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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL COVER SHEET
Complete Only Applicable Items

1. QA: QA

Page: 1 of: 45

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 analyses 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
- [ ] Input to other Technical Products

Describe use:

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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL REVISION RECORD

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EXECUTIVE SUMMARY

The purpose of this Analysis/Model Report (AMR) is to determine the sensitivity of the calculated non-disruptive event (groundwater contamination) 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 non-disruptive event BDCF AMR (CRWMS M&O 2000d). However, in addition to the original 28 GENII-S input parameters specified as distributions (ranges) for the BDCF calculations, an additional twelve 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 twelve 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, fish and tap water. In all, 40 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.

Leafy vegetable consumption rate was the most significant contributor to variance in the BCDF for all radionuclides except carbon-14, technetium-99, and cesium-137. Drinking water consumption rate was the second most important contributor to variance for all the heavy elements, strontium-90, and iodine-129. Crop interception fraction was the third most important contributor for all radionuclides except carbon-14, technetium-99, and cesium-137. Milk consumption rate is the leading contributor to BDCF variance for technetium-99 and was also a significant factor for iodine-129. Fish consumption rate accounts for essentially all the BDCF variance for carbon-14 and is also the most important contributor for cesium-137. Soil-plant transfer factor is a significant contributor to BDCF variance only for technetium-99. Beef consumption rate is the second leading contributor to BDCF variance for cesium-137 and was also a significant factor for iodine-129 and strontium-90.

Inhalation and external exposure pathways are not significant contributors to the BDCF values. The ingestion pathway accounts for essentially the entire BDCF. For all radionuclides of interest except carbon-14 and cesium-137, ingestion of drinking water is the most important contributor to BDCFs, followed by ingestion of leafy vegetables. Together, consumption of drinking water and leafy vegetables account for 80 to 95 percent of the BDCF values for those radionuclides. Although consumption of drinking water and leafy vegetables are still the most important contributors to the BDCFs for strontium-90, technetium-99 and iodine-129, consumption of other vegetables, fruit, eggs, meat, and milk are more significant than for the heavy elements. For carbon-14, consumption of fish is by far the greatest single contributor. For cesium-137, fish consumption is the leading contributor to the BDCF, followed by consumption of drinking water, leafy vegetables and meat.

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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
OCRWM	Office of Civilian Radioactive Waste Management
LHS	Latin Hypercube Sampling
MC	Monte Carlo (Sampling)
RSS	residual sums of squares
SR	Site Recommendation
STD	Standard Deviation
TBD	To Be determined
TBV	To Be Verified
TEDE	Total Effective Dose Equivalent
TSP	Total suspended particulate
TSPA	Total System Performance Assessment
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
TSP	total suspended particulates
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 modeling 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 purpose of this Analysis/Model Report (AMR) is to provide a sensitivity analysis for the Non-disruptive 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 contributions 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 eighteen (18) radionuclides of interest (see Section 6.2) to provide radionuclide-specific insights. Only variable parameters (i.e., those GENII-S inputs identified 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 the Non-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. 0, 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

Sixteen radionuclides were identified by the Performance Assessment Operations Organization as relevant to groundwater contamination (non-disruptive events) (CRWMS M&O 1999f): Ac-227, Am-241, Am-243, C-14, I-129, Np-237, Pu-238, Pu-239, Pu-240, Tc-99, Th-229, U-232, U-233, U-234, U-236 and U-238. The same reference provides a list of nuclides of interest for the human intrusion scenario. This list and the list of nuclides of interest for groundwater contamination (non-disruptive events) differ by two nuclides, Cs-137 and Sr-90. In order that the sensitivity analysis be applicable to both the groundwater contamination (non-disruptive events) and the human intrusion scenario, Cs-137 and Sr-90 have been included in this analysis.

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: CRWM 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 that developed the BDCFs, *Non-disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000d). The following describes the assumptions applicable to this analysis. All assumptions listed below are used in Section 6.

An individual lives in the vicinity of Yucca Mountain and draws untreated ground water for drinking water supply. This individual also uses the ground water to irrigate crops and lawns and raise livestock. It is assumed that the groundwater is contaminated by various radionuclides, due to a failure in the repository containment system. As a result, this individual will be exposed to radiation resulting from ingestion of contaminated water, as well as locally produced food; inhalation of resuspended dust; and direct external exposure to contaminated soil. The BDCF is the radiation dose to this individual due to unit radionuclide concentration in groundwater for a radionuclide of interest. To account for exposure due to consumption of locally grown fish (e.g., local fish farm) surface water was also assumed to be contaminated with a unit radionuclide concentration. The ground and surface water concentration unit used for this analysis is pCi/L.

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).

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.

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.

This sensitivity analysis was performed using the initial zero prior irrigation time BDCFs. The validity of this approach is supported by the fact that sensitivity analysis realizations using data from BDCF calculations for longer irrigation times generally identified the same group of parameters as primary contributors to BDCF uncertainty. Although the realizations showed some changes in the relative rankings of individual parameters for some radionuclides, the same group of parameters tended to dominate BDCF uncertainty for all prior irrigation times. Therefore, the results of this sensitivity analysis are judged to be valid for the 10,000 year period of interest.

