children relative to adults are a combination of different DCFs, the time spent outdoors, and the plant ingestion rate (EPA 2011). To provide for protective, yet reasonable, estimates of exposure values, upper-bound estimates of the mean were used for time outdoors and plant ingestion rather than the extreme upper percentile (95^{th}) values in 2011 EFH, which were regarded as overestimates. The basis for this conclusion for plant ingestion was that the 95^{th} percentile plant ingestion rates in Table 13-1 of 2011 EFH are approximately 5 to 6 times the mean plant ingestion rates and are therefore biased high. To compensate for using mean values and still represent the RME, the largest mean time spent outdoors among the child values is used, and the plant ingestion rate is biased high to an older child/pre-adult (0 to <21 yr). These adjustments increased the age-weighted mean time outdoors from 1.275 h/d to 2.32 h/d for a child (outdoor time fraction increased from 0.0509 to 0.0926) and increased the plant ingestion rate from 11.2 kg/yr to 14 kg/yr for a child (adult ingestion rate is 22.1 kg/yr). Although these parameter values are lower than currently used (approximately 41% and 25% of current values), they are protective and represent a RME for a child based on 2011 EFH data. The current values for these parameters are overly protective and not necessarily representative of a RME.

2.4 Sensitivity Analysis

Table 6 provides the results of the sensitivity analysis by radionuclide. The multipliers were selected based on reasonable upper- and lower-boundary values. Sensitive parameters include precipitation, field capacity in the contaminated zone, soil-ingestion rate, produce-ingestion rate, indoor time fraction, and the external shielding factor. These parameters were sensitive only for certain radionuclides, depending on the main exposure pathway. The other parameters had a much lower relative influence on the calculation of the SALs. Protective parameter values were then selected for each of the sensitive parameters.

3.0 RECOMMENDATION

The Laboratory recommends that residential SALs, as calculated by RESRAD using age-dependent DCFs from ICRP 72 derived by linear interpolation of the individual age-dependent DCFs for ingestion and inhalation for ages 0 to <6 yr, be approved for use by LANL. The input exposure parameters used in the calculations are those obtained from the 2011 EFH (EPA 2011), and the values represent the RME for a young child, the sensitive receptor. The site parameters are those presented in the RESRAD printout and are listed in the Table 1, which are a combination of RESRAD default values and local values, defined to effectively create static conditions in the contaminated zone with respect to radionuclide concentrations and thereby maximize dose. Furthermore, the Laboratory recommends that the 25 mrem/yr dose limit be used as the basis for the SALs and as the cleanup or land transfer goal for a site. Therefore, approval for Authorized Limits is sought for the 25 mrem/yr SALs per DOE Order 458.1. In addition, the ALARA process will be used to verify whether doses to members of the public and releases to the environment are minimized based on appropriate cost/benefit analysis, and whether further site cleanup is warranted (LANL 2009a).

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Table 1
RESRAD Version 6.5 Model Simulations for SALs Parameter Justification

