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Date: SEP 28 2015
Refer To: ADESH-15-133
LAUR: 15-24859
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John Kieling, Bureau Chief
Hazardous Waste Bureau
New Mexico Environment Department
2905 Rodeo Park Drive East, Building 1
Santa Fe, NM 87505-6303

Subject: Submittal of the Derivation and Use of Radionuclide Screening Action Levels, Revision 4

Dear Mr. Kieling:

Enclosed please find two hard copies with electronic files of the Derivation and Use of Radionuclide Screening Action Levels, Revision 4. Revision 4 of this report uses RESRAD, Version 7.0 (current version) to calculate the screening action levels (SALs) for each scenario. This revision also addresses the New Mexico Environment Department's comments on Revision 3 received in a letter dated February 26, 2015. The SALs calculated and presented herein will be used to assess environmental data and calculate dose to the public as well as to other receptors. The SALs will also be used to make corrective action decisions for Los Alamos National Laboratory sites and support land transfer decisions by the Laboratory and the U.S. Department of Energy.

If you have any questions, please contact Richard Mirenda at (505) 665-6953 (rmirenda@lanl.gov) or Arturo Duran at (505) 665-7772 (arturo.duran@em.doe.gov).

Sincerely,

FOR B. ROBINSON
Bruce Robinson, Program Director
Environmental Remediation Program
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Sincerely,

Douglas E. Hintze, Manager
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BR/DH/RM:sm

Enclosures: Two hard copies with electronic files – Derivation and Use of Radionuclide Screening Action Levels, Revision 4 (EP2015-0122)

Cy: (w/enc.)
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Derivation and Use of Radionuclide Screening Action Levels, Revision 4

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Prepared by the Environmental Programs Directorate

CONTENTS

Tables

Appendixes

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	Department of Energy (U.S.)
EPA	Environmental Protection Agency (U.S.)
EFH	Exposure Factors Handbook
ESH	Environment, Safety, and Health
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
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 contribution of different exposure routes 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 https://web.evs.anl.gov/resrad/home2/index.cfm. A description of the quality assurance program for verification, benchmarking, and validation of RESRAD is also 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 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, 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) and ICRP Publication 119 (ICRP 2012, 600497). 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 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 Laboratory 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 2014, 600496). 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 for dose from all DOE sources. 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 7.0 (printouts of RESRAD Summary Reports for SALs calculated using a 25-mrem/yr dose limit are provided in Appendix A on CD). Before DOE Order 458.1 was released in 2011, SALs were calculated using a 15-mrem/yr dose limit. Although 25 mrem/yr is proposed as the ultimate basis for site decisions, SALs related to a 15-mrem/yr threshold are also provided in Appendix B.

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). If 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 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 and around 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 2015, 600336). 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).

Table 5.0-1
Radionuclide SALs Based on 25 mrem/yr Using RESRAD Version 7.0

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	83	1000	230	1500	0.0
Cesium-134	5.0	17	15	150	0.0
Cesium-137+D[b]	12	41	37	370	0.0
Cobalt-60	2.6	9.0	8.1	81	0.0
Iodine-129	96	2300	710	2000	0.0
Plutonium-238	84	1300	230	1400	0.0
Plutonium-239/240[c]	79	1200	200	1300	0.0
Sodium-22	3.4	11	10	100	0.0
Strontium-90+D[b]	15	2400	1400	4900	0.0
Technetium-99	21	330,000	110,000	220,000	0.0
Thorium-228+D[b]	4.6	17	15	130	0.0
Thorium-230[d]	5	5	5	5[e]	Not applicable[f]
Thorium-232[d]	5	5	5	5[e]	Not applicable[f]
Tritium	1700	2,400,000	1,600,000	5,700,000	0.0
Uranium-234	290	3100	1000	3900	1000
Uranium-235+D[b]	42	160	130	1000	1000
Uranium-238+D[b]	150	710	470	2800	1000

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

[b] Includes contribution to dose of radioactive progeny (plus daughters). Cesium-137 progeny is barium-137m; strontium-90 progeny is yttrium-90; thorium-228 progeny include radium-224, radon-220, polonium-216, lead-212, bismuth-212, and thallium-208; uranium-235 progeny is thorium-231, and uranium-238 progeny include thorium-234, protactinium-234m and protactinium-234.

