B0060

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL COVER SHEET

1. QA: QA

Complete Only Applicable Items

2. ☑ Analysis — Check all that apply

Type of Analysis:
- ☐ Engineering
- ☑ Performance Assessment
- ☐ Scientific

Intended Use of Analysis:
- ☐ Input to Calculation
- ☐ Input to another Analysis or Model
- ☐ Input to Technical Document
- ☑ Input to other Technical Products

Describe use: Results to be used in subsequent iterations of BDCF calculations to make analysis and modeling decisions

3. ☐ Model — Check all that apply

Type of Model:
- ☐ Conceptual Model
- ☐ Abstraction Model
- ☐ Mathematical Model
- ☐ System Model
- ☐ Process Model

Intended Use of Model:
- ☐ Input to Calculation
- ☐ Input to another Model or Analysis
- ☐ Input to Technical Document
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Describe use:

4. Title:
Disruptive Event Biosphere Dose Conversion Factor Sensitivity Analysis

5. Document Identifier (including Rev. No. and Change No., if applicable):
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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL REVISION RECORD

1. Page: 2 of: 46

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Rev. 00/ICN 0	Initial issue.

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EXECUTIVE SUMMARY

The purpose of this Analysis/Model Report (AMR) is to determine the sensitivity of the calculated disruptive volcanic event Biosphere Dose Conversion Factors (BDCFs) to variations in the input parameters and to the different pathways by which the critical group may be exposed to radioactive material in their environment. The sensitivity analysis has provided insights regarding parameters and exposure pathways having the greatest impact on the BDCFs. The results of the analysis will be used in subsequent iterations to make important analysis and modeling decisions and to help focus resources on key parameters.

To conduct the sensitivity analysis, an additional set of BDCF calculations was done. The method of calculation was identical to the "reasonable representation" cases reported in the disruptive event BDCF AMR (CRWMS M&O 1999g). However, in addition to the original 28 GENII-S input parameters specified as distributions (ranges) for the BDCF calculations, an additional eleven input parameters, which had been fixed at "best estimate" values, were entered as distributions. As indicated in Table 2, distributions were specified for the following eleven input parameters; inhalation exposure time and soil exposure time as well as consumption rates for leafy vegetables, root vegetables, grains, fruit, poultry, meat, eggs, milk, and tap water. In all, 39 input parameters were specified as distributions. Next a stepwise linear regression was performed on each variable using a standard statistical software package. The regression analysis identified the parameters that had the greatest influence on the BDCF variance and provided a quantitative estimate of that influence.

The soil-plant transfer factor was the most significant contributor to variance in the BCDF for all but two radionuclides, and for those (cesium-137 and thorium-229) it was the second-ranked contributor. Mass loading (of dust in the ambient air) is a significant contributor to BCDF variance for a number of alpha-emitting radionuclides. Soil exposure (the hours per year that a person is exposed to the contaminated soil surface) is the most significant contributor to BDCF variance for cesium-137 and the third ranking contributor for two other radionuclides. Consumption rates for leafy vegetables, root vegetables and fruits are significant contributors to BDCF variance for many radionuclides. Beef consumption rate is the second leading contributor to BDCF variance for strontium-90 and is ranked third for cesium-137.

These contributions to the BDCF variances are consistent with exposure pathways believed to be important for the Yucca Mountain Project (YMP) biosphere, including uptake of radioactive material from the soil by crops with subsequent human ingestion of the crops and meat, inhalation of dust raised from the contaminated soil, and external exposure. The results of this analysis suggest that the BDCF uncertainty for all radionuclides of interest can be reduced by refining the soil-plant transfer factors for fruits and vegetables that are actually grown in the Amargosa valley for local consumption. Improving the estimates of long-term air particulate mass loading in an agricultural area that has received volcanic ashfall will reduce BDCF uncertainty for several radionuclides, as will narrowing the range of consumption rates for locally grown fruits and vegetables.

To determine the contributions of different exposure pathways to the BDCF values, a single GENII-S deterministic simulation was performed for each radionuclide. In this deterministic simulation, a "best estimate" or average value was used for each of the 39 input parameters that had been specified as distributions for purposes of the input parameter sensitivity analysis. The contribution to the BDCFs from external exposure, inhalation, inadvertent soil ingestion and ingestion of various foodstuffs was reported.

Inadvertent soil ingestion is the dominant pathway and inhalation is an important contributor to the BDCF for isotopes of actinium, americium, protactinium and plutonium. For thorium-229 the inhalation and soil ingestion pathways are approximately of equal importance, with lesser contributions from external exposure and food ingestion. For strontium-90 and isotopes of uranium, ingestion of vegetables and fruits is the dominant pathway. However, inhalation and inadvertent soil ingestion are also significant contributors for uranium. External exposure is the dominant pathway for cesium-137, which emits a relatively high-energy gamma, with a minor contribution from ingestion of fruit, vegetables and meat.

CONTENTS

Page

EXECUTIVE SUMMARY 3

ACRONYMS AND ABBREVIATIONS 7

1. PURPOSE 9

2. QUALITY ASSURANCE 10

3. COMPUTER SOFTWARE AND MODEL USAGE 11

4. INPUTS 12
   - 4.1 DATA AND PARAMETERS 12
   - 4.2 CRITERIA 12
   - 4.3 CODES AND STANDARDS 12

5. ASSUMPTIONS 15

6. ANALYSIS/MODEL 16
   - 6.1 DATA ANALYSIS METHOD 16
     - 6.1.1 Stepwise Linear Regression Analysis 16
     - 6.1.2 Determination of Contribution to BDCFs by Pathway 18
   - 6.2 GENERATION OF DATA 18
   - 6.3 RESULTS 30
     - 6.3.1 Interpretation of Regression Analysis Results 30
     - 6.3.2 Sensitivity to Input Parameters 32
     - 6.3.3 Sensitivity to Pathway 34

7. CONCLUSIONS 39

8. INPUTS AND REFERENCES 41
   - 8.1 INPUTS 41
   - 8.2 REFERENCES 41
   - 8.3 REGULATIONS AND PROCEDURES 43
   - 8.4 SOFTWARE 45

ATTACHMENTS 46

ATTACHMENT I LIST OF ANALYSIS INPUT AND OUTPUT FILES I-1

ATTACHMENT II DOCUMENTATION FOR SOFTWARE ROUTINES II-1

TABLES

Page

Table 1. List of Biosphere Model Input Parameters and Their Sources. 13
Table 2. Listing of GENII-S Menu-Accessible Input Parameters. 22
Table 3. Listing of Parameters That Are Major Contributors to BDCF Variance 34
Table 4. Contributions by Pathway to BDCFs (in percent) 35
Table 5. BDCF Multipliers to Approximate Effects of Higher Air Mass Loading Assumption 38

FIGURES

Page

Figure 1. Listing of GENII-S Food Transfer and Soil Leaching Factor Library 21
Figure 2. Example of "Z-score Transformation" Routine II-4
Figure 3. Example of "Pathway Contribution" Routine II-8

ACRONYMS AND ABBREVIATIONS

Acronyms

AMR	Analysis/Model Report
ANOVA	Analysis of variance
BDCF	Biosphere Dose Conversion Factor
CRWMS M&O	Civilian Radioactive Waste Management System Management and Operating Contractor
CEDE	Committed Effective Dose Equivalent
Cp	Mallows Statistic
EDE	Effective Dose Equivalent
LHS	Latin Hypercube Sampling
MC	Monte Carlo (Sampling)
OCRWM	Office of Civilian Radioactive Waste Management
RSS	residual sums of squares
SR	Site Recommendation
STD	Standard Deviation
TBD	To Be determined
TBV	To Be Verified
TEDE	Total Effective Dose Equivalent
TSPA	Total System Performance Assessment
TSP	total suspended particulate
YMP	Yucca Mountain Project

Abbreviations

Ac	Actinium
Am	Americium
Bq	Becquerel
C	Carbon
Ci	Curie
Cs	Cesium
I	Iodine
Mo	Molybdenum
Ni	Nickel
Np	Neptunium
Pa	Protactinium
pCi	picocurie
Pu	Plutonium
Ra	Radium
rem	historically derived from Roentgen Equivalent Man, unit of dose
Sr	Strontium
Tc	Technetium
Th	Thorium
U	Uranium
Y	Yttrium

1. PURPOSE

Biosphere is one of the component process models supporting the Total System Performance Assessment (TSPA) used to predict the long-term behavior of the potential repository at Yucca Mountain. The biosphere model considers the movement of radionuclides in the accessible environment, exposure of humans to these radionuclides, and the resulting Biosphere Dose Conversion Factors (BDCFs). The biosphere model allows assessment of BDCFs following internal and external exposure to radionuclides present in environmental media, such as water, soil, air, and food. Internal exposure pathways under consideration include ingestion and inhalation of radionuclides; the external exposure pathway considers external irradiation from contaminated soil. Doses will be calculated as part of the TSPA process.

GENII-S is the computer code used to execute the biosphere model for the TSPA (Leigh et al. 1993). GENII-S has been selected for its capabilities to support modeling of environmental transport and to perform multipathway dose calculations (Harris 1997). GENII-S implements a comprehensive set of environmental pathway models and associated computer codes to estimate potential radiation doses to humans from radionuclides in the environment.

The objective of this Analysis/Model Report (AMR) is to provide a sensitivity analysis for the Disruptive Volcanic Event BDCFs. The sensitivity analysis will provide insights into which parameters and exposure pathways have the greatest impact on the BDCFs. The results of the analysis can be used in subsequent iterations to make important analysis and modeling decisions and help focus resources on key parameters.

The scope of work includes determination of correlation between the variable input parameters and the output BDCFs and the calculation of contribution to BDCFs by each exposure pathway. Different radionuclides may have different characteristics in terms of environment transport and exposure pathways. As a result, the sensitivity analysis has been conducted for each of the twelve (12) radionuclides of interest (see Section 6.2) to provide radionuclide-specific insights. Only variable parameters (i.e., those GENII-S inputs defined as ranges in the generation of BDCFs for this sensitivity analysis) will be addressed in the sensitivity analysis.

This analysis was conducted within the intended use of the GENII-S code for the TSPA modeling, as described in the software qualification report (CRWMS M&O 1998). The conclusions in this report only apply to radionuclides listed in Section 6, and not the full suite of radionuclides considered in GENII-S.

Activities described in this report were conducted in accordance with the *Development Plan for Disruptive Event Biosphere Dose Conversion Factor Sensitivity Analysis* (CRWMS M&O 2000a).

2. QUALITY ASSURANCE

This analysis has been determined to be Quality Affecting in accordance with Civilian Radioactive Waste Management System Management and Operating Contractor (CRWMS M&O) procedure QAP-2-0, *Conduct of Activities,* because the information will be used to support Performance Assessment and other quality-affecting activities. Therefore, this analysis is subject to the requirements of the *Quality Assurance Requirements and Description for the Civilian Radioactive Waste Management Program* (DOE 1998) document. This analysis is covered by the Activity Evaluation for *Scientific Investigation of Radiological Doses in the Biosphere* (CRWMS M&O 1999a).

Personnel performing work on this analysis were trained and qualified according to Office of Civilian Radioactive Waste Management (OCRWM) procedures AP-2.1Q, *Indoctrination and Training of Personnel* and AP-2.2Q, *Establishment and Verification of Required Education and Experience of Personnel.* Preparation of this analysis did not require the classification of items in accordance with CRWMS M&O procedure QAP-2-3, *Classification of Permanent Items.* This analysis was not a field activity. Therefore, a determination of importance in accordance with CRWMS M&O procedure NLP-2-0, *Determination of Importance Evaluation,* was not required.

This report was written in accordance with OCRWM procedure AP-3.10Q, *Analyses and Models* and the following procedures invoked by AP-3.10Q:

AP-2.13Q, Rev. 0, ICN 1.	*Technical Product Development Planning.*
AP-2.14Q, Rev. 0, ICN 0.	*Review of Technical Products.*
AP-3.4Q, Rev. 1, ICN 2.	*Level 3 Change Control.*
AP-3.14Q, Rev. 0, ICN 0.	*Transmittal of Inputs.*
AP-3.15Q, Rev. 1, ICN 1.	*Managing Technical Product Inputs.*
AP-6.1Q, Rev. 4, ICN 0.	*Controlled Documents.*
AP-17.1Q, Rev. 1, ICN 2.	*Record Source Responsibilities for Inclusionary Records.*
AP-SI.1Q, Rev.2, ICN 4.	*Software Management.*
AP-SIII.2Q. Rev. 1, ICN 2.	*Qualification of Unqualified Data and the Documentation of Rationale for Accepted Data.*
AP-SIII.3Q. Rev. 0, ICN 2.	*Submittal and Incorporation of Data to the Technical Data Management System.*
AP-SIII.4Q, Rev. 0, ICN 1.	*Development, Review, Online Placement, and Maintenance of Individual Reference Information Base Data Items.*
YAP-SV.1Q. Rev. 0, ICN 1.	*Control of the Electronic Management of Data.*

3. COMPUTER SOFTWARE AND MODEL USAGE

The conceptual biosphere model and implementing software used to produce the data for this sensitivity analysis was the same as that which was used to generate the BDCFs. Since the purpose of this analysis is to determine the sensitivity of the calculated BDCFs to variations in the input parameters used in the software, the model and software are appropriate for this application. The model and software was used within the range of validation in accordance with AP-SI.1Q, *Software Management*, as described in the software qualification report (CRWMS M&O 1998).