Parameter	Default Value	User Input Value	Units	Comments	Reference
Pathway Selections					
External gamma	Active	Active	n/a*	Credible pathway	Part of exposure scenario
Inhalation (w/o radon)	Active	Active	n/a	Credible pathway	Part of exposure scenario
Plant ingestion	Active	Active	n/a	Credible pathway	Part of exposure scenario
Meat ingestion	Active	Suppressed	n/a	No credible sources at site	Not part of exposure scenario
Milk ingestion	Active	Suppressed	n/a	No credible sources at site	Not part of exposure scenario
Aquatic foods	Active	Suppressed	n/a	No credible sources at site	Not part of exposure scenario
Drinking water	Active	Suppressed	n/a	No credible sources at site	Not part of exposure scenario
Soil ingestion	Active	Active	n/a	Credible pathway	Part of exposure scenario
Radon	Suppressed	Suppressed	n/a	No credible sources at site	Not part of exposure scenario
Contaminated Zone Parameters					
Area of contaminated zone	10,000	10,000	m^2	RESRAD default: protectively assumes an area that is effectively infinite for ingestion and external irradiation exposure pathways	Yu et al. 2001
Thickness of contaminated zone	2	2	m	RESRAD default	Yu et al. 2001
Length parallel to aquifer	100	100	m	RESRAD default	Yu et al. 2001
Times for Calculation	User defined	User defined	yr	User defined	n/a
Cover and Contaminated Zone Hydrological Data					
Cover Depth	0	0	m	RESRAD default; assumes site is contaminated at ground surface	Yu et al. 2001
Density of cover material	1.5	1.5	g/cm^3	RESRAD default	Yu et al. 2001
Cover erosion rate	0.001	Not used	m/yr	n/a	n/a
Density of contaminated zone	1.5	1.5	g/cm^3	RESRAD default	Yu et al. 2001
Contaminated zone erosion rate	0.001	0	m/yr	Results in constant depth of contamination over time; protectively assumes contamination is not lost by erosion	n/a

Table 1 (continued)

Parameter	Default Value	User Input Value	Units	Comments	Reference
Contaminated zone total porosity	0.4	0.48	unitless	Value for crushed tuff used in Material Disposal Area (MDA) G performance assessment/composite analysis (PA/CA)	Hollis et al. 1997, Appendix 2e
Contaminated zone field capacity	0.2	0.2	unitless	RESRAD default	Yu et al. 2001
Contaminated zone b parameter	5.3	5.3	unitless	RESRAD default	Yu et al. 1993 (Section 13)
Humidity in air	8	5.55	g/m^3	Range is 2.4 (January) to 8.7 g/m^3 (July-August) over a year; 5.55 g/m^3 is range midpoint.	(source: http://www.weather.lanl.gov/documentation.asp)
Evapotranspiration coefficient	0.5	0.999	unitless	Maximum allowed value: results in effectively no water infiltration through contaminated zone; assumption maximizes potential dose by soil exposure over time	n/a
Wind speed	2	3	m/s	Annual average wind speed at Laboratory is 2.5 m/s (rounded to 3 to give an upper bound limit), with sustained winds over 4 m/s occurring 20% of the time between mid-March and early June	source: http://www.weather.lanl.gov/documentation.asp
Precipitation	1	0.29	m/yr	5th percentile annual precipitation rate	Bowen 1990
Irrigation	0.2	0	m/yr	Consistent with evapotranspiration coefficient of 0.999; assumption maximizes potential dose via soil exposure over time	n/a
Irrigation mode	Overhead	Overhead	unitless	RESRAD default	Yu et al. 2001
Runoff coefficient	0.2	0.9	unitless	High value minimizes water infiltration; consistent with evapotranspiration coefficient of 0.999; assumption maximizes potential dose via soil exposure over time	n/a
Watershed area for nearby stream or pond	1,000,000	1,000,000	m^2	RESRAD default	Yu et al. 1993 (Section 17)
Accuracy for water/ soil computations	0.001	0.001	unitless	RESRAD default	Yu et al. 2001

Table 1 (continued)

