(33) Perona et al. 1998
ER ID 62049

LA-UR-98-5523

DOCUMENTATION OF THE CANYONS HUMAN HEALTH RISK SCREENING MODEL

prepared by

Ralph Perona, Mark Tardiff, and Randall Ryti
Neptune and Company, Inc.

for

Los Alamos National Laboratory
Environmental Restoration Project
Canyons Focus Area

December 14, 1998

Received by ER-RPF
DEC 16 1998
MA

7437

CONTENTS

1.0	Introduction	1
2.0	Exposure Scenarios and Pathways	2
2.1	Residential Scenario	3
2.2	Trail User Scenario	3
2.3	Resource User Scenario	3
2.4	Construction Worker Scenario	4
2.5	Long-Term Laboratory Employee	4
3.0	Identification of Risk and Dose Levels for Calculation Of PRGs	4
4.0	Relationship of PRGs and Their Use to the Canyons Core Document	5
5.0	Key Sources of Uncertainty in the Calculation of PRGs	5
5.1	Exposure Parameter Uncertainty	6
5.2	Uncertainty in Contaminant Transport Submodels	7
5.3	Toxicity Value Uncertainty	8
5.4	Model Uncertainty	9
6.0	Acknowledgements	9
7.0	References	10
Attachment A	Model Equations	12
Attachment B	Exposure Parameter Values and References	21
Attachment C	Plant and Meat Transfer factors from Soil	24
Attachment D	Chemical and Radionuclide Toxicity Values	26
Attachment E	Model Validation Data Sets	30

1.0 INTRODUCTION

The Canyons risk model is a spreadsheet-based analytical model that can be used to calculate risk (or risk-based screening concentrations) for various land use scenarios. The model was used to calculate preliminary remediation goals (PRGs) for soils and sediments in the reach reports for Los Alamos Canyon and Pueblo Canyon (Reneau et al. 1998a, 1998b, 1998c), as part of the Environmental Restoration (ER) Project at Los Alamos National Laboratory ("the Laboratory"). The model calculates risk or PRG values by analyte and exposure pathway for inorganic chemicals, organic chemicals, and radionuclides. Human health endpoints include hazard (noncarcinogens), incremental cancer risk (chemical carcinogens and radionuclides), and effective dose equivalent (radionuclides). Exposure scenarios that have been developed for the reach reports referenced above include residential, trail user, resource user, and construction worker. A fifth scenario, a long-term Laboratory employee, has also been developed but was not applied in the 1998 reach reports.

The model also supports quantitative and semiquantitative sensitivity and uncertainty analyses. All toxicity and exposure input parameters are specified separately, and each pathway is separated in the model, allowing evaluation of both parameter and pathway sensitivity. Independent worksheets were created for risk calculations, PRGs, submodels (Volatilization Factor (VF), Particulate Emission Factor (PEF), biota transfer factors), input of contaminant of potential concern (COPC) concentrations, and toxicity values. The Microsoft Excel® Scenario Manager tool was used to vary input parameter values in the risk calculation and contaminant concentration worksheets, allowing multiple exposure or source term scenarios to be evaluated within a single worksheet. The modular structure of the model allows new scenarios and pathways to be created with relative ease. For these reasons, the Canyons risk model is an appropriate tool for supporting risk characterization in a baseline risk assessment or evaluating risk reduction associated with possible remedial actions.

The Canyons risk model is documented in this report so that a complete description of the model does not have to be included with every application. Model documentation also allows other ER Project personnel to utilize the spreadsheets for applications beyond the Canyons assessments. A validation set of risk estimates and PRG values is provided for each scenario and chemical class so that users can verify their calculations.

Preliminary remediation goals described in this report are not equivalent to SALs used for potential release site (PRS) screening assessments. SALs are applicable primarily to mesa-top sites where potential residential land use is expected to be urban or suburban in nature. SALs for metals and organic chemicals (which are based on published EPA Region IX PRGs) do not include exposure pathways addressing contaminant uptake by homegrown fruits and vegetables because homegrown foods are not expected to make up significant portions of an urban residents diet. Radionuclide SALs do include ingestion of produce from a home garden, but do not address other pathways such as meat ingestion. Current and/or future land use in some canyon areas may, however, reasonably include significant exposure via both plant and meat ingestion pathways and these pathways are contained in the residential and resource user exposure scenarios in the Canyons model.

The model presently contains equations to allow calculation of risk associated with contaminated soil and water media. Risk associated with exposure to other potentially contaminated media including air (via suspended dust particles or organic vapors) and biota (fruits, vegetables, or meat) is addressed by modeling the concentration of contaminants in these media in equilibrium with contaminated soil. Contribution to risk from contaminated water through exposure pathways other than direct ingestion, either via inhalation of vapors or due to use of water for agriculture purposes, is not addressed in the model. The focus of the Canyons risk model on soil and sediment reflects it's use to date for developing PRG values for these media. The model may be modified in the future as need dictates to allow risk calculations to be performed with data from

samples of air or biotic media, or to assess contaminant movement through the environment using different transport submodels.

2.0 EXPOSURE SCENARIOS AND PATHWAYS

The following exposure scenarios and pathways are included in the model for the calculation of soil and sediment risk estimates and PRGs:

PATHWAYS	SOIL EXPOSURE SCENARIOS				
	Residential	Trail User	Resource User	Construction Worker	Long-Term Employee
Soil Ingestion	✓	✓	✓	✓	✓
Dust/VOC Inhalation	✓	✓	✓	✓	✓
Dermal Absorption, Soil	✓	✓	✓	✓	✓
Fruit/Vegetable Ingestion	✓		✓		
Meat Ingestion			✓		
External Gamma Irradiation	✓	✓	✓	✓	✓

Standard Environmental Protection Agency (EPA) default parameter values were used in the exposure scenarios, when available. These values are consistent with the objective of estimating risk under conditions of reasonable maximum exposure. Where EPA default parameters are not available, professional judgment has been used in selecting conservative values from other publications or setting site-specific assumptions. Exposure parameter values, and references, are provided in Attachment B.

Primary sources for obtaining exposure parameter values include *Use of Standard Default Exposure Factors* (EPA 1991a), *Exposure Factors Handbook* (EPA 1989a), and *Dermal Exposure Assessment: Principles and Applications* (EPA 1992). Transfer factors for metals and radionuclides used in the assessment of intake via fruit, vegetable, and meat ingestion were primarily obtained from *A Compilation of Radionuclide Transfer Factors for the Plant, Meat, Milk, and Aquatic Foods Pathways and the Suggested Values for the RESRAD Code* (Yu et al. 1993).

The intent of varying both pathways and parameter values among the scenarios is to provide intrinsic differences in the manner and intensity of exposure across different land uses. As an example, risk estimates for the resource user scenario are generally sensitive to the transfer of contaminants from sediments to plants and from plants to meat animals. Risk estimates for the residential scenario are generally sensitive to plant uptake of contaminants and also to direct ingestion and inhalation of soils and sediments, due to longer exposure duration and frequency. By evaluating multiple land use scenarios with different pathways and intensities of exposure the relative importance of assumptions regarding activity patterns and land use can be determined.

The residential scenario is the only exposure scenario in which both child and adult exposure is evaluated. The remaining exposure scenarios (trail user, resource user, construction worker, and long-term Laboratory employee) are evaluated only for adult receptors. EPA default exposure parameters generally distinguish between adults and children at an age of 6 years. Because activities for exposure scenarios other than residential are expected to primarily be associated with older children and/or adults, parameters for exposure of younger children are not included. However, the screening model was developed to allow assessment of exposure to both children and adults via the soil ingestion, inhalation, and dermal pathways for all scenarios if desired.

2.1 Residential Scenario

The residential scenario considers both adult and child receptors, although the ages of the receptor is dependent on both the exposure pathway and toxicological endpoint. The following table identifies receptors used in the residential scenario.

TOXICITY ENDPOINT	EXPOSURE PATHWAY				
	Soil Ingestion	Dust/VOC Inhalation	Fruit/ Vegetable Ingestion	Dermal Absorption, Soil	External Gamma Irradiation
Radionuclide Cancer Risk	child + adult[1]	child + adult[1]	adult	child + adult[1]	adult[2]
Radionuclide Dose	child or adult[3]	child or adult[3]	adult	child or adult[3]	adult[2]
Chemical Cancer Risk	child + adult[1]	child + adult[1]	adult	child + adult[1]	not applicable
Chemical Hazard	child	child	adult	child	not applicable

[1]Intake is additive over child and adult exposure duration.
[2]Exposure duration is adult, otherwise receptor age is not specified by exposure parameters.
[3]Whichever is highest. Receptor exposure not additive because endpoint is *annual* dose.

Exposure duration for a child is 6 years and 24 years for adult exposure. The child and adult ingestion rates for soil are 200 mg/d and 100 mg/d respectively. Both adult and child components of the scenario assume an exposure frequency of 350 d/yr and on-site exposure time of 24 hr/d. Each day, adults and children are assumed to retain 5.3 and 2.8 g of soil on their skin, respectively, and inhale 2 mg of soil as suspended dust. The resident is assumed to get 100% of her fruits (51 kg/yr)and vegetables (73 kg/yr) from plants growing in the contaminated sediments. Professional judgment was used to partition the external exposure from radionuclides into 18-hr indoor exposure and 6-hr outdoor exposure. The resident is assumed to be exposed to any gamma-emitting radionuclides in soil as an effectively infinite source.

Fruit and vegetable ingestion was evaluated for an adult receptor, but not a child, in the residential screening assessments performed in the lower Los Alamos Canyon reach report (Reneau et al. 1998c). Although ingestion per unit body weight of fruits and vegetables may in fact be higher for children of certain ages than adults, the additional model complexity required to accurately represent changes in diet and intake rates over time was considered inappropriate for a screening-level model.

2.2 Trail User Scenario

The trail user scenario is defined as an adult who is exposed within the contaminated area 75 days per year during a 30-year period. Each daily visit to the area has a duration of one hour. During each hike, the individual ingests 100 mg of soil and inhales 0.25 mg of soil as suspended dust. During the hike, the skin is assumed to collect 5.3 g of soil and the hiker is assumed to be exposed to any gamma-emitting radionuclides in soil as an effectively infinite source.

2.3 Resource User Scenario

The resource user scenario also employs an adult receptor and the same temporal and exposure parameters as for the trail user, but adds the consumption of fruits, vegetables, and meat. The parameters used for consumption of fruits, vegetables, and meat are 51 kg/yr, 73 kg/yr, and 36.5 kg/yr, respectively. The resource users are assumed to obtain 10% of their annual fruit and vegetable intake (5.1 kg/yr and 7.3 kg/yr) from the contaminated area. Seventy-five percent of

their annual meat consumption (27 kg/yr) is assumed to derive from cattle grazed in the contaminated area. These exposure conditions are assumed to remain constant over a 30-year exposure duration. As for the residential scenario, the additional complexity required to accurately differentiate between child and adult intake rates of fruits, vegetables, and meat was considered inappropriate for a screening-level model.