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.

Eighteen (18) 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 disruption (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 40 parameters, and the lower model was specified as "NULL" (i.e., contains no parameters).

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 (i.e., input 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 input parameters in accounting for the variance in the BDCF 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, the "best estimate" value (see Table 2) was used for each of the 40 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 *Non-disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000d).

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 conditions as described in *Non-disruptive Event Biosphere Dose Conversion Factor Analysis*, Sections 4 and 6 (CRWMS M&O 2000d). Eighteen radionuclides were identified as relevant for treatment in this sensitivity analysis (see Section 4.2): Ac-227, Am-241, Am-243, C-14, Cs-137, I-129, Np-237, Pu-238, Pu-239, Pu-240, Sr-90, Tc-99, Th-229, U-232, U-233, U-234, U-236 and U-238.

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, fish 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 twelve additional parameters identified above. Calculations for each radionuclide consisted of 130 realizations in which values for each of the 40 input parameters were selected randomly, using LHS. Thus, for each of the 18 radionuclides of interest, 130 sets of data were available for analysis. Each set contained the specific values of the 40 input variables used by GENII-S in that realization, plus the value of the output -- the BDCF calculated using those input values. A sample size of 130 was chosen because tests indicated this is close to the maximum size the GENII-S code could process. However, with 40 sampled parameters, the chosen sample size is well above the minimum sample size (~53) 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 40 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 18 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 *Non-disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000d). 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 RRS represents the stochastic case and RRP 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 BDCF.

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	<u>Scenario Options</u>						
	- Near-Field Scenario	Y	NA	NA	NA	NA	Assumptions
	- Population Dose	N	NA	NA	NA	NA	
	- Acute Release	N	NA	NA	NA	NA	
	<u>Transport Options</u>						
	- 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	
	<u>Exposure Pathway Options</u>						
	- 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	Y	NA	NA	NA	NA	
	- Aquatic Food Ingestion	Y	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	
	<u>Deterministic Output Options</u>						
	- Both Committed and Cumulative	N	NA	NA	NA	NA	Assumptions
	- EDE by Nuclide	N	NA	NA	NA	NA	
	- EDE by Pathway	N/Y	NA	NA	NA	NA	Y for det. runs
	<u>Run Options</u>						
	- 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	-	-	-	-	Varies for each run

Table 2. Continued

Menu(s)	Option/ Parameter, Unit	Selection	Values: Minimum	Values: Best Estimate	Values: Maximum	Distribution	Reference[a]/ Comments
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[e]	Input source #2
	- Animal Uptake Scale Factor, (-)	NA	0.117	--	8.51	Lognormal[e]	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: Minimum	Values: Best Estimate	Values: Maximum	Distribution	Reference[a]/ Comments
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[f]	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[e]	Input source #3
	- Transit Time to Rec. Site, hr	NA	--	0	--	Fixed	Parameters not used
	- Swimming Exposure Time, hr	NA	--	0	--	Fixed	Parameters not used
	- Boating Exposure Time, hr	NA	--	0	--	Fixed	Parameters not used
	- Shoreline Exposure Time, hr	NA	--	0	--	Fixed	Parameters not used
	- Type of Shoreline Index (1-4)	1	NA	NA	NA	NA	Parameters not used
	- H2O/Sediment Transfer1/m^2/yr	NA	--	0	--	Fixed	Parameters not used
	- Soil Exposure Time, hr	NA	206.75	827	3,947	Triangular[f]	Input source #3
	- Home Irrigation Flag (0/1 = N/Y)	1	NA	NA	NA	NA	Assumption
	- Irrigation Water Index (1-2)	1	NA	NA	NA	NA	1= ground water
	- Home Irrigation Rate, in/yr	NA	52	69.5	87	Uniform	Input source #3
	- Home Irrigation Duration, mo/yr	NA	--	12	--	Fixed	Input source #3
	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[e]	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[e]	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	1	NA	NA	NA	NA	Assumption
	- Bioaccumulation Flag (0/1 = N/Y)	0	NA	NA	NA	NA	Not used
	- Population Drinking Contaminated Water	1	NA	NA	NA	NA	Assumption
	- Drink Water Source Index (0-3)	1	NA	NA	NA	NA	1 = ground water
	- Drink Water Treated (0/1 = N/Y)	0	NA	NA	NA	NA	Assumption
	- Drink Water Holdup Time, days	NA	--	0	--	Fixed	Assumption
	- Drink Water Consumption, l/y	NA	0	752.85	1,487.45	Uniform[f]	Input source #5

Table 2. Continued.