Parameter	Default Value	User Input Value	Units	Comments	Reference
Saturated Zone Hydraulic Parameters					
Density of saturated zone	1.5	1.5	g/cm^3	RESRAD default was selected as a reasonable average	Yu et al. 1993 (Section 2)
Saturated zone total porosity	0.4	0.4	unitless	RESRAD default	Yu et al. 2001
Saturated zone effective porosity	0.2	0.2	unitless	RESRAD default	Yu et al. 2001
Saturated zone field capacity	0.2	0.2	unitless	RESRAD default	Yu et al. 2001
Saturated zone hydraulic conductivity	100	100	m/yr	RESRAD default	Yu et al. 2001
Saturated zone hydraulic gradient	0.02	0.02	unitless	RESRAD default	Yu et al. 2001
Saturated zone b parameter	5.3	5.3	unitless	RESRAD default	Yu et al. 2001
Water table drop rate	0.001	0.001	m/yr	RESRAD default	Yu et al. 1993 (Section 18)
Model for water transport parameters [nondispersion (ND) or mass balance (MB)]	ND	ND	unitless	RESRAD default	NRC 2006
Well pumping rate	250	250	m^3/yr	RESRAD default	Yu et al. 2001
Uncontaminated Unsaturated Zone Parameters					
Number of unsaturated zone strata	1	1	unitless	RESRAD default	Yu et al. 2001
Unsaturated zone 1 thickness	4	300	m	Approximate thickness of vadose zone for Pajarito Plateau	Hollis et al. 1997
Unsaturated zone 1 soil density	1.5	1.5	g/cm^3	RESRAD default	Yu et al. 2001
Unsaturated zone 1 total porosity	0.4	0.48	unitless	Value for crushed tuff used in MDA G PA/CA	Hollis et al. 1997, Appendix 2e
Unsaturated zone 1 effective porosity	0.2	0.4	unitless	Calculated as total porosity minus water content of approximately 0.08	Hollis et al. 1997, Appendix 2e
Unsaturated zone 1 field capacity	0.2	0.2	unitless	RESRAD default	Yu et al. 2001
Unsaturated zone 1 hydraulic conductivity	10	10	m/yr	RESRAD default	Yu et al. 2001

Table 1 (continued)

Parameter	Default Value	User Input Value	Units	Comments	Reference
Unsaturated zone 1 b parameter	5.3	5.3	unitless	RESRAD default	Yu et al. 2001
Inhalation rate	8400	4712	m^3/yr	Calculated as 12.9 m^3/d × 365.25 d/yr, where 12.9 m^3/d is the mean of 95th percentile values from 0 to <6 yr old.	EPA 2011, Table 6-1
Mass loading for inhalation	0.0001	0.00000015	g/m^3	Calculated as (1 / 6.6 × 10^9 m^3/kg) × 1000 g/kg, where 6.6 × 10^9 m^3/kg is the particulate emission factor.	NMED 2012
Exposure duration	30	6	yr	Young child exposure 0 to <6 yr	NMED 2012
Inhalation shielding factor	0.4	1.0	unitless	No attenuation of outdoor dust concentration for indoors	n/a
External shielding factor	0.7	0.7	unitless	RESRAD default (Value is considered conservative for gamma energies < 1 MeV, but could be adjusted if larger amounts of higher-energy gamma emitters are present.)	Yu et al. 2001
Occupancy, Inhalation, and External Gamma Parameters					
Indoor time fraction	0.5	0.8656	unitless	Calculated as [(24 h/d–2.32 h/d) × 350 d/yr] / 8766 h/yr. (Note: An exposure frequency of 350 d/yr is used because this is the standard default exposure frequency used for the residential scenario as presented in NMED guidance (NMED 2012) and EPA regional screening tables (http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm).	n/a

Table 1 (continued)