[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: 114 pCi/g
- Thorium-232: 40.4 pCi/g

[f] The generic soil guideline of 5 pCi/g is not a calculated value.

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 have 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 per 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.

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[a]	X	X	X	X
Ingestion of garden produce	X	—[b]	—	—

[a] This exposure route is not specifically identified as a distinct pathway in the RESRAD summary reports provided in Appendix A.

[b] — = Not applicable.

The primary sources of exposure parameter values used in the SAL calculations are NMED's risk assessment guidance for investigations and remediation (NMED 2015, 600675) 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 2014, 600495). Selection of exposure parameter values and the scenario-specific assumptions constraining potential exposure conditions are described in section 6.0.

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 2015, 600575). 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. Residential radionuclide SALs (Table 5.0-1 and Appendix B) are defined based on the receptor with the highest potential dose: the child receptor. The residential exposure parameter values and their derivation (described in the table notes) are presented in Table 6.1-1. The input exposure parameters used in the calculations are those obtained from the EFH (EPA 2011, 208374) as well as from NMED guidance (NMED 2015, 600575). 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 to a receptor exposed to site soil (Appendix A).

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)	1.51×10^{-7}[c]	1.51×10^{-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 / 6.61×10^9 m^3/kg) × 1000 g/kg, where 6.61×10^9 m^3/kg is the particulate emission factor (NMED 2015, 600575).

[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 2015, 600575; 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 2015, 600575).

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 of the handbook (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) include consumption of garden vegetables and fruits. These ingestion rates are the age-weighted body-weight normalized sum of the mean per capita fruit and vegetable ingestion rates for home-produced foods (EPA 2011, 208374). The mean plant ingestion rate for the less-than-6-yr-old child receptor is biased high to include an older child/pre-adult (1 to less than 21 yr) to provide an RME estimate (EPA 2011, 208374, Tables 13-1, 8-10, and 8-13). The adult mean plant ingestion rate is based on ages 21 to 65 yr (EPA 2011, 208374, Tables 13-1 and 8-1). Inclusion of older age groups in the calculation of home-grown plant ingestion rates is protective because body-weight normalized intake rates of combined fruits and vegetables increase with each age group provided in Table 13-1 of the EFH (EPA 2011, 208374).

Because the plant-ingestion rate values applied to calculate radionuclide SALs are based on per capita statistics rather than consumer-only, they include individuals in farming and gardening households that did not consume home-raised produce during the 1-wk survey period over which the ingestion data were acquired. The per capita values may be compared with the higher produce consumption rates in EFH Tables 13-5 and 13-10, which are consumer-only, unadjusted values. As stated in section 13.3.2 of the EFH (EPA 2011, 208374), consumer-only intake values may overestimate exposure over residential scenario time periods that are much longer than a 1-wk survey. In the case of residential SALs, produce ingestion rates are derived from data representing a 20-yr time period for children and a 45-yr period for adults. This is the principal reason for applying per capita rather than consumer-only intake rates. In addition, the consumer-only data represent the unadjusted weight of food brought into the home rather than “as-consumed” weights. Consistent with section 13.2 of the EFH, preparation and cooking-loss factors were applied in deriving the produce-ingestion rate values in EFH Table 13-1 used in calculating residential SALs. The average percent decrease in weight is approximately 30% for fruits and 20% for vegetables (EFH 2011, 208374, Table 13-69).

The inputs from Tables 13-1, 8-1, 8-10, and 8-13 of the EFH (EPA 2011, 208374) used to calculate child and adult plant ingestion rates are shown in Table 6.1-2. The age groups for which per-capita home-produced fruit and vegetable rates are provided in Table 13-1 include 1 to less than 3 yr, 3 to less than 6 yr, 6 to less than 11 yr, 11 to less than 21 yr, 21 to less than 50 yr, and greater than or equal to 50 yr. The annual fruit and vegetable intake rates for each age group (kg/yr), calculated as the product of the produce-ingestion rates and mean body weights in Table 6.1-2 with adjustment for units, are shown in Table 6.1-3.