2.4 Construction Worker Scenario

The construction worker scenario assumes an adult worker with a 250-day work year and eight-hour workdays. The duration of the scenario is one year. The individual is assumed to ingest soil at a rate of 480 mg/day and to inhale soil as airborne dust at a rate of 2 mg/day. Each working day the skin is assumed to collect 5.3 g of soil and the worker is assumed to be exposed to any gamma-emitting radionuclides in soil as an effectively infinite planar source. All exposure to external irradiation during the workday is assumed to occur outside.

2.5 Long-Term Laboratory Employee Scenario

The employee scenario is similar to the construction worker scenario except that exposure duration is increased to 25 yr and the soil ingestion rate is decreased to 50 mg/d. All exposure is also assumed to occur outdoors, as might be the case for groundskeepers or a similar occupation.

3.0 IDENTIFICATION OF RISK AND DOSE LEVELS FOR CALCULATION OF PRGs

An excess incremental cancer risk (ICR) level of 10^{-6} is used in the calculation of PRG values for carcinogens. This risk level is consistent with the National Contingency Plan [55 Federal Register 8666 (March 8, 1990)], where risks at or below 10^{-6} are considered negligible and risks greater than 10^{-4} are deemed unacceptable. Use of 10^{-6} for the calculation of PRGs is also consistent with the intent of calculating *preliminary* screening values that may be applied without explicit consideration of factors that might result in the proposal of higher residual risk levels.

The screening values for noncarcinogens are based upon a hazard quotient (HQ) of one. The HQ is calculated as the ratio of the site concentration to the PRG concentration. Because adverse effects are not expected when concentrations are at or below the PRG, an HQ of one is considered protective.

Dose-based PRG values for radionuclides are calculated using a total effective dose equivalent of 15 mrem/year above background dose. A dose limit of 15 mrem/year is consistent with EPA guidance stated in *Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination* (EPA 1997a). Although other dose limits may ultimately be selected depending on land ownership and application of the Department of Energy's (DOE) as-low-as-reasonably-achievable (ALARA) principle, a value of 15 mrem/year has been selected for preliminary screening.

Preliminary remediation goals calculated using these risk and dose levels implicitly assume that no other contaminants contribute to site-related risk or dose. When two or more site-related contaminants are present, simultaneous exposure to multiple contaminants may result in risk or dose at levels exceeding the values used for the calculation of the individual PRGs (10^{-6} risk and 15 mrem/yr). However, multiple chemical impacts may involve antagonistic or synergistic effects so that simple additivity cannot always be assumed. The potential significance of these effects, and any methodological precautions for the application of PRGs at sites where multiple contaminants are present, must be specific to each assessment and is not addressed in this screening model.

4.0 RELATIONSHIP OF PRGs AND THEIR USE TO THE CANYONS CORE DOCUMENT

Chapter 6 of the Core Document for Canyons Investigations (LANL 1997) addresses the approach for assessing human and ecological risk from residual contamination in the canyons system. A key aspect of this approach is the appropriate treatment of uncertainty in the spatial distribution of contaminants used as input to the risk models. One of the criteria for determining whether the magnitude of uncertainties may be acceptable is the relative position of a PRG value to the range of contaminant concentrations. For example, even if the range of concentrations is as large as 1 to 1000 mg/kg, this variability may be insignificant if the PRG value is 30,000 mg/kg.

The primary land use scenarios described in the Core Document include American Indian use, recreational use, and continued Laboratory operations. These scenarios are to be applied to specific areas as appropriate, consistent with reasonable and likely future land uses. It was recognized in the Core Document that members of the American Indian communities surrounding the Laboratory may be exposed to residual contaminants via exposure pathways that are not commonly evaluated in a residential scenario as described in various EPA guidance documents. Furthermore, exposure intensity via certain common pathways may be higher for individuals engaged in subsistence or near-subsistence lifestyles than is routinely expected.

Because pathways and activities consistent with American Indian land use are associated with the highest potential exposure intensity, risk levels calculated for this scenario can serve as an initial indicator of possible health concerns. Therefore, an American Indian land use scenario was originally intended to constitute the basis for much of the initial risk analyses, including PRG calculations. However, efforts between the Laboratory and neighboring Indian Pueblos to develop and parameterize one or more exposure scenarios that satisfactorily address American Indian land use activities have not yet been concluded. For this reason, another basis for the calculation and application of screening values has been developed.

The Core Document states in Section 6.2.4 that, "Semiquantitative preliminary analyses for less conservative exposure scenarios that might have a higher probability of occurrence will also be examined in early stages to warn of any immediate health risks that might require interim measures". The PRGs developed with the Canyons screening model are used in the reach reports for the specific purpose of identifying "immediate health risks that might require interim measures". The scenarios defined for the PRGs are applied in the reach reports to areas where these land uses constitute potential or *de facto* present-day and near-term future land uses.

Although none of the scenarios defined for calculating PRG values address all of the pathways envisioned in the Core Document for evaluating exposure associated with American Indian land use, adding intake from the meat ingestion pathway (Resource User scenario) to exposure calculated for the Residential scenario addresses many of the key exposure pathways described in the Core Document. However, exposure associated with certain traditional uses of wood, medicinal plants, game meat, and clays and pigments has not been addressed. Additionally, exposure to residual contaminants in surface, alluvial, or perched aquifer waters is not included in the scenarios for calculating soil PRG values.

5.0 KEY SOURCES OF UNCERTAINTY IN THE CALCULATION OF PRGs

It is possible to evaluate uncertainty in the PRG values by addressing four different aspects of the screening model as it used to calculate PRG values.

1. Exposure parameter uncertainty. This addresses uncertainty in the values of those parameters presented in Attachment B.

2. Uncertainty in those model parameters that describe contaminant migration in the physical or biotic environment. These parameter values (including the volatilization factor, particulate

emission factor, dermal absorption coefficients, and transfer factors for contaminants from soil to garden plants, fodder, and meat) are associated with particular models used to describe these phenomena.

3. Toxicity value uncertainty. Addresses uncertainty in the toxicity models that relate intake (or external irradiation) to an endpoint such as hazard, cancer risk, or annual dose.

4. Model uncertainty. This source of uncertainty addresses the form of the model algorithms and the boundary conditions, or constraints, of the model.

There is a fifth very important source of uncertainty associated with the use of PRG values that is not intrinsic to the PRG calculations but is related to the comparison of PRGs with site concentration values. Every pathway in every scenario included in the Canyons model has an implicit spatial scale. As described below, these pathway-specific spatial scales are not necessarily consistent within a scenario. For this reason, the use of a single source term concentration for comparison to a PRG comprised of several pathways introduces a host of potential inconsistencies.

In the 1998 reach reports (Reneau et al. 1998a, 1998b, 1998c), average concentrations for individual geomorphic units or entire reaches were used for comparison with PRG values. The following approximate size areas are associated with the specific exposure pathways described and are provided to exemplify the potential variability in pathway-specific exposure areas. The soil source area for dust and vapor inhalation for the PRG calculations is defined as 30 acres regardless of the actual area represented by the geomorphic unit or reach. The external irradiation pathway does not correct for the actual size, shape, or depth of a contaminated area but instead assumes an effectively infinite volume (greater than approximately 1,200 m^2 and 0.5 m depth). The size of a home garden and orchard for supplying much of an individual's yearly needs is intrinsically variable but may be assumed to be ¼ acre at a minimum. The area associated with soil ingestion and dermal contact may approximate the area of a garden for the residential scenario, but may include up to several miles of canyon bottom for the recreational and resource user scenarios. The area of range required for one or more cattle may encompass all or parts of one or more canyon systems.

It is not practical to quantitatively identify in this document the key pathways and parameters to which each contaminant-specific PRG value is most sensitive for each of the five exposure scenarios. In addition to being very time-consuming, the results would not incorporate uncertainty associated with spatial scale and so would have only limited utility for assisting in the interpretation of actual PRG screening results. Experience and judgment are used to identify those sources of uncertainty which are most important to interpreting the results of PRG comparisons. The following paragraphs provide such a general discussion of uncertainty ordered by the four categories listed above.

5.1 Exposure Parameter Uncertainty

For many of the exposure parameters described in Attachment B, values were obtained from *Use of Standard Default Exposure Factors* (EPA 1991a) and are described therein as, "...intended to be used for calculating reasonable maximum exposure (RME) estimates". For example, values for soil ingestion rate, inhalation rate, exposure frequency, and exposure duration are all appropriate for calculating RME estimates and were largely obtained from this reference. Other parameter values that are also consistent with upper-bound estimates for calculating an RME estimate include surface area and adherence factor for dermal uptake, annual ingestion rates for fruits, vegetables, and meat, and the fraction of these products raised in the contaminated area.

Although the term "reasonable" is inherently subjective, it is evident that the use of so many upper-bound values across several exposure pathways that are combined to calculate a single PRG should result in an exceedingly conservative estimate of high-end exposure. In the

residential scenario, for example, a single individual is assumed to simultaneously be exposed under RME conditions via soil ingestion, dermal uptake, dust inhalation, and garden produce ingestion pathways over the entire exposure duration period.

5.2 Uncertainty in Contaminant Transport Submodels

The concentration of volatile organic compounds (VOCs) in the ambient air breathing zone associated with VOCs in site soils is calculated in the screening model using a steady-state volatilization factor (VF) model originally described in Risk Assessment Guidance for Superfund (RAGS), Part B, *Development of Risk-Based Preliminary Remediation Goals* (EPA 1991b). The version of the VF model that will be used for calculating SAL values is presented in the User's Guide and Technical Background Document of EPA's *Soil Screening Guidance* (EPA 1996a and 1996b). The primary difference with the later version of the VF model is that the output of a separate air dispersion model (based on one year of meteorological data) has now replaced the earlier box model component.

The VF model assumes an effectively infinite depth of contaminated soil and no cover of clean soil. The first assumption in particular may contribute to significant overestimates of risk for areas with a relatively small volume of contamination because calculated VOC emissions over a chronic exposure period of many years can easily violate conservation of mass. However, if the ambient air VF model is applied within the residential or long-term employee scenarios where a building may be constructed over the affected soils, indoor air VOC concentrations at a site may be considerably higher than local concentrations in ambient air. Application of the VF model in the calculation of PRGs, and sources for obtaining chemical-specific physical properties, follows the general guidance described in Appendix C of the Installation Work Plan for Environmental Restoration.

The concentration of dust in the air above contaminated soils and sediment is calculated using EPA's particulate emission factor (PEF) model. This model was originally described in *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites* (Cowherd et al, 1985). The version of the PEF model that is used in the screening model is presented in the User's Guide and Technical Background Document of EPA's *Soil Screening Guidance* (EPA 1996a and 1996b). The primary difference with the later version of the PEF model is that, like the VF model, the output of a separate air dispersion model has now replaced the earlier box model component.