Parameter	Default Value	User Input Value	Units	Comments	Reference
Outdoor time fraction	0.25	0.0926	unitless	Calculated as (2.32 h/d × 350 d/yr) / 8766 h/yr, where 2.32 h/d is the largest amount of time spent outdoors for child age groups between 1 to <3 mo and 3 to <6 yr (Note: An exposure frequency of 350 d/yr is used because this is the standard default exposure frequency used for the residential scenario as presented in NMED guidance (NMED 2012) and EPA regional screening tables (http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm).	EPA 2011, Table 16-20
Shape of contaminated zone	Circular	Circular	unitless	RESRAD default	Yu et al. 1993 (Section 50)
Radon Data					
Cover total porosity	0.4	Not used	unitless	n/a	n/a
Cover volumetric water content	0.05	Not used	unitless	n/a	n/a
Cover radon diffusion coefficient	0.000002	Not used	m^2/s	n/a	n/a
Bldg foundation thickness	0.15	Not used	m	n/a	n/a
Bldg foundation density	2.4	Not used	g/cm^3	n/a	n/a
Bldg foundation volumetric water content	0.03	Not used	unitless	n/a	n/a
Bldg foundation radon diffusion coefficient	0.0000003	Not used	m^2/s	n/a	n/a
Contaminated radon diffusion coefficient	0.000002	Not used	m^2/s	n/a	n/a
Radon vertical dimension of mixing	2	Not used	m	n/a	n/a
Bldg air exchange rate	0.5	Not used	1/h	n/a	n/a
Bldg room height	2.5	Not used	m	n/a	n/a
Building Indoor Area factor	0	Not used	unitless	n/a	n/a
Foundation depth below ground surface	1	Not used	m	n/a	n/a
Rn-222 Emanation Coefficient	0.25	Not used	unitless	n/a	n/a

Table 1 (continued)

Parameter	Default Value	User Input Value	Units	Comments	Reference
Rn-220 Emanation Coefficient	0.15	Not used	unitless	n/a	n/a
Ingestion Pathway (Dietary Data)					
Fruits, vegetables, and grains consumption	160	14	kg/yr	Age-weighted body-weight normalized sum of mean per capita fruit and vegetable ingestion rates for populations that garden; child age 1 to <21 yr [(fruits+vegetables per age group × body weight per age group × 365.25 ÷ 1000) then sum age group totals × age weight over 20 yr]	EPA 2011, Table 13-1 and Table 8-10
Leafy vegetable consumption	14	0	kg/yr	Assumes that home production of leafy vegetables is negligible	n/a
Milk consumption	92	Not used	L/yr	Pathway suppressed	n/a
Meat and poultry consumption	63	Not used	kg/yr	Pathway suppressed	n/a
Fish consumption	5.4	Not used	kg/yr	Pathway suppressed	n/a
Other seafood consumption	0.9	Not used	kg/yr	Pathway suppressed	n/a
Soil ingestion rate	36.5	73	g/yr	Calculated as [0.2 g/d × 350 d/yr] / [indoor + outdoor time fractions], where 0.2 g/d is the child soil ingestion rate (Note: An exposure frequency of 350 d/yr is used because this is the standard default exposure frequency used for the residential scenario as presented in NMED guidance (NMED 2012) and EPA regional screening tables (http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm).	NMED 2012; EPA 2011, Table 5-1
Contamination fraction of household water	1	Not used	unitless	Pathway suppressed	n/a
Contamination fraction of livestock water	1	Not used	unitless	Pathway suppressed	n/a
Contamination fraction of irrigation water	1	Not used	unitless	Pathway suppressed	n/a
Contamination fraction of plant food	1	1	unitless	RESRAD default	Yu et. al.1993
Contamination fraction of meat	1	Not used	unitless	Pathway suppressed	n/a

Table 1 (continued)