Menu(s)	Option/ Parameter, Unit	Selection	Values Minimum	Values Best Estimate	Values Maximum	Distribution	Reference[a]/ Comments
MAIN EDITING MENU (continued)							
Array Data Input Variable Distribution	Aquatic Food Ingestion						
	- Use (0/1 = F/T)						
	Fish	1	N/A	N/A	N/A	N/A	Assumptions
	Mollusc	0	N/A	N/A	N/A	N/A	
	Crustacea	0	N/A	N/A	N/A	N/A	
	Plants	0	N/A	N/A	N/A	N/A	
	- Transit Time (Hr)						
	Fish	N/A	N/A	N/A	N/A	N/A	Parameter not used
	Mollusc	N/A	N/A	N/A	N/A	N/A	
	Crustacea	N/A	N/A	N/A	N/A	N/A	
	Plants	N/A	N/A	N/A	N/A	N/A	
	- Production (Kg/yr)						
	Fish	N/A	N/A	N/A	N/A	N/A	Parameter not used
	Mollusc	N/A	N/A	N/A	N/A	N/A	
	Crustacea	N/A	N/A	N/A	N/A	N/A	
	Plants	N/A	N/A	N/A	N/A	N/A	
	- Holdup (days)						
	Fish	N/A	N/A	N/A	N/A	N/A	Parameter not used
	Mollusc	N/A	N/A	N/A	N/A	N/A	
	Crustacea	N/A	N/A	N/A	N/A	N/A	
	Plants	N/A	N/A	N/A	N/A	N/A	
	- Consumption (kg/yr)						
	Fish	N/A	6.63E-08	0.47	8.79	Log Uniform[f]	Input source #5
	Mollusc	N/A	N/A	N/A	N/A	N/A	Parameter not used
	Crustacea	N/A	N/A	N/A	N/A	N/A	
	Plants	N/A	N/A	N/A	N/A	N/A	

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						
	- 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	1	NA	NA	NA	NA	Assumption
	Root Vegetables	1	NA	NA	NA	NA	
	Fruit	1	NA	NA	NA	NA	
	Grain	1	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	Input source #4
	Fruit	NA	30.00	(37.69)	45.37	Uniform	Input source #4
	Grain	NA	55.85	(68.11)	80.37	Uniform	Input source #4
	- 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	Input source #4
	Fruit	NA	2.9	(4.5)	6.0	Uniform	Input source #4
	Grain	NA	4.9	(6.5)	8.0	Uniform	Input source #4
	- 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	Parameter not used
	Root Vegetables	NA	--	0	--	Fixed	
	Fruit	NA	--	0	--	Fixed	
	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[f]	Input source #5
	Root Vegetables	NA	0.65	7.81	29.86	Log Uniform[f]	Input source #5
	Fruit	NA	0.18	15.57	97.69	Log Uniform[f]	Input source #5
	Grain	NA	8.61E-11	0.48	12.33	Log Uniform[f]	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[f]	Input source #5
	Poultry	NA	2.09E-05	0.80	10.50	Log Uniform[f]	Input source #5
	Milk	NA	2.98E-09	4.14	100.36	Log Uniform[f]	Input source #5
	Eggs	NA	0.23	6.68	33.34	Log Uniform[f]	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 (cont.)						
	- 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	--	1	--	Fixed	| 100% of water
	Poultry (corn)	NA	--	1	--	Fixed	| contaminated
	Milk	NA	--	1	--	Fixed	|
	Eggs (corn)	NA	--	1	--	Fixed	| Assumption
	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	1	NA	NA.	NA	NA	|1 = ground water
	Poultry (corn)	1	NA	NA	NA	NA	|
	Milk	1	NA	NA	NA	NA	| Assumption
	Eggs (corn)	1	NA	NA	NA	NA	|
	- Irrigation Rate, in/yr						
	Beef	NA	--	0	--	Fixed	Input source #4
	Poultry (corn)	NA	--	80.37	--	Fixed	Input source #4
	Milk	NA	--	0	--	Fixed	Input source #4
	Eggs (corn)	NA	--	80.37	--	Fixed	Input source #4
	- Irrigation Time, mo/yr						
	Beef	NA	--	0	--	Fixed	Input source #4
	Poultry (corn)	NA	--	4.9	--	Fixed	Input source #4
	Milk	NA	--	0	--	Fixed	Input source #4
	Eggs (corn)	NA	--	4.9	--	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 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)	1	NA	NA	NA	NA	|1 = ground water
	Milk (alfalfa)	1	NA	NA	NA	NA	| Assumption
	- Irrigation Rate, in/yr						
	Beef (alfalfa)	NA	--	94.66	--	Fixed	Input source #4
	Milk (alfalfa)	NA	--	94.66	--	Fixed	Input source #4
	- Irrigation Time, mo/yr						
	Beef (alfalfa)	NA	--	12	--	Fixed	Input source #4
	Milk (alfalfa)	NA	--	12	--	Fixed	Input source #4
	- 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	--	0	--	Fixed	
	- Deep Soil, pCi/kg	NA	--	0	--	Fixed	
	- Ground Water, pCi/l	NA	--	1	--	Fxed	
	- Surface Water, pCi/l	NA	--	1[d]	--	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] It is necessary to assume a unit concentration in the surface water in order for the fish pathway to contribute to the BDCF.