The PEF model used for screening the dust inhalation pathway is based on the wind erosion of surfaces with an unlimited reservoir of particles. The model calculates the concentration of respirable particles in the air due to wind erosion. Depending on site soil conditions, there may not, in fact, be an unlimited supply of particles of this size available throughout the exposure period. This may result in a significant overestimation of intake via dust inhalation. A limitation of the model is that it does not address resuspension of particulates due to mechanical forces. Therefore, fugitive dust concentrations calculated using the PEF model may underestimate actual dust resuspension under conditions where the Construction Worker scenario pertains.

Dermal uptake from soil is evaluated using an absorption factor (ABS) to model desorption of a chemical from soil, absorption into skin, and transfer to the bloodstream. The approach used to model dermal uptake incorporates several assumptions that may result in an overestimation of actual uptake. The ABS value reflects an assumption that uptake is independent of concentration and also does not change with time. One hundred percent of a chemical is assumed to be available for uptake from soil adhered to the skin. Particularly, no loss of volatile or semivolatile chemicals is assumed to occur due to volatilization when soil is present on the skin. In the screening model, however, oral toxicity values based on feeding studies were not corrected for the actual or presumed absorption efficiency in the gut prior to their use for evaluating dermal uptake. This may result in an underestimation of dose via dermal uptake for certain chemicals.

Transfer of contaminants from soil to plants and meat was modeled using published plant-soil concentration ratios and meat transfer factors obtained primarily from *A Compilation of Radionuclide Transfer Factors for the Plant, Meat, Milk, and Aquatic Food Pathways and the Suggested Default Values for the RESRAD Code* (Wang, et al 1993). The 'suggested values' tabulated in Wang, et al (1993), rather than the 'current default value' also provided, were used because they represent the best professional judgment of the authors based on their most recent review of published radiological assessment models of elemental transfer factors. The fodder-to-meat transfer factors were also applied to uptake of contaminants from direct soil ingestion by cattle. Although it is possible that bioavailability of metals from soil and fodder may in fact be different, no transfer factors are readily available to quantify beef concentrations of metals as a function of ingestion of contaminated soil while grazing.

The plant-soil concentration ratios used are specific to root uptake from soil. No attempt was made to evaluate plant uptake via other mechanisms such as airborne deposition, rainsplash, or uptake from contaminated irrigation water. The plant-soil ratios are affected by such variables as the type of plant, the plant tissue being evaluated, the time of harvest, soil properties, and the chemical form of the contaminant. For these reasons, there is a great degree of uncertainty in the accuracy of these values as they are applied in the screening model.

5.3 Toxicity Value Uncertainty

The uncertainties associated with reference dose and slope factor values for chemicals are discussed in *Risk Assessment Guidance for Superfund, Part A* (EPA 1989b) and in a number of more detailed subsequent EPA publications. These uncertainties deriving from the toxicity models are not repeated here, beyond a reminder that the uncertainty associated with these values is generally considered to be one of the largest potential sources of bias in a risk calculation. In the screening model, route-to-route extrapolation of toxicity values when a value has been published for one route only was not be performed for metals due to the potential differences in absorption efficiencies between intake routes. If a toxicity value was not available for a route of intake, that route was not evaluated for that metal and toxicity endpoint. Because absorption of organic chemicals more closely approximates 100% for both ingestion and inhalation, route-to-route extrapolations was performed for organic chemicals.

Chemical toxicity values (reference doses and cancer slope factors) associated with chronic exposure were used for calculating PRG values. The preferential ranking of sources of toxicity values is 1) EPA's Integrated Risk Information System (EPA 1998), 2) EPA's Health Effects Assessment Summary Tables (EPA 1997b), and, 3) provisional toxicity values obtained from internal memoranda published by EPA's National Center for Environmental Assessment.

Slope factors for radionuclides were obtained from EPA's Health Effects Assessment Summary Tables while dose conversion factors were obtained from DOE publications. A unique source of uncertainty for the dose conversion factors is that they were developed by DOE for application to adult workers. Therefore, there is considerable uncertainty associated with their application to the general public and particularly to infants and children who may be more susceptible to the effects of ionizing radiation than adults. Another possible source of uncertainty for radionuclide PRG calculations is that slope factors and dose conversion factors for external irradiation both assume that an effectively infinite source of contaminated soil exists.

5.4 Model Uncertainty

Uncertainty is introduced in the screening model via the form of the risk equations and the transport models used to generate exposure estimates for the various media. One source of this uncertainty is whether all relevant pathways for a potentially exposed population are covered. In this case it is known that some activities specific to American Indian land use, and some

exposure pathways via water media, have not been addressed in the screening model. In the case of some exposure pathways such as produce and meat ingestion, only one subgroup (adults) has been modeled in the exposed population.

The model equations also introduce uncertainty due to their relatively simple form, as befits a screening model. For example, a single estimate of intake via soil ingestion or inhalation is specified in the model, although these rates may in fact vary widely depending upon the amount of time spent engaging in specific activities that may apply to the scenario. Both the risk equations and transport submodels (such as the biota transfer factors) assume equilibrium steady-state conditions and ignore dynamic considerations such as transfer rates among environmental compartments or feedback mechanisms that may limit biotic uptake or alter exposure activity patterns under *in situ* conditions. Other rate-dependent factors (such as radionuclide decay, chemical transformations, and the effects of hydrological processes on contaminant distributions over time) are also not addressed in the model. The effect of modeling a dynamic system using a steady-state model may be of lesser concern for reach report PRG calculations, however, since these are specific to present-day or near-future conditions.

6.0 ACKNOWLEDGEMENTS

This work was conducted as part of the Environmental Restoration Project of Los Alamos National Laboratory. Identification of exposure scenarios and pathways involved participation of all members of the early Canyons Focus Area; primary collaborators included Alison Dorries (EES-13), Johnnye Lewis (Environmental Health Associates), and Orrin Myers (EES-15). Review of the spreadsheet model provided by Heidi Hartmann and Jing-Jy Cheng (Argonne National Laboratory), and review of this manuscript by Steven Reneau (EES-1), is greatly appreciated. Tracy McFarland (Neptune and Company) provided valuable technical support for identifying the origin of many originally unreferenced parameter values.

7.0 REFERENCES

Baes, C.F., Sharp, R.D., Sjoreen, A.L., and Shor, R.W. 1984. A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture. Prepared for the U.S. Department of Energy. Health and Safety Research Division, Oak Ridge National Laboratory, Tennessee. September 1984.

Cowherd, C., Muleski G., Englehart P., and Gillette, D. 1985. Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites. EPA/600/8-85/002. Office of Health and Environmental Assessment, U.S. Environmental Protection Agency, Washington, D.C.

Los Alamos National Laboratory (LANL). 1997. Core Document for Canyons Investigation, Los Alamos National Laboratory Report LA-UR-96-2083, Los Alamos, New Mexico. April 1997.

Reneau, S., Ryti, R., Tardiff, M., and Linn, J., 1998a. Evaluation of Sediment Contamination in Pueblo Canyon: Reaches P-1, P-2, P-3, and P-4: Los Alamos National Laboratory report LA-UR-98-3324. September 1998.

Reneau, S., Ryti, R., Tardiff, M., and Linn, J., 1998b. Evaluation of Sediment Contamination in Upper Los Alamos Canyon: Reaches LA-1, LA-2, and LA-3: Los Alamos National Laboratory report LA-UR-98-3974. September 1998.

Reneau, S., Ryti, R., Tardiff, M., and Linn, J., 1998c. Evaluation of Sediment Contamination in Lower Los Alamos Canyon: Reaches LA-4 and LA-5: Los Alamos National Laboratory report LA-UR-98-3975. September 1998.

U.S. Department of Energy (DOE). 1988a. External Dose-Rate Conversion Factors for Calculation of Dose to the Public. DOE/EH-0070. U.S. Department of Energy, Washington, D.C. July 1988.

U.S. Department of Energy (DOE). 1988b. Internal Dose Conversion Factors for Calculation of Dose to the Public. DOE/EH-0071. U.S. Department of Energy, Washington, D.C. July 1988.

U.S. Environmental Protection Agency (EPA). 1989a. Exposure Factors Handbook. EPA/600/8-89/043. Office of Health and Environmental Assessment, U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1989b. Risk Assessment Guidance for Superfund (RAGS), Volume I, Human Health Evaluation Manual (Part A), Interim Final, OSWER Directive 9285.7-01A. Washington, D.C.: U.S. Environmental Protection Agency, Office of Emergency and Remedial Response.

U.S. Environmental Protection Agency (EPA). 1991a. Human Health Evaluation Manual, Supplemental Guidance, Standard Default Exposure Factors, OSWER Directive 9285.6-03. Washington, D.C.: U.S. Environmental Protection Agency, Office of Emergency and Remedial Response. March.

U.S. Environmental Protection Agency (EPA). 1991b. Risk Assessment Guidance for Superfund (RAGS), Volume I, Human Health Evaluation Manual (Part B, Development of Preliminary Remediation Goals), Interim. OSWER Directive 9285.7-01B. Washington, D.C.: U.S. Environmental Protection Agency, Office of Emergency and Remedial Response.

U.S. Environmental Protection Agency (EPA). 1992b. Dermal Exposure Assessment: Principles and Applications, EPA/600/8-91/011B. Washington, D.C.: U.S. Environmental Protection Agency, Office of Health and Environmental Assessment. January.

U.S. Environmental Protection Agency (EPA). 1994b. Revised Interim Soil Lead Guidance for CERCLA Sites and RCRA Corrective Action Facilities, OSWER Directive 9355.4-12. Washington, D.C.: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response.

U.S. Environmental Protection Agency (EPA). 1996a. Soil Screening Guidance: User's Guide, EPA/540/R-95/128. OSWER Directive 9355.4-17A. Washington, D.C.: U.S. Environmental Protection Agency, Office of Emergency and Remedial Response.

U.S. Environmental Protection Agency (EPA). 1996b. Technical Background Document, EPA/540/R-95/128. OSWER Directive 9355.4-17A. Washington, D.C.: U.S. Environmental Protection Agency, Office of Emergency and Remedial Response.

U.S. Environmental Protection Agency (EPA). 1997a. Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination. OSWER Directive 9200.4-18. Memorandum, from Stephen D. Luftig, Director, Office of Emergency and Remedial Response to Larry Weinstock, Acting Director, Office of Radiation and Air. August, 1997.

U.S. Environmental Protection Agency (EPA). 1997b. Health Effects Assessment Summary Tables, Fiscal Year 1997 Update, EPA-540-R-97-036. OSWER Directive 9200.6-303 (97-1). Washington, D.C.: U.S. Environmental Protection Agency, Office of Emergency and Remedial Response.