Parameter	Default Value	User Input Value	Units	Comments	Reference
Contamination fraction of milk	1	Not used	unitless	Pathway suppressed	n/a
Ingestion Pathway (Non-Dietary Data)					
Livestock fodder intake for meat	68	Not used	kg/d	Pathway suppressed	n/a
Livestock fodder intake for milk	55	Not used	kg/d	Pathway suppressed	n/a
Livestock water intake for meat	50	Not used	L/d	Pathway suppressed	n/a
Livestock water intake for milk	160	Not used	L/d	Pathway suppressed	n/a
Livestock intake of soil	0.5	Not used	kg/d	Pathway suppressed	n/a
Mass loading for foliar deposition	0.0001	0.0001	g/m^3	RESRAD default	Yu et. al.1993
Depth of soil mixing layer	0.15	0.15	m	RESRAD default	Yu et. al.1993
Depth of roots	0.9	0.9	m	RESRAD default	Yu et. al.1993
Groundwater fractional usage: drinking water	1	Not used	unitless	Pathway suppressed	n/a
Groundwater fractional usage: household water	1	Not used	unitless	Pathway suppressed	n/a
Plant Transport Factors					
Wet weight crop yield: nonleafy vegetables	0.7	0.7	kg/m^2	RESRAD default	Yu et. al.1993; NRC 2000
Wet weight crop yield: leafy vegetables	1.5	1.5	kg/m^2	RESRAD default	Yu et. al.1993; NRC 2000
Wet weight crop yield: fodder	1.1	Not used	kg/m^2	Pathway suppressed	n/a
Length of growing season: nonleafy vegetables	0.17	0.17	yr	RESRAD default	Yu 1993; NRC 2000
Length of growing season: leafy vegetables	0.25	0.25	yr	RESRAD default	Yu et. al.1993; NRC 2000
Length of growing season: fodder	0.08	Not used	yr	Pathway suppressed	n/a
Translocation factor: nonleafy vegetables	0.1	0.1	unitless	RESRAD default	Yu et. al.1993; NRC 2000

Table 1 (continued)

Parameter	Default Value	User Input Value	Units	Comments	Reference
Translocation factor: leafy vegetables	1	1	unitless	RESRAD default	Yu et. al.1993; NRC 2000
Translocation factor: fodder	1	Not used	unitless	Pathway suppressed	n/a
Weather removal constant	20	20	1/yr	RESRAD default	Yu et. al.1993; NRC 2000
Wet foliar interception fraction: nonleafy vegetables	0.25	0.25	unitless	RESRAD default	Yu et. al.1993; NRC 2000
Wet foliar interception fraction: leafy vegetables	0.25	0.25	unitless	RESRAD default	Yu et. al.1993; NRC 2000
Wet foliar interception fraction: fodder	0.25	Not used	unitless	Pathway suppressed	n/a
Dry foliar interception fraction: nonleafy vegetables	0.25	0.25	unitless	RESRAD default	Yu et. al.1993; NRC 2000
Dry foliar interception fraction: leafy vegetables	0.25	0.25	unitless	RESRAD default	Yu et. al.1993; NRC 2000
Storage Times Before Use					
Fruits, non-leafy vegetables, and grain	14	1	days	RESRAD default	Yu 1993 and Yu et al. 2001, model assumption for home-grown produce
Leafy vegetables	1	1	days	RESRAD default	Yu et. al.1993, Yu et al. 2001
Milk	1	1	days	RESRAD default	Yu et. al.1993, Yu et al. 2001
Meat	20	20	days	RESRAD default	Yu et. al.1993, Yu et al. 2001
Fish	7	7	days	RESRAD default	Yu et. al.1993, Yu et al. 2001
Crustacea and mollusks	7	7	days	RESRAD default	Yu et. al.1993, Yu et al. 2001
Well water	1	1	days	RESRAD default	Yu et. al.1993, Yu et al. 2001
Surface water	1	1	days	RESRAD default	Yu et. al.1993, Yu et al. 2001
Livestock fodder	45	45	days	RESRAD default	Yu et. al.1993, Yu et al. 2001

*n/a = Not applicable.

Table 2
Residential Scenario: Variable Exposure Parameters from 2011 EFH

Parameters	Residential, Child	Residential, Adult
Outdoor time fraction	0.0926[a]	0.0934[b]
Indoor time fraction	0.8656[c]	0.8648[d]
Inhalation rate (m^3/year)	4,712[e]	7,780[f]
Mass loading (g/m^3)	1.51×10^{-7}[g]	1.51×10^{-7}[g]
Soil ingestion (g/year)	73[h]	36.5[i]
Produce ingestion (kg/year)	14[j]	22.1[k]

Note: An exposure frequency of 350 d/yr is used because this is the standard default exposure frequency used for the residential scenario as presented in NMED guidance (NMED 2012) and EPA regional screening tables at http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm.