The software used to execute the biosphere model is GENII-S version 1.4.8.5 (Leigh et al. 1993). It is a computer code used to calculate stochastic and deterministic values of radiation doses to humans from exposure to radionuclides in the environment. GENII-S is acquired software, which was qualified for use on the Yucca Mountain Project (CRWMS M&O 1998). Validation of the biosphere model, as executed using GENII-S, was performed in accordance with OCRWM Procedure AP-3.10Q Revision 2, ICN 0, *Analysis and Models*, and documented in *Evaluation of Applicability of Biosphere-Related Features, Events, and Processes* (CRWMS M&O 2000d). The software consists of an executable code and auxiliary files, all of which are maintained under Configuration Management (CSCI: 30034 V1.4.8.5). The analysis was performed using a Gateway 2000 Personal Computer, CPU# 111210.

A commercial statistical software package, S PLUS 2000, Professional (MathSoft 1999a), was used to analyze the GENII-S output in order to determine correlation between the variable input parameters and the BDCF values. The specific software option used in S PLUS to perform the analysis has been designated as a "software routine" and is titled, Stepwise Linear Regression, Rev. 0. Prior to processing the GENII-S data in S PLUS, a transformation was performed using a Microsoft Excel 97 spread sheet application. This application has been identified as a "software routine" and is titled, Z-score Transformation, Rev. 0. The contribution to the BDCFs from each exposure pathway was calculated using a Microsoft Excel 97 spreadsheet application. This application is also identified as a "software routine" and is titled, Pathway Contribution, Rev. 0. The three software routines are documented in Attachment II in accordance with the requirements of AP-SI.1Q, Section 5.1.1. Other software used in the creation of this report, such as Microsoft WORD, is exempt from the requirements in AP-SI.1Q, *Software Management*.

4. INPUTS

4.1 DATA AND PARAMETERS

Inputs utilized in this analysis were developed in a series of AP-3.10Q analyses, as listed in Table 1 or transmitted using Input Transmittals per AP-3.14Q. Table 1 includes input identifications, sources, and the list of parameters from a given source that are used in this analysis. Further information on input parameters is provided in Section 6 (see Tables 2 and 3).

4.2 CRITERIA

Twelve radionuclides were identified by the Performance Assessment Operations Organization as relevant for a direct release scenario (disruptive volcanic events) (CRWMS M&O 1999f): ^{227}Ac, ^{241}Am, ^{243}Am, ^{137}Cs, ^{231}Pa, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{90}Sr, ^{229}Th, ^{232}U, ^{233}U. The analysis was conducted for these radionuclides.

4.3 CODES AND STANDARDS

There are no approved applicable standards at this time.

Table 1. List of Biosphere Model Input Parameters and Their Sources.

Input No.	Document Title and Source Identification	Data Title and Data Tracking Number	Parameter Name/ Input Description
1	CRWMS M&O 1999b. Environmental Transport Parameter Analysis. DI: ANL-MGR-MD-000007 Rev. 00. Las Vegas, Nevada. CRWMS M&O. MOL.19991115.0238	Environmental Transport Parameter Values for Dose Assessment MO9911RIB00064.000	(1) Deposition velocity: particle for deposition on crops (2) Resuspension factor (3) Crop biomass for all crop types under consideration (4) Basic soil data: depth of surface soil, fraction of plant root in surface soil, fraction of plant root in deep soil, surface soil density, bulk soil density. (5) Soil ingestion rate (6) Weathering half-life (7) Translocation factor for all crop types/animal food products under consideration (8) Animal feed and water consumption rates for all animal food products under consideration (9) Dry-to-wet ratio for all crop types under consideration.
2	CRWMS M&O 1999c. Transfer Coefficient Analysis. DI: ANL-MGR-MD-000008 Rev. 00. Las Vegas, Nevada. CRWMS M&O. MOL.19991115.0237	Parameter Values for Transfer Coefficients MO0001RIB00065.001	(1) Transfer parameters for elements and food types under consideration. (2) Soil-to-plant transfer scale factor and animal uptake scale factor.
3	CRWMS M&O 1999d. Input Parameter Values for External and Inhalation Radiation Exposure Analysis. DI: ANL-MGR-MD-000001 Rev. 00. Las Vegas, Nevada. CRWMS M&O. MOL.19990923.0235	Input Parameter Values for External and Inhalation Radiation Exposure Analysis MO9910RIB00061.000	(1) Mass loading (2) Inhalation exposure time, chronic breathing rate, and soil exposure time for the receptor of interest
4	CRWMS M&O 2000b. Identification of Ingestion Exposure Parameters. DI: ANL-MGR-MD-000006, Rev, 00. Las Vegas, Nevada: CRWMS M&O. MOL.20000216.0104.	Ingestion Exposure Parameter Values MO0002RIB00068.000	(1) Crop interception fraction (2) Plant growing times (3) Holdup times for plant and animal food products (4) Feed storage time (5) Animal dietary fractions
5	CRWMS M&O 2000c. Identification of the Critical Group (Consumption of Locally Produced Food and Tap Water). DI: ANL-MGR-MD-000005, Rev. 00. Las Vegas, Nevada: CRWMS M&O. MOL.20000224.0399.	Parameter Values for Consumption of Locally Produced Food and Tap Water. MO0002RIB00062.000	Locally grown food consumption rates for the receptor of interest

Table 1 continued.

	Document Title and Source identification	Data Title and Data Tracking Number	Parameter Name/ Input Description
6	CRWMS M&O 1999e. Dose Conversion Factor Analysis: Evaluation of GENII-S Dose Assessment Methods. DI: ANL-MGR-MD-000002 Rev. 00. Las Vegas, Nevada: CRWMS M&O. MOL.19991207.0215.	Parameter Values for Internal and External Dose Conversion Factors MO9912RIB00066.000	(1) Modifying factors for ingestion and inhalation (2) Dose coefficients for exposure to contaminated soil (3) Dose coefficients for air submersion.
7	CRWMS M&O 2000e. Evaluate Soil/Radionuclide Removal by Erosion and Leaching. ANL-NBS-MD-000009, Rev. 00. Las Vegas, Nevada: CRWMS M&O. MOL.200000310.0057	Leaching Coefficients for GENII-S Code. SN0002T0512299.003	Leaching coefficients for elements under consideration

5. ASSUMPTIONS

The basic assumptions employed for calculating the BDCFs and supporting data used to perform this sensitivity analysis are the same as those described in the AMR which developed the BDCFs, *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 1999g). The following describes the assumptions applicable to this analysis. All assumptions listed below are used in Section 6.

Surface soil was assumed to be the source of contamination for this analysis, per the agreement obtained at the meeting on dose calculations for volcanic disruptions (Smith 1999). Calculations were performed for unit activity concentration in surface soil (1 pCi m^{-2}) uniformly distributed throughout the surface soil layer (Smith 1999, Burck 1999). The thickness of volcanic ash deposited on soil surface was determined to be insignificant, when compared with the thickness of surface soil (Burck 1999), therefore the ash-soil mixture was assumed to have properties of soil.

Groundwater was assumed to be uncontaminated. Drinking water ingestion and aquatic food ingestion, usually considered for the undisrupted performance, were not included because of the assumption that groundwater was not contaminated.

Calculations were performed for a near-field scenario, in which interest is focused on the doses an individual could receive at a particular location as a result of initial contamination or external sources (Leigh et al. 1993, p. 1-2). Radionuclide inventory was considered in terms of basic radionuclide concentrations in surface soil, which exist after immediate volcanic transport has occurred. The radioactivity is assumed to be uniformly plowed into the surface soil layer of 15-cm in depth (Smith 1999). The ash-soil mixture was assumed to have properties of soil (Burck 1999).

The receptor of interest for the reasonable representation is the average member of the critical group. Consumption rates for the average critical group member are based on the mean values of the corresponding distributions of the locally-produced food consumption, consistent with the description of characteristics of the reference biosphere and critical group (Dyer 1999, Sec. 115 (b)(4)).

In order to select some of the GENII-S run options/flags (see Table 2) the following assumptions were made: there is no surface water (lakes, rivers) in the vicinity of Yucca Mountain, therefore surface water transport was not considered; biotic transport and waste form degradation were not included because these processes are characteristic of shallow burial of waste; and, it was assumed that all contaminated food is locally grown.

To support a discussion of the effect of increased air mass loading in Section 6.3.3, it is assumed that the radioactivity ejected from the repository as the result of a volcanic event is uniformly distributed throughout the respirable ash particles and that the increased loading persists throughout the year.

6. ANALYSIS/MODEL

The objective of this analysis is to determine which input parameters and exposure pathways have the most influence on the BDCF value for each nuclide.

6.1 DATA ANALYSIS METHOD

To establish the sensitivity of calculated BCDFs to changes in the input parameters, a stepwise linear regression was performed. To determine the sensitivity of the BDCFs to the different exposure pathways, the dose from each pathway is determined and the percentage contribution to the BDCF is calculated.

6.1.1 Stepwise Linear Regression Analysis

Stepwise linear regression is an efficient method for providing insights into the structure of the data. Regression analysis provides a best fit (least squares) model, which contains those variables (i.e., GENII-S input parameters specified as ranges, see Table 2) that best explain the variance in a given output. The goal of this analysis was to determine the smallest set of parameters that does the best job of accounting for the variation in BDCF. For this analysis method to be valid, the following conditions must be met: the dependent variable observations (BDCFs) are independent from one another (usually assured by random sampling); the independent variables each have a linear relationship with dependent variable; outliers are not artificially inflating the regression model; residuals values have a normal distribution centered on the regression line and have equal variances; and, the independent variables have low correlation's. Interpretation of the results must be tempered by the understanding that not all of the assumptions of regression analysis were quantitatively evaluated.

Twelve (12) regression analyses were performed, one for each radionuclide. The first step in the analysis was to perform a linear transformation of the data (Z-score transformation) to better accommodate the input needs of the statistical analysis software package (MathSoft 1999a) and to provide for generation of standardized regression coefficients. Z-scores are a special application of the transformation rules. The Z-score for an item indicates how far and in what direction, that item deviates from the mean of its distribution, expressed in units of the standard deviation of the distribution (Runyon 1980). The mathematics of the Z-score transformation are such that if every item in a distribution is converted to its Z-score, the transformed scores will necessarily have a mean of zero and a standard deviation of one. Z-scores are sometimes called "standard scores". Z scores are especially useful when comparing the relative standings of items from distributions with different units. The process of Z-score transformation is performed in an Excel spreadsheet using a software routine titled *Z-score Transformation, Rev. 0*. This routine is documented in Attachment II.

Next a stepwise linear regression was performed on each response variable separately which allowed both inclusion and exclusion of variables. The upper model was specified to contain all

39 parameters, and the lower model was specified as "NULL" (i.e., containing no parameters). All operations performed with the statistical software utilized the standard build-in functions

The "best" model is the one that simultaneously contains the fewest parameters and explains the greatest amount of the variance in the BDCFs. Stepwise regression is considered the most efficient way to achieve this goal. Stepwise regression uses a strategy of adding and dropping parameters until the best fitting model is found. Specifically, stepwise regression is an iterative process that combines the strategies of forward inclusion and backward exclusion to decide which parameters to add to or delete from the current model.

The backward exclusion strategy begins with a model that includes all parameters. That is, all parameters are used to predict BDCFs. The next step is to decide which parameter, if any, should be deleted. This is done by dropping each parameter, in turn, from the full model and comparing each reduced model against the full model to determine the impact of dropping each parameter. An ANOVA (analysis of variance) table is produced for each reduced model that contains the residual sums of squares (RSS) of the term deleted from that model. The smaller the RSS, the larger the Multiple R-Squared (coefficient of variation). The model with lowest RSS provides the best least squares fit of the data – that is, the best prediction of the BDCF. If several models have low RSS, then there are several numerical criteria available upon which to rank the models. The two most commonly used are adjusted R-Squared and the Mallows "Cp" statistic. The models which yield the best (lowest) values of Cp will tend to be similar to those which yield the best (highest) values of adjusted R-squared, but the exact ranking may be slightly different. Other things being equal, the Cp criterion tends to favor models with fewer parameters, so it is perhaps more robust to over-fitting the data. The Cp statistic is closely related to the RSS and is a commonly used criterion for determining whether a model is improved by dropping a term. If any term has a Cp statistic lower than that of the current model, the term with the lowest Cp statistic is dropped. If the current model has the lowest Cp statistic, the model is not improved by dropping any term. Additional information concerning stepwise linear regression analysis and the terms used its interpretation can be found in the S-PLUS Guide to Statistics (MathSoft 1999b).

The forward inclusion strategy is also an iterative process. One parameter at a time is added to the model, creating an augmented model. As with backward exclusion, an ANOVA table is calculated for all of the augmented models. Each row of the ANOVA table represents the effects of adding a single term to the current model. In general, it is worth adding a term if the Cp statistic for that model is lowest among the rows in the table, including the base model term.

Stepwise regression automates the selection process implied by adding and dropping terms. That is, it calculates the Cp statistic for the current model, as well as those for all reduced or augmented models, then adds or drops the terms that reduce Cp the most. This process is iterated until either adding or deleting any parameters can no longer enhance the model.

Since the input data was standardized, the resulting regression coefficients are standardized and indicate the magnitude by which the calculated BDCFs change for each fractional change in an input parameter. Standardization of the regression coefficient removes the effect of the unit of

measure from the regression results. The standardized regression coefficients are used to rank the importance of the parameters in accounting for the variance in the BDCFs for a radionuclide.