U.S. Environmental Protection Agency (EPA). 1998. Integrated Risk Information System (IRIS). www.epa.gov/iris/

U.S. Environmental Protection Agency (EPA) Region IX. 1998. Region IX Preliminary Remediation Goals (PRGs) 1998. www.epa.gov/region09/

Wang, Y.-Y., Biwer, BM, and Yu, C., 1993. A Compilation of Radionuclide Transfer Factors for the Plant, Meat, Milk, and Aquatic Food Pathways and the Suggested Default Values for the RESRAD Code. Environmental Assessment and Information Sciences Division, Argonne National Laboratory, Argonne, Illinois. August.

Attachment A - Model Equations

Model equations are organized in several subsections of this attachment. Section A-1 and A-2 provide equations for non-radionuclides and radionuclides, respectively. These sections each provide first a general equation for calculating contaminant intake followed by equations for calculating risk, hazard, or dose associated with the intake. The bulk of these sections then provides pathway-specific equations for calculating contaminant intake. Section A-3 shows how PRGs are calculated based on the equations provided in Sections A-1 and A-2. Sections A-4 and A-5 provide the equations for the volatilization factor and particulate emission factor models, respectively. These models are used to calculate contaminant concentrations in air based on concentrations in contaminated soil.

Each of the pathway-specific equations (A-1.1 to A-1.5 for non-radionuclides and A-2.1 to 2.6 for radionuclides) correspond to one of the exposure pathways in the screening model. The pathways included in each exposure scenario are identified in Section 2. Use the appropriate equation (A-2 or A-3 for non-radionuclides and A-11 or A-12 for radionuclides) for each contaminant to calculate risk, hazard, or dose using the intake value from the pathway-specific equations. For each contaminant, pathway-specific risks, hazard quotients, or doses can then be summed to calculate the risk, hazard quotient, or dose associated with the scenario. The risk, hazard quotient or dose (calculated using a soil concentration of 1 mg/kg or 1 pCi/g) can also be used to calculate PRGs according to directions provided in Section A-3.0.

A-1.0 CHEMICAL CARCINOGENS AND NONCARCINOGENS

The basic model for calculating contaminant intake is:

$$\text{Intake} = \frac{C \times CR \times EF \times ED}{BW \times AT} \qquad \text{A-1}$$

where,

Intake	=	chronic daily chemical intake (mg / kg body weight / d)
C	=	chemical concentration in exposure medium (*e.g.*, mg / kg soil or mg / L water)
CR	=	contact rate (*e.g.*, mg soil / d or L / d)
EF	=	exposure frequency (d / yr)
ED	=	exposure duration (yr)
BW	=	body weight (kg)
AT	=	time over which exposure is averaged for experiencing adverse effect (d)

Slope factors specific for chemical and intake route are used to convert estimated daily intake over an exposure period to lifetime incremental cancer risk. The equation for calculating cancer risk is:

$$ICR = \text{Intake} \times SF \qquad \text{A-2}$$

where,

ICR	=	lifetime incremental cancer risk
Intake	=	chronic daily intake (mg/kg-d)
SF	=	slope factor $(mg/kg\text{-}d)^{-1}$

Reference doses specific for chemical and intake route are used to convert estimated daily intake over an exposure period to an HQ. Unlike an ICR, an HQ does not reflect the probability of an effect occurring. However, larger values of HQ are generally associated with potentially increased severity of effects. The equation for calculating the HQ is:

$$HQ = \frac{Intake}{RfD} \qquad \text{A-3}$$

where,

HQ	=	hazard quotient
Intake	=	chronic daily intake (mg/kg-d)
RfD	=	reference dose (mg/kg-d)

The basic model for calculating contaminant intake can be modified in the following manner to obtain intake estimates for each of the exposure routes addressed in the risk assessment.

A-1.1 Ingestion of Soil or Water

The general intake equation is directly applicable for the calculation of intake associated with direct soil or water ingestion. For soil ingestion, a units conversion factor of 10^{-6} kg per mg is required in the numerator. In both cases, however, intake of carcinogens is evaluated over an exposure duration that includes both adult and child exposure times when the exposure scenario includes both adult and child receptors. The basic equation can be modified for chemical carcinogens to address both adult and child exposure in the following manner:

$$Intake = \frac{C \times (CR_C \times EF_C \times ED_C / BW_C) + (CR_A \times EF_A \times ED_A / BW_A)}{AT} \qquad \text{A-4}$$

where the subscripts A and C refer to child and adult, respectively.

A-1.2 Inhalation of Dust or Organic Vapors

$$Intake = \frac{C_s \times InhR \times ET \times EF \times ED}{(PEF \text{ or } VF) \times BW \times AT} \qquad \text{A-5}$$

where,

Intake	=	chronic daily chemical intake (mg/kg body weight/d)
C_s	=	chemical concentration in soil (mg/kg soil)
InhR	=	inhalation rate (m^3/hr)
ET	=	exposure time (hr/d)
EF	=	exposure frequency (d/yr)
ED	=	exposure duration (yr)
PEF	=	particulate emission factor, see A-4.0 (m^3/kg)
VF	=	volatilization factor, see A-5.0 (m^3/kg)
BW	=	body weight (kg)
AT	=	averaging time (d)

As for soil and water ingestion, intake of contaminants via inhalation is evaluated over an exposure period that includes both adult and child exposure times when the exposure scenario includes both adult and child receptors. Parameters that vary according to age include inhalation rate, exposure frequency, exposure duration, and body weight.

A-1.3 Dermal Absorption from Soil or Sediment

$$Intake = \frac{C_s \times AF \times ABS \times SA \times EF \times ED \times CF}{BW \times AT} \qquad \text{A-6}$$

where,

Intake	=	chronic daily chemical intake (mg/kg body weight/d)
C_s	=	chemical concentration in soil (mg/kg soil)
AF	=	soil to skin adherence factor (mg/cm^2/event)
ABS	=	skin absorption factor (unitless)
SA	=	skin surface area (cm^2)
EF	=	exposure duration (d/yr)
ED	=	exposure duration (yr)
CF	=	conversion factor (kg/g)
BW	=	body weight (kg)
AT	=	averaging time (d)

Intake of contaminants via dermal absorption is also evaluated over an exposure period that includes both adult and child exposure times when the exposure scenario includes both adult and child receptors. Parameters that vary according to age include surface area, exposure frequency, exposure duration, and body weight.

A-1.4 Ingestion of Fruits or Vegetables

$$\text{Intake} = \frac{C_s \times K_{p\text{-}s} \times IR_p \times F_p \times (\text{depth}_{cz}/\text{depth}_{root}) \times ED}{BW \times AT} \qquad \text{A-7}$$

where,

Intake	=	chronic daily chemical intake (mg/kg body weight/d)
C_s	=	chemical concentration in soil (mg/kg soil)
$K_{p\text{-}s}$	=	plant – soil concentration ratio (mg/kg plant per mg/kg soil)
IR_p	=	plant ingestion rate (kg/yr)
F_p	=	fraction of plants ingested that are grown in affected area
depth_{cz}	=	depth of contaminated zone (m)
depth_{root}	=	depth of plant root zone (m)
ED	=	exposure duration (yr)
BW	=	body weight (kg)
AT	=	averaging time (d)

Intake of contaminants via fruit or vegetable ingestion is evaluated only for adult receptors.

A-1.5 Ingestion of Meat

$$\text{Intake} = \frac{C_s \times TF_{s\text{-}m} \times ((UR_f \times K_{f\text{-}s}) + UR_s) \times IR_m \times F_m \times F_R \times ED}{BW \times AT} \qquad \text{A-8}$$

where,

Intake	=	chronic daily chemical intake (mg/ kg body weight/d)
C_s	=	chemical concentration in soil (mg/kg soil)
$TF_{s\text{-}m}$	=	soil-to-meat transfer factor (mg/kg$_{meat}$ per mg/d)
UR_f	=	uptake rate of feed by animal (kg/d)
$K_{f\text{-}s}$	=	feed – soil concentration ratio (mg/kg feed per mg/kg soil)
UR_s	=	uptake rate of soil by animal (kg/d)
IR_m	=	meat ingestion rate (kg/yr)
F_m	=	fraction of meat ingested that is raised in affected area

F_R	=	fraction of livestock range associated with affected area
ED	=	exposure duration (yr)
BW	=	body weight (kg)
AT	=	averaging time (d)

Intake of contaminants via meat ingestion is evaluated only for adult receptors.

A-2.0 RADIONUCLIDES

The basic model for calculating radionuclide intake associated with an effective dose equivalent (dose) is:

$$\text{Intake} = C \times CR \times EF \qquad \text{A-9}$$

where,

Intake	=	chronic annual intake (pCi/yr)
C	=	radionuclide concentration in exposure medium (*e.g.*, pCi/g soil or pCi/L water)
CR	=	contact rate (*e.g.*, mg soil/d or L water/d)
EF	=	exposure frequency (d/yr)

For calculating radionuclide intake associated with cancer risk, the basic model is:

$$\text{Intake} = C \times CR \times EF \times ED \qquad \text{A-10}$$

where,

Intake	=	lifetime intake (pCi)
C	=	radionuclide concentration in exposure medium (*e.g.*, pCi/g soil or pCi/L water)
CR	=	contact rate (*e.g.*, mg soil/d or L water/d)
EF	=	exposure frequency (d/yr)
ED	=	exposure duration (yr)

Dose conversion factors specific for ingestion and inhalation intake routes are used to convert estimated annual intake to dose. The equation for calculating dose is:

$$\text{Dose} = \text{Intake} \times DCF \qquad \text{A-11}$$

where,

Dose	=	effective annual dose equivalent (pCi/yr)
DCF	=	dose conversion factors (mrem/yr)

Slope factors specific for ingestion and inhalation intake routes are used to convert lifetime intake over an exposure period to lifetime incremental cancer risk. The equation for calculating cancer risk is:

$$ICR = \text{Intake} \times SF \qquad \text{A-12}$$

where,

ICR	=	lifetime incremental cancer risk
Intake	=	lifetime intake (pCi)
SF	=	slope factor $(pCi)^{-1}$

The basic models for calculating contaminant intake can be modified in the following manner to obtain intake estimates for each of the exposure routes addressed in the risk assessment, with the exception of external irradiation. Because external irradiation does not involve actual intake of radionuclides into the body, these models differ somewhat from the basic models. External irradiation models are also provided below.

A-2.1 Ingestion of Soil or Water

The general intake equations are directly applicable for the calculation of intake associated with direct soil or water ingestion. For soil ingestion, a units conversion factor of 10^{-3} g per mg is required in the numerator. When estimating cancer risk, intake of radionuclides is evaluated over an exposure duration that includes both adult and child exposure times (when the exposure scenario includes both adult and child receptors). Because dose is evaluated on an annual basis, adult and child exposures are not combined in the dose calculations. Dose is calculated for the higher of either a child or adult exposure when the exposure scenario includes both adult and child receptors, although strictly speaking DCFs do not apply to children. The basic equation for calculating radionuclide intake associated with cancer risk can be modified to address both adult and child exposure in the following manner:

$$\text{Intake} = C \times \left(\left(CR_C \times EF_C \times ED_C \right) + \left(CR_A \times EF_A \times ED_A \right) \right) \qquad \text{A-13}$$

where the subscripts A and C refer to child and adult, respectively.