[a] Calculated as (2.32 h/d × 350 d/yr) / 8766 h/yr, where 2.32 h/d (139 min) is the largest amount of time spent outdoors for child age groups between 1 to <3 mo and 3 to <6 yr (EPA 2011; Table 16-1) and is comparable with the adult time spent outdoors at a residence.

[b] Calculated as (2.34 h/d × 350 d/yr) / 8766 h/yr. 4.68 h/d is the average total time spent outdoors for adults age 18 to <65 yr in all environments (EPA 2011; Table 16-1); 50% of this value (2.34 h/d) was applied to time spent outdoors at a residence and is similar to mean time outdoors at a residence for this age group (Table 16-22).

[c] Calculated as [(24 – 2.32 h/d) × 350 d/yr] / 8766 h/yr.

[d] Calculated as [(24 – 2.34 h/d) × 350 d/yr] / 8766 h/yr.

[e] Calculated as 12.9 m^3/d × 365.25 d/yr, where 12.9 m^3/d is the age-weighted daily inhalation rate of a child age 0 to <6 yr (EPA 2011; Table 6-1).

[f] Calculated as 21.3 m^3/d × 365.25 d/yr, where 21.3 m^3/d is the age-weighted daily inhalation rate of an adult age 21 to <61 yr (EPA 2011; Table 6-1).

[g] Calculated as (1 / 6.61×10^9 m^3/kg) x 1000 g/kg; where 6.61×10^9 m^3/kg is particulate emission factor from NMED (NMED 2012).

[h] The soil ingestion rate compensates for the time-based occupancy factor applied by RESRAD in calculating exposure from the soil ingestion pathway. Calculated as [0.2 g/d × 350 d/yr] / [indoor + outdoor time fractions]; where 0.2 g/d is the 3 to <6 yr child upper percentile soil ingestion rate (EPA 2011; Table 5-1).

[i] The soil ingestion rate compensates for the time-based occupancy factor applied by RESRAD in calculating exposure from the soil ingestion pathway. Calculated as [0.1 g/d × 350 d/yr] / [indoor + outdoor time fractions]; where 0.1 g/d is a central tendency soil ingestion rate for ages 6 to <21 yr and is 2× the adult central tendency soil ingestion rate (EPA 2011; Table 5-1).

[j] Calculated as the age-weighted body-weight normalized sum of mean per capita fruit and vegetable ingestion rates for populations that garden; child age 1 to <21 yr (EPA 2011; Tables 13-1 and 8-10).

[k] Calculated as the age-weighted body-weight normalized sum of mean per capita fruit and vegetable ingestion rates for populations that garden; adult age 21 to 65 yr (EPA 2011; Tables 13-1 and 8-1).