The S-PLUS options necessary to perform the stepwise linear regression analysis are considered a software routine. This routine has been titled *Stepwise Linear Regression, Rev. 0* and is documented in Attachment II.

6.1.2 Determination of Contribution to BDCFs by Pathway

Examining the relative importance of different exposure pathways to the BDCF provides a different perspective on sensitivity. To determine the contributions of different exposure pathways to the BDCF values, a single GENII-S deterministic simulation was performed for each radionuclide. In this deterministic simulation, a "best estimate" value, as indicated in Table 2, was used for each of the 39 input parameters that had been specified as distributions for purposes of the input parameter sensitivity analysis described in the previous section.

For the deterministic runs a GENII-S input parameter flag was set so that the code output would tabulate the EDE by exposure pathway. The output provides a single value for the external dose contribution to the BDCF. However, for the inhalation and ingestion pathways the output is provided in terms of the dose to each organ. For ingestion, the organ doses are reported by food group. As a result, for each pathway it was necessary to multiply the dose to each organ by the organ's weighting factor (the fraction of the annual EDE attributed to the dose to that organ) and then sum the results for each pathway. This produces the contribution to the BDCF from each pathway. The total for each pathway is then divided by the total BDCF to obtain the fractional contribution from each pathway. As a note, organ weighting factors are part of the basic default values required to perform a GENII-S calculation and cannot be modified by the user (Leigh 1993). The weighting factors are displayed in each GENII-S deterministic output file as part of the summary table for Annual Effective Dose Equivalent.

To automate this process, an Excel spreadsheet application was created to perform the basic mathematical operations. As indicated in Section 3.0, this software routine is titled *Pathway Contribution, Rev. 0.* Documentation and an example for this routine are provided in Attachment II.

Exposure pathways addressed in this analysis include ingestion, inhalation, and external. Additional information concerning the components of these pathways is provided in *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 1999g).

6.2 GENERATION OF DATA

GENII-S has been selected as the computer code to support the biosphere modeling effort. Selection of the model and supporting software has been previously conducted and the rationale has been documented (Harris 1997).

GENII-S code was used to calculate BDCFs for the conditions following volcanic eruption as described in *Disruptive Event Biosphere Dose Conversion Factor Analysis*, Section 6 (CRWMS M&O 1999g). Twelve radionuclides were identified as relevant for a direct release scenario

(disruptive events) (CRWMS M&O 1999f): ^{227}Ac, ^{241}Am, ^{243}Am, ^{137}Cs, ^{231}Pa, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{90}Sr, ^{229}Th, ^{232}U, ^{233}U.

Data to support the determination of sensitivity were generated by performing stochastic runs using the GENII-S option of Latin Hypercube Sampling (LHS) (Leigh 1993). Data used to determine the contribution to BDCFs by pathway were calculated in deterministic runs. Resulting BDCFs for both were calculated in units of rem y^{-1} pCi^{-1} m^2.

The BDCFs are intended to support the calculation of dose by the TSPA to the *average* member of the critical group. Therefore, several parameters describing human behavior that influences dose to individuals were set at fixed or "best estimate" values when calculating the BDCFs in the AMR referenced above. In the calculations performed to support this analysis, distributions (ranges) were specified for eleven GENII-S input parameters that had been fixed at "best estimate" values for purposes of the BDCF calculations. Distributions were specified for inhalation exposure time and soil exposure time as well as consumption rates for leafy vegetables, root vegetables, grains, fruit, poultry, meat, eggs, milk and tap water. An understanding of the sensitivity of BDCFs to these parameters is helpful in applying the concept of "Reasonably Maximally Exposed Individual," defining the "Critical Group" and identifying important elements of the interface between the geosphere and biosphere models.

For the stochastic runs, input parameter ranges from the "reasonable representation" BDCF calculations were used. Ranges were also specified for the eleven additional parameters identified above. Calculations for each radionuclide consisted of 130 realizations in which values for each of the 39 input parameters were selected randomly, using LHS. Thus, for each of the 12 radionuclides of interest, 130 sets of data were available for analysis. Each set contained the specific values of the 39 input variables used by GENII-S in that realization, plus the value of the output -- the BDCF calculated using those input values. However, with 39 sampled parameters, the chosen sample size is well above the minimum sample size (~52) recommended by the developers of GENII-S (Leigh 1993).

GENII-S deterministic calculations use fixed input parameter values. The resulting BDCFs for radionuclides under consideration were subsequently expressed as single values. For the 39 variables specified as ranges in the stochastic runs the "best estimate" value (see Table 2) was used to calculate a BDCF for each of the 12 nuclides of interest. Each output file contains the contribution to the BDCF from external dose as well as the committed dose equivalent to internal organs from inhalation and from each component of the ingestion pathway.

Biosphere modeling for the calculation of BDCFs was site specific to the extent practicable. An effort was made to use site-specific values of model parameters whenever possible. Input parameters, developed in a series of AMRs, were entered (see Table 1). Two methods are used for inputting parameters into GENII-S. The first is to modify input data files, and the second is through a series of interactive input screens. The fixed parameter values entered into the code via data files are discussed in Section 6, of the AMR *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 1999g). The AMR presents tables that contain the input parameter values from the data files for environmental parameters, bioaccumulation, food transfer coefficients, soil leaching factors, and external dose factors. During the completion of this AMR updated values for food transfer coefficients and leaching factors were received. As a

result, the data file (FTRANRR.TXT) was updated. Figure 1 lists the modified FTRANRR.TXT, which has been renamed FTRANSN.TXT for the sensitivity and pathway calculations. The sources of the data contained in this file are listed in Table 1.

Table 2 contains the descriptions and sources of all input parameters entered using the interactive menu-driven interface for both the stochastic and deterministic GENII-S calculations. For the stochastic runs the ranges indicated were used and for the deterministic runs the values listed in the "Best Estimates" column of the table were used. This table has been constructed to resemble the GENII-S input menus, more detailed information regarding the terms, options, parameters, and distributions presented in the table can be found in the GENII-S User's Guide (Leigh 1993).

Some of the parameters/options available in GENII-S were not used because they were irrelevant to the exposure scenario of interest. Nevertheless, the names of these parameters appear in the tables consistent with the GENII-S input format, and the nomenclature used is consistent with the usage in the code.

GENII-S working files used by the computer code for computational purposes are listed in Attachment I. Working files for the stochastic and deterministic runs are grouped in sets of six and five files respectively. Each file root name includes the radionuclide and a case identification, where RR4 represents the stochastic case and PW the deterministic. There are four input files for each type of run, with the following extensions: ".flg", ".inp", ".pti", and ".vec". These files are used by the code to store the input data. There are two output files created for each stochastic run, with the following file extensions ".out" and ".sum". The ".out" file contains no data for the stochastic runs and the ".sum" file is an ASCII file created by the operator following code execution which contains a summary of the results. One ASCII output file is created by the code for each deterministic run with a file extension of ".out". In addition, the attachment contains a listing of the regression analysis files created by the S PLUS software. These files contain the results for each regression model created, with the final or "best" model being the last one in the file. There is one file for each nuclide, the name of the nuclide is part of the file root name, the file extensions are all ".srp" and the files are in ASCII format. Also included are the Excel spreadsheet files, with file extensions of ".xls", which contain the software routines used to calculate the Z-score transformation and the contribution by pathway to the BDCFs.

Food Transfer Factors for Reasonalb Representation (2/09/00)

Ele-men	Dep Vel m/sec	Leafy Veg	Root Veg	Fruit --	Grain --	Beef day/kg	Poulty day/kg	Milk day/L	Egg day/kg	Leaching Factor
AC	1.0E-3	3.5E-3	3.5E-4	3.5E-4	3.5E-4	2.5E-5	4.0E-3	2.0E-5	2.0E-3	1.5E-03
AM	1.0E-3	2.0E-3	4.7E-4	4.1E-4	9.0E-5	2.0E-5	6.0E-3	2.0E-6	4.0E-3	3.6E-04
C	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	1.3E-01
CS	1.0E-3	1.3E-1	4.9E-2	2.2E-1	2.6E-2	5.0E-2	4.4E+0	8.0E-3	4.0E-1	2.4E-03
I	1.0E-2	3.4E-3	5.0E-2	5.0E-2	5.0E-2	7.0E-3	1.8E-2	1.0E-2	3.0E+0	5.9E-01
MO	1.0E-3	2.5E-1	6.0E-2	6.0E-2	6.0E-2	1.0E-3	1.9E-1	1.5E-3	9.0E-1	6.7E-02
NI	1.0E-3	1.8E-1	6.0E-2	6.0E-2	3.0E-2	5.0E-3	1.0E-3	2.0E-2	1.0E-1	1.7E-03
NP	1.0E-3	3.7E-2	1.7E-2	1.7E-2	2.7E-3	1.0E-3	4.0E-3	5.0E-6	2.0E-3	1.3E-01
PA	1.0E-3	2.5E-3	2.5E-4	2.5E-4	2.5E-4	1.0E-5	4.0E-3	5.0E-6	2.0E-3	1.2E-03
PU	1.0E-3	3.9E-4	2.0E-4	1.9E-4	2.6E-5	1.0E-5	4.0E-3	1.1E-6	8.0E-3	1.2E-03
RA	1.0E-3	8.0E-2	1.3E-2	6.1E-3	1.2E-3	9.0E-4	3.0E-2	1.3E-3	2.0E-5	1.4E-03
SR	1.0E-3	2.0E+0	1.2E+0	2.0E-1	2.0E-1	8.0E-3	3.5E-2	1.5E-3	3.0E-1	4.5E-02
TC	1.0E-3	4.0E+1	6.6E+0	1.5E+0	7.3E-1	1.0E-4	3.0E-2	9.9E-3	3.0E+0	2.8E+00
TH	1.0E-3	4.0E-3	3.0E-4	2.1E-4	3.4E-5	6.0E-6	4.0E-3	5.0E-6	2.0E-3	2.1E-04
U	1.0E-3	8.5E-3	1.4E-2	4.0E-3	1.3E-3	3.0E-4	1.2E+0	6.0E-4	1.0E+0	1.9E-02
Y	1.0E-3	1.5E-2	6.0E-3	6.0E-3	6.0E-3	1.0E-3	1.0E-2	2.0E-5	2.0E-3	4.0E-03

Figure 1. Listing of GENII-S Food Transfer and Soil Leaching Factor Library

Table 2. Listing of GENII-S Menu-Accessible Input Parameters.

Menu(s)	Option/ Parameter, Unit	Selection	Values			Distribution	Reference[a]/ Comments
			Minimum	Best Estimate	Maximum		
PRE-GENII							
Edit Flags and Options	Scenario Options						
	- Near-Field Scenario	Y	NA	NA	NA	NA	Assumptions
	- Population Dose	N	NA	NA	NA	NA	
	- Acute Release	N	NA	NA	NA	NA	
	Transport Options						
	- Air Transport	N	NA	NA	NA	NA	Assumptions
	- Surface Water Transport	N	NA	NA	NA	NA	
	- Biotic Transport	N	NA	NA	NA	NA	
	- Waste From Degradation	N	NA	NA	NA	NA	
	Exposure Pathway Options						
	- External Finite Plume	N	NA	NA	NA	NA	Assumptions
	- External Infinite Plume	N	NA	NA	NA	NA	
	- External Ground Exposure	Y	NA	NA	NA	NA	
	- External Recreational Exposure	N	NA	NA	NA	NA	
	- Inhalation Uptake	Y	NA	NA	NA	NA	
	- Drinking Water Ingestion	N	NA	NA	NA	NA	
	- Aquatic Food Ingestion	N	NA	NA	NA	NA	
	- Terrestrial Food Ingestion	Y	NA	NA	NA	NA	
	- Animal Product Ingestion	Y	NA	NA	NA	NA	
	- Inadvertent Soil Ingestion	Y	NA	NA	NA	NA	
	Deterministic Output Options						
	- Both Committed and Cumulative	N	NA	NA	NA	NA	Assumptions
	- EDE by Nuclide	N	NA	NA	NA	NA	
	- EDE by Pathway	N	NA	NA	NA	NA	
	Run Options						
	- Inventory Unit Index (1-5)	1, pCi	NA	NA	NA	NA	Assumptions/ Unit selection
	- Soil Inventory Unit Index (1-3)	1, per m^2	NA	NA	NA	NA	
	- Inventory Input Option (1-3)	2	NA	NA	NA	NA	
	- Det Run/Stat Run/Both (1/2/3)	2	NA	NA	NA	NA	
	- Nuclide Intake Duration, yr	1	NA	NA	NA	NA	
Select Nuclides	Radionuclide selection	Y/N	-	-	-	-	Input source #7

Table 2. Continued

Menu(s)	Option/ Parameter, Unit	Selection	Values			Distribution	Reference[a]/ Comments
			Minimum	Best Estimate	Maximum		
PRE-GENII (continued)							
Select Statistical Output	- Statistical Committed Dose Summary	Y	NA[b]	NA	NA	NA	
	- Statistical Committed Nuclide Dose	N	NA	NA	NA	NA	
	- Statistical Committed Pathway Dose	N	NA	NA	NA	NA	
	- Statistical Committed Organ Dose	N	NA	NA	NA	NA	
	- Statistical Cumulative Pathway Dose	N	NA	NA	NA	NA	
	- Statistical Cumulative Organ Dose	N	NA	NA	NA	NA	
	- Statistical External Dose Summary	N	NA	NA	NA	NA	
MAIN EDITING MENU							
Titles And Run Controls	- Model Name		NA	NA	NA	NA	
	- Title (2 lines)		NA	NA	NA	NA	
	- Latin Hypercube (LHS) or Monte Carlo (MC) Sampling	LHS	NA	NA	NA	NA	
	- The Number of Trials (<=500)	130	NA	NA	NA	NA	
	- A Random Seed (0.0<=Seed<=1.0)	0.333	NA	NA	NA	NA	
Fixed Data Input Variable Distribution	Population/Soil/Scenario Data						
	- Total Population	1	NA	NA	NA	--	Not used
	- Population Scale Factor	NA	--	1	--	Fixed	Not used
	- Soil/Plant Transfer Scale Factor, (-)	NA	0.0275	--	36.4	Lognormal[d]	Input source #2
	- Animal Uptake Scale Factor, (-)	NA	0.117	--	8.51	Lognormal[d]	Input source #2
	- Human Dose Factor Scale Factor, (-)	NA	--	1	--	Fixed	Input source #6
	- Dose Commitment Period, yr	NA	NA	50	NA	NA	Assumption
	- Surface Soil Depth, cm	NA	--	15	--	Fixed	Input source #1
	- Surface Soil Density, kg/m^2	NA	--	225	--	Fixed	Input source #1
	- Deep Soil Density, kg/m^3	NA	--	1500	--	Fixed	Input source #1
	- Roots in Upper Soil, fraction	NA	--	1	--	Fixed	Input source #1
	- Roots in Deep Soil, fraction	NA	--	0	--	Fixed	Input source #1
	- Air Release Time Before Intake, yr	NA	NA	0	NA	NA	Not used
	- H2O Release Time Before Intake, yr	NA	NA	0	NA	NA	Not used
	Biotic Trans./Near Field Data Not used	--	--	--	--	--	--

Table 2. Continued.