A-2.2 Inhalation of Dust

For calculating radionuclide intake associated with an effective dose equivalent, the equation is:

$$\text{Intake} = \frac{C_s \times InhR \times EF \times ET \times CF}{PEF} \qquad \text{A-14}$$

where,

Intake	=	chronic annual intake (pCi/yr)
C_s	=	radionuclide concentration in soil (pCi/g soil)
InhR	=	inhalation rate (m^3/hr)
EF	=	exposure frequency (d/yr)
ET	=	exposure time (hr/d)
CF	=	units conversion factor (1000 g/kg)
PEF	=	particulate emission factor, see A-5.0 (m^3/kg)

When calculating intake for assessing cancer risk, intake of contaminants via inhalation is evaluated over an exposure period that includes both adult and child exposure times (when the exposure scenario includes both adult and child receptors). Also, as per the basic intake model for assessing cancer risk, exposure duration is included as a parameter. Parameters that vary according to age include inhalation rate, exposure frequency, and exposure duration.

Inhalation of tritium as water vapor, or of radon daughters, is not evaluated.

A-2.3 Dermal Absorption from Soil or Sediment

Dermal absorption is not evaluated for radionuclides, including tritium.

A-2.4 Ingestion of Fruits or Vegetables

For calculating radionuclide intake associated with an effective dose equivalent, the equation is:

$$\text{Intake} = C_s \times K_{p\text{-}s} \times IR_p \times F_p \times (\text{depth}_{cz}/\text{depth}_{root}) \times CF \qquad \text{A-15}$$

where,

Intake	=	chronic annual intake (pCi/yr)
C_s	=	radionuclide concentration in soil (pCi/g soil)
$K_{p\text{-}s}$	=	plant – soil concentration ratio (pCi/kg plant per pCi/kg soil)
IR_p	=	plant ingestion rate (kg/yr)
F_p	=	fraction of plants ingested that are grown in affected area
depth_{cz}	=	depth of contaminated zone (m)
depth_{root}	=	depth of plant root zone (m)
CF	=	units conversion factor (1000 g/kg)

When calculating intake of contaminants for assessing cancer risk, fruit or vegetable ingestion is evaluated only for adult receptors. Also, as per the basic intake model for assessing cancer risk, exposure duration is included as a parameter. Finally, this exposure pathway is presently evaluated only for metals and radionuclides pending identification of appropriate $K_{p\text{-}s}$ values for organic chemicals.

A-2.5 Ingestion of Meat

For calculating radionuclide intake associated with an effective dose equivalent, the equation is:

$$\text{Intake} = C_s \times TF_{s\text{-}m} \times ((UR_f \times K_{f\text{-}s}) + UR_s) \times IR_m \times F_m \times F_R \times CF \qquad \text{A-16}$$

where,

Intake	=	chronic annual intake (pCi/yr)
C_s	=	radionuclide concentration in soil (pCi/g soil)
$TF_{s\text{-}m}$	=	soil-to-meat transfer factor (pCi/kg_{meat} per pCi/d)
UR_f	=	uptake rate of feed by animal (kg/d)
$K_{f\text{-}s}$	=	feed – soil concentration ratio (pCi/kg feed per pCi/kg soil)
UR_s	=	uptake rate of soil by animal (kg/d)
IR_m	=	meat ingestion rate (kg/yr)
F_m	=	fraction of meat ingested that is raised in affected area
F_R	=	fraction of livestock range associated with affected area
CF	=	units conversion factor (1000 g/kg)

When calculating intake of contaminants for assessing cancer risk, meat ingestion is evaluated only for adult receptors. Also, as per the basic intake model for assessing cancer risk, exposure duration is included as a parameter. Finally, this exposure pathway is presently evaluated only for metals and radionuclides pending identification of appropriate $TF_{s\text{-}m}$ and $K_{f\text{-}s}$ values for organic chemicals.

A-2.6 External Irradiation

For calculating external exposure associated with an effective dose equivalent, the equation is:

$$\text{Intake} = C_s \times EF \times ((ET_{in} \times DRF) + ET_{out}) \times CF \qquad \text{A-17}$$

where,

Intake	=	external exposure to radionuclide (pCi/g soil)

C_s	=	radionuclide concentration in soil (pCi/g soil)
EF	=	exposure frequency (d/yr)
ET_{in}	=	exposure time inside a structure (hr/d)
DRF	=	dose reduction factor for shielding offered by structure
ET_{out}	=	exposure time outside a structure (hr/d)
CF	=	units conversion factor (1.14×10^4 yr/ hr)

The parameters associated with external irradiation are not specific for adult or child exposure. Exposure duration is included as a parameter when assessing cancer risk.

A-3.0 CALCULATION OF PRGs

The calculation of PRGs is performed by simply inverting the risk equations when the concentration term is set equal to one, and multiplying this value by the target risk. For example, the basic equation for calculation of a PRG for a chemical carcinogen is:

$$\text{conc} = \frac{TR \times AT \times BW}{CR \times SF \times EF \times ED} \qquad \text{Eq. A-18}$$

where,

conc	=	chemical concentration in exposure medium (*e.g.*, mg kg soil)
TR	=	target incremental cancer risk
AT	=	time over which exposure is averaged for experiencing adverse effect (d)
BW	=	body weight (kg)
CR	=	contact rate (*e.g.*, mg soil/d for soil ingestion)
SF	=	chemical-specific slope factor $(\text{mg/kg body weight/d})^{-1}$
EF	=	exposure frequency (d/yr)
ED	=	exposure duration (yr)

Comparing this equation to Equation A-1, the transformation is apparent. In the case of chemical carcinogens, the inverse of the risk value calculated for a chemical concentration of 1 mg/kg is simply multiplied by 10^{-6} (the target risk) to obtain the PRG. For noncarcinogens and radionuclide dose, the target risk multipliers are a hazard quotient of 1 and dose limit of 15 mrem/yr, respectively.

The PRGs for each individual exposure pathway are then combined to calculate a PRG for each COPC and individual exposure scenario as the inverse of the sum of the reciprocals. For example, for a scenario having two exposure pathways:

$$PRG_s = \frac{1}{1/P_1 + 1/P_2} \qquad \text{A-19}$$

where,

PRG_s	=	chemical-specific risk-based screening level for scenario 's'
P_1	=	PRG for exposure pathway 1
P_2	=	PRG for exposure pathway 2

A-4.0 Derivation of the Volatilization Factor

$$VF = Q/C \times \frac{(\Pi \times D_A \times T)^{1/2}}{2 \times \rho_b \times D_A} \times 10^{-4}\ m^2/cm^2 \qquad \text{A-20}$$

where:

VF	=	volatilization factor	(m^3/kg)
Q/C	=	inverse of the mean conc. at the center of a 30-acre square source	46.84 g/m^2-s per kg/m^3
D_A	=	apparent diffusivity in air	see below (cm^2/s)
T	=	exposure interval	equal to exposure duration (s)
ρ_b	=	dry soil bulk density	1.5 g/cm^3

and:

$$D_A = \frac{\left[\left(P_{air}^{10/3} \times D_i \times H' + P_{water}^{10/3} \times D_w\right) / P_{tot}^{2}\right]}{\rho_b \times K_d + P_{water} + P_{air} \times H'} \qquad \text{A-21}$$

where:

P_{air}	=	air filled soil porosity	= $P_{tot} - (P_{air} \times \theta_w)$
D_i	=	diffusivity in air	chemical-specific (cm^2/s)
H'	=	dimensionless Henry's Law constant	chemical-specific
P_{water}	=	water filled soil porosity	= $P_{tot} - P_{air}$
D_w	=	diffusivity in water	chemical-specific (cm^2/s)
P_{tot}	=	total soil porosity	= $1 - (\rho_b/\rho_s)$
ρ_b	=	bulk soil density	1.5 g/cm^3
K_d	=	soil-water partition coefficient	= $K_{oc} \times f_{oc}$ (cm^3/g)
θ_w	=	soil moisture content	0.1 kg_{water} / kg_{soil}
ρ_s	=	soil particle density	2.65 g/cm^3
K_{oc}	=	soil organic carbon/water partition coefficient	chemical specific (cm^3/g)
F_{oc}	=	fraction organic carbon content of soil	0.006 (g_{oc}/g_{soil})

A-5.0 Derivation of the Particulate Emission Factor

$$PEF = Q/C \times \frac{3{,}600\ sec/hr}{0.036 \times (1 - V) \times (U_m/U_{t\text{-}7})^3 \times F(x)} \qquad \text{A-22}$$

where:

PEF	=	particulate emission factor	(m^3/kg)
Q/C	=	inverse of the mean conc. at the center of a 30-acre square source	46.84 g/m^2-s per kg/m^3
V	=	fraction of vegetative cover	0.1 (unitless)
U_m	=	mean annual windspeed	3 m/s
$U_{t\text{-}7}$	=	equivalent threshold value of windspeed at 7m	4.124 m/s
F(x)	=	function dependent on $U_m/U_{t\text{-}7}$ derived using Cowherd et al. (1985)	1.31 (unitless)

and:

$$U_{t\text{-}7} = {}^{U_t}\!/_{0.4} \times \ln\left({}^{Z}\!/_{Z_0}\right) \qquad \text{A-23}$$

where:

U_t	=	threshold friction velocity	0.625 m/s
Z	=	height above surface	700 cm
Z_0	=	surface roughness height	50 cm