Table 6.1-2
Inputs for Calculating Plant Ingestion Rates

Age Range	Mean, Fruit (g/kg-d)	Mean, Vegetable (g/kg-d)	Mean, Body Weight (kg)	Body Weight EFH Table Reference
1–<3 yr	1.0	1.3	12.15	Table 8-10 (avg. of 1 and 2 yr)
3–<6 yr	0.78	1.1	17.2	Table 8-10 (avg. of 3, 4, and 5 yr)
6–<11 yr	0.4	0.8	28.72	Table 8-10 (avg. of 6, 7, 8, 9, and 10 yr)
11–<21 yr	0.13	0.56	60.66	Weighted 11–14 (Table 8-10) and 15–19 yr (Table 8-13)
21–<50 yr	0.15	0.56	80	Adults; 21+ yr (Table 8-1)
50+ yr	0.24	0.6	80	Adults; 21+ yr (Table 8-1)

Table 6.1-3
Annual Fruit and Vegetable Ingestion Rates

Age Range	Mean, Fruit* (g/kg-d)	Mean, Vegetable* (g/kg-d)	Mean, Sum of Fruit and Vegetable (kg/yr)
1–<3 yr	4.44	5.77	10.2
3–<6 yr	4.90	6.91	11.8
6–<11 yr	4.20	8.39	12.6
11–<21 yr	2.88	12.41	15.3
21–<50 yr	4.38	16.4	20.7
50–65 yr	7.01	17.5	24.5

* Calculated as the product of mean intake (g/kg-d) and body weight (kg) shown in Table 6.1-2, with unit adjustments of 1 kg/1000g and 365.25 d/yr.

Child and adult plant-ingestion rates were calculated by summing the age-weighted total produce ingestion rates shown in Table 6.1-3. For children, the mean value for ages up to 21 yr was used to be protective, as described above. The calculation of 14 kg/yr, protectively rounded upwards from 13.6 kg/yr, is as follows:

$$(2\text{ yr}/20\text{ yr} \times 10.2\text{ kg/yr}) + (3\text{ yr}/20\text{ yr} \times 11.8\text{ kg/yr}) + (5\text{ yr}/20\text{ yr} \times 12.6\text{ kg/yr}) + (10\text{ yr}/20\text{ yr} \times 15.3\text{ kg/yr})$$

Equation 6.1-1

For adults evaluated over an assumed exposure period from age 21 up to less than 66 yr of age, the calculation of 22.1 kg/yr is as follows:

$$(29\text{ yr}/45\text{ yr} \times 20.7\text{ kg/yr}) + (16\text{ yr}/45\text{ yr} \times 24.5\text{ kg/yr})$$

Equation 6.1-2

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 2015, 600575) as well as those obtained from the EFH (EPA 2011, 208374). These values and their derivation (described in table notes) are presented in Table 6.1-4.

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 2015, 600575) 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 6.1-5.

Table 6.1-4
Commercial/Industrial Scenario: Variable Exposure Parameters

Parameters	Commercial/Industrial, Adult
Inhalation rate (m^3/yr)	7780[a]
Mass loading (g/m^3)	1.51×10^{-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 / 6.61×10^9 m^3/kg) x 1000 g/kg, where 6.61×10^9 m^3/kg is the particulate emission factor (NMED 2015, 600575).

[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 2015, 600575).

[d] The commercial/industrial worker is defined as someone who "spends most of the work day conducting maintenance or manual labor activities outdoors" (NMED 2015, 600575).

[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 2015, 600575).

Table 6.1-5
Construction Worker Scenario: Variable Exposure Parameters

Parameters	Construction Worker, Adult
Inhalation rate (m^3/yr)	7780[a]
Mass loading (g/m^3)	4.76×10^{-4} [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 2015, 600575).

[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 2015, 600575).

[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 2015, 600575).

6.1.4 Recreational Scenario Variable Exposure Parameters

A recreational exposure scenario is defined in "Technical Approach for Calculating Recreational Soil Screening Levels for Chemicals, Revision 4" (LANL 2015, 600336) 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; the child. 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 2015, 600575) and the EFH (EPA 2011, 208374) and their derivation (described in the table notes) are presented in Table 6.1-6.

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.