Menu(s)	Option/ Parameter, Unit	Selection	Values			Distribution	Reference[a]/ Comments
			Minimum	Best Estimate	Maximum		
MAIN EDITING MENU (continued)							
Fixed Data Input Variable Distribution	External/Inhalation Exposure (cont.)						
	- Chronic Plume Exposure Time, hr	NA	--	0	--	Fixed	Not used
	- Acute Plume Exposure Time, hr/phr	NA	--	0	--	Fixed	Not used
	- Inhalation Exposure Time, hr/yr	NA	3,483.38	3,918.5	6,353.5	Triangular[e]	Input source #3
	- Resuspension Model Flag (0-2)	1	NA	NA	NA	NA	Mass loading
	- Mass Loading, g/m^3	NA	7.4E-07	8.7E-06	6.4E-05	Lognormal[d]	Input source #3
	- Transit Time to Rec. Site, hr	NA	--	0	--	Fixed	|
	- Swimming Exposure Time, hr	NA	--	0	--	Fixed	|
	- Boating Exposure Time, hr	NA	--	0	--	Fixed	| Parameters
	- Shoreline Exposure Time, hr	NA	--	0	--	Fixed	| not used
	- Type of Shoreline Index (1-4)	0	NA	NA	NA	NA	|
	- H2O/Sediment Transfer1/m^2/yr	NA	--	0	--	Fixed	|
	- Soil Exposure Time, hr	NA	206.75	827	3,947	Triangular[e]	Input source #3
	- Home Irrigation Flag (0/1 = N/Y)	0	NA	NA	NA	NA	|
	- Irrigation Water Index (1-2)	1	NA	NA	NA	NA	| Water not
	- Home Irrigation Rate, in/yr	NA	52	69.5	87	Uniform	| contaminated
	- Home Irrigation Duration, mo/yr	NA	--	12	--	Fixed	|
	Ingestion Exposure						
	- Food Production Option	0	NA	NA	NA	NA	Not used
	- Food-Weighted Chi/Q, kg-s/m^3	0	--	0	--	Fixed	Not used
	- Crop Resuspension Factor, 1/m	NA	9.6E-12	8.3E-11	7.2E-10	Lognormal[d]	Input source #1
	- Crop Deposition Velocity, m/s	NA	--	0.001	--	Fixed	Input source #1
	- Crop Interception Fraction	NA	0.044	0.259	0.474	Normal[d]	Input source #4
	- Exported Food Dose (0/1 = N/Y)	0	NA	NA	NA	NA	Not used
	- Soil Ingestion Rate, mg/day	NA	--	50	--	Fixed	Input source #1
	- Swim H2O Ingestion Rate, l/h	NA	--	0	--	Fixed	Not used
	- Population Ingesting Aquatic Food	0	NA	NA	NA	NA	Not used
	- Bioaccumulation Flag (0/1 = N/Y)	0	NA	NA	NA	NA	Not used
	- Population Drinking Contaminated Water	0	NA	NA	NA	NA	| Drinking water
	- Drink Water Source Index (0-3)	0	NA	NA	NA	NA	| not
	- Drink Water Treated (0/1 = N/Y)	0	NA	NA	NA	NA	| contaminated
	- Drink Water Holdup Time, days	NA	--	0	--	Fixed	|
	- Drink Water Consumption, l/y	NA	0	752.85	1,487.45	Uniform[e]	|

Table 2. Continued.

Menu(s)	Option/ Parameter, Unit	Selection	Values			Distribution	Reference[a]/ Comments
			Minimum	Best Estimate	Maximum		
MAIN EDITING MENU (continued)							
Array Data Input (cont.) Variable Distribution	Aquatic Food Ingestion						
	Not used	--	--	--	--	--	--
	Terrestrial Food Ingestion						
	- Use (0/1 = F/T)						
	Leafy Vegetables	1	NA	NA	NA	NA	Input source #5
	Root Vegetables	1	NA	NA	NA	NA	Input source #5
	Fruit	1	NA	NA	NA	NA	Input source #5
	Grain	1	NA	NA	NA	NA	Input source #5
	- Growing Time, days						
	Leafy Vegetables	NA	45	64.5	75	Triangular	Input source #4
	Root Vegetables	NA	70	(84)[c]	98	Uniform	Input source #4
	Fruit	NA	88	(136)	184	Uniform	Input source #4
	Grain	NA	75	(159)	244	Uniform	Input source #4
	- Water Source Flag (0-2)						
	Leafy Vegetables	0	NA	NA	NA	NA	|
	Root Vegetables	0	NA	NA	NA	NA	| Water not
	Fruit	0	NA	NA	NA	NA	| contaminated
	Grain	0	NA	NA	NA	NA	|
	- Irrigation Rate, in/yr						
	Leafy Vegetables	NA	28.17	42.11	80.37	Triangular	| Input source #4
	Root Vegetables	NA	47.34	(49.46)	51.58	Uniform	|
	Fruit	NA	30.00	(37.69)	45.37	Uniform	| Water not
	Grain	NA	55.85	(68.11)	80.37	Uniform	| contaminated
	- Irrigation Time, mo/yr						
	Leafy Vegetables	NA	2.0	3.2	4.9	Triangular	| Input source #4
	Root Vegetables	NA	3.2	(3.9)	4.6	Uniform	|
	Fruit	NA	2.9	(4.5)	6.0	Uniform	| Water not
	Grain	NA	4.9	(6.5)	8.0	Uniform	| contaminated
	- Crop Yield, kg/m^2						
	Leafy Vegetables	NA	0.59	1.82	4.11	Triangular	Input source #4
	Root Vegetables	NA	1.73	4.33	5.87	Triangular	Input source #4
	Fruit	NA	1.57	(1.91)	2.25	Uniform	Input source #4
	Grain	NA	0.33	(0.56)	0.78	Uniform	Input source #4

Table 2. Continued.

Menu(s)	Option/ Parameter, Unit	Selection	Values			Distribution	Reference[a]/ Comments
			Minimum	Best Estimate	Maximum		
MAIN EDITING MENU (continued)							
Array Data Input (cont.) Variable Distribution	Terrestrial Food Ingestion (cont.)						
	- Production, kg/yr						
	Leafy Vegetables	NA	--	0	--	Fixed	|
	Root Vegetables	NA	--	0	--	Fixed	| Parameter
	Fruit	NA	--	0	--	Fixed	| not used
	Grain	NA	--	0	--	Fixed	|
	- Holdup, days						
	Leafy Vegetables	NA	--	1	--	Fixed	Input source #4
	Root Vegetables	NA	--	14	--	Fixed	Input source #4
	Fruit	NA	--	14	--	Fixed	Input source #4
	Grain	NA	--	14	--	Fixed	Input source #4
	- Consumption Rate, kg/yr						
	Leafy Vegetables	NA	1.16	15.14	59.68	Log Uniform[e]	Input source #5
	Root Vegetables	NA	0.65	7.81	29.86	Log Uniform[e]	Input source #5
	Fruit	NA	0.18	15.57	97.69	Log Uniform[e]	Input source #5
	Grain	NA	8.61E-11	0.48	12.33	Log Uniform[e]	Input source #5
	Animal Product Consumption						
	- Use (0/1 = F/T)						
	Beef	1	NA	NA	NA	NA	Input source #5
	Poultry	1	NA	NA	NA	NA	Input source #5
	Milk	1	NA	NA	NA	NA	Input source #5
	Eggs	1	NA	NA	NA	NA	Input source #5
	• Consumption Rate, kg/yr						
	Beef	NA	7.13E-07	2.93	53.11	Log Uniform[e]	Input source #5
	Poultry	NA	2.09E-05	0.80	10.50	Log Uniform[e]	Input source #5
	Milk	NA	2.98E-09	4.14	100.36	Log Uniform[e]	Input source #5
	Eggs	NA	0.23	6.68	33.34	Log Uniform[e]	Input source #5
	• Holdup, days						
	Beef	NA	--	20	--	Fixed	Input source #4
	Poultry	NA	--	1	--	Fixed	Input source #4
	Milk	NA	--	1	--	Fixed	Input source #4
	Eggs	NA	--	1	--	Fixed	Input source #4

Table 2. Continued.

Menu(s)	Option/ Parameter, Unit	Selection	Values			Distribution	Reference[a]/ Comments
			Minimum	Best Estimate	Maximum		
MAIN EDITING MENU (continued)							
Array Data Input (cont.) Variable Distribution	Animal Product Consumption						
	- Production, kg/yr						
	Beef	NA	--	0	--	Fixed	|
	Poultry	NA	--	0	--	Fixed	| Parameter
	Milk	NA	--	0	--	Fixed	| not used
	Eggs	NA	--	0	--	Fixed	|
	- Contaminated Water Fraction						
	Beef	NA	--	0	--	Fixed	|
	Poultry (corn)	NA	--	0	--	Fixed	| Water not
	Milk	NA	--	0	--	Fixed	| contaminated
	Eggs (corn)	NA	--	0	--	Fixed	|
	Animal Products (Stored Feed Data)						
	- Dietary Fraction						
	Beef	NA	--	0	--	Fixed	Input source #4
	Poultry (corn)	NA	--	1	--	Fixed	Input source #4
	Milk	NA	--	0	--	Fixed	Input source #4
	Eggs (corn)	NA	--	1	--	Fixed	Input source #4
	- Growing Time, days						
	Beef	NA	--	0	--	Fixed	Input source #4
	Poultry (corn)	NA	--	75	--	Fixed	Input source #4
	Milk	NA	--	0	--	Fixed	Input source #4
	Eggs (corn)	NA	--	75	--	Fixed	Input source #4
	- Water Source Flag						
	Beef	0	NA	NA	NA	NA	|
	Poultry (corn)	0	NA	NA	NA	NA	| Water not
	Milk	0	NA	NA	NA	NA	| contaminated
	Eggs (corn)	0	NA	NA	NA	NA	|
	- Irrigation Rate, in/yr						
	Beef	NA	--	0	--	Fixed	| Input source #4
	Poultry (corn)	NA	--	80.37	--	Fixed	|
	Milk	NA	--	0	--	Fixed	| Water not
	Eggs (corn)	NA	--	80.37	--	Fixed	| contaminated
	- Irrigation Time, mo/yr						
	Beef	NA	--	0	--	Fixed	| Input source #4
	Poultry (corn)	NA	--	4.9	--	Fixed	|
	Milk	NA	--	0	--	Fixed	| Water not
	Eggs (corn)	NA	--	4.9	--	Fixed	| contaminated

Table 2. Continued.

Menu(s)	Option/ Parameter, Unit	Selection	Values			Distribution	Reference[a]/ Comments
			Minimum	Best Estimate	Maximum		
MAIN EDITING MENU (continued)							
Array Data Input (cont.) Variable Distribution	Animal Products (Stored Feed Data) cont.						
	- Feed Yield, kg/m^2						
	Beef	NA	--	0	--	Fixed	Input source #4
	Poultry (corn)	NA	0.59	(0.69)	0.78	Uniform	Input source #4
	Milk	NA	--	0	--	Fixed	Input source #4
	Eggs (corn)	NA	0.59	(0.69)	0.78	Uniform	Input source #4
	- Storage, days						
	Beef	NA	--	0	--	Fixed	Input source #4
	Poultry (corn)	NA	--	14	--	Fixed	Input source #4
	Milk	NA	--	0	--	Fixed	Input source #4
	Eggs (corn)	NA	--	14	--	Fixed	Input source #4
	Animal Products (Fresh Forage Data)						
	- Dietary Fraction						
	Beef (alfalfa)	NA	--	1	--	Fixed	Input source #4
	Milk (alfalfa)	NA	--	1	--	Fixed	Input source #4
	- Grow Time, days						
	Beef (alfalfa)	NA	46	47	135	Triangular	Input source #4
	Milk (alfalfa)	NA	46	47	135	Triangular	Input source #4
	- H2O Source Flag						
	Beef (alfalfa)	0	NA	NA	NA	NA	| Water not
	Milk (alfalfa)	0	NA	NA	NA	NA	| contaminated
	- Irrigation Rate, in/yr						
	Beef (alfalfa)	NA	--	94.66	--	Fixed	| Water not
	Milk (alfalfa)	NA	--	94.66	--	Fixed	| contaminated
	- Irrigation Time, mo/yr						
	Beef (alfalfa)	NA	--	12	--	Fixed	| Water not
	Milk (alfalfa)	NA	--	12	--	Fixed	| contaminated
	- Feed Yield, kg/m^2						
	Beef (alfalfa)	NA	0.25	(0.7)	1.15	Uniform	Input source #4
	Milk (alfalfa)	NA	0.25	(0.7)	1.15	Uniform	Input source #4
	- Storage, days						
	Beef (alfalfa)	NA	--	0	--	Fixed	Input source #4
	Milk (alfalfa)	NA	--	0	--	Fixed	Input source #4

Table 2. Continued.