[e] For Normal and Lognormal distributions, Minimum = 0.1 percentile and Maximum = 99.9 percentile.

[f] 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 contains 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 Tc-99 (example taken from S-PLUS output file NDCTc99.srp, located on CD ROM) will be used to illustrate the interpretation of results of the regression process.

```
Call: lm(formula = Tc99 ~ Soil.Plant.Trans + Inhal.Expos + Crop.Resusp +
Crop.Intercpt + Drink.Water.CR + Leaf.Veg.CR + Milk.CR + Milk.YLD,
data = NDC.Master.Feb.11, na.action = na.exclude)

Residuals:
    Min      1Q    Median     3Q   Max
  -2.51 -0.2056 -0.006889 0.1603 4.453

Coefficients:
                    Value Std. Error t value Pr(>|t|)
      (Intercept)  0.0000  0.0509     0.0000  1.0000
 Soil.Plant.Trans  0.3666  0.0522     7.0241  0.0000
      Inhal.Expos -0.1079  0.0515    -2.0963  0.0381
      Crop.Resusp -0.0976  0.0516    -1.8915  0.0609
    Crop.Intercpt  0.1982  0.0521     3.8039  0.0002
   Drink.Water.CR  0.3100  0.0518     5.9860  0.0000
      Leaf.Veg.CR  0.4230  0.0512     8.2587  0.0000
          Milk.CR  0.4874  0.0519     9.3950  0.0000
         Milk.YLD -0.0969  0.0514    -1.8843  0.0619

Residual standard error: 0.5805 on 121 degrees of freedom
Multiple R-Squared: 0.684
F-statistic: 32.73 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 Tc-99 example, 0.684 (68%) 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 Tc-99 example above, the F-statistic is 32.73, 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 parameters 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 Tc-99 example (listed above), milk consumption rate has the highest absolute coefficient, it is appropriate to conclude that milk consumption is the most important parameter. Also note that the coefficient for leafy vegetable consumption rate is roughly twice that of the crop interception factor. This means that leafy vegetable consumption rate is roughly twice as important as crop interception 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 Tc-99 example, all parameters have a p-value less than 0.05 except for crop resuspension and milk yield. Note that the absolute values of the regression coefficients for those parameters are 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 different 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 Tc-99 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 7 and maximum of 17 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 correlations (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 7 to 17 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.

Some key observations on these correlation's are:

- Leafy vegetable consumption rate was the most significant contributor to variance in the BCDF for all radionuclides except C-14, Tc-99, and Cs-137. For Tc-99 it was the second-ranked contributor.

- Drinking water consumption rate was the second most important contributor to variance for all the heavy elements, Sr-90, and I-129. It was third in importance for Tc-99 and Cs-137.

- Crop interception fraction—the fraction of contamination in rainfall, irrigation water, or aerosols that adhere to the plant surfaces—was the third most important contributor for all radionuclides except C-14, Tc-99, and Cs-137.

- Milk consumption rate is the leading contributor to BDCF variance for Tc-99 and was also a significant factor for I-129.

- Fish consumption rate accounts for essentially all the BDCF variance for C-14 and is also the most important contributor for Cs-137.

- Soil-plant transfer factor is a significant contributor to BDCF variance only for the biologically mobile radionuclide Tc-99.

- Beef consumption rate is the second leading contributor to BDCF variance for Cs-137 and was also a significant factor for I-129 and Sr-90.

These contributions to the BDCFs are consistent with the relatively low biological mobility of the heavy elements and the fact that all the heavy element isotopes of interest are alpha particle emitters that must be taken into the body to contribute to the dose. The results suggest two key exposure pathways for the heavy elements: consumption of drinking water and deposition of radioactive material on crops (by irrigation and resuspension) with subsequent human ingestion of the crops. Ingestion of crops and animal products is also indicated as the most important pathway for the biologically mobile radionuclides Sr-90, Tc-99, I-129 and Cs 137. However, the relatively high significance of animal and crop transfer coefficients for some of these radionuclides suggest that biological incorporation into the crops is the most important mechanism, as opposed to the surficial deposition process implied by the heavy element results.

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

- Growing time for vegetables, grains, fruits, forage, beef, and milk
- Irrigation rates and irrigation time for any crops except leafy vegetables
- Animal uptake factor
- Yields for most foodstuffs.

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[a]