Table 3
DCFs Calculated by Linear Interpolation and ICRP 72 Age-Dependent DCFs

Radionuclide	Ingestion DCFs (mrem/pCi)				Inhalation DCFs (mrem/pCi)			
	0 to <6 yr*	3 mo	1 yr	5 yr	0 to <6 yr*	3 mo	1 yr	5 yr
Americium-241	3.268E-03	1.369E-02	1.369E-03	9.990E-04	5.735E-01	6.660E-01	6.660E-01	4.440E-01
Cobalt-60	1.011E-04	1.998E-04	9.990E-05	6.290E-05	2.803E-04	3.404E-04	3.182E-04	2.183E-04
Cesium-134	6.074E-05	9.620E-05	5.920E-05	4.810E-05	2.035E-04	2.590E-04	2.331E-04	1.517E-04
Cesium-137+D	4.625E-05	7.770E-05	4.440E-05	3.552E-05	3.299E-04	4.070E-04	3.700E-04	2.590E-04
Tritium	3.715E-07	4.440E-07	4.440E-07	2.701E-07	1.613E-07	2.368E-07	1.776E-07	1.147E-07
Iodine-129	7.123E-04	6.660E-04	8.140E-04	6.290E-04	6.598E-04	6.290E-04	7.400E-04	5.920E-04
Sodium-22	4.903E-05	7.770E-05	5.550E-05	3.108E-05	2.309E-05	3.589E-05	2.701E-05	1.406E-05
Plutonium-238	3.561E-03	1.480E-02	1.480E-03	1.147E-03	6.321E-01	7.400E-01	7.030E-01	5.180E-01
Plutonium-239	3.746E-03	1.554E-02	1.554E-03	1.221E-03	6.691E-01	7.770E-01	7.400E-01	5.550E-01
Strontium-90+D	3.922E-04	9.657E-04	3.441E-04	2.109E-04	1.320E-03	1.602E-03	1.513E-03	1.015E-03
Technetium-99	1.711E-05	3.700E-05	1.776E-05	8.510E-06	1.193E-04	1.517E-04	1.369E-04	8.880E-05
Thorium-228+D	6.660E-03	2.425E-02	4.051E-03	2.234E-03	5.029E-01	7.135E-01	5.913E-01	3.304E-01
Uranium-234	5.643E-04	1.369E-03	4.810E-04	3.256E-04	9.435E-02	1.221E-01	1.073E-01	7.030E-02
Uranium-235+D	5.554E-04	1.309E-03	4.903E-04	3.189E-04	8.480E-02	1.110E-01	9.621E-02	6.290E-02
Uranium-238+D	6.013E-04	1.406E-03	5.365E-04	3.441E-04	8.119E-02	1.075E-01	9.261E-02	5.926E-02

* 0 to <6 yr old DCFs derived by linear interpolation of the individual age-dependent DCFs from ICRP 72 (ICRP 1996).

Table 4
Residential SALs for Child and Adult Receptors

Radionuclides	Child Current SALs 15 mrem/yr (FGR 11)	Child 2011 EFH Parameters 15 mrem/yr (ICRP 72 0 to <6 yr)	Child 2011 EFH Parameters 25 mrem/yr (ICRP 72 0 to <6 yr)	Adult 2011 EFH Parameters 15 mrem/yr (ICRP 72 adult)	Adult 2011 EFH Parameters 25 mrem/yr (ICRP 72 adult)
Americium-241	30	49	82	210	350
Cobalt-60	1.3	1.5	2.5	1.5	2.5
Cesium-134	2.4	2.8	4.7	2.8	4.7
Cesium-137+D	5.6	6.7	11	6.7	11
Tritium	750	510	850	750	1300
Iodine-129	44	58	97	74	120
Sodium-22	1.6	1.9	3.2	1.9	3.2
Plutonium-238	37	50	84	310	510
Plutonium-239	33	48	79	280	470
Strontium-90+D	5.7	9	15	20	33
Technetium-99	36	13	21	57	95
Thorium-228+D	2.3	2.5	4.1	2.7	4.4
Thorium-230	5*	5	5	5	5
Thorium-232	5*	5	5	5	5
Uranium-234	170	160	270	440	740
Uranium-235+D	17	23	39	26	44
Uranium-238+D	87	92	150	130	220

Note: Units are pCi/g for all SAL values.

* The SAL is the generic soil guideline for release of property published in Chapter 4 (Requirements) of DOE Order 458.1. A value of 5 pCi/g applies to the concentration averaged over the first 15 cm of soil below the surface; for subsequent 15-cm-thick layers the generic soil guideline is 15 pCi/g.