Menu(s)	Option/ Parameter, Unit	Selection	Values			Distribution	Reference[a]/ Comments
			Minimum	Best Estimate	Maximum		
MAIN EDITING MENU (continued)							
Array Data Input (cont.) Variable Distribution	Inventory – Basic Concentrations						
	- Air, pCi/m^3	NA	--	0	--	Fixed	Assumption
	- Surface Soil, pCi/m^2	NA	--	1	--	Fixed	
	- Deep Soil, pCi/kg	NA	--	0	--	Fixed	
	- Ground Water, pCi/l	NA	--	0	--	Fixed	
	- Surface Water, pCi/l	NA	--	0	--	Fixed	

[a] Input source identification in Reference/Comment column (e.g. #1, #3) refers to input numbers in Table 1.

[b] NA as an entry means that a given selection/option/value does not appear in GENII-S.

[c] If data for best estimate value of uniform distribution was not provided by the input source, the average value was used (number in parentheses).

[d] For Normal and LogNormal distributions, Minimum = 0.1 percentile and Maximum = 99.9 percentile.

[e] One of the 11 input parameters entered as 'Fixed' during the BDCF calculations, and now entered as a distribution for the sensitivity analysis.

6.3 RESULTS

The results of this analysis include GENII-S input and output files, S PLUS 2000 output files and Excel files for calculating contributions for each pathway. Due to the large volume of files, they have been put on a CD ROM as an attachment to this document. Attachment I provides a list of the files stored on the CD ROM.

6.3.1 Interpretation of Regression Analysis Results

The S PLUS output file contains the results from each model created by the iteration process. The final result or "best" model is the last one in the file. The following example of the results from the final regression model for the nuclide Pa-231 (example taken from S-PLUS output file DE PA231.srp, located on CD ROM) will be used to illustrate the interpretation of results of the regression process.

```
Call: lm(formula = Pa231 ~ Soil.Plant.Trans + Mass.Load +
Soil.Expos + Drink.Water.CR + Grain.YLD + Leaf.Veg.CR + Fruit.CR
+ Eggs.CR, data = DC.Master.Feb.9, na.action = na.exclude)
Residuals:
     Min       1Q   Median     3Q   Max
  -1.181 -0.1914 -0.01301 0.177 2.069

 Coefficients:
                    Value Std. Error t value Pr(>|t|)
      (Intercept)  0.0000  0.0440     0.0000  1.0000
 Soil.Plant.Trans  0.6961  0.0452    15.3981  0.0000
        Mass.Load  0.1853  0.0446     4.1504  0.0001
       Soil.Expos  0.1336  0.0444     3.0068  0.0032
   Drink.Water.CR  0.0962  0.0449     2.1416  0.0342
        Grain.YLD  0.0967  0.0446     2.1668  0.0322
      Leaf.Veg.CR  0.4090  0.0447     9.1457  0.0000
         Fruit.CR  0.2064  0.0446     4.6296  0.0000
          Eggs.CR  0.0749  0.0449     1.6689  0.0977

Residual standard error: 0.5022 on 121 degrees of freedom
Multiple R-Squared: 0.7634
F-statistic: 48.8 on 8 and 121 degrees of freedom, the p-value
is 0
```

Where:

"Value" = The standardized regression coefficient for that parameter. The standardized regression coefficient is a measure of how important that parameter is to the predictive ability of the final model. The larger the absolute value of standardized regression coefficient, the more important that parameter is to strength of the model. Negative values indicate a negative correlation with the output

(dependent) variable (i.e., increasing the value of the input parameter causes the value of the output variable to decrease).

"Std. Error" = The standard error of the regression coefficient.

"t value" = Another measure of the whether a parameter is significant. The larger the absolute value of "t", the greater the significance of that parameter to the model.

"Pr(>|t|)"= The probability of getting the observed statistic (the "t value") or something more extreme by chance alone. Generally, when this value is about 0.05 or less, it is concluded that the corresponding "t value" is large enough to indicate a real effect. That is, the results are not due to chance or random data.

"(Intercept)" The point at the origin for all x-axes where the linear relationship modeled by the regression analysis intercepts the y-axis.

As stated previously, the goal is to identify the fewest parameters that explain the greatest proportion of the variance in the BDCFs. In other words, to maximize the amount of variance in the BDCF accounted for and to minimize the amount of variance in the BDCF not explained by the regression model. One way to evaluate how well the final regression model meets this goal is to look at the "Multiple R-Squared". The value of Multiple R-Squared is equal to the BDCF variance accounted for by the final model divided by the total BDCF variance. In the Pa-231 example, 0.7634 (76.3%) of the variance in the BDCF was accounted for by the parameters included in the final model.

The "F-statistic" is another measure of the success of the regression modeling. If the F-statistic equals 1, the model accounts for essentially none of the BDCF variance. A value increasingly greater than 1 indicates that the model is successful in accounting for larger and larger portions of the variance. The "p-value" is the probability of getting the observed "F-statistic", or something more extreme, by chance alone. In the Pa-231 example above, the F-statistic is 48.8, suggesting that the final model successfully accounts for a significant portion of the total variance in the BDCF. The p-value is given as zero, suggesting that the F-statistic value is "real" and not a result of chance or random data. (Note: The p-value is not truly zero, just very small). Additional information on the statistical terms used to represent the results of the stepwise linear regression analysis can be found in the S-PLUS Guide to Statistics (MathSoft 1999b).

Having concluded that the regression process produced a "good" model, one way to determine which parameters are important is to determine which have standardized regression coefficients that are significantly greater than zero. Since the input variables were standardized using the Z-score transformation, the regression coefficients are standardized also and their magnitudes may be directly compared. This would not be the case if the parameters were not standardized, since the unit of measure would largely determine the magnitude of the coefficient. Since, in the Pa-231 example (listed above), soil-plant transfer factor has the highest absolute coefficient, it is appropriate to conclude that soil-plant transfer factor is the most important parameter. Also note that the coefficient for leafy vegetable consumption rate is roughly twice that of the fruit

consumption rate. This means that leafy vegetable consumption rate is roughly twice as important fruit consumption rate in predicting the BDCF.

Each parameter listed in the final regression model has a t-value and corresponding p-value (listed as "`Pr(>|t|)`") associated with it. The t-value is another measure of whether a parameter is significant. The larger the value of "t", the greater the significance of that parameter to the model. The p-value represents the probability of getting the observed t-value or something more extreme by chance alone. If the t-value is much different than zero, the parameter is making an "important" contribution to the model. If the p-value is < 0.05, then the observed t-value is probably "real" and is not a chance occurrence. In the Pa-231 example, all parameters have a p-value less than 0.05 except for egg consumption rate. Note that the absolute value of the regression coefficient for that parameter is comparatively small.

If the GENII-S model were rerun with a different seed value(e.g., numeric value that serves as the starting point for the LHS process), different parameter values would be selected in each of the 130 realizations. As a consequence, rerunning the regression model might give different results. While the new regression model would have different parameter values in it, it is likely that the parameters contained in the final regression models would have similar values for the regression coefficients. In order to determine how "stable" or "robust" each regression coefficient is, the standard error should be reviewed. The standard error of the regression coefficient reflects how much the coefficient would likely vary if the regression were repeated multiple times. In the Pa-231 example, most of the standard errors are small with respect to the magnitude of the coefficient, indicating that they are relatively stable.

6.3.2 Sensitivity to Input Parameters

The results of the regression analyses indicate that a small subset of input parameters consistently explains most of the variation in the radionuclide-specific BDCFs. A minimum of 6 and maximum of 16 parameters were included in the final regression model for any radionuclide (see S-PLUS output files listed in Attachment I).

The ability of the statistical analysis to distinguish between parameters, which are minor contributors to the BDCF variance, is limited. However, the standardized regression coefficient for each parameter is a direct indicator of the relative importance of that parameter to the predictive ability of the final model. The strongest indicated correlation's (that is, the largest absolute values of standardized regression coefficients) are consistent with the conceptual exposure model. In other words, the top few parameters in each final model tend to be associated with the dominant exposure pathways and processes for the particular radionuclide.

Although 6 to 16 parameters were included in the final regression models, the standardized regression coefficient values indicate that a much smaller number of parameters (usually two or three) have the most influence on the variation in the BDCF values. Parameters with small standardized regression coefficients are judged to be insignificant contributors to the variation in the BDCF values and may even represent outliers in the data sets used to conduct the sensitivity analysis. For example, drinking water consumption rate shows a weak positive correlation with BDCF variability for most radionuclides even though the drinking water consumption exposure pathway was turned off in the GENII-S simulation. In that case, the set of 130 drinking water

consumption rates generated by GENII-S was observed to be somewhat skewed, giving indication of a weak correlation where in fact, none exists.

Some key observations on these correlation's are:

- The soil-plant transfer factor was the most significant contributor to variance in the BCDF for all but two radionuclides, and for those (Cs-137 and Th-229) it was the second-ranked contributor. This correlation is consistent with a strong contribution from the soil-plant-ingestion pathway.

- Mass loading (of dust in the ambient air) is a significant contributor to BCDF variance for a number of alpha-emitting radionuclides. This appears consistent with an important contribution from inhalation, as might be expected if people are living in an agricultural area with contaminated soil.

- Soil exposure (the hours per year that a person is exposed to the contaminated soil surface) is the most significant contributor to BDCF variance for Cs-137 and the third ranking contributor for two other radionuclides. This correlation is consistent with an important contribution from direct external gamma radiation.

- Consumption rates for leafy vegetables, root vegetables and fruits are important contributors to BDCF variance for many radionuclides. This is consistent with the previously described correlation for soil-plant transfer factor and a strong contribution from the soil-plant-ingestion pathway.

- Beef consumption rate is the second leading contributor to BDCF variance for Sr-90 and is ranked third for Cs-137. The importance of beef as a contributor is consistent with the movement and concentration characteristics of Sr and Cs in plants and animals.

These contributions to the BDCF variances are consistent with key exposure pathways that involve uptake of radioactive material from the soil by crops with subsequent human ingestion of the crops and meat, inhalation of dust raised from the contaminated soil, and external exposure. The results of this analysis suggest that the BDCF uncertainty for all radionuclides of interest can be reduced by refining the soil-plant transfer factors for fruits and vegetables that are actually grown in the Amargosa valley for local consumption. Improving the estimates of long-term air particulate mass loading in an agricultural area that has received volcanic ashfall might reduce BDCF uncertainty for several radionuclides, as should narrowing the range of consumption rates for locally grown fruits and vegetables.

The parameters that contribute most significantly to BDCF variance for each radionuclide are summarized in Table 3.

Table 3. Listing of Parameters That Are Major Contributors to BDCF Variance*

	^{90}Sr	^{137}Cs	^{227}Ac	^{229}Th	^{231}Pa	^{232}U	^{233}U	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Am	^{243}Am
Soil-plant Transfer Factor	1	2	1	2	1	1	1	1	1	1	1	1
Mass Loading			2	1				2	2	2		
Soil Exposure		1										
Leafy Vegetable Consump. Rate			3	3	2						2	2
Root Vegetable Consump. Rate	3					2	2					
Fruit Consump. Rate					3	3	3	3	3	3	3	3
Beef Consump. Rate	2	3										

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* Numbers indicate ranking as contributor to BDCF variance for each radionuclide.

Parameters that were not important to the BDCF variation for any radionuclide or only of minor importance to a few include:

- Crop interception factor
- Growing times for vegetables, grain, fruits, beef and milk.
- Fruit and vegetable crop yields.
- Consumption rates for poultry, milk and grain.
- Yields for milk, eggs, poultry, fruit and vegetables.

6.3.3 Sensitivity to Pathway

To determine the contributions of different exposure pathways to the BDCF values, a single GENII-S deterministic simulation was performed for each radionuclide. In this deterministic simulation, a "best estimate" value, as indicated in Table 2, was used for each of the 39 input parameters that had been specified as distributions for purposes of the input parameter sensitivity analysis described in the previous section.