	^{227}Ac	^{241}Am	^{243}Am	^{14}C	^{137}Cs	^{129}I	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{90}Sr	^{99}Tc	^{229}Th	^{232}U	^{233}U	^{234}U	^{236}U	^{238}U
Soil-plant transfer factor												3^c						
Crop interception fraction	3	3	3			3	3	3	3	3	3^c		3	3	3	3	3	3
Drinking water consumption rate	2	2	2		3	2	2	2	2	2	2	3^c	2	2	2	2	2	2
Fish consumption rate				1^b	1													
Leafy vegetable consumption rate	1	1	1			1	1	1	1	1	1	2	1	1	1	1	1	1
Beef consumption rate					2						3^c							
Milk consumption rate												1						

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[a] Numbers indicate ranking as contributor to BDCF variance for each radionuclide

[b] Fish consumption rate accounts for 99+ percent of the BDCF variance for C-14.

[c] Parameters with approximately equal contribution to BDCF variance.

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 40 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
  - Consumption of fish
  - Inadvertent soil ingestion
- Inhalation of resuspended particulate matter
- External exposure to contaminated soil

For the groundwater contamination case, inhalation and external exposure pathways are not significant, and the ingestion pathway accounts for essentially all of the BDCF. For all radionuclides of interest except C-14 and Cs-137, ingestion of drinking water is the most important contributor to BDCFs, followed by ingestion of leafy vegetables. Together, consumption of drinking water and leafy vegetables account for 80 to 95 percent of the BDCF values for those radionuclides, with the balance resulting from consumption of fruits and other vegetables. For the biologically mobile radionuclides Sr-90, Tc-99 and I-129, the contributions to the BDCF values are slightly different. Although consumption of drinking water and leafy vegetables are still the most important contributors to the BDCFs, consumption of other vegetables, fruit, eggs, meat, and milk are more significant than for the heavy elements.

For C-14 the ingestion pathway still dominates the total BDCF. However, consumption of fish, which is assumed to be raised in ponds filled from groundwater sources, is by far the greatest single contributor. For Cs-137, fish consumption is also the leading contributor to the BDCF, followed by consumption of drinking water, leafy vegetables and meat.

The exposure pathway contributions to the BDCFs for the radionuclides of interest are summarized in Table 4. As stated above, the inhalation and external exposure pathways were not significant and therefore do not show in the table. 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. Pathway Contribution to Groundwater Contamination Biosphere Dose Conversion Factors*

Radionuclide	Drinking Water	Leafy Vegetables	Fruit	Other Vegetables	Eggs	Milk	Meat	Fish	Other
Ac-227	61	35	2	2	–	–	–	1	–
Am-241	61	34	2	2	–	–	–	1	–
Am-243	61	34	2	2	–	–	–	1	–
C-14	3	1	–	–	1	–	–	92	2
Cs-137	29	16	1	1	–	2	12	37	2
I-129	55	31	–	2	2	4	3	–	3
Np-237	61	34	2	2	–	–	–	1	1
Pu-238	61	34	2	2	–	–	–	1	–
Pu-239	61	34	2	2	–	–	–	1	–
Pu-240	61	34	2	2	–	–	–	1	–
Sr-90	54	34	2	3	–	–	5	2	1
Tc-99	51	35		2	2	8	–	–	2
Th-229	59	34	2	2	–	–	–	4	–
U-232	61	34	2	2	–	–	–	–	2
U-233	61	34	2	2	–	–	–	–	2
U-234	60	34	2	2	–	–	–	–	2
U-236	60	34	2	2	–	–	–	–	2
U-238	60	35	2	2	–	–	–	–	2

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* Table values are in percent and totals may not equal 100 percent because of rounding errors.

As seen from the results summarized in Table 4, the soil ingestion and inhalation pathways are not major contributors to the BDCF values associated with groundwater contamination (non-disruptive event scenario). The largest contribution by the inhalation pathway is 1.3E-4 (0.013%) for thorium-229 and the largest soil ingestion contribution is 1.2E-4 (0.012%) for uranium-232. However, if one hypothesizes agricultural practices and other soil-disturbing human activities that cause the air mass loading in the region occupied by the critical group to substantially exceed the level used in the BDCF calculations, both the inhalation and ingestion contributions would be expected to increase.

The soil ingestion rate used in the BDCF calculations is 50 mg/day (CRWMS M&O 1999b, Section 6.6), the value recommended by the EPA for soil ingestion by an adult. That value was developed to account for ingestion of soil via the mouth (for example, soil on food). But it may not specifically account for ingestion of non-respirable airborne particles that become lodged in the upper (nasopharyngeal) region of the respiratory system, are subsequently swallowed and pass through the GI (gastrointestinal) tract. The respirable air mass loading was represented in the BDCF calculation as a truncated lognormal distribution with a minimum of 7.4E-7 g/m^3 (0.74 $\mu g/m^3$), a maximum of 6.4E-5 g/m^3 (64 $\mu g/m^3$), and a mean of 8.7E-6 g/m^3 (8.7 $\mu g/m^3$) (see Table 2).

The potential effect on BDCFs of elevated air mass loading values, both respirable (<10 microns) and non-respirable (>10 microns) is examined here. Higher air mass loading levels in both particle size ranges are postulated and the influence on calculated BDCF values is determined.