Attachment B – Exposure Parameter Values and References

Parameter Name	units	Trail Use		Resource Use		Residential Use		Long-Term LANL Employee		Construction Worker	
Changing cells		value	reference	value	reference	value	reference	value	reference	value	reference
IR_child	mg/d	0	0-6 yr child not evaluated	0	0-6 yr child not evaluated	200	EPA 1991a (note 1)	0	0-6 yr child not evaluated	0	0-6 yr child not evaluated
IR_adult	mg/d	100	EPA 1991a (note 1)	100	EPA 1991a (note 1)	100	EPA 1991a (note 1)	50	EPA 1991a (note 1)	480	EPA 1991a (note 1)
EF_child	d/yr	0	0-6 yr child not evaluated	0	0-6 yr child not evaluated	350	EPA 1991a	0	0-6 yr child not evaluated	0	0-6 yr child not evaluated
EF_adult	d/yr	75	BPJ (a)	75	BPJ (a)	350	EPA 1991a	250	EPA 1991a	250	EPA 1991a
ED_child	yr	0	0-6 yr child not evaluated	0	0-6 yr child not evaluated	6	EPA 1991a	0	0-6 yr child not evaluated	0	0-6 yr child not evaluated
ED_adult	yr	30	EPA 1991a	30	EPA 1991a	24	EPA 1991a	25	EPA 1991a	1	BPJ (j)
AT_si_carc	yr	70	lifetime, by convention	70	lifetime, by convention	70	lifetime, by convention	70	lifetime, by convention	70	lifetime, by convention
AT_si_nc	yr	30	equal to exposure duration	30	equal to exposure duration	6	equal to exposure duration	25	equal to exposure duration	1	equal to exposure duration
Inh_child	m3/hr	0	0-6 yr child not evaluated	0	0-6 yr child not evaluated	0.833	EPA 1991a	0	0-6 yr child not evaluated	0	0-6 yr child not evaluated
Inh_adult	m3/hr	2.5	EPA 1989 (note 2)	2.5	EPA 1989 (note 2)	0.833	EPA 1991a	2.5	EPA 1991a (note 8)	2.5	EPA 1991a (note 8)
ET_child	hr/d	0	0-6 yr child not evaluated	0	0-6 yr child not evaluated	24	provides 20 m^3/d inh. rate	0	0-6 yr child not evaluated	0	0-6 yr child not evaluated
ET_adult	hr/d	1	BPJ (b)	1	BPJ (b)	24	provides 20 m^3/d inh. rate	8	length of workday	8	length of workday
EF_inh	d/yr	75	BPJ (a)	75	BPJ (a)	350	EPA 1991a	250	EPA 1991a	250	EPA 1991a
EF_derm	d/yr	75	BPJ (a)	75	BPJ (a)	350	EPA 1991a	250	EPA 1991a	250	EPA 1991a
SA_adult	cm2	5300	EPA 1992 (note 3)	5300	EPA 1992 (note 3)	5300	EPA 1992 (note 3)	5300	EPA 1992 (note 3)	5300	EPA 1992 (note 3)
SA_child	cm2	0	0-6 yr child not evaluated	0	0-6 yr child not evaluated	2800	EPA 1992 (note 7)	0	0-6 yr child not evaluated	0	0-6 yr child not evaluated
IR_veg	kg/yr	0	pathway not included	73	EPA 1989 (note 4)	73	EPA 1989 (note 4)	0	pathway not included	0	pathway not included
IR_fruit	kg/yr	0	pathway not included	51	EPA 1989 (note 4)	51	EPA 1989 (note 4)	0	pathway not included	0	pathway not included
fract_veg	unitless	0	pathway not included	0.1	BPJ (c)	1	BPJ (g)	0	pathway not included	0	pathway not included
fract_fruit	unitless	0	pathway not included	0.1	BPJ (c)	1	BPJ (g)	0	pathway not included	0	pathway not included
depth_cz	m	0	pathway not included	1	BPJ (d)	1	BPJ	0	pathway not included	0	pathway not included

depth_root	m	1	pathway not included	1	BPJ (d)	1	BPJ	1	pathway not included	1	pathway not included
AT_pi_nc	yr	30	pathway not included	30	equal to exposure duration	24	equal to adult exposure duration	25	pathway not included	1	pathway not included
UR_fodder	kg/d	0	pathway not included	50	Baes et al 1984 (note 5)	0	pathway not included	0	pathway not included	0	pathway not included
UR_soil	kg/d	0	pathway not included	2	BPJ (e)	0	pathway not included	0	pathway not included	0	pathway not included
IR_meat	kg/yr	0	pathway not included	36.5	EPA 1989 (note 6)	0	pathway not included	0	pathway not included	0	pathway not included
fract_meat	unitless	0	pathway not included	0.75	EPA 1989 (note 6)	0	pathway not included	0	pathway not included	0	pathway not included
fract_range	unitless	0	pathway not included	1	BPJ (f)	0	pathway not included	0	pathway not included	0	pathway not included
EF_ext	d/yr	75	BPJ (a)	75	BPJ (a)	350	RAGS 1991 p.5	250	EPA 1991a	250	EPA 1991a
ED_ext	yr	30	EPA 1991a	30	EPA 1991a	24	RAGS 1991 p.6	25	EPA 1991a	25	EPA 1991a
ET_in	hr/d	0	pathway not included	0	pathway not included	18	BPJ (h)	0	BPJ (i)	0	BPJ (i)
ET_out	hr/d	1	BPJ (b)	1	BPJ (b)	6	BPJ (h)	8	length of workday	8	length of workday
Static Cells											
BW_child	kg	-	pathway not applicable	-	pathway not applicable	15	EPA 1991a	-	pathway not applicable	-	pathway not applicable
BW_adult	kg	70	EPA 1991a	70	EPA 1991a	70	EPA 1991a	70	EPA 1991a	70	EPA 1991a
AF	mg/cm^2-d	1	EPA 1992 (note 9)	1	EPA 1992 (note 9)	1	EPA 1992 (note 9)	1	EPA 1992 (note 9)	1	EPA 1992 (note 9)
ABS_rad	unitless	0.01	EPA Reg IX 1998	0.01	EPA Reg IX 1998	0.01	EPA Reg IX 1998	0.01	EPA Reg IX 1998	0.01	EPA Reg IX 1998
ABS_met	unitless	0.01	EPA Reg IX 1998	0.01	EPA Reg IX 1998	0.01	EPA Reg IX 1998	0.01	EPA Reg IX 1998	0.01	EPA Reg IX 1998
ABS_org	unitless	0.1	EPA Reg IX 1998	0.1	EPA Reg IX 1998	0.1	EPA Reg IX 1998	0.1	EPA Reg IX 1998	0.1	EPA Reg IX 1998
GWIng_child	l/d	-	pathway not applicable	-	pathway not applicable	2	EPA 1989 (note 10)	-	pathway not applicable	-	pathway not applicable
GWIng_adult	l/d	-	pathway not applicable	-	pathway not applicable	2	EPA 1991a	-	pathway not applicable	-	pathway not applicable
DRF	unitless	0.7	Yu et al 1993 (note 11)	0.7	Yu et al 1993 (note 11)	0.7	Yu et al 1993 (note 11)	0.7	Yu et al 1993 (note 11)	0.7	Yu et al 1993 (note 11)

(BPJ) Best Professional Judgment

BPJ (a): Assumes an individual is in the affected area three days every two weeks, 50 weeks per year

BPJ (b): Assumption for time spent within affected area

BPJ (c): Assumes 10% of fruits and vegetables consumed in a year is gathered from affected area

BPJ (d): Assumes contamination is uniformly present throughout root zone

BPJ (e): Accounts for direct soil ingestion by cattle during grazing

BPJ (f): Assumes affected area is 100% of cattle range and no supplemental feed is used

BPJ (g): Assumes 100% of fruits and vegetables are home-grown (a homesteading assumption)

BPJ (h): Assumes 24 hr/d at the residence, with a yearly average of 6 hr/d outside

BPJ (i): Assumes all work is outdoor, maximizing exposure to external irradiation

BPJ (j): Assumes construction worker is working on-site for one year

NOTES

1. Assumes 100% of daily soil ingestion is of soil from the affected area.
2. Based on moderate activity performed by an adult male.
3. Reasonable worst case example, pg 8-10.
4. Reasonable worst case adult consumption, Part II, pg 1-9.
5. Wet feed consumption rate, pg 49.
6. Reasonable worst case consumption, Part II, pg 1-12.
7. Based on 95th percentile of total body are of a male child, age 6, corrected by the ratio of adult area of hand, hands, forearms, and lower legs to total area.
8. Assumes an 8-hr workday.
9. Recommended default value for upper bound, from Table 8-6.
10. Value of 2 L/d pertains to a child weighing > 10 kg, pg 2-1.
11. Assumes indoor external irradiation is 70% of outdoor level, pg 130.

Attachment C – Plant and Meat Transfer Factors from Soil

Chemical Contaminant	plant/soil ratio	fodder/soil ratio	meat transfer factor
	(unitless)[a]	(unitless)[b]	mg/kg_{beef} per mg/d
aluminum	5.0E-04	7.3E-04	1.5E-03
antimony	1.0E-02	1.8E-02	1.0E-03
arsenic	8.0E-02	3.6E-02	1.5E-03
barium	5.0E-03	1.8E-02	2.0E-04
beryllium	4.0E-03	1.8E-02	1.0E-03
boron	5.0E-01	7.3E-01	8.0E-04
cadmium	3.0E-01	1.8E-01	4.0E-04
chromium	2.5E-04	1.8E-02	9.0E-03
cobalt	8.0E-02	7.3E-02	2.0E-02
copper	1.3E-01	1.5E-01	1.0E-02
cyanide	0.0E+00	0.0E+00	0.0E+00
iron	1.0E-03	5.5E-04	2.0E-02
mercury	3.8E-01	1.8E-01	1.0E-01
nickel	5.0E-02	2.0E-02	5.0E-03
selenium	1.0E-01	9.1E-02	1.0E-01
silver	1.5E-01	1.8E-02	3.0E-03
thallium	5.0E-04	7.3E-04	4.0E-02
vanadium	6.9E-04	1.0E-03	2.5E-03
zinc	4.0E-01	9.1E-02	1.0E-01
aldrin	0.0E+00	0.0E+00	0.0E+00
BHC[delta]	0.0E+00	0.0E+00	0.0E+00
chlordane[alpha]	0.0E+00	0.0E+00	0.0E+00
chlordane[gamma]	0.0E+00	0.0E+00	0.0E+00
DDT[4,4]	0.0E+00	0.0E+00	0.0E+00
Aroclor-1254 (PCBs)	0.0E+00	0.0E+00	0.0E+00
Aroclor-1260 (PCBs)	0.0E+00	0.0E+00	0.0E+00
acenaphthene	0.0E+00	0.0E+00	0.0E+00
acenaphthylene	0.0E+00	0.0E+00	0.0E+00
anthracene	0.0E+00	0.0E+00	0.0E+00
benz(a)anthracene	0.0E+00	0.0E+00	0.0E+00
benzo(a)pyrene	0.0E+00	0.0E+00	0.0E+00
benzo(b)fluoranthene	0.0E+00	0.0E+00	0.0E+00
benzo(g,h,i)perylene	0.0E+00	0.0E+00	0.0E+00
benzo(k)fluoranthene	0.0E+00	0.0E+00	0.0E+00
benzoic acid	0.0E+00	0.0E+00	0.0E+00
bis(2-ethylhexyl)phthalate	0.0E+00	0.0E+00	0.0E+00
carbazole	0.0E+00	0.0E+00	0.0E+00
chrysene	0.0E+00	0.0E+00	0.0E+00
dibutylphthalate	0.0E+00	0.0E+00	0.0E+00
di-n-octylphthalate	0.0E+00	0.0E+00	0.0E+00
dibenz(a,h)anthracene	0.0E+00	0.0E+00	0.0E+00
dibenzofuran	0.0E+00	0.0E+00	0.0E+00
fluoranthene	0.0E+00	0.0E+00	0.0E+00
fluorene	0.0E+00	0.0E+00	0.0E+00
indeno(1,2,3-cd)pyrene	0.0E+00	0.0E+00	0.0E+00
methylnaphthalene(2)	0.0E+00	0.0E+00	0.0E+00
naphthalene	0.0E+00	0.0E+00	0.0E+00
phenanthrene	0.0E+00	0.0E+00	0.0E+00
pyrene	0.0E+00	0.0E+00	0.0E+00