The following exposure pathways were considered:

- Ingestion
  - Consumption of locally produced leafy vegetables
  - Consumption of other (root) locally produced vegetables
  - Consumption of locally produced fruit
  - Consumption of locally produced grain

- Consumption of locally produced meat (beef and pork)
- Consumption of locally produced poultry
- Consumption of locally produced milk
- Consumption of locally produced eggs
- Inadvertent soil ingestion

- Inhalation of resuspended particulate matter
- External exposure to contaminated soil

For the disruptive (volcanic) case, inadvertent soil ingestion is the dominant pathway and inhalation is an important contributor to the BDCF for isotopes of Ac, Am, Pa and Pu. For Th-229, the inhalation and soil ingestion pathways are approximately of equal importance, with lesser contributions from external exposure and food ingestion. For Sr-90 and isotopes of uranium, ingestion of vegetables and fruits is the dominant pathway. However, inadvertent soil ingestion and inhalation are also significant contributors for uranium. External exposure is the dominant pathway for Cs-137, which emits a relatively high-energy gamma, with a minor contribution from ingestion of fruit, vegetables and meat.

The exposure pathway contributions to the BDCFs for the radionuclides of interest are summarized in Table 4. For all nuclides the contributions due to ingestion from the poultry and grain consumption pathways were small and have been combined in the column labeled "other".

Table 4. Contributions by Pathway to BDCFs (in percent)*

Radionuclide	External Exposure	Inhalation	Ingestion							
			Soil Ingestion	Leafy Veg.	Other Veg.	Fruit	Meat	Eggs	Milk	Other
Ac-227		37	45	13		2				2
Am-241	4	13	64	11	3	4				
Am-243	11	12	59	10	3	4				
Cs-137	82			3	1	9	4			1
Pa-231	5	13	64	13	2	3				
Pu-238		16	77	3	2	2				
Pu-239		16	77	3	2	2				
Pu-240		16	77	3	2	2				
Sr-90				42	35	9	10		2	2
Th-229	15	37	35	12						2
U-232		18	21	15	31	13				2
U-233		17	21	15	31	13				3

MO0003SPAPAT04.006

* Totals may not equal 100% because of rounding errors.

The disruptive event BDCFs were calculated using a lognormal distribution of mass loading values with a minimum of 7.4E-7 g/m^3 (0.74 μg/m^3), a maximum of 6.4E-5 g/m^3 (64 μg/m^3), and a mean value of 8.7E-6 g/m^3 (8.7 μg/m^3) (see Table 2). Because of the significance of the inhalation pathway to most BDCF values and the wide variation in air particulate mass loading that may occur in an agricultural area affected by volcanic ashfall, some consideration needs to be given here to the impact on BDCF values of increasing the assumed levels of respirable particulate matter.

As illustrated by measurements of Total Suspended Particulate (TSP) made in areas of eastern Washington State following the May 1980 eruption of Mount St. Helens, it is possible that air mass loading in the days and weeks following a volcanic eruption could far exceed the values used in the BDCF calculations. In the city of Yakima, some 135 km from the mountain, measurements during the 5 days following the eruption yielded 24-hour average TSP concentrations ranging from 5,800 to 13,000 $\mu g/m^3$. These measurements represent conditions during the relatively short period (i.e., days) of actual ashfall and ensuing high levels of resuspension due to wind, traffic, and ash removal efforts. The TSP levels dropped rapidly after the first rainfall, but continued to be in the range of 50 – 250 $\mu g/m^3$ for some weeks. Greater than 90% of the particles in some samples were in the respirable size range (Bernstein, et. al, 1986). Over the ensuing weeks and months, measurements of respirable dusts gave mean concentrations of 30 to 100 $\mu g/m^3$ in homes, schools and commercial establishments. Breathing zone sampling on workers in various occupations produced mean values in the range of 200 to 700 $\mu g/m^3$ with transient exposures to certain categories of workers (principally loggers and agricultural workers) exceeding 800 $\mu g/m^3$ in heavy ashfall areas during dry weather (Buist, et.al, 1986).

Based on the measurement values and conditions discussed in the references, two levels of high air particulate mass loading are postulated (100 $\mu g/m^3$ and 800 $\mu g/m^3$) and the effects on the calculated BDCF values examined here. The first value, (100 $\mu g/m^3$) is a factor of 11.5 times the mean mass loading value used in the BDCF calculations. It corresponds to the higher of the reported measurements taken in non-occupational settings during the post-eruption period. The second value (800 $\mu g/m^3$) corresponds to the highest measured values for all but the most extreme occupational exposure conditions. It is a factor 92 times the mean mass loading value used in the BDCF calculations. To simplify the assessment of impact on BDCF values, these postulated conditions will be approximated as factors of 10 ("elevated" case) and 100 ("extreme" case) above the mean mass loading value used in the BDCF calculations.

Assuming the radioactivity ejected from the repository is uniformly distributed throughout the respirable ash particles, increasing the air mass loading by a factor of 10 or 100 will produce a proportionate increase in the inhalation pathway component of the BDCF. This assumption is believed to be quite conservative. The increased mass loading is assumed throughout the year. If the airborne material includes a significant fraction of larger, non-respirable particles, the BDCFs would be lower because larger particles are more likely to be trapped in the upper airways, from which they are typically removed by the mucocilliary clearance process, swallowed and excreted via the gastrointestinal tract. Because the inhalation dose factors exceed the ingestion dose factors by 1–3 orders of magnitude for all radionuclides of interest except Cs-137 (for which the two dose factors are approximately equal), the assumption of 100% respirable particles is conservative (Leigh 1993).

Table 5 shows the approximate factors by which the disruptive BDCF values would need to be multiplied to reflect the hypothetical factor of 10 and 100 increases in the airborne mass loading discussed above. The references cited above make it clear that air mass loading may far exceed even the postulated "extreme" level during and shortly after heavy ashfall. However, it is plausible that warnings issued by public health officials, together with the natural tendency of people to avoid exposure to high levels of dust would have the effect of limiting the integrated

exposure to receptors of interest during periods of ashfall and maximum resuspension. In the aftermath of the Mount St. Helens ashfall, concern over the health effects of ash inhalation caused public health officials to issue numerous warnings and advisories on how to avoid or minimize ash inhalation.

Table 5. BDCF Multipliers to Approximate Effects of Higher Air Mass Loading Assumption

Radionuclide	Fraction of BDCF From Inhalation	BDCF Multiplier for "Elevated" Air Mass Loading (times 10)	BDCF Multiplier for "Extreme" Air Mass Loading (times 100)
Ac-227	0.37	4.3	37.6
Am-241	0.13	2.2	13.9
Am-243	0.12	2.1	12.9
Cs-137	<0.001	~1	~1
Pa-231	0.13	2.2	13.9
Pu-238	0.16	2.4	16.8
Pu-239	0.16	2.4	16.8
Pu-240	0.16	2.4	16.8
Sr-90	<0.001	~1	~1
Th-229	0.37	4.3	37.6
U-232	0.18	2.6	18.8
U-233	0.17	2.6	17.8

If other exposure conditions involving increased mass loading are hypothesized (for example, exposure during an ashfall) an increase in the inhalation pathway component of the BDCF will result. The factor by which the inhalation component of the BDCF increases during the period of exposure is approximately equal to the product of (1) the inhalation component of the BDCF, (2) the ratio of the increased mass loading to the mean mass loading value used in the BDCF calculations, and (3) the fraction of a year that people are assumed to breath air with the increased mass loading.

7. CONCLUSIONS

Although the number of parameters included in the final regression models for the different radionuclides ranged from 6 to 16 (see S-PLUS output files listed in Attachment I), the standardized regression coefficient values indicate that a much smaller number of parameters (usually two or three) are responsible for most of the variation in the BDCF values.

The soil-plant transfer factor was the most significant contributor to variance in the BCDF for all but two radionuclides, and for those (Cs-137 and Th-229) it was the second-ranked contributor. Mass loading (of dust in the ambient air) is a significant contributor to BCDF variance for a number of alpha-emitting radionuclides. Soil exposure (the hours per year that a person is exposed to the contaminated soil surface) is the most significant contributor to BDCF variance for Cs-137 and the second or third ranking contributor for several other radionuclides that emit gamma radiation. Consumption rates for leafy vegetables, root vegetables and fruits are important contributors to BDCF variance for many radionuclides. Beef consumption rate is the second leading contributor to BDCF variance for Sr-90 and is ranked third for Cs-137.

Parameters that were not important to the BDCF variation for any radionuclide or only of minor importance to a few include: growing times for vegetables, grain, fruits, beef and milk; fruit and vegetable crop yields; irrigation rates and irrigation times; consumption rates for poultry, milk and grain; and yields for milk, eggs, poultry, fruit and vegetables.

Soil ingestion is the dominant pathway and inhalation is an important contributor to the BDCF for isotopes of Ac, Am, Pa and Pu. For Th-229, the inhalation and soil ingestion pathways are approximately of equal importance, with lesser contributions from external exposure and food ingestion. For Sr-90 and isotopes of uranium, ingestion of vegetables and fruits is the dominant pathway, although soil ingestion and inhalation are also significant contributors for uranium. External exposure is the dominant pathway for Cs-137, which emits a relatively high-energy gamma, with a minor contribution from ingestion of fruit, vegetables and meat.

The parameter and pathway sensitivity analyses suggest several possibilities for improving the BDCF estimates and reducing uncertainty.

- Inadvertent soil ingestion, which was taken as a fixed value of 50 mg/day for purposes of this analysis, contributes a major fraction of the BDCF value for many radionuclides of interest. Refinement of the soil ingestion rate estimate may have a significant impact on the BDCF values.

- Refinement of soil-plant transfer factors and consumption rates for fruits and vegetables that are actually grown in the Amargosa Valley for local consumption should have a significant influence on the BDCF uncertainty for most radionuclides listed in Table 3.

- Improving the estimates of long-term air particulate mass loading in an arid agricultural area that has received volcanic ashfall should reduce the BDCF uncertainty for several radionuclides listed in Table 3.

The results of this analysis apply to radionuclides specified in preliminary screening analysis (CRWMS M&O 1999f), which is subject to potential modifications. Upon receipt of the final results of radionuclide screening, this report may need to be revised. The inputs to this analysis have been obtained from several other AMRs, revisions to these AMRs may effect some of the inputs used in this analysis, resulting in the need for a revision to this AMR.

The conclusions of this sensitivity analysis are applicable to the biosphere model when input parameters are approximately represented by the range of values given in this report. Significant changes in parametric values may alter the results presented here and will require re-evaluation or recalculation.

8. INPUTS AND REFERENCES

8.1 INPUTS

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ATTACHMENTS

Attachment	Title
I	List of Analysis Input and Output Files
II	Information on Use of Software

ATTACHMENT I

LIST OF ANALYSIS INPUT AND OUTPUT FILES

(6 pages and CD-ROM)

LIST OF FILES PROVIDED ON CD-ROM

GENII-S Input and Out Files for Stochastic Runs
..\DE Sensitivity\Stochastic Data

ROOT NAME	FILE EXTENSION	FILE SIZE	DATE	TIME
RR4AC227	.FLG	795	1/18/00	06:20p
RR4AC227	.INP	21,151	1/18/00	06:20p
RR4AC227	.OUT	832	1/18/00	06:23p
RR4AC227	.PTI	14,447	1/18/00	06:23p
RR4AC227	.SUM	134,785	1/18/00	06:24p
RR4AC227	.VEC	234,000	1/18/00	06:23p
RR4AM241	.FLG	795	1/18/00	06:26p
RR4AM241	.INP	21,151	1/18/00	06:26p
RR4AM241	.OUT	888	1/18/00	06:29p
RR4AM241	.PTI	14,447	1/18/00	06:29p
RR4AM241	.SUM	134,785	1/18/00	06:29p
RR4AM241	.VEC	234,000	1/18/00	06:29p
RR4AM243	.FLG	795	1/18/00	06:31p
RR4AM243	.INP	21,151	1/18/00	06:31p
RR4AM243	.OUT	832	1/18/00	06:33p
RR4AM243	.PTI	14,447	1/18/00	06:33p
RR4AM243	.SUM	134,785	1/18/00	06:33p
RR4AM243	.VEC	234,000	1/18/00	06:33p
RR4CS137	.FLG	712	2/9/00	02:06p
RR4CS137	.INP	14,260	2/9/00	02:06p
RR4CS137	.OUT	832	2/9/00	02:07p
RR4CS137	.PTI	7,397	2/9/00	02:07p
RR4CS137	.SUM	134,785	2/9/00	02:07p
RR4CS137	.VEC	49,200	2/9/00	02:07p
RR4PA231	.FLG	712	2/9/00	02:04p
RR4PA231	.INP	14,260	2/9/00	02:04p
RR4PA231	.OUT	832	2/9/00	02:05p
RR4PA231	.PTI	7,397	2/9/00	02:05p
RR4PA231	.SUM	134,785	2/9/00	02:06p
RR4PA231	.VEC	49,200	2/9/00	02:05p
RR4PU238	.FLG	712	2/9/00	02:08p
RR4PU238	.INP	14,260	2/9/00	02:08p
RR4PU238	.OUT	832	2/9/00	02:08p
RR4PU238	.PTI	7,397	2/9/00	02:08p
RR4PU238	.SUM	134,785	2/9/00	02:09p
RR4PU238	.VEC	49,200	2/9/00	02:08p