Inhalation. A postulated increase in the respirable air mass loading value might result from changes the amount and type of agricultural activity in the Amargosa Valley, the amount of other soil-disturbing activity (construction, traffic on dirt roads, etc.), and the type of soil that is disturbed. In seeking an analogue for the postulated condition, EPA air quality data for all counties in Nevada for the years 1994 - 1999 were reviewed. Clark County (Las Vegas) consistently recorded the highest PM_{10} (<10 micron) levels, both annual mean and maximum 24-hour average values. Although not agricultural in origin, much of the air particulate loading in the Las Vegas metropolitan area has been attributed to local soil disturbance, principally from construction activity (Chow 1999). Over the 1994-99 period the annual mean PM_{10} values ranged from 45.2 to 59.7 $\mu g/m^3$ and the maximum 24-hour averages ranged from 114 to 328 $\mu g/m^3$.

The Clark County data are judged to better reflect the soil and climate conditions of the critical group located in the Amargosa Valley than would data taken from other regions of the country. Therefore, for the purpose of determining the sensitivity of the BDCFs to increased respirable air mass loading, a value corresponding to the highest annual mean recorded in Clark County from 1994-99 (59.7 $\mu g/m^3$) is assumed for the critical group. This assumption is considered conservative for long-term exposure of the critical group because:

- The Clark County PM_{10} measurement data consistently exceed those from other, more rural counties in Nevada.

- The Clark County annual mean PM_{10} values consistently exceed (by a factor of 2 or more) the reported values for counties in the northwest that have similar annual rainfall, very fine aeolean silt soils and extensive agricultural activity, much of which is dryland wheat farming in which half the land is left fallow every year and mechanical tillage is used to prevent weed growth.

If a mean respirable air mass loading of 59.7 $\mu g/m^3$ is assumed (a factor of 6.86 times the mean value of the distribution used in the BDCF calculations) a proportionate increase in the inhalation contribution to the BDCF would be expected. A factor of 6.86 increase in the tiny inhalation contribution to the BDCF (0.013% for the worst case nuclide) would be expected to increase the most affected BDCF by less than one tenth of one percent. It is concluded that the non-disruptive performance scenario BDCF values are very insensitive to respirable air mass loading.

Ingestion. Inhalation of particulate matter in the >10 micron size range will add to the inadvertent soil ingestion contribution to the BDCF. To estimate the amount of additional soil that might be ingested by a member of the critical group as a result of inhaling particles in the >10 micron size range, the relationship between total suspended particulate (TSP) mass loading and PM_{10} was examined.

Air particulate measurements taken near the Yucca Mountain site for the period 1989-1997 shows that TSP air mass loading typically exceeds PM_{10} values by a factor of 2-3 both for the highest 24-hour average and the annual averages. During that nine-year period, the highest observed TSP/ PM_{10} ratio was 4.63 (CRWMS M&O 1999g). If that bounding ratio is applied to the elevated PM_{10} value that was postulated earlier (59.7 $\mu g/m^3$) the resulting TSP value is 276.4 $\mu g/m^3$ and the corresponding non-respirable air mass loading (TSP minus PM_{10}) is 216.7 $\mu g/m^3$. Assuming an inhalation rate of 23 m^3/day (CRWMS M&O 1999d, Section 6.3), a member of the critical group breathing that concentration of TSP would inhale 4.98 mg/day of soil particles. These particles would subsequently be trapped in the nasopharyngeal region, swallowed, and contribute to the inadvertent soil ingestion component of the BDCF. This amount represents an increase of about 10% over the 50 mg/day inadvertent soil ingestion rate that was used in the BDCF calculations (CRWMS M&O 1999b). Since no more than 0.012% of any radionuclide BDCF value is due to the inadvertent soil ingestion pathway, increasing that contribution by 10% would only cause the BDCF value to increase by a tiny fraction of one percent. Thus, it is concluded that the groundwater contamination case BDCF values are extremely insensitive to non-respirable air particulate mass loading.

7. CONCLUSIONS

Although 7 to 17 parameters (see S-PLUS output files listed in Attachment I) 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.

Leafy vegetable consumption rate was the most significant contributor to variance in the BCDF for all radionuclides except C-14, Tc-99, and Cs-137. Drinking water consumption rate was the second most important contributor to variance for all the heavy elements, Sr-90, and I-129. Crop interception fraction—the fraction of contamination in rainfall, irrigation water, or aerosols that adhere to the plant surfaces—was the third most important contributor for all radionuclides except C-14, Tc-99, and Cs-137. Milk consumption rate is the leading contributor to BDCF variance for Tc-99 and was also a significant factor for I-129. Fish consumption rate accounts for essentially all the BDCF variance for C-14 and is also the most important contributor for Cs-137. Soil-plant transfer factor is a significant contributor to BDCF variance only for Tc-99. Beef consumption rate is the second leading contributor to BDCF variance for Cs-137 and is also a significant factor for I-129 and Sr-90.