Table 6.1-6
Recreational Scenario: Variable Exposure Parameters

Parameters	Recreational, Child	Recreational, Adult
Inhalation rate (m^3/yr)	15,250[a]	19,460[b]
Mass loading (g/m^3)	1.51×10^{-7} [c]	1.51×10^{-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 / 6.61×10^9 m^3/kg) × 1000 g/kg, where 6.61×10^9 m^3/kg is the particulate emission factor used for residential and industrial scenarios (NMED 2015, 600575).

[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 day 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 2015, 600575).

[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 2015, 600575).

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 less-than-6-yr-old child according to EPA (EPA 2011, 208374, Table 5-1) and is the soil ingestion rate used by NMED (2015, 600575) 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 a 6- to less-than-11-yr-old child 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

SALs before 2012 employed dose coefficients published in FGR 11 (EPA 1988, 050123), which are based on older uptake, metabolism, and internal dosimetry models from the late 1970s. The FGR 11 dose coefficients also pertain only to adults. With the release of RESRAD Version 6.4 in December 2007, RESRAD has included ICRP 72 DCFs, which have been developed for ages infant (3 mo), 1 yr, 5 yr, 10 yr, 15 yr, and adult (ICRP 1996, 223038). The ICRP 72 DCFs are based on the internal dosimetry methodology described in ICRP Publication 60 (ICRP 1991, 223037). 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 were recalculated using the ICRP 72 DCFs in 2012 (LANL 2012, 228852). With the release of RESRAD Version 7.0 in April 2014, the latest nuclear decay data from ICRP Publication 107 have been included in RESRAD (https://web.evs.anl.gov/resrad/home2/reshstry.cfm). These decay data are used in conjunction with the internal dosimetry methodology described in ICRP Publication 60 (ICRP 1991, 223037), and the resulting DCFs are referred to as “DCFPAK 3.02” in RESRAD’s internal dose library.

The SALs published in this report use the DCFPAK 3.02 DCFs available in RESRAD Version 7.0. 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 DCFPAK 3.02 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 DCFPAK 3.02 DCFs for ages 5 yr, 10 yr, and 15 yr interpolated over the 6- to less-than-12-yr age range. The Excel workbook used in the calculations of the residential and recreational child DCFs is provided in Appendix C (on CD).

The adult DCFPAK 3.02 DCFs were used to calculate the SALs for the industrial and construction worker scenarios. RESRAD Version 7.0 also includes a new set of DCFs that pertain to a Reference Person, as described in DOE guidance (2011, 600493). The Reference Person uses ICRP 72 age-specific DCFs and reflects the age and gender structure and air and water intake rates of the U.S. population. In this regard, the Reference Person reflects the same population-level approach to radiation protection applied by EPA in developing radionuclide cancer risk coefficients (EPA 1999, 600494). However, evaluating children using the interpolated DCFs is more protective in the residential and recreational scenarios relative to the population-average approach more commonly applied for radiation protection of the public. The use of interpolated DCFs is also consistent with previous versions of the radionuclide SALs. For these reasons, the Reference Person DCFs available in RESRAD Version 7.0 were not applied in the SAL calculations.

The external DCFs used in the dose calculations described in this report also employ the latest nuclear decay data from ICRP Publication 107 that have been included in RESRAD Version 7.0. These external DCFs are based on the same dosimetry as those used in the previous SALs, as described 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.

The default tritium ingestion DCFs in the RESRAD DCF libraries pertain to organically bound tritium and the inhalation DCFs to tritium bound to a particulate. Previous SAL calculations had employed these default DCFs even though the relevant form of tritium related to Laboratory operations and environmental sampling is water vapor. In this report, the tritium SALs employ DCFs that are specific to tritiated water.

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 attributes 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 in 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

Table 6.2-1 (continued)

RESRAD Data Field	Parameter	Units	Values	Rationale
Cover and CZ Hydrological Data (continued)	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 (LANL 2005, 088493)
	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 (LANL 2005, 088493)
	Precipitation	m/yr	0.29	Lower 5th percentile of annual precipitation (LANL 2005, 088493); 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
	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 × 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

Table 6.2-1 (continued)

RESRAD Data Field	Parameter	Units	Values	Rationale
Occupancy	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
	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	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 soil 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), radioactive 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. Hence, the static site conditions are most relevant in ensuring protective SALs for the uranium isotopes.