RR4PU239	.FLG	712	2/9/00	02:09p
RR4PU239	.INP	14,260	2/9/00	02:09p
RR4PU239	.OUT	832	2/9/00	02:10p
RR4PU239	.PTI	7,397	2/9/00	02:10p
RR4PU239	.SUM	134,785	2/9/00	02:10p
RR4PU239	.VEC	49,200	2/9/00	02:10p
RR4PU240	.FLG	712	2/9/00	02:10p
RR4PU240	.INP	14,260	2/9/00	02:11p
RR4PU240	.OUT	832	2/9/00	02:11p
RR4PU240	.PTI	7,397	2/9/00	02:11p
RR4PU240	.SUM	134,785	2/9/00	02:11p
RR4PU240	.VEC	49,200	2/9/00	02:11p
RR4SR90.	FLG	711	2/9/00	02:12p
RR4SR90.	INP	14,260	2/9/00	02:13p
RR4SR90.	OUT	832	2/9/00	02:14p
RR4SR90.	PTI	7,397	2/9/00	02:14p
RR4SR90.	SUM	134,784	2/9/00	02:14p
RR4SR90.	VEC	49,200	2/9/00	02:14p
RR4TH229	.FLG	712	2/9/00	02:17p
RR4TH229	.INP	14,260	2/9/00	02:17p
RR4TH229	.OUT	832	2/9/00	02:17p
RR4TH229	.PTI	7,397	2/9/00	02:17p
RR4TH229	.SUM	134,785	2/9/00	02:18p
RR4TH229	.VEC	49,200	2/9/00	02:17p
RR4U232.	FLG	795	1/18/00	07:05p
RR4U232.	INP	21,151	1/18/00	07:05p
RR4U232.	OUT	1,000	1/18/00	07:09p
RR4U232.	PTI	14,447	1/18/00	07:09p
RR4U232.	SUM	134,784	1/18/00	07:10p
RR4U232.	VEC	234,000	1/18/00	07:09p
RR4U233.	FLG	795	1/18/00	07:11p
RR4U233.	INP	21,151	1/18/00	07:11p
RR4U233.	OUT	832	1/18/00	07:14p
RR4U233.	PTI	14,447	1/18/00	07:14p
RR4U233.	SUM	134,784	1/18/00	07:14p
RR4U233.	VEC	234,000	1/18/00	07:14p

GENII-S Input and Out Files for Deterministic Runs
..\DE Sensitivity\Deterministic Data

ROOT NAME	FILE EXTENSION	FILE SIZE	DATE	TIME
PWAC227	.FLG	664	1/25/00	12:23p
PWAC227	.INP	6,312	1/25/00	12:23p
PWAC227	.OUT	16,345	1/25/00	12:23p
PWAC227	.PTI	1,311	1/25/00	12:23p
PWAC227	.VEC	3,132	1/25/00	12:23p
PWAM241	.FLG	664	1/25/00	12:31p
PWAM241	.INP	6,312	1/25/00	12:31p
PWAM241	.OUT	16,513	1/25/00	12:31p
PWAM241	.PTI	1,311	1/25/00	12:31p
PWAM241	.VEC	3,132	1/25/00	12:31p
PWAM243	.FLG	664	1/25/00	12:32p
PWAM243	.INP	6,312	1/25/00	12:32p
PWAM243	.OUT	16,272	1/25/00	12:33p
PWAM243	.PTI	1,311	1/25/00	12:33p
PWAM243	.VEC	3,132	1/25/00	12:33p
PWCS137	.FLG	664	2/9/00	02:45p
PWCS137	.INP	6,312	2/9/00	02:45p
PWCS137	.OUT	14,804	2/9/00	02:45p
PWCS137	.PTI	1,311	2/9/00	02:45p
PWCS137	.VEC	3,132	2/9/00	02:45p
PWPA231	.FLG	664	2/9/00	02:46p
PWPA231	.INP	6,312	2/9/00	02:46p
PWPA231	.OUT	16,530	2/9/00	02:47p
PWPA231	.PTI	1,311	2/9/00	02:47p
PWPA231	.VEC	3,132	2/9/00	02:47p
PWPU238	.FLG	664	2/9/00	02:47p
PWPU238	.INP	6,312	2/9/00	02:47p
PWPU238	.OUT	16,311	2/9/00	02:47p
PWPU238	.PTI	1,311	2/9/00	02:47p
PWPU238	.VEC	3,132	2/9/00	02:47p
PWPU239	.FLG	664	2/9/00	02:47p
PWPU239	.INP	6,312	2/9/00	02:47p
PWPU239	.OUT	14,974	2/9/00	02:48p
PWPU239	.PTI	1,311	2/9/00	02:48p
PWPU239	.VEC	3,132	2/9/00	02:48p
PWPU240	.FLG	664	2/9/00	02:48p
PWPU240	.INP	6,312	2/9/00	02:48p
PWPU240	.OUT	16,311	2/9/00	02:48p
PWPU240	.PTI	1,311	2/9/00	02:48p

PWPU240	.VEC	3,132	2/9/00	02:48p
PWSR90.	FLG	663	2/9/00	02:48p
PWSR90.	INP	6,312	2/9/00	02:48p
PWSR90.	OUT	16,199	2/9/00	02:49p
PWSR90.	PTI	1,311	2/9/00	02:49p
PWSR90.	VEC	3,132	2/9/00	02:49p
PWTH229	.FLG	664	2/9/00	02:50p
PWTH229	.INP	6,312	2/9/00	02:50p
PWTH229	.OUT	16,272	2/9/00	02:50p
PWTH229	.PTI	1,311	2/9/00	02:50p
PWTH229	.VEC	3,132	2/9/00	02:50p
PWU232.	FLG	664	1/25/00	12:26p
PWU232.	INP	6,312	1/25/00	12:26p
PWU232.	OUT	16,917	1/25/00	12:26p
PWU232.	PTI	1,311	1/25/00	12:26p
PWU232.	VEC	3,132	1/25/00	12:26p
PWU233.	FLG	664	1/25/00	12:27p
PWU233.	INP	6,312	1/25/00	12:27p
PWU233.	OUT	16,457	1/25/00	12:27p
PWU233.	PTI	1,311	1/25/00	12:27p
PWU233.	VEC	3,132	1/25/00	12:27p

Regression analysis output files from S PLUS Professional.
..\DE Sensitivity\S+ Output

ROOT NAME	FILE EXTENSION	FILE SIZE	DATE	TIME
DE Ac227	.srp	120,832	2/9/00	04:16p
DE Am241	.srp	112,640	2/9/00	04:18p
DE Am243	.srp	112,640	2/9/00	04:19p
DE Cs137	.srp	100,352	2/9/00	04:13p
DE Pa231	.srp	117,760	2/9/00	04:14p
DE Pu238	.srp	109,568	2/9/00	04:20p
DE Pu239	.srp	109,568	2/9/00	04:21p
DE Pu240	.srp	109,568	2/9/00	04:22p
DE Sr90.	srp	94,720	2/9/00	04:12p
DE Th229	.srp	117,760	2/9/00	04:23p
DE U232.	srp	100,352	2/9/00	04:25p
DE U233.	srp	100,352	2/9/00	04:26p

Results of S-PLUS Validation tests
..\S-PLUS Validation

ROOT NAME	FILE EXTENSION	FILE SIZE	DATE	TIME
Regression Validation	.txt	25,098	2/24/00	12:53p

Software routine *Pathway Contribution, Rev. 0*
..\DE Sensitivity\Pathway

ROOT NAME	FILE EXTENSION	FILE SIZE	DATE	TIME
DE PATH	.XLS	161,280	2/9/00	04:07p

Software routine *Z-score Transformation, Rev. 0*
..\DE Sensitivity\Z-score

ROOT NAME	FILE EXTENSION	FILE SIZE	DATE	TIME
DE Z-score	.XLS	357,376	3/9/00	09:52p

ATTACHMENT II

DOCUMENTATION FOR SOFTWARE ROUTINES

(9 pages)

INTRODUCTION

As indicated in Section 3, a commercial statistical package and two spreadsheet applications were used in the performance of the analyses discussed in Section 6. These applications have been designated as "software routines" per AP-SI.1Q Rev. 2 ICN 4, *Software Management*, and are subject to the documentation requirements of Section 5.1.1, Control of Software Routines and Macros Single Use, of that procedure. This attachment provides the documentation required by the referenced procedure.

Two routines are used in performing the stepwise linear regression analysis and one is used in determining the contribution to the BDCFs from each pathway. Microsoft Excel 97 was used to create the routines titled *Z-score Transformation, Rev. 0* and *Pathway Contribution, Rev. 0.* These files are listed in Attachment II and are included on the accompanying CD ROM.

STEPWISE LINEAR REGRESSION ANALYSIS

There are two main operations involved with performing the stepwise linear regression. The first is to prepare the raw data from the GENII-S output file by performing a Z-score transformation using the software routine titled *Z-score Transformation, Rev. 0.* The second is to import the data into the statistical software and execute the software routine titled *Stepwise Linear Regression, Rev. 0.* The following describes the steps necessary to set up and operate each routine.

Z-score Transformation, Rev. 0

Set-up and Operation of Software Routine;

To assist the reader in understanding the set-up and operation of the routine an example of the spreadsheet within which the routine is run is included as Figure 2 below. Due to the size of the spreadsheet only a portion of the data is represented in the example. (Note: This is an example only, the values do not match those found in the file contained on the CD ROM.)

1. Obtain the raw data from the GENII-S ASCII output file by blocking and copying the columns containing the 130 realization values for the 39 input variables and the one column containing the 130 BDCF results. Note: Because the seed value for the LHS is a fixed, the parameter values selected for each of the 130 realizations are the same for each nuclide. Therefore, only one set of parameter values needs to be entered into the spreadsheet. The single set of parameter values is contained in Block #1 in the example and the BDCF values for each nuclide are contained in Block #3 in the example.

2. Paste the data into the spreadsheet and use the "Text to columns" submenu item under "Data" from the tool bar to arrange the data into individual cells. (Blocks #1 and #3 in the example.)

3. Use the built-in function for calculating the arithmetic mean (AVERAGE), calculate the mean value for each set of input parameters and the BDCFs.

4. Use the built-in standard deviation function (STDEV), calculate the standard deviation for each set of input parameters and the BDCFs.

5. Calculate the Z-score transformation for the 130 realization values for each input parameter and the BDCFs by subtracting the average for a specific variable from each realization value and dividing the result by the standard deviation for that variable. This calculation is performed in Blocks #2 and #4 in the example.

6. Before closing the file, for each column containing raw data(i.e., data imported from the GENII-S output file and not yet transformed) modify the column header (i.e., Mass. Load, U-238, etc.) to differentiate it from the Z-transformed column with the same heading. When this file is imported in to S-PLUS 2000 to perform the *Stepwise Linear Regression* routine, the software will use the column header as a data label and it does not allow duplicate labels.

Confirmation Of Correct Operation

To verify that the transformation has been performed correctly, calculate the arithmetic mean and standard deviation again for the transformed data. If the transformation is correct, the mean values should be very close to zero and the standard deviation should equal one.

Figure 2. Example of "Z-score Transformation" Routine

	Block #1				Block #2				Block #3				Block #4			
	Raw Input Parameter Values From GENII-S Output				Transformed Parameter Values				Raw BDCF Values From GENII-S Output				Transformed BDCF Values			
Number of Trials	Soil/Plant Trans	Animal Uptake	Inhal Expos	(Plus 36 more)	Soil/Plant Trans	Animal Uptake	Inhal Expos	(Plus 36 more)	Ac227	Am241	Am243	(Plus 9 more)	Ac227	Am241	Am243	(Plus 9 more)
1	5.62E-01	2.26E+00	4.43E+03	.....	1.76E-02	4.53E-03	4.52E-03	.....	1.76E-02	4.53E-03	4.52E-03	.....	-2.55E-02	-3.17E-02	-3.15E-02	.....
2	3.65E-01	1.44E-01	4.40E+03	.....	2.52E-02	6.49E-03	6.47E-03	.....	2.52E-02	6.49E-03	6.47E-03	.....	7.52E-01	7.53E-01	7.52E-01	.....
3	6.43E+00	2.48E+00	5.67E+03	.....	2.02E-02	5.22E-03	5.21E-03	.....	2.02E-02	5.22E-03	5.21E-03	.....	2.44E-01	2.45E-01	2.44E-01	.....
4	1.16E+01	2.57E+00	4.37E+03	.....	1.73E-02	4.46E-03	4.45E-03	.....	1.73E-02	4.46E-03	4.45E-03	.....	-5.65E-02	-6.04E-02	-6.04E-02	.....
5	3.01E+00	1.07E+00	5.32E+03	.....	2.21E-02	5.68E-03	5.67E-03	.....	2.21E-02	5.68E-03	5.67E-03	.....	4.37E-01	4.30E-01	4.31E-01	.....
.	.	.	.	.....	.	.	.	.....	.	.	.	.....	.	.	.	.....
.	.	.	.	.....	.	.	.	.....	.	.	.	.....	.	.	.	.....
.	.	.	.	.....	.	.	.	.....	.	.	.	.....	.	.	.	.....
126	7.88E-01	3.88E-01	4.12E+03	.....	2.05E-02	5.29E-03	5.28E-03	.....	2.05E-02	5.29E-03	5.28E-03	.....	2.74E-01	2.74E-01	2.73E-01	.....
127	1.16E+00	2.63E-01	4.47E+03	.....	1.99E-02	5.10E-03	5.09E-03	.....	1.99E-02	5.10E-03	5.09E-03	.....	2.05E-01	1.95E-01	1.96E-01	.....
128	8.47E-01	1.69E+00	5.28E+03	.....	2.11E-02	5.44E-03	5.43E-03	.....	2.11E-02	5.44E-03	5.43E-03	.....	3.34E-01	3.34E-01	3.34E-01	.....
129	8.64E-01	1.25E+00	4.50E+03	.....	4.72E-03	1.22E-03	1.21E-03	.....	4.72E-03	1.22E-03	1.21E-03	.....	-1.36E+00	-1.36E+00	-1.36E+00	.....
130	7.35E+00	8.46E-01	3.82E+03	.....	2.17E-02	5.59E-03	5.58E-03	.....	2.17E-02	5.59E-03	5.58E-03	.....	3.97E-01	3.95E-01	3.95E-01	.....
Arithmetic Mean	1.95E+00	1.27E+00	4.58E+03	.....	-3.40E-16	3.59E-16	-2.67E-15	.....	1.79E-02	4.61E-03	4.60E-03	.....	-5E-16	-1.7E-15	-2.5E-16	.....
Standard Deviation	3.03E+00	1.02E+00	6.34E+02	.....	1	1	1	.....	9.71E-03	2.50E-03	2.49E-03	.....	1	1	1	.....