Radionuclide Contaminant	plant/soil ratio	fodder/soil ratio	meat transfer factor
	(unitless)[c]	(unitless)[d]	pCi/kg$_{beef}$ per pCi/d
americium-241	1.0E-03	7.3E-04	5.0E-05
cesium-134	4.0E-02	3.6E-02	3.0E-02
cesium-137+D	4.0E-02	3.6E-02	3.0E-02
cobalt-60	8.0E-02	7.3E-02	2.0E-02
europium-152	2.5E-03	1.8E-02	2.0E-03
plutonium-238	1.0E-03	4.9E-05	1.0E-04
plutonium-239	1.0E-03	4.9E-05	1.0E-04
radium-226+D	4.0E-02	3.6E-02	1.0E-03
strontium-90+D	3.0E-01	3.6E-01	8.0E-03
tritium	4.8E+00	8.7E-01	1.2E-02
uranium-234	2.5E-03	1.8E-02	3.4E-04
uranium-235+D	2.5E-03	1.8E-02	3.4E-04
uranium-238+D	2.5E-03	1.8E-02	3.4E-04

a: mg/kg wet plant per mg/kg dry soil

b: mg/kg wet plant per mg/kg dry soil; converted using dry-to-wet ratio of 0.182 for grass (Wang et al, 1993; Table 2)

c: pCi/kg wet plant per pCi/kg dry soil

d: pCi/kg wet plant per pCi/kg dry soil; converted using dry-to-wet ratio of 0.182 for grass (Wang et al, 1993; Table 2)

Unless otherwise footnoted, plant/soil and meat transfer values for metals are suggested values taken from Tables 9, 10, and 11 of Wang et al. (1993).

Composite values for metals are used for plant/soil ratios from Wang, et al., (1993).

Aluminum: Plant/soil and fodder/soil ratio (B_v) and meat transfer factor (F_f) from Baes, et al., (1984).
Thallium: Plant/soil and fodder/soil ratio (B_v) and meat transfer factor (F_f) from Baes, et al., (1984).
Vanadium: Plant/soil and fodder/soil ratio (B_v) and meat transfer factor (F_f) from Baes, et al., (1984).
Boron: Plant/soil and fodder/soil ratio (B_v) and meat transfer factor (F_f) from Baes, et al., (1984).

For all Baes et al. (1984) references, B_v was converted to wet weight values for plant/soil ratio using exposed produce conversion factor (0.126) from Table 2.3.

All units in Wang et al. (1993) have pCi in the numerator - substituting 'mg' for 'pCi' does not effect the value because the units cancel.

Attachment D – Chemical and Radionuclide Toxicity Values

The preferred source of chemical toxicity values used in the model is EPA's Integrated Risk Information System (IRIS) (EPA 1998). EPA's Health Effects Assessment Summary Tables (HEAST) (EPA 1997b) is a secondary source of toxicity values. A third source of toxicity values are the provisional toxicity values obtained for some chemicals and routes of exposure from memoranda published by EPA's National Center for Environmental Assessment. These provisional values have not, however, been subjected to rigorous scientific review and therefore cannot be used with the confidence of values obtained from the other EPA sources. Finally, a few of the tabulated values are from earlier EPA-approved toxicity values that have since been withdrawn pending revision.

Toxicity values are specified separately for the ingestion and inhalation exposure routes. Route-to-route extrapolation of toxicity values was performed for organic chemicals but not for inorganic chemicals. In the evaluation of the dermal uptake exposure route, oral toxicity values were not adjusted to account for the chemical-specific oral absorption fraction associated with the toxicity value.

All radionuclide slope factors were obtained from HEAST and all dose conversion factors (DCFs) were obtained from tabulations of such values in Version 5.1 of the RESRAD computer code developed by Argonne National Laboratory. The RESRAD values are referenced to *External Dose-Rate Conversion Factors for Calculation of Dose to the Public* (DOE 1988a) and *Internal Dose Conversion Factors for Calculation of Dose to the Public* (DOE 1988b).

TABLE D-1
CHEMCAL TOXICITY VALUES

CHEMICAL TOXICITY VALUES								
	Oral RfD		**Inhal RfD**		**Oral SF**		**Inhal SF**	
Contaminant	(mg/kg-d)	Source[a]	(mg/kg-d)	Source[a]	$(mg/kg\text{-}d)^{-1}$	Source[a]	$(mg/kg\text{-}d)^{-1}$	Source[a]
aluminum	1.0E+00	NCEA	1.0E-03	NCEA				
antimony	4.0E-04	IRIS						
arsenic	3.0E-04	IRIS			1.5E+00	IRIS	1.5E+01	IRIS
barium	7.0E-02	IRIS						
beryllium	2.0E-03	IRIS	5.7E-06	IRIS			8.4E+00	
cadmium	1.0E-03	IRIS	5.7E-05	Withdrawn			6.3E+00	IRIS
chromium	5.0E-03	IRIS					4.2E+01	IRIS
cobalt	6.0E-02	NCEA	5.7E-06	Withdrawn				
copper	4.0E-02	NCEA						
cyanide	2.0E-02	IRIS						
iron	3.0E-01	NCEA						
mercury	3.0E-04	IRIS	8.6E-05	IRIS				
nickel	2.0E-02	IRIS						

selenium	5.0E-03	IRIS						
silver	5.0E-03	IRIS						
thallium	8.0E-05	HEAST						
vanadium	7.0E-03	HEAST						
zinc	3.0E-01	IRIS						
aldrin	3.0E-05	IRIS			1.70E+01	IRIS	1.71E+01	IRIS
BHC[delta]					6.3E+00	IRIS	6.3E+00	IRIS
chlordane[alpha]	5.0E-04	IRIS	2.0E-04	IRIS	3.5E-01	IRIS	3.5E-01	IRIS
chlordane[gamma]	5.0E-04	IRIS	2.0E-04	IRIS	3.5E-01	IRIS	3.5E-01	IRIS
DDT[4,4]	5.0E-04	IRIS			3.4E-01	IRIS	3.4E-01	IRIS
Aroclor-1254 (PCBs)	2.0E-05	IRIS	2.0E-05	R-R ext.				
Aroclor-1260 (PCBs)					2.0E+00	IRIS	2.0E+00	IRIS
acenaphthene	6.0E-02	IRIS	6.0E-02	R-R ext.				
acenaphthylene	6.0E-02	SURR	6.0E-02	R-R ext.				
anthracene	3.0E-01	IRIS	3.0E-01	R-R ext.				
benz(a)anthracene					7.3E-01	NCEA	3.1E-01	NCEA
benzo(a)pyrene					7.3E+00	IRIS	3.1E+00	NCEA
benzo(b)fluoranthene					7.3E-01	NCEA	3.1E-01	NCEA
benzo(g,h,i)perylene								
benzo(k)fluoranthene					7.3E-02	NCEA	3.1E-02	NCEA
benzoic acid	4.0E+00	IRIS	4.0E+00	R-R ext.				
bis(2-ethylhexyl)phthalate	2.0E-02	IRIS			1.4E-02	IRIS	1.4E-02	R-R ext.
carbazole					2.0E-02	HEAST	2.0E-02	R-R ext.
chrysene					7.3E-03	NCEA	3.1E-03	NCEA
dibutylphthalate	1.0E-01	IRIS	1.0E-01	R-R ext.				
di-n-octylphthalate	2.0E-02	HEAST	2.0E-02	R-R ext.				
dibenz(a,h)anthracene					7.3E+00	NCEA	3.1E+00	NCEA
dibenzofuran	4.0E-03	Withdrawn	4.0E-03	R-R ext.				
fluoranthene	4.0E-02	IRIS	4.0E-02	R-R ext.				
fluorene	4.0E-02	IRIS	4.0E-02	R-R ext.				
indeno(1,2,3-cd)pyrene					7.3E-01	NCEA	3.1E-01	NCEA
methylnaphthalene(2)	4.0E-03	SURR	4.0E-03	SURR				
naphthalene	4.0E-03	NCEA	4.0E-03	R-R ext.				
phenanthrene	3.0E-02	SURR	3.0E-02	R-R ext.				
pyrene	3.0E-02	IRIS	3.0E-02	R-R ext.				
boron	9.0E-02	IRIS						

Cadmium oral RfD used; based on ingestion from food rather than water.
Inhalation SF for chromium as 6:1 ratio of CrIII to CrVI.
Oral RfD for chromium VI.
Cyanide as free cyanide.
Mercury as mercuric chloride (oral) or elemental mercury (inhalation).
Nickel as nickel (soluble salts).
Thallium as thallium sulfate, chloride, or carbonate.
Alpha BHC (HCH), an isomer, used as a surrogate for delta BHC, which has no toxicity value.
Alpha and gamma chlordane as 'technical grade' chlordane.
PCB toxicity values taken from IRIS directly on 5/11/98; based on recommendations for application of 'high risk and persistence'.
Toxicity value for acenaphthene used as a surrogate for acenaphthylene.
Toxicity value for naphthalene used as a surrogate for 2-methylnaphthalene.
Toxicity value for pyrene used as a surrogate for phenanthrene.

IRIS: EPA's Intergrated Risk Information System
HEAST: EPA's Health Effects Assessment Summary Tables
NCEA: EPA's National Center for Environmental Assessment
Withdrawn: Toxicity value withdrawn from IRIS or HEAST
SURR: Surrogate chemical used to evaluate toxicity
R-R ext.: Route-to-route extrapolation used to obtain route-specific toxicity value for organics if no other pathway value was available.