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 or ESH ID. This information is also included in text citations. ER IDs were assigned by the Environmental Programs Directorate's Records Processing Facility (IDs through 599999), and ESH IDs are assigned by the Environment, Safety, and Health (ESH) Directorate (IDs 600000 and above). IDs are used to locate documents in the Laboratory's Electronic Document Management System 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 summary reports from residual radioactivity (RESRAD) 7.0 computer code present details on the input parameter values, results of interim calculations, and single radionuclide soil guidelines related to the screening action levels (SALs) for each scenario. SALs are linearly proportional to the user-defined annual dose threshold. SALs based on a 15-mrem/yr dose threshold were derived from the 25-mrem/yr values by multiplying the 25-mrem/yr results by (15/25).

The summary reports also include total dose values related to the soil concentrations of each radionuclide. These dose results are not meaningful; the RESRAD simulations were conducted for the purpose of calculating the single radionuclide soil guidelines and the initial soil concentrations are arbitrary and have no influence on the soil guidelines.

- 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
- Recreational 25 mrem/yr, adult

Appendix B

Radionuclide Screening Action Levels

The radionuclide screening action levels (SALs) calculated according to the methods described in this guidance are shown in Table B-1. SALs are provided based on the 25 mrem/yr public dose limit specified in DOE Order 458.1 as well as the SALs based on 15 mrem/yr. The exposure pathway(s) contributing most to the SALs are presented in Table B-2. Residential and recreational 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 SALs for the child (ages 0 to less than 6 yr) were lower than or approximately equal to those for an adult. Therefore, the residential SALs from the residual radioactivity (RESRAD) 7.0 results for the child receptor are used. For the child, the residential 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.

The child recreational scenario is based on an “extended backyard” in which a child of age 6 to less than 12 yr 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. Because recreational SALs for children are also approximately equal to or lower than those for adults, the RESRAD 7.0 results for the child receptor are presented.

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

Table B-1
Radionuclide SALs Using RESRAD Version 7.0

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	50	83	610	1000	140	230	890	1500	0.0
Cesium-134	3.0	5.0	10	17	9.3	15	92	150	0.0
Cesium-137+D[b]	7.2	12	25	41	22	37	220	370	0.0
Cobalt-60	1.6	2.6	5.4	9.0	4.8	8.1	48	81	0.0
Iodine-129	57	96	1400	2300	430	710	1200	2000	0.0
Plutonium-238	51	84	790	1300	140	230	850	1400	0.0
Plutonium-239/240[c]	48	79	710	1200	120	200	770	1300	0.0
Sodium-22	2.0	3.4	6.9	11	6.2	10	62	100	0.0
Strontium-90+D[b]	9.0	15	1500	2400	840	1400	3000	4900	0.0
Technetium-99	12	21	200,000	330,000	67,000	110,000	130,000	220,000	0.0
Thorium-228+D[b]	3.0	4.6	10	17	8.9	15	79	130	0.0
Thorium-230[d]	5	5	5	5	5	5	5[e]	5[e]	Not applicable[f]
Thorium-232[d]	5	5	5	5	5	5	5[e]	5[e]	Not applicable[f]
Tritium	1000	1700	1,500,000	2,400,000	990,000	1,600,000	3,400,000	5,700,000	0.0
Uranium-234	180	290	1800	3100	610	1000	2300	3900	1000
Uranium-235+D[b]	25	42	95	160	77	130	620	1000	1000
Uranium-238+D[b]	88	150	420	710	280	470	1700	2800	1000

Notes: See RESRAD summary reports on CD in Appendix A for details of the inputs to the calculations. Values for 15 mrem/yr and 25 mrem/yr may differ slightly from the exact ratio of 15/25 because the values were rounded independently.

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

[b] Includes contribution to dose of radioactive progeny (plus Daughters). Cesium-137 progeny is barium-137m; strontium-90 progeny is yttrium-90; thorium-228 progeny include radium-224, radon-220, polonium-216, lead-212, bismuth-212, and thallium-208; uranium-235 progeny is thorium-231, and uranium-238 progeny include thorium-234, protactinium-234m and protactinium-234.

[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:

- Thorium-230: 68.4 pCi/g at 15 mrem/yr; 114 at 25 mrem/yr (at model year 1000)
- Thorium-232: 24.2 pCi/g at 15 mrem/yr; 40.4 at 25 mrem/yr (at model years 100–1000)

[f] The generic soil guideline of 5 pCi/g is not a calculated value.