Stepwise Linear Regression, Rev. 0

Set-up and Operation of Software Routine;

1. To import the data from *Z-score Transformation*; at the main menu select "File > Import Data > From File". When the "Import Data" dialog box opens select (Microsoft Excel Files (*.xls)) in the "Files of type" box. Navigate to the appropriate folder and select the name of the file. In the "Data Set" combo box of the "Import To" group, specify the data set to which you want to import the data. Click "Open".

2. With the data displayed in the S-PLUS Data Window, using the mouse, select the Z-score transformed column with the dependent variable (i.e., nuclide as header), and then, while holding down the control key (Ctrl), select the columns with Z-score transformed independent variables (i.e., input parameters). (Note: It is important to select the dependent value first.)

3. With the variables identified, on the main tool bar select the "Statistical > Regression > Stepwise". Click "OK" and the stepwise linear regression is performed on the data.

4. From the main menu select "File > Save As" to save the results as an ASCII file.

Confirmation Of Correct Operation

Information received from the manufactures technical support personnel (MathSoft, Inc.) indicates that the maximum value the software can process correctly is 1.797693E+308 and the minimum value is 2.225074E-308. This is the same precision that is achievable from any software package that uses double precision arithmetic and that runs on a 32-bit processor. From Table 2 it is seen that the range of input parameters is approximately from 9.6E-12 to 6.35E+03. The range of values specified by the manufacturer encompasses any input parameter range that could be considered for use in the biosphere model.

In order to check the accuracy of the S-PLUS algorithms and routines as they run on a specific computer, the software manufacturer has provided a special function called "validate" (MathSoft 1999a). This function draws upon a suite of tests, which refer to published examples of both typical and extreme data sets in a variety of statistical routines.

Steps to verify correct operation:

1. Open the Commands Window and enter "validate(file=c("regress"), verbose=T)".

2. Press "Enter" and the command executes.

3. The results are displayed in the bottom portion of the split window. Examine the end of the file to identify any problems detected or if all tests were passed.

An ASCII file, with file extension ",txt", containing the results is automatically created and written to the hard disk on which the software is installed. The file created when the tests were

performed for this installation is contained on the CD-ROM which accompanies this document. The file can be found in ..\Regression Validation. The results of this test were "All tests PASSED".

DETERMINATION OF PATHWAY CONTRIBUTION

A software routine, built into a Microsoft Excel spreadsheet, was used to automate the determination of contribution to the BDCF by each pathway. The routine is titled *Pathway Contribution, Rev. 0.*

Pathway Contribution, Rev. 0.

Set-up and Operation of Software Routine:

An example of the application is provided to assist the user in understanding the organization and function of the routine used to determine the contribution to the BDCF by each pathway. Figure 3 is a representation of the spreadsheet for Am-243. The spreadsheet has been divided into three areas (i.e., A, B and C) for ease of explanation.

All data imported from the GENII-S output files is obtained by blocking and copying the desired data and then pasting it into the appropriate section of the spreadsheet. Inserting the data into the spreadsheet is accomplished by using the "Paste" command and the "Text to columns" submenu item under "Data" from the tool bar to arrange the data into individual cells.

Area "A" is a table imported directly from the GENII-S output file which shows the contributions to the annual Effective Dose Equivalent from internal Effective Dose Equivalent (i.e., inhalation and ingestion) and the External Dose. GENII-S calculates internal Effective Dose Equivalent by multiplying the Committed Dose Equivalent to each organ times the weighting factor for that organ, then summing the weighted organ Dose Equivalents. The sum of the Internal Effective Dose Equivalent and the External Dose equals the Annual Effective Dose Equivalent.

The upper portion of area "B" is a table imported directly from the GENII-S output file. This table contains the Committed Dose Equivalent to each organ from each individual pathway. The totals at the bottom of the organ columns are the same as the values shown in the Committed Dose Equivalent column from the table shown in area "A". In order to determine the contribution by pathway to the Annual Effective Dose Equivalent it is necessary to calculate the weighted Dose Equivalent to each organ from each pathway. This is done by multiplying the values in the upper table by each organ's weighting factor. The results are contained in the table in the lower portion of area "B". The total contribution for each pathway is obtained by summing the weighted organ Dose Equivalents. The results are found in the lower right corner of area "B" under the column titled "Total".

In area "C" the totals for each pathway have been arranged from largest to smallest. The percentage contribution from the top 4-5 contributors have been calculated by dividing the pathway contribution by the Annual Effective Dose Equivalent and multiplying the result by 100.

Confirmation of Correct Operation:

The individual calculations have been spot checked with hand calculations to ensure that correct results are being produced. Also, as a spot check for each use of the routine, the total from the lower right hand corner of area "B" is compared to the "Internal Effective Dose Equivalent" value from the bottom of area "A". These values should be almost the same.

DC-BDCFs: Average 1x, Am-243

A

Organ	Committed Dose Equivalent	Weighting Factors	Weighted Dose Equivalent
Gonads	1.20E-10	2.50E-01	2.90E-11
Breast	7.20E-14	1.50E-01	1.10E-14
R Marrow	6.40E-10	1.20E-01	7.70E-11
Lung	9.50E-12	1.20E-01	1.10E-12
Thyroid	3.60E-14	3.00E-02	1.10E-15
Bone Sur	8.10E-09	3.00E-02	2.40E-10
Liver	1.50E-09	6.00E-02	8.80E-11
LL Int.	2.40E-11	6.00E-02	1.40E-12
UL Int.	7.60E-12	6.00E-02	4.50E-13
S Int.	1.40E-12	6.00E-02	8.40E-14
Stomach	5.70E-13	6.00E-02	3.40E-14
Internal Effective Dose Equivalent			4.40E-10
External Dose			5.60E-11
Annual Effective Dose Equivalent			5.00E-10

B

Committed Dose Equivalent by Exposure Pathway

Pathway	Lung	Stomach	S Int.	UL Int.	LL Int.	Bone Su	R Marro	Testes	Ovaries	Muscle	Thyroid	Liver	
Inhale	9.40E-12	9.80E-15	1.00E-14	1.70E-14	2.30E-14	1.10E-09	9.00E-11	1.60E-11	1.60E-11	9.30E-15	5.10E-15	2.00E-10	
Leaf Veg	1.20E-14	7.70E-14	1.90E-13	1.00E-12	3.20E-12	9.40E-10	7.40E-11	1.30E-11	1.30E-11	8.50E-15	4.20E-15	1.70E-10	
Oth. Veg	3.50E-15	2.70E-14	6.60E-14	3.50E-13	1.00E-12	2.70E-10	2.20E-11	3.90E-12	3.90E-12	2.70E-15	1.20E-15	4.90E-11	
Fruit	4.50E-15	3.40E-14	8.40E-14	4.40E-13	1.30E-12	3.50E-10	2.80E-11	5.00E-12	4.90E-12	3.40E-15	1.60E-15	6.30E-11	
Cereals	1.50E-16	1.20E-15	2.90E-15	1.50E-14	4.60E-14	1.20E-11	9.60E-13	1.70E-13	1.70E-13	1.20E-16	5.40E-17	2.20E-12	
Meat	6.30E-18	4.70E-17	1.20E-16	6.20E-16	1.90E-15	4.90E-13	3.90E-14	7.00E-15	6.90E-15	4.80E-18	2.20E-18	8.80E-14	
Poultry	1.90E-19	1.30E-18	3.40E-18	1.80E-17	5.40E-17	1.50E-14	1.20E-15	2.10E-16	2.10E-16	1.40E-19	6.60E-20	2.60E-15	
Cow Milk	7.10E-19	4.60E-18	1.20E-17	6.20E-17	1.90E-16	5.50E-14	4.40E-15	7.90E-16	7.80E-16	5.10E-19	2.50E-19	1.00E-14	
Eggs	1.00E-18	7.20E-18	1.80E-17	9.50E-17	2.90E-16	8.00E-14	6.40E-15	1.10E-15	1.10E-15	7.60E-19	3.60E-19	1.40E-14	
Soil Ing	6.90E-14	4.20E-13	1.00E-12	5.70E-12	1.80E-11	5.40E-09	4.30E-10	7.70E-11	7.60E-11	4.80E-14	2.40E-14	9.70E-10	
Total	9.50E-12	5.70E-13	1.40E-12	7.60E-12	2.40E-11	8.10E-09	6.40E-10	1.20E-10	1.10E-10	7.20E-14	3.60E-14	1.50E-09	
Weighting Factor	1.20E-01	6.00E-02	6.00E-02	6.00E-02	6.00E-02	3.00E-02	1.20E-01	2.50E-01		1.50E-01	3.00E-02	6.00E-02	
CEDE													Total
Inhale	1.13E-12	5.88E-16	6.00E-16	1.02E-15	1.38E-15	3.30E-11	1.08E-11	4.00E-12		1.40E-15	1.53E-16	1.20E-11	6.09E-11
Leaf Veg	1.44E-15	4.62E-15	1.14E-14	6.00E-14	1.92E-13	2.82E-11	8.88E-12	3.25E-12		1.28E-15	1.26E-16	1.02E-11	5.08E-11
Oth. Veg	4.20E-16	1.62E-15	3.96E-15	2.10E-14	6.00E-14	8.10E-12	2.64E-12	9.75E-13		4.05E-16	3.60E-17	2.94E-12	1.47E-11
Fruit	5.40E-16	2.04E-15	5.04E-15	2.64E-14	7.80E-14	1.05E-11	3.36E-12	1.25E-12		5.10E-16	4.80E-17	3.78E-12	1.90E-11
Cereals	1.80E-17	7.20E-17	1.74E-16	9.00E-16	2.76E-15	3.60E-13	1.15E-13	4.25E-14		1.80E-17	1.62E-18	1.32E-13	6.54E-13
Meat	7.56E-19	2.82E-18	7.20E-18	3.72E-17	1.14E-16	1.47E-14	4.68E-15	1.75E-15		7.20E-19	6.60E-20	5.28E-15	2.66E-14
Poultry	2.28E-20	7.80E-20	2.04E-19	1.08E-18	3.24E-18	4.50E-16	1.44E-16	5.25E-17		2.10E-20	1.98E-21	1.56E-16	8.07E-16
Cow Milk	8.52E-20	2.76E-19	7.20E-19	3.72E-18	1.14E-17	1.65E-15	5.28E-16	1.98E-16		7.65E-20	7.50E-21	6.00E-16	2.99E-15
Eggs	1.20E-19	4.32E-19	1.08E-18	5.70E-18	1.74E-17	2.40E-15	7.68E-16	2.75E-16		1.14E-19	1.08E-20	8.40E-16	4.31E-15
Soil Ing	8.28E-15	2.52E-14	6.00E-14	3.42E-13	1.08E-12	1.62E-10	5.16E-11	1.93E-11		7.20E-15	7.20E-16	5.82E-11	2.93E-10
Total	1.14E-12	3.42E-14	8.40E-14	4.56E-13	1.44E-12	2.43E-10	7.68E-11	3.00E-11		1.08E-14	1.08E-15	9.00E-11	4.39E-10

C

pathway	rem/yr	mrem/yr	Pathway	Mrem/yr	%
Soil Ing	2.93E-10	2.93E-07	Soil Ing	2.93E-07	59%
Inhale	6.09E-11	6.09E-08	Inhale	6.09E-08	12%
Ext Dose	5.60E-11	5.60E-08	Ext Dose	5.60E-08	11%
Leaf Veg	5.08E-11	5.08E-08	Leaf Veg	5.08E-08	10%
Fruit	1.90E-11	1.90E-08	Others	3.44E-08	7%
Oth. Veg	1.47E-11	1.47E-08			
Cereals	6.54E-13	6.54E-10			
Meat	2.66E-14	2.66E-11			
Eggs	4.31E-15	4.31E-12			
Cow Milk	2.99E-15	2.99E-12			
Poultry	8.07E-16	8.07E-13			
Total	4.95E-10	4.95E-07		4.95E-07	

Figure 3. Example of "Pathway Contribution" Routine

SOFTWARE AND HARDWARE

Software used:

Microsoft Excel 97
Microsoft Corporation
Redmond, WA

S-PLUS 2000, Release 1
Data Analysis Division
MathSoft, Inc.
Seattle, WA
Serial # WN55164

Locations of software installation and use:

SUM1/226D
1211 Town Center Dr
Las Vegas, NV 89144

SAIC
3250 Port of Benton Blvd.
Richland, WA 99352

Computers on which the software is installed and the operating system employed:

Richland, WA:
Compaq DeskPro
Serial # 6946 CR23 K829
Windows 98

Las Vegas:
Gateway 2000
CPU#111210
Microsoft NT