Table 5
Comparison of Residential SALs for a Child

Radionuclides	Child 2011 EFH Parameters 15 mrem/yr (ICRP 72 0 to <6 yr)	Child 2011 EFH Parameters 25 mrem/yr (ICRP 72 0 to <6 yr)	Child 2011 EFH Parameters 15 mrem/yr (ICRP 72 3 mo)	Child 2011 EFH Parameters 25 mrem/yr (ICRP 72 3 mo)
Americium-241	49	82	47	78
Cobalt-60	1.5	2.5	1.4	2.3
Cesium-134	2.8	4.7	2.6	4.3
Cesium-137+D	6.7	11	6.2	10.3
Tritium	510	850	12000	20000
Iodine-129	58	97	630	1050
Sodium-22	1.9	3.2	1.7	2.8
Plutonium-238	50	84	48	80
Plutonium-239	48	79	46	77
Strontium-90+D	9	15	400	670
Technetium-99	13	21	17000	28300
Thorium-228+D	2.5	4.1	2.3	3.8
Thorium-230	5*	5	5	5
Thorium-232	5*	5	5	5
Uranium-234	160	270	300	500
Uranium-235+D	23	39	21	35
Uranium-238+D	92	150	110	180

Note: Units are pCi/g for all SAL values.

* The SAL is the generic soil guideline for release of property published in Chapter 4 (Requirements) of DOE Order 458.1. The value of 5 pCi/g applies to the concentration averaged over the first 15 cm of soil below the surface; for subsequent 15-cm-thick layers the generic soil guideline is 15 pCi/g.

Table 6
Sensitivity Analysis of RESRAD Input Parameters

Parameter	Multiplier	Americium-241	Strontium-90	Tritium	Cesium-137	Plutonium-239	Uranium-238
Contaminated Zone							
Distribution coefficient (K_d)	10	<	<	<	<	<	<
Soil density (two levels tested)	1.5 1.1	< <	< <	> <	< <	< <	< <
Total porosity	1.5	<	<	<	<	<	<
Field capacity (two levels tested)	1.5 1.1	< <	< <	> <	< <	< <	< <
Hydraulic conductivity	1.5	<	<	<	<	<	<
Site Conditions							
Precipitation	2	<	<	>	<	<	<
Average wind velocity	1.5	<	<	<	<	<	<
Runoff coefficient	Maximum value	n/a*	n/a	n/a	n/a	n/a	n/a
Evapotranspiration	Maximum value	n/a	n/a	n/a	n/a	n/a	n/a
Saturated Zone							
Density	1.1	<	<	<	<	<	<
Total porosity	1.5	<	<	<	<	<	<
Field capacity	1.5	<	<	<	<	<	<
Hydraulic conductivity	1.5	<	<	<	<	<	<
Hydraulic gradient	1.5	<	<	<	<	<	<
Unsaturated Zone							
Thickness	1.5	<	<	<	<	<	<
Density	1.5	<	<	<	<	<	<
Total porosity	1.5	<	<	<	<	<	<
Effective porosity	1.5	<	<	<	<	<	<
Field capacity	1.5	<	<	<	<	<	<
Hydraulic conductivity	1.5	<	<	<	<	<	<
Receptor Parameters							
Inhalation rate	1.5	<	<	<	<	<	<
Mass loading	2	<	<	<	<	<	<
External gamma shielding	1.25	<	<	<	>	<	>
Indoor time fraction	1.1	<	<	<	>	<	>
Outdoor time fraction	1.1	<	<	<	<	<	<
Fruit, vegetable, grain ingestion	1.5	>	>	>	<	<	>
Soil ingestion	1.5	>	<	<	<	>	<

Table 6 (continued)

Parameter	Multiplier	Americium-241	Strontium-90	Tritium	Cesium-137	Plutonium-239	Uranium-238
Mass loading foliar deposition	1.5	<	<	<	<	<	<
Depth of mixing layer	1.5	<	<	<	<	<	<
Depth of root	1.5	<	<	<	<	<	<
Storage time	2	<	<	<	<	<	<

Note: Threshold for significance is 10% difference between the middle and upper-bound value (i.e., < indicates a percent difference less than 10%; > indicates a percent difference greater than 10%).

* n/a = Not applicable.