C-14 is unique among the nuclides as it is readily incorporated into human systems as carbon dioxide gas or carbohydrates. As such, a separate activity model within GENII-S is used for C-14 dose analysis. All inhaled or ingested C-14 is assumed to be absorbed immediately by the lungs and the gastrointestinal tract. The code developers recognized that plants acquire most of their carbon from air, but the model assumes the specific activity of C-14 (i.e., curies of radionuclide per Kg of soluble element) of the environmental media (plants and animals) is equivalent to that of the contaminating medium (air or water) and adds a correction factor for water/plant transfer (Leigh 1993). As a result, the estimated concentration of C-14 in plants is higher than what might be expected.

The above results are consistent with the relatively low biological mobility of the heavy elements and the fact that all the heavy element isotopes of interest are alpha particle emitters that must be taken into the body to contribute to the dose. The results suggest two key exposure pathways for the heavy elements: consumption of drinking water and deposition of radioactive material on crops (by irrigation and resuspension) with subsequent human ingestion of the crops. Ingestion of crops and animal products is indicated as the most important pathway for the biologically mobile radionuclides Sr-90, Tc-99, I-129 and Cs-137. However, the relatively high significance of animal and crop transfer coefficients for some of these radionuclides suggest that biological incorporation into the crops is the most important mechanism, as opposed to the surficial deposition process implied by the heavy element results.

Parameters that were not important to the BDCF variation for any radionuclide, or were only of minor importance to a few, include: growing time for vegetables, grains, fruits, forage, beef, and milk; irrigation rates and irrigation time for any crops except leafy vegetables; animal uptake factor; and, yields for most foodstuffs.

Inhalation and external exposure pathways are not significant, and the ingestion pathway accounts for essentially the entire BDCF. For all radionuclides of interest except C-14 and Cs-137, ingestion of drinking water is the most important contributor to BDCF, followed by ingestion of leafy vegetables. Together, consumption of drinking water and leafy vegetables account for 80 to 95 percent of the BDCF values for those radionuclides, with the balance resulting from consumption of fruits and other vegetables. Although consumption of drinking water and leafy vegetables are still the most important contributors to the BDCFs for Sr-90, Tc-99 and I-129, consumption of other vegetables, fruit, eggs, meat, and milk are more significant than for the heavy elements. For C-14, consumption of fish is by far the greatest single contributor. For Cs-137, fish consumption is the leading contributor to the BDCF, followed by consumption of drinking water, leafy vegetables and meat.

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

- Improving the estimates of drinking water consumption rates should reduce the BDCF uncertainty for most radionuclides.

- Refinement of crop interception fractions and consumption rates for vegetables that are actually grown in the Amargosa Valley for local consumption should have a major influence on the BDCF uncertainty for most radionuclides.

- Improving the estimates of fish consumption rates should significantly reduce the BDCF uncertainty for C-14 and, to a lesser degree, Cs-137.

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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MO9911RIB00065.001. *Parameter Values for Transfer Coefficients.* Submittal date: 01/26/2000.

MO9910RIB00061.000. *Input Parameter Values for External and Inhalation Radiation Exposure Analysis.* Submittal date: 10/07/1999. ACC: MOL19991110.0266.

MO9912RIB00066.000. *Parameter Values for Internal and External Dose Conversion Factors.* Submittal date: 12/03/1999.

MO0002RIB00068.000. *Ingestion Exposure Parameters Values.* Submittal date: 02/03/2000.

MO0002RIB00062.000. *Parameter Values for Consumption of Locally Produced Food and Tap Water.* Submittal date: 02/03/2000.

SN9912T0512299.003. *Leaching Coefficients for GENII-S Code.* Submittal date: 02/09/2000.

8.2 REFERENCES

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8.4 SOFTWARE

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ATTACHMENTS

ATTACHMENT I

LIST OF ANALYSIS INPUT AND OUTPUT FILES

(8 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
RRSAC227	.FLG	712	1/26/00	03:11p
RRSAC227	.INP	15,513	1/26/00	03:11p
RRSAC227	.OUT	832	1/26/00	03:11p
RRSAC227	.PTI	8,173	1/26/00	03:11p