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: 76% Plant Ingestion: 15% External: 9%	Soil Ingestion: 69% External: 31%	Soil Ingestion: 57% Inhalation: 35% External: 8%	Soil Ingestion: 95% External: 5%
CS-134	Cesium-134	External: 99%	External: 100%	External: 100%	External: 100%
CS-137	Cesium-137+D	External: 99%	External: 100%	External: 99%	External: 99%
CO-60	Cobalt-60	External: 99%	External: 100%	External: 100%	External: 100%
H-3[a]	Tritium	Plant Ingestion: 100%	Inhalation: 85% Soil Ingestion: 15%	Inhalation: 64% Soil Ingestion: 36%	Inhalation: 60% Soil Ingestion: 40%
I-129	Iodine-129	Plant Ingestion: 78% Soil Ingestion: 19%	Soil Ingestion: 82% External: 18%	Soil Ingestion: 94% External: 6%	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%	Soil Ingestion: 62% Inhalation: 37%	Soil Ingestion: 100%
PU-239	Plutonium-239	Soil Ingestion: 83% Plant Ingestion: 17%	Soil Ingestion: 100%	Soil Ingestion: 62% Inhalation: 38%	Soil Ingestion: 100%
SR-90	Strontium-90+D	Plant Ingestion: 97%	External: 76% Soil Ingestion: 24%	Soil Ingestion: 51% External: 48%	Soil Ingestion: 83% External: 17%
TC-99	Technetium-99	Plant Ingestion: 100%	Soil Ingestion: 71% External: 29%	Soil Ingestion: 87% External: 11%	Soil Ingestion: 98%
TH-228	Thorium-228+D	External: 91% Soil Ingestion: 7%	External: 99%	External: 97%	External: 86% Soil Ingestion: 14%
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: 53% Plant Ingestion: 33% External: 14%	Soil Ingestion: 56% External: 44%	Soil Ingestion: 68% Inhalation: 16% External: 16%	Soil Ingestion: 94% External: 6%
U-235[c]	Uranium-235+D	External: 87% Soil Ingestion: 8% Plant Ingestion: 5%	External: 97%	External: 86% Soil Ingestion: 10%	External: 70% Soil Ingestion: 30%
U-238[c]	Uranium-238+D	External: 63% Soil Ingestion 25% Plant Ingestion: 12%	External: 89% Soil Ingestion: 11%	External: 66% Soil Ingestion: 28% Inhalation: 6%	Soil Ingestion: 61% External: 39%

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

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Appendix C

Interpolated Dose Conversion Factors
for the Residential and Recreational Scenarios
(on CD included with this document)

The Excel workbook ‘DCF interpolation.xlsx’ was used to calculate interpolated residential scenario child (age 0 to less than 6 yr) and recreational scenario child (ages 6 to less than 12 yr) DCFs. Note that this workbook contains calculations for radionuclides that are not commonly associated with LANL operations and for which SALs are not generated.

The following is a description of the worksheets contained in ‘DCF interpolation.xlsx’.

- inputs. ICRP 72 DCFPAK 3.02 ingestion and inhalation DCFs pasted from the RESRAD Version 7.0 dose conversion factor editor for age groups infant, 1 year, 5 year, 10 year, 15 year, and adult. This worksheet also contains the DCFs for radionuclides that include the contribution of radioactive progeny, and DCFs for these radionuclides (designated with “+D” to signify the value includes the contribution of radioactive daughters) were copied from the RESRAD summary reports.
- inputs +D. ICRP 72 DCFPAK 3.02 ingestion and inhalation DCFs pasted from the RESRAD Version 7.0 dose conversion factor editor for age groups infant, 1 year, 5 year, 10 year, 15 year, and adult. This worksheet also contains the DCFs for the individual progeny radionuclides identified with “+D” in the worksheet ‘inputs’.
- calculation. Calculation of interpolated DCFs for the age categories ”0 to less than 6 yr” and “6 to less than 12 yr”.
- paste to RESRAD. Tabulation of rounded ingestion and inhalation interpolated DCF values for pasting into a new dose library in RESRAD version 7.0.