TABLE D-2
RADIONUCLIUDE TOXICITY VALUES

RADIONUCLIDE TOXICITY VALUES[a]												
	Ingestion SF		Inhalation SF		External SF		Ingestion DCF		Inhalation DCF		External DCF	
Isotope	risk/pCi	Source	risk/pCi	Source	risk-g/pCi-yr	Source	mrem/pCi	Source	mrem/pCi	Source	mrem-g/pCi-yr[b]	Source
Am-241	3.28E-10	H 11/94	3.85E-08	H 11/94	4.59E-09	H 11/94	3.64E-03	RES 5.61	4.44E-01	RES 5.61	4.37E-02	RES 5.61
Cs-134	4.73E-11	H 7/97	2.89E-11	H 7/97	5.88E-06	H 7/97	7.33E-05	RES 5.61	4.63E-05	RES 5.61	9.47E+00	RES 5.61
Cs-137+D	3.16E-11	H 11/94	1.91E-11	H 11/94	2.09E-06	H 11/94	5.00E-05	RES 5.61	3.19E-05	RES 5.61	3.41E+00	RES 5.61
Co-60	1.89E-11	H 7/97	6.88E-11	H 7/97	9.76E-06	H 7/97	2.69E-05	RES 5.61	2.19E-04	RES 5.61	1.62E+01	RES 5.61
Eu-152	5.73E-12	H 7/97	7.91E-11	H 7/97	4.08E-06	H 7/97	6.48E-06	RES 5.61	2.21E-04	RES 5.61	7.01E+00	RES 5.61
Pu-238	2.95E-10	H 11/94	2.74E-08	H 11/94	1.94E-11	H 11/94	3.20E-03	RES 5.61	3.92E-01	RES 5.61	1.51E-04	RES 5.61
Pu-239	3.16E-10	H 11/94	2.78E-08	H 11/94	1.26E-11	H 11/94	3.54E-03	RES 5.61	4.29E-01	RES 5.61	2.95E-04	RES 5.61
Ra-226+D	2.96E-10	H 11/94	2.75E-09	H 11/94	6.74E-06	H 11/94	1.33E-03	RES 5.61	8.60E-03	RES 5.61	1.12E+01	RES 5.61
Sr-90+D	5.59E-11	H 11/94	6.93E-11	H 11/94			1.53E-04	RES 5.61	1.31E-03	RES 5.61	2.46E-02	RES 5.61
H-3	7.15E-14	H 11/94	9.59E-14	H 11/94			6.40E-08	RES 5.61	6.40E-08	RES 5.61		
U-234	4.44E-11	H 11/94	1.40E-08	H 11/94	2.14E-11	H 11/94	2.83E-04	RES 5.61	1.32E-01	RES 5.61	4.02E-04	RES 5.61
U-235+D	4.70E-11	H 11/94	1.30E-08	H 11/94	2.65E-07	H 11/94	2.67E-04	RES 5.61	1.23E-01	RES 5.61	7.57E-01	RES 5.61
U-238+D	6.20E-11	H 11/94	1.24E-08	H 11/94	5.25E-08	H 11/94	2.69E-04	RES 5.61	1.18E-01	RES 5.61	1.37E-01	RES 5.61

[a]RESRAD DCFs provided as "+D" for radionuclides with short-lived daughters.

[b]Converted from volume to mass in RESRAD using an assumption of 1.25 g/cm^3 sediment density.

H=HEAST; RES=RESRAD

Attachment E - Model Validation Data Sets

The data validation sets in this attachment allow users to validate the models output using the scenarios and parameters provided in this document. Validation data are provided for risk, dose, and hazard endpoints, for each pathway in each scenario, and for both 'forward' and 'backward' (*i.e.*, PRG) calculations. Validation data are provided for a single chemical within each of the three chemical classifications of 1) chemical carcinogen [benzo(a)pyrene], 2) noncarcinogen [mercury], and 3) radionuclide [cesium-137]. Each of these chemicals have published toxicity values for both ingestion and inhalation exposure routes.

All calculations for the validation data are performed using soil concentrations of 1 mg/kg, and 1 pCi/g, for nonradionuclides and radionuclides, respectively.

TABLE E-1
RISK AND DOSE CALCULATION VALIDATION DATA SET

TRAIL USER SCENARIO								
chemical	endpoint	soil ingestion	dust inhalation	dermal absorption	plant ingestion	meat ingestion	external gamma	pathway sum
Cs-137	dose	3.8E-04	5.8E-07	0.0E+00	0.0E+00	0.0E+00	2.9E-02	3.0E-02
Cs-137	risk	7.1E-09	1.0E-11	0.0E+00	0.0E+00	0.0E+00	5.4E-07	5.4E-07
B(a)P	risk	9.2E-07	9.4E-10	4.9E-06	0.0E+00	0.0E+00	0.0E+00	5.8E-06
Hg	hazard	9.8E-04	8.3E-06	5.2E-04	0.0E+00	0.0E+00	0.0E+00	1.5E-03
RESOURCE USER SCENARIO								
chemical	endpoint	soil ingestion	dust inhalation	dermal absorption	plant ingestion	meat ingestion	external gamma	pathway sum
Cs-137	dose	3.8E-04	5.8E-07	0.0E+00	2.5E-02	1.6E-01	2.9E-02	2.1E-01
Cs-137	risk	7.1E-09	1.0E-11	0.0E+00	4.7E-07	3.0E-06	5.4E-07	4.0E-06
B(a)P	risk	9.2E-07	9.4E-10	4.9E-06	0.0E+00	0.0E+00	0.0E+00	5.8E-06
Hg	hazard	9.8E-04	8.3E-06	5.2E-04	6.1E-01	4.0E+00	0.0E+00	4.6E+00
RESIDENTIAL SCENARIO								
chemical	endpoint	soil ingestion	dust inhalation	dermal absorption	plant ingestion	meat ingestion	external gamma	pathway sum
Cs-137	dose	3.5E-03	2.2E-05	0.0E+00	2.5E-01	0.0E+00	2.5E+00	2.8E+00
Cs-137	risk	4.0E-08	3.9E-10	0.0E+00	3.8E-06	0.0E+00	3.7E-05	4.1E-05
B(a)P	risk	1.1E-05	6.1E-08	2.9E-05	0.0E+00	0.0E+00	0.0E+00	4.1E-05
Hg	hazard	4.3E-02	1.4E-03	6.0E-03	6.1E+00	0.0E+00	0.0E+00	6.2E+00
LANL EMPLOYEE SCENARIO								
chemical	endpoint	soil ingestion	dust inhalation	dermal absorption	plant ingestion	meat ingestion	external gamma	pathway sum
Cs-137	dose	6.3E-04	1.5E-05	0.0E+00	0.0E+00	0.0E+00	7.8E-01	7.8E-01
Cs-137	risk	9.9E-09	2.3E-10	0.0E+00	0.0E+00	0.0E+00	1.2E-05	1.2E-05
B(a)P	risk	1.3E-06	2.1E-08	1.4E-05	0.0E+00	0.0E+00	0.0E+00	1.5E-05
Hg	hazard	1.6E-03	2.2E-04	1.7E-03	0.0E+00	0.0E+00	0.0E+00	3.6E-03
CONSTRUCTION WORKER SCENARIO								
chemical	endpoint	soil ingestion	dust inhalation	dermal absorption	plant ingestion	meat ingestion	external gamma	pathway sum
Cs-137	dose	6.0E-03	1.5E-05	0.0E+00	0.0E+00	0.0E+00	7.8E-01	7.8E-01
Cs-137	risk	3.8E-09	9.2E-12	0.0E+00	0.0E+00	0.0E+00	4.8E-07	4.8E-07
B(a)P	risk	4.9E-07	8.4E-10	5.4E-07	0.0E+00	0.0E+00	0.0E+00	1.0E-06
Hg	hazard	1.6E-02	2.2E-04	1.7E-03	0.0E+00	0.0E+00	0.0E+00	1.8E-02

Abbr. - Cs: Cesium, B(a)P: Benzo(a)pyrene, Hg: Mercury

Values of zero indicate that the pathway is not evaluated within the scenario.

TABLE E-2
PRG CALCULATION VALIDATION DATA SET

TRAIL USER SCENARIO								
chemical	endpoint	soil ingestion	dust inhalation	dermal absorption	plant ingestion	meat ingestion	external gamma	PRG
Cs-137	dose	4.0E+04	2.6E+07	1.0E+07	1.0E+07	1.0E+07	5.1E+02	5.1E+02
Cs-137	risk	1.4E+02	9.6E+04	1.0E+07	1.0E+07	1.0E+07	1.9E+00	1.8E+00
B(a)P	risk	1.1E+00	1.1E+03	2.1E-01	1.0E+07	1.0E+07	1.0E+07	1.7E-01
Hg	hazard	1.0E+03	1.2E+05	1.9E+03	1.0E+07	1.0E+07	1.0E+07	6.6E+02
RESOURCE USER SCENARIO								
chemical	endpoint	soil ingestion	dust inhalation	dermal absorption	plant ingestion	meat ingestion	external gamma	PRG
Cs-137	dose	4.0E+04	2.6E+07	1.0E+07	6.0E+02	9.6E+01	5.1E+02	7.1E+01
Cs-137	risk	1.4E+02	9.6E+04	1.0E+07	2.1E+00	3.4E-01	1.9E+00	2.5E-01
B(a)P	risk	1.1E+00	1.1E+03	2.1E-01	1.0E+07	1.0E+07	1.0E+07	1.7E-01
Hg	hazard	1.0E+03	1.2E+05	1.9E+03	1.6E+00	2.5E-01	1.0E+07	2.2E-01
RESIDENTIAL SCENARIO								
chemical	endpoint	soil ingestion	dust inhalation	dermal absorption	plant ingestion	meat ingestion	external gamma	PRG
Cs-137	dose	4.3E+03	6.9E+05	1.0E+07	6.0E+01	1.0E+07	5.9E+00	5.4E+00
Cs-137	risk	2.5E+01	2.6E+03	1.0E+07	2.7E-01	1.0E+07	2.7E-02	2.4E-02
B(a)P	risk	8.8E-02	1.6E+01	3.4E-02	1.0E+07	1.0E+07	1.0E+07	2.4E-02
Hg	hazard	2.3E+01	7.0E+02	1.7E+02	1.6E-01	1.0E+07	1.0E+07	1.6E-01
LANL EMPLOYEE SCENARIO								
chemical	endpoint	soil ingestion	dust inhalation	dermal absorption	plant ingestion	meat ingestion	external gamma	PRG
Cs-137	dose	2.4E+04	9.7E+05	1.0E+07	1.0E+07	1.0E+07	1.9E+01	1.9E+01
Cs-137	risk	1.0E+02	4.3E+03	1.0E+07	1.0E+07	1.0E+07	8.4E-02	8.4E-02
B(a)P	risk	7.8E-01	4.8E+01	7.4E-02	1.0E+07	1.0E+07	1.0E+07	6.7E-02
Hg	hazard	6.1E+02	4.5E+03	5.8E+02	1.0E+07	1.0E+07	1.0E+07	2.8E+02
CONSTRUCTION WORKER SCENARIO								
chemical	endpoint	soil ingestion	dust inhalation	dermal absorption	plant ingestion	meat ingestion	external gamma	PRG
Cs-137	dose	2.5E+03	9.7E+05	1.0E+07	1.0E+07	1.0E+07	1.9E+01	1.9E+01
Cs-137	risk	2.6E+02	1.1E+05	1.0E+07	1.0E+07	1.0E+07	2.1E+00	2.1E+00
B(a)P	risk	2.0E+00	1.2E+03	1.8E+00	1.0E+07	1.0E+07	1.0E+07	9.7E-01
Hg	hazard	6.4E+01	4.5E+03	5.8E+02	1.0E+07	1.0E+07	1.0E+07	5.7E+01

Abbr. - Cs: Cesium, B(a)P: Benzo(a)pyrene, Hg: Mercury

Values of 1.0E+07 indicate that the pathway is not evaluated within the scenario. A very large value for any specific pathway results in negligible contribution to the PRG - See Equation A-19.