RRSAC227	.SUM	136,765	1/27/00	02:54p
RRSAC227	.VEC	50,256	1/26/00	03:11p
RRSAM241	.FLG	712	1/26/00	03:11p
RRSAM241	.INP	15,513	1/26/00	03:12p
RRSAM241	.OUT	888	1/26/00	03:12p
RRSAM241	.PTI	8,173	1/26/00	03:12p
RRSAM241	.SUM	136,765	1/27/00	02:54p
RRSAM241	.VEC	50,256	1/26/00	03:12p
RRSAM243	.FLG	712	1/26/00	03:12p
RRSAM243	.INP	15,513	1/26/00	03:13p
RRSAM243	.OUT	832	1/26/00	03:13p
RRSAM243	.PTI	8,173	1/26/00	03:13p
RRSAM243	.SUM	136,765	1/27/00	03:02p
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RRSC14.P	TI	8,173	2/9/00	04:50p
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RRSI129.	VEC	50,256	1/26/00	03:15p

RRSNP237	.FLG	712	1/26/00	03:34p
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RRSPU239	.FLG	712	2/9/00	04:38p
RRSPU239	.INP	15,513	2/9/00	04:38p
RRSPU239	.OUT	832	2/9/00	04:38p
RRSPU239	.PTI	8,173	2/9/00	04:38p
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RRSPU240	.FLG	712	2/9/00	04:40p
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RRSTH229	.INP	15,513	2/9/00	04:42p
RRSTH229	.OUT	832	2/9/00	04:42p
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RRSU233.	INP	15,513	1/26/00	03:22p
RRSU233.	OUT	832	1/26/00	03:23p
RRSU233.	PTI	8,173	1/26/00	03:23p
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RRSU233.	VEC	50,256	1/26/00	03:23p
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RRSU234.	INP	15,513	1/26/00	03:24p
RRSU234.	OUT	832	1/26/00	03:24p
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RRSU234.	VEC	50,256	1/26/00	03:24p
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RRSU236.	INP	15,513	1/26/00	03:25p
RRSU236.	OUT	832	1/26/00	03:25p
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RRSU236.	VEC	50,256	1/26/00	03:25p
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RRSU238.	INP	15,513	1/26/00	03:26p
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RRSU238.	PTI	8,173	1/26/00	03:27p
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GENII-S Input and Out Files for Deterministic Runs
..\DE Sensitivity\Deterministic Data

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RRPAC227	.VEC	3,132	1/26/00	12:15p
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RRPCS137	.PTI	1,311	2/9/00	04:33p
RRPCS137	.VEC	3,132	2/9/00	04:33p
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RRPPU238	.OUT	17,618	2/9/00	04:29p
RRPPU238	.PTI	1,311	2/9/00	04:29p

RRPPU238	.VEC	3,132	2/9/00	04:29p
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RRPPU239	.INP	6,679	2/9/00	04:30p
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RRPPU239	.PTI	1,311	2/9/00	04:30p
RRPPU239	.VEC	3,132	2/9/00	04:30p
RRPPU240	.FLG	664	2/9/00	04:30p
RRPPU240	.INP	6,679	2/9/00	04:30p
RRPPU240	.OUT	17,618	2/9/00	04:31p
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RRPTC99.	PTI	1,311	2/9/00	04:31p
RRPTC99.	VEC	3,132	2/9/00	04:31p
RRPTH229	.FLG	664	2/9/00	04:31p
RRPTH229	.INP	6,679	2/9/00	04:32p
RRPTH229	.OUT	17,563	2/9/00	04:32p
RRPTH229	.PTI	1,311	2/9/00	04:32p
RRPTH229	.VEC	3,132	2/9/00	04:32p
RRPU232.	FLG	664	1/26/00	12:23p
RRPU232.	INP	6,679	1/26/00	12:23p
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RRPU232.	PTI	1,311	1/26/00	12:24p
RRPU232.	VEC	3,132	1/26/00	12:24p
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RRPU233.	INP	6,679	1/26/00	12:24p
RRPU233.	OUT	17,764	1/26/00	12:24p
RRPU233.	PTI	1,311	1/26/00	12:24p
RRPU233.	VEC	3,132	1/26/00	12:24p
RRPU234.	FLG	664	1/26/00	12:25p
RRPU234.	INP	6,679	1/26/00	12:26p
RRPU234.	OUT	16,265	1/26/00	12:26p
RRPU234.	PTI	1,311	1/26/00	12:26p
RRPU234.	VEC	3,132	1/26/00	12:26p
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RRPU236.	INP	6,679	1/26/00	12:25p
RRPU236.	OUT	16,265	1/26/00	12:25p
RRPU236.	PTI	1,311	1/26/00	12:25p

RRPU236.	VEC	3,132	1/26/00	12:25p
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RRPU238.	VEC	3,132	1/26/00	12:30p

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

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NDC Am243	.srp	126,976	1/28/00	09:59a
NDC C14	.srp	105,472	2/11/00	11:45a
NDC Cs137	.srp	109,056	2/11/00	11:39a
NDC I129	.srp	104,960	1/28/00	10:02a
NDC Np237	.srp	121,344	1/28/00	10:03a
NDC Pu238	.srp	123,904	2/11/00	11:44a
NDC PU239	.srp	123,904	2/11/00	11:43a
NDC Pu240	.srp	123,904	2/11/00	11:41a
NDC Sr90	.srp	108,544	2/11/00	11:40a
NDC Tc99	.srp	122,880	2/11/00	11:38a
NDC Th229	.srp	123,904	2/11/00	11:36a
NDC U232	.srp	123,904	1/28/00	10:12a
NDC U233	.srp	124,416	1/28/00	10:13a
NDC U234	.srp	124,416	1/28/00	10:15a
NDC U236	.srp	124,416	1/28/00	10:16a
NDC U238	.srp	123,904	1/28/00	10:17a

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
NDE PATH	.XLS	247,808	2/9/00	05:57p

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

ROOT NAME	FILE EXTENSION	FILE SIZE	DATE	TIME
NDE Z-score	.XLS	309,656	3/9/00	10:56a

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 Realizations	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	.....

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 for 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.

D' ~s: 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

~ommitted Dose Equivalent by Exposure Pathway